Extended Abstract with Poster

Surgical Techniques and Their Reliability

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Abstract

This paper investigates the reliability of two suturing techniques, which anchor surgical drains to the human skin/. Two suturing techniques are explored, namely the Roman Sandal (RS) and the modified Roman Sandal (MRS) suturing techniques. It was hypothesized that the MRS is more reliable than the RS suturing technique.

Introduction

Surgical drains are used to extract unwanted fluid from the organs of the body. The surgeon places them into the patient's body and secures them to an underlying organ such as skin via surgical sutures. Based on the oscillatory breathing motion of the patient's skin, the sutures loosen up and their grip on the drains weakens. The drain can then be displaced from its intended position. A secondary surgery is required to place it back into its intended location. The focus of this research is to investigate and compare two different suturing techniques that are used to anchor the drains.

Methods

The mechanical reliability of the RS and the MRS suturing techniques are tested via the use of the Instron tensile testing machine (Fig. 1). The loosening of the suture knots in a natural setting initiates after long periods of respiratory cycling of a patient's skin or drain and resembles a fatigue testing.

To simulate such the oscillatory behavior a custom-made fixture was designed and constructed (Fig. 1), which was attached to the stationary arm of the IM. The stationary sponge mimics the skin of a patient through which the drain runs through and oscillates.

RS suturing technique

Fig. 2 shows one of the RS test trials that were experimented with in the laboratory. The RS suturing technique involves two knot units. See Fig. 3. Each knot unit consists of 4 surgeon's knots.

MRS suturing technique

Fig. 4 shows one of the MRS test trials that were experimented with in the laboratory. The MRS suturing technique involves three knot units. See Fig. 5. Each knot unit consists of 4 surgeon's knots.

Failure Criteria

Suture unit displacement

The suture unit displacement or slippage is defined as the distance of dislodgment of the LB of the suturing from a previously specified datum, namely the black marking shown in Figs. 6 and 7. The suture unit displacement determines the deviation of the LB, involved in either the RS or the MRS experimental trial from the datum. The location of marking/datum is indicated by the white dashed lines in Figs. 2 and 4.

Suture unit collapse

The suture unit collapse is defined by the difference between the initial and the final distance between the LB and the second knot unit in the case of the RS suturing technique. With regards to the MRS, the collapse is defined by the difference between the final and the initial distance between the LB and the UB. See Figs. 6 and 7. Note that the collapse is measured once the knot unit has slipped 5.0 mm or more.

Number of oscillations needed to fail

The number of oscillations needed to fail was the third failure criterion tracked during all the experimental settings. For each experimental run involving both suturing techniques, the number of oscillations needed to reach the 5.0 mm mark was closely documented.

Results

RS Suture units

A total of 42 experimental runs were conducted for the RS suture technique. This number exceeds the necessary 40 number of trials required for obtaining statistically viable results. 36 RS trials failed during the first oscillation. Six of them failed during the second oscillation. The obtained results regarding the RS suture units were therefore sorted in two different categories. Graphs 1 & 2 show the results for the RS.

MRS Suture units

A total of 5 experimental runs were conducted. This is due to fact that each run needed more than 100 oscillations to result in the failure of the MRS suture units. This positive jump in the effectiveness of the MRS suture unit performance was so overwhelming that five trials were sufficient to contrast the difference between the reliability of the RS and MRS suturing techniques. Graphs 3 to 8 show these the results for the MRS.

Conclusion

Displacement of surgical drains from their intended location of attachment can lead to postoperative complications. After such displacements, the patient usually undergoes a secondary operation so that a new drain can be placed at the correct location. The usual drain anchoring mechanisms involve the use of a common suturing technique, namely the RS suturing technique. This research mechanically investigated the RS and the MRS to determine the reliability of these suturing techniques.

Under similar mechanical conditions, on average, the RS suture units failed only after one oscillation. However, the MRS suture units failed after more than 100 oscillations. The average RS suture unit slippage along the drain was 9.0 mm, whereas the average MRS suture unit slippage along the drain was 5.0 mm.

Based on the above findings the hypothesis of this research has been verified. The hypothesis was to prove that the MRS suturing technique is a more reliable and effective anchoring technique compared to the RS suturing technique.

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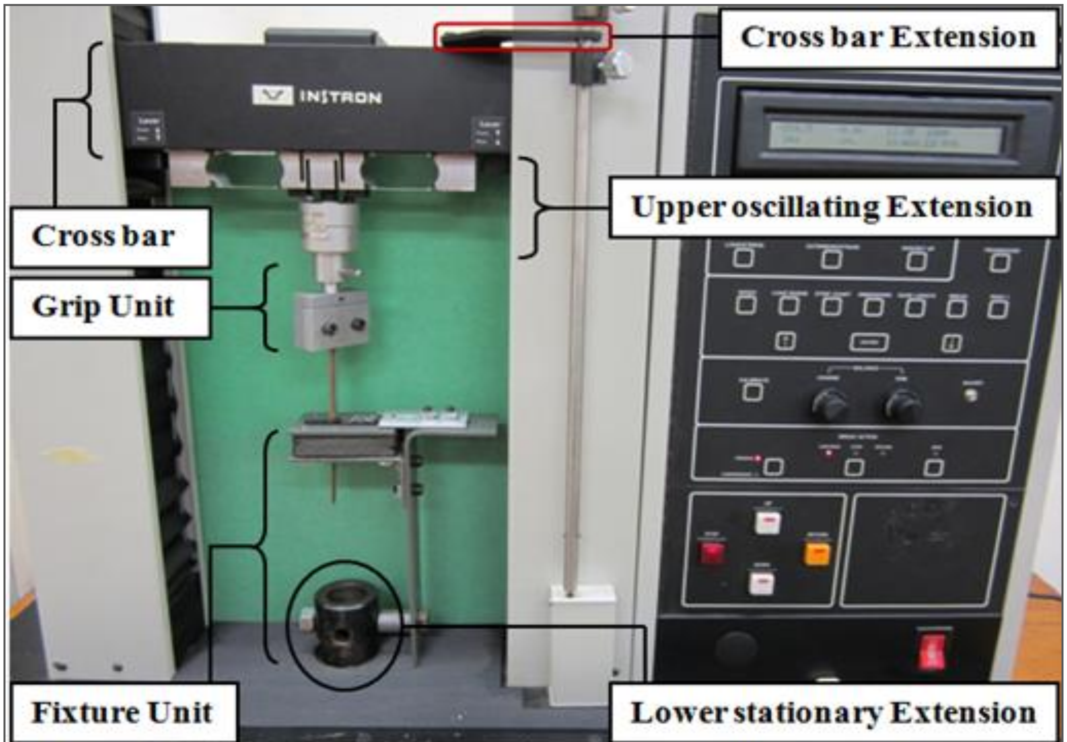


Figure 1: Instron tensile testing machine & the Fixture/Grip system.

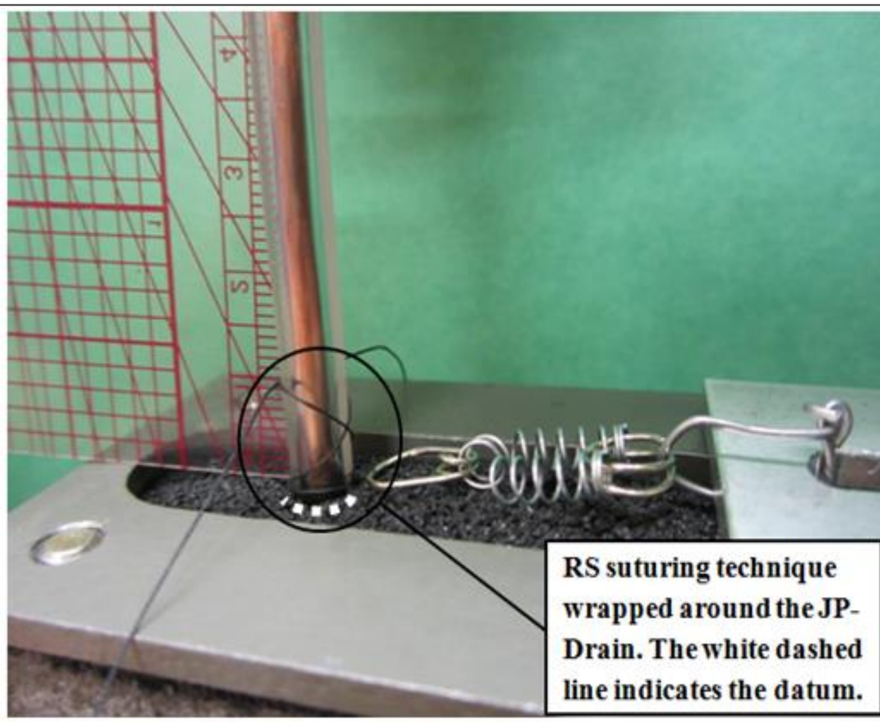


Figure 2: RS suturing technique with 1.0 cm initial separation between the lower base and the second knot unit used in the research setting.

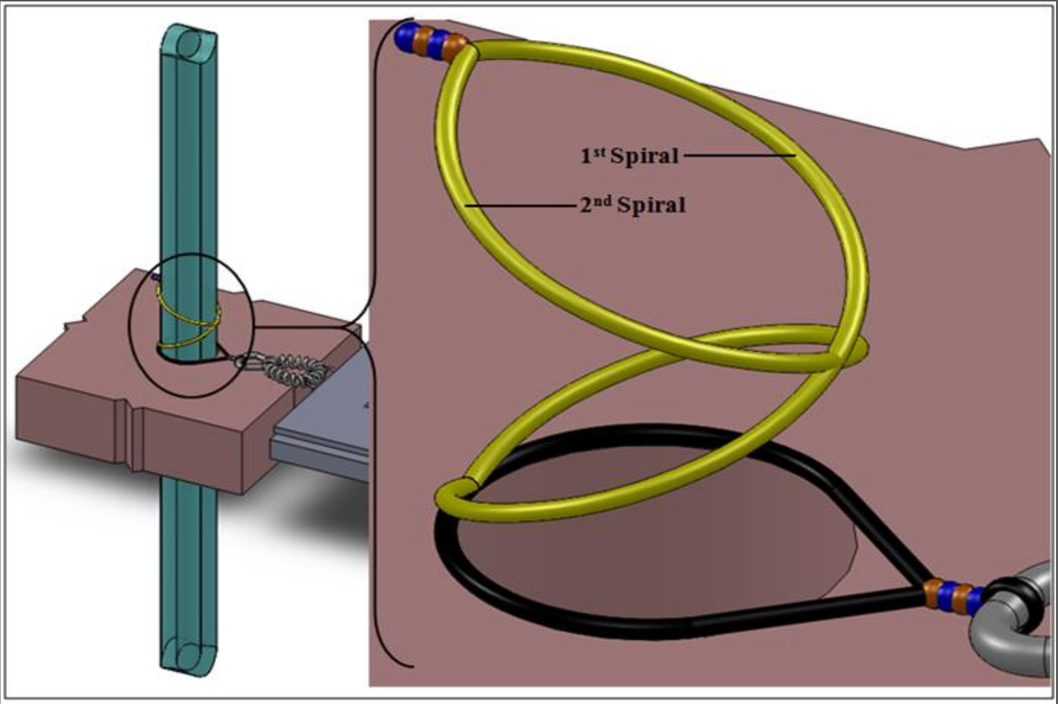


Figure 3: Isometric View. The RS suturing technique. On the left the RS is employed around the JP-Drain, which passes through the skin. On the right, a zoomed view of the RS suture technique. Note that the black segment is considered as the lower base (LB).

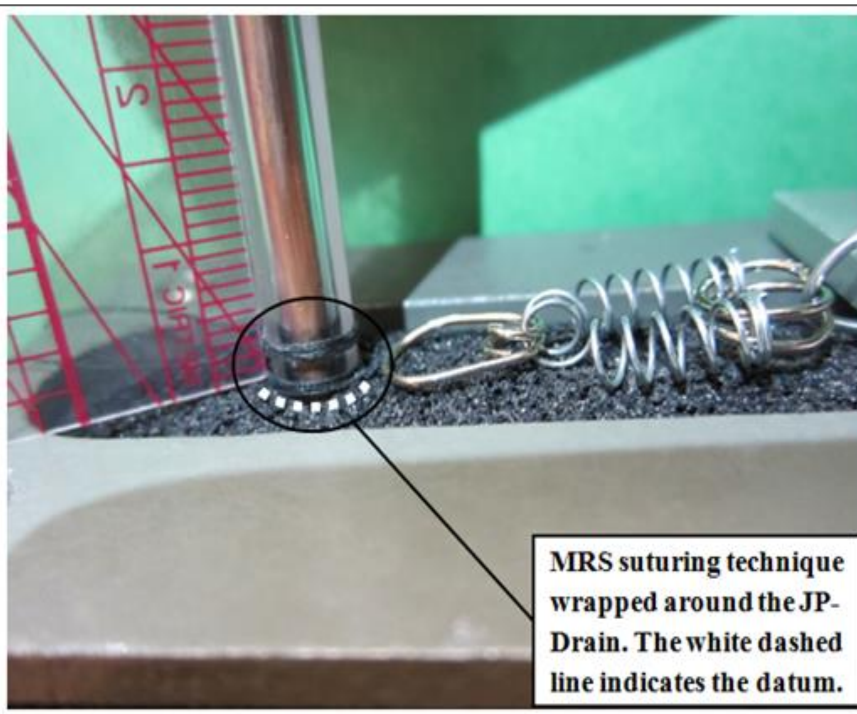


Figure 4: MRS suturing technique with 2.5 mm initial separation between the lower base and the upper based used in the research setting.

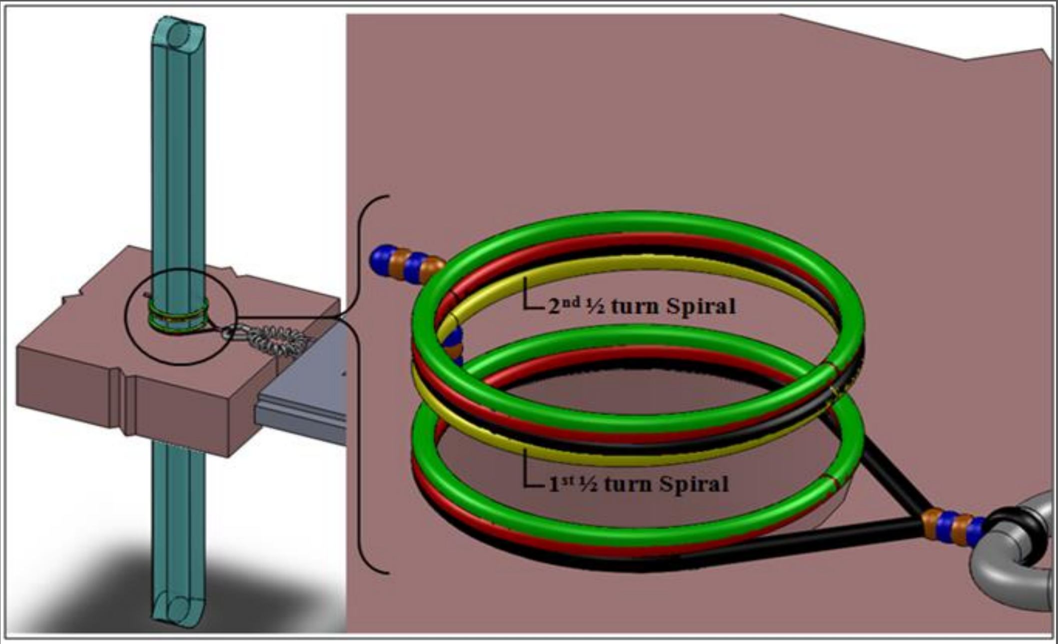


Figure 5: Isometric View. The MRS suturing technique. On the left the MRS is employed around the JP-Drain, which passes through the skin. On the right, a zoomed view of the MRS suture technique, the three knot units as well as the mode of attachment to the moveable ring. Note that the lower black segment is considered as the lower base (LB) and the upper black segment is considered as the upper base (UB).

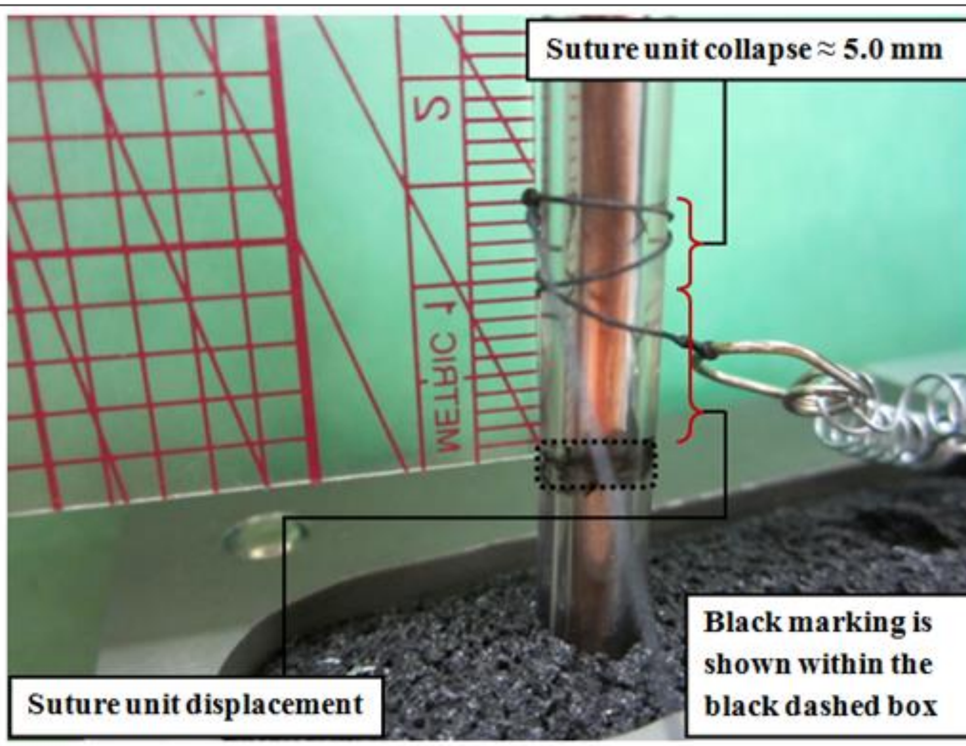


Figure 6: The RS suturing technique reaching a suture unit displacement of 9.0 mm.

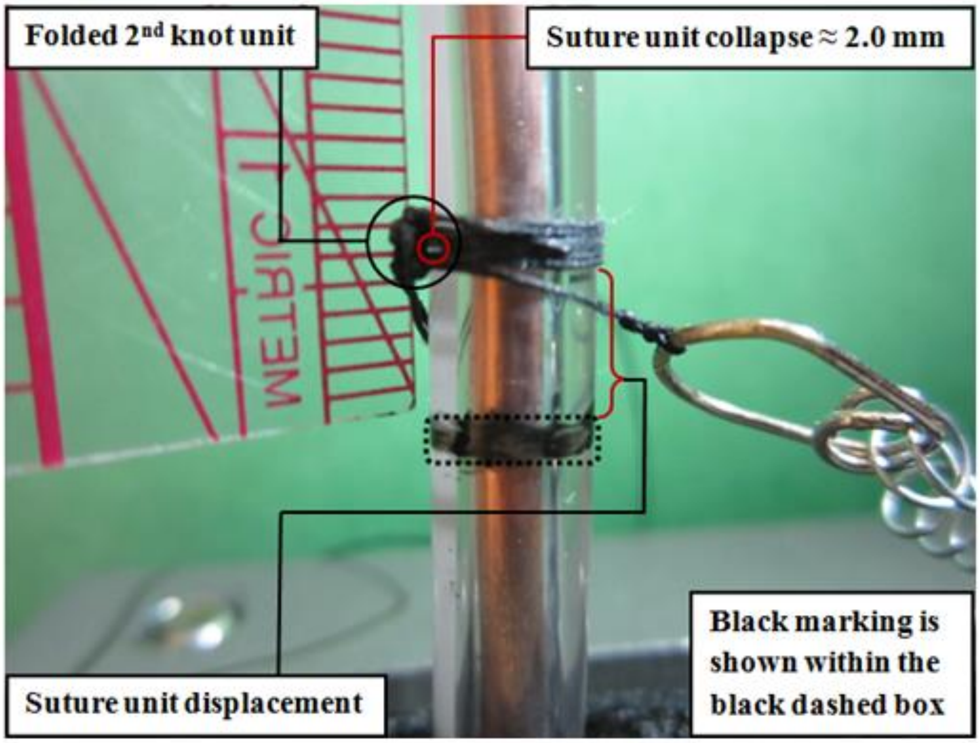
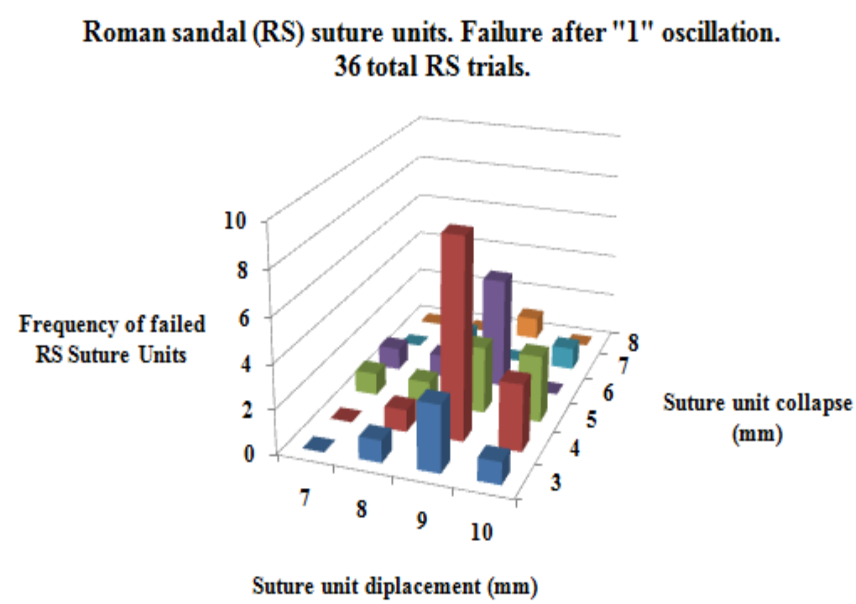
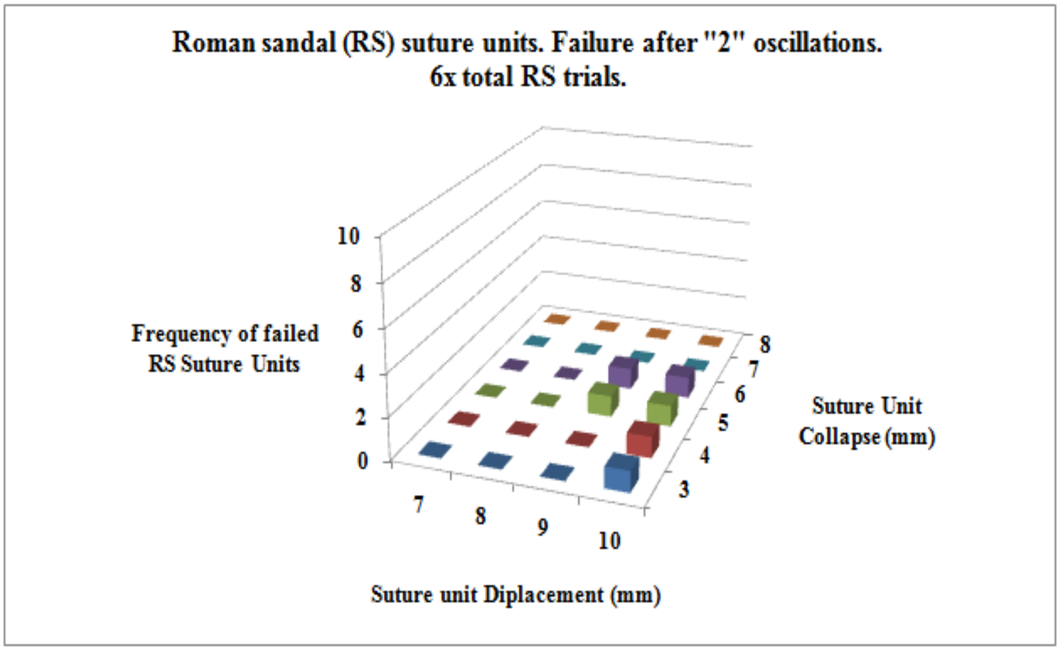


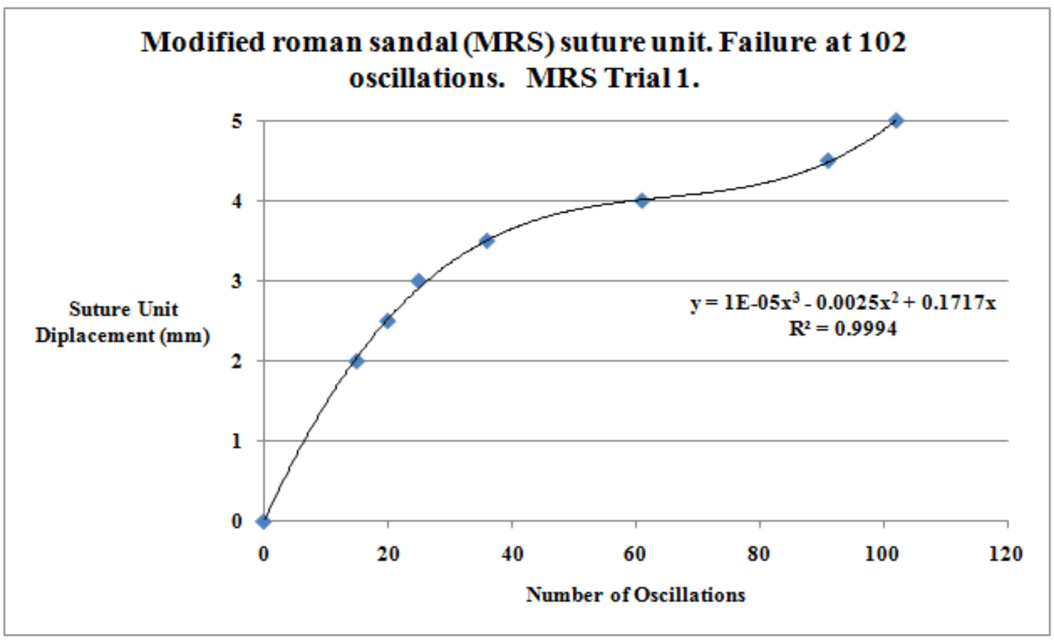
Figure 7: The MRS suturing technique reaching a suture unit displacement of 5.0 mm.



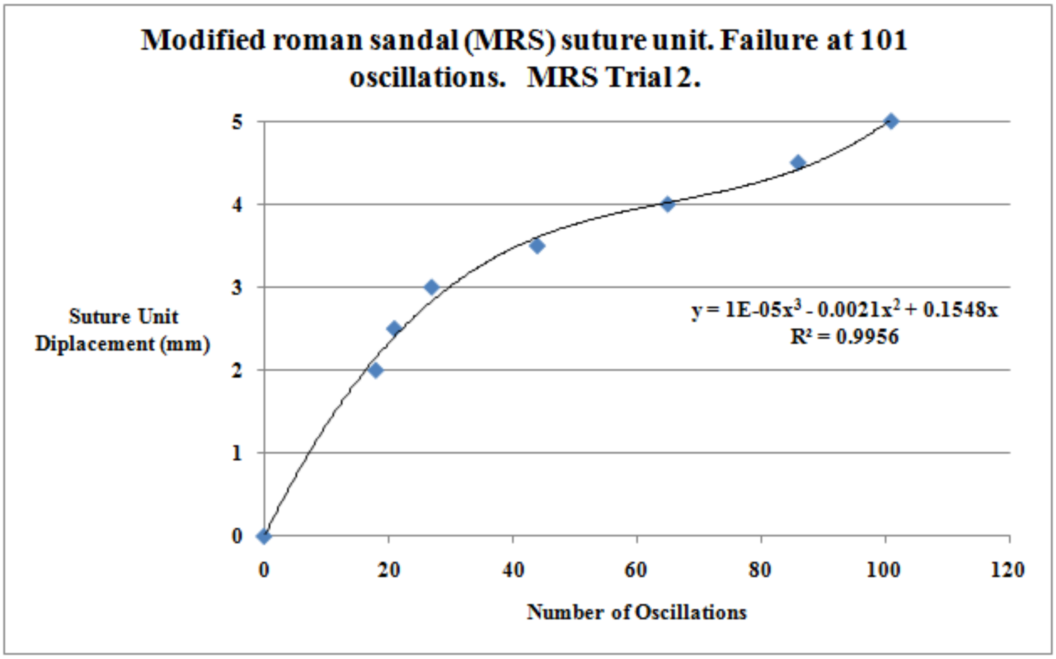
Graph 1: 36 total of RS experimental trials all failed after “1” oscillation.



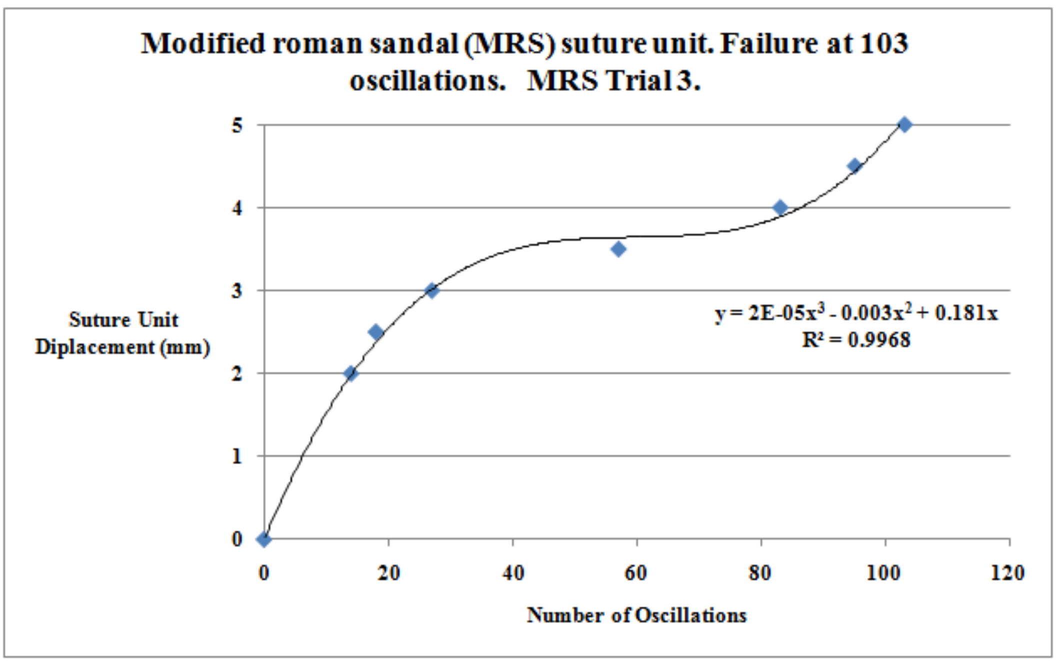
Graph 2: 6 RS experimental trials all failed after "2" oscillations.



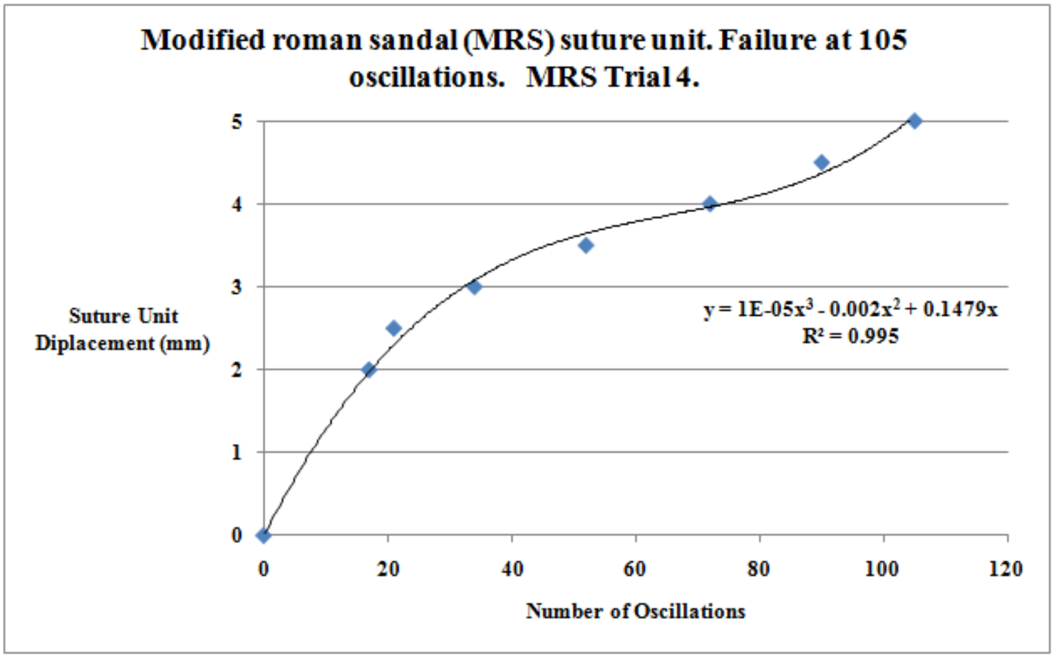
Graph 3: first MRS Experimental Trial. Failure occurred after 102 oscillations.



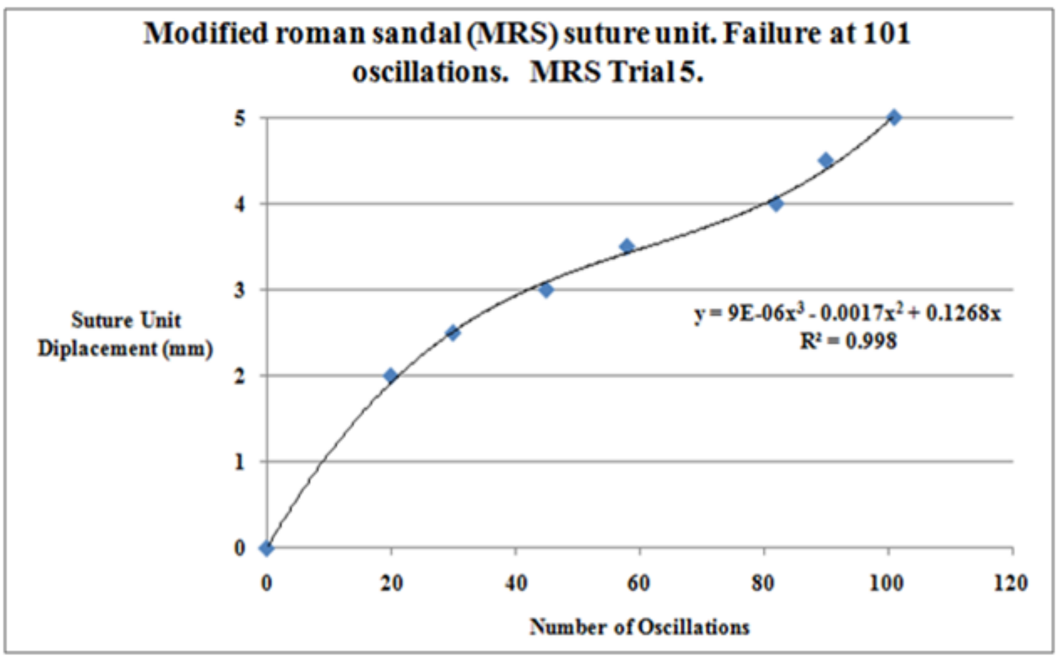
Graph 4: second MRS Experimental Trial. Failure occurred after 101 oscillations.



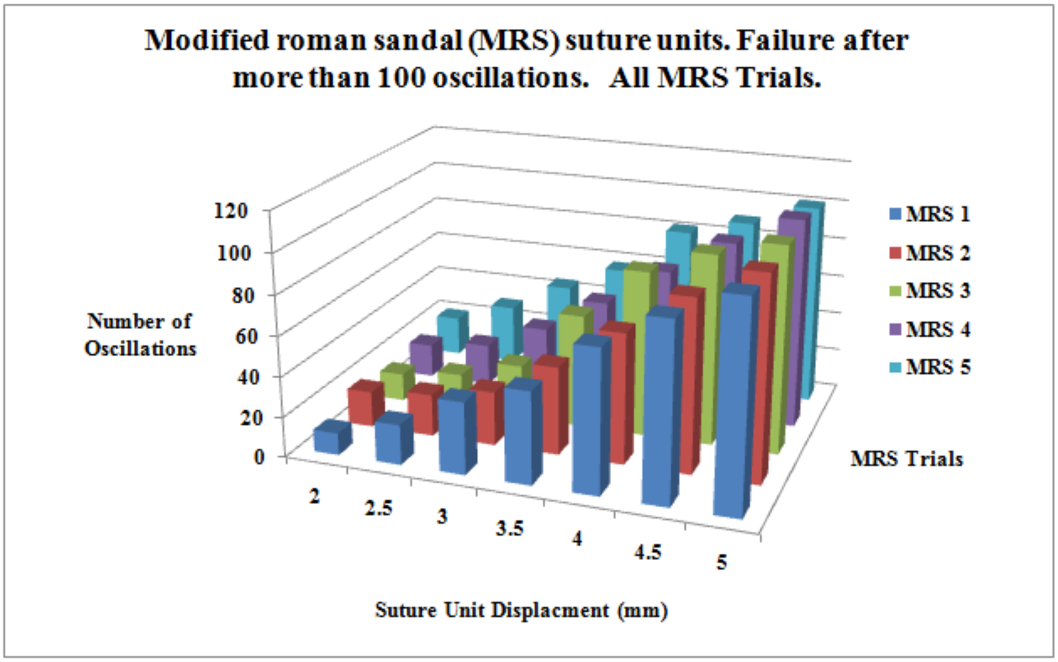
Graph 5: 3rd MRS Experimental Trial. Failure occurred after 103 oscillations.



Graph 6: 4th MRS Experimental Trial. Failure occurred after 105 oscillations.



Graph 7: 5th MRS Experimental Trial. Failure occurred after 101 oscillations.



Graph 8: All MRS Experimental Trials.

Extended Abstract with Poster

Nanotechnology Concepts through Lab Modules for K-12 and Community College Students

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Abstract

The advancement of technology has led researchers to explore further the real life problems in more detail. Interestingly, the solutions to these problems demand expertise in more than one discipline. This has necessitated various skills to come together. In engineering, a new discipline has emerged which we call *nanotechnology*. Nanotechnology is purely interdisciplinary in its nature. This is the need of the hour that we amend our conventional ways of dealing with the contemporary problems and start thinking beyond the conventional ways. Nanotechnology is one such example where we have extended the boundaries of various engineering disciplines. This is really important that the next generations of students are familiar with this revolutionary field and are motivated to pursue their education in this area. In this paper we present lab modules which can help familiarizing K-12 and community college level students with basics of nanotechnology without the need of sophisticated lab facilities.

Introduction

Nanotechnology has become cynosure for the scientific world during the last few years. The reason is that this emerging technology has had an impact on almost every field of science and engineering. The further advancements in this field are going to have far-reaching effects on almost all aspects of our daily life. A well-prepared and highly motivated work force is the key need for every nation to lead in emerging fields. Unfortunately there is a lack of awareness in youth about this technology because currently there are no courses or introductory modules of nanotechnology offered at the K-12 and community college levels [1]. Interest among students for various fields of science start at very early stages. If students don't get know-how of nanotechnology early on, it will be very difficult for them to develop interest and get motivation to do some work in this new field [2]. This is the need of the hour that suitable methods should be developed like lab modules etc. to familiarize K-12 and community college level students with this emerging field. This paper presents some basic modules that have been developed in a way that the basic concepts of nanotechnology like top-down fabrication and bottom-up self-assembly are delivered without the need for cleanroom and sophisticated equipment. The simple lab-modules also depict concepts of lithography, pattern transfer and etching to deliver the essence of this technology with hands-on exercises. The students can better understand the concepts and can apply these to understand the phenomenon like hydrophobicity, hydrophilicity and self-assembly etc.

Approach and Methodology

We have designed lab modules to familiarize K-12 and college level students with basic concepts of solid-state fabrication and properties at nanoscale. The simple processes like photolithography, pattern transfer, etching, etc. are depicted using silly putty, printed ink (laser print-outs, newspaper), compact discs, DVDs, etc. The special properties of materials at nanoscale like self-assembly, quantum confinement, etc. are explained with simple hands-on activities. Once the 'big ideas' are explained through the important critical concepts, the students are challenged to come up applications where this knowledge can be useful. It is then easy to explain examples of clothes that don't get dirty, car wash soap that wouldn't let dust settle on the body, etc. These activities provide evidence that students have understood the concepts. A possible next step would be to use the learning from the workshop to define more rigorous benchmarks for the students willing to take advanced workshops in various departments involved.

Fabrication process is the key element of nanotechnology and currently only graduate students get hands-on-experience with these processes. These concepts should be made available, through simple lab exercises, to K-12 and college level students as well so that the interest for this emerging field evolve at an early stage and once these students reach at the graduate level they have enough taste and expertise in this area that they can play an active role and can be more productive in their work. Previously only a top-down approach was used for solid-state fabrication but there were some major limitations with that technique which made grounds for bottom-up fabrication process.

First, students are introduced to the fabrication process through the instructional manuals. This instructional manual is developed in a way to make it easy and understandable for K-12 students. Once students get some taste of these processes and concepts like photolithography, etching, self-assembly and deposition etc. they are involved in simple exercises so that they can get some hands-on experience of these basic concepts.

Figure 1. Module Design

Conclusion

To cope up with the fast moving technological developments and to make sure that we have well-prepared manpower to actively participate in emerging fields like nanotechnology, it is a very timely effort to familiarize and motivate youth with the basics of this field. The approach is very simple and doesn't require any sophisticated lab equipment.

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Extended Abstract with Poster

Auto-imaging, Predefined Stepping and Exposure through Submicron 3-Axis Inspection Microscope

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Abstract

This paper presents a simple and inexpensive design approach to provide 3-axis control of a legacy microscope with submicron resolution for live-cell imaging. Cell imaging is an essential tool in biomedical research, extensively used to analyze the building blocks of life. The imaging requires high-resolution microscopes that can scan large areas of cell populations. However, such microscopes have very limited field of view and can only image a small portion of the whole sample. In this paper, we describe the modifications done to a microscope to achieve an additional degree of freedom through an auto movement of stage and lens. It improves the speed of cell behavior analysis while decreasing operational errors. A digital logic circuit is designed and implemented to achieve this control. The circuit is composed of off-the-shelf components. A very accurate positioning of lens and stage and hence high precision and control of speed has been achieved. The comparison of legacy microscope that used a joystick, with the logic circuit accompanied with MATLAB code validates how our scheme provides automated and error-free control of the microscope movements. Instead of controlling the lens and stage manually, the technique only needs operator to input desired parameters in the program to scan a certain area of the sample.

Introduction

Live-cell imaging has become an important analytical tool for biologists. It is getting increased attention among life science and biomedical research communities. Submicron imaging is also used to obtain information on particle mobility and molecular interactions.[1] Scientists and researchers have been investigating cellular processes for deep understanding of disease progression, to design novel diagnostic approaches and to validate therapeutic methods. In this regard, microscopes have always played vital role. Increasingly complex systems like cell culturing in microfluidic environments also utilize live cell imaging. Temporal microscopy of live cells in combination with confocal fluorescence laser scanning microscopy has been shown to distinguish bona fide human induced pluripotent stem cells.[2-4] However, methods like membrane-integrated cell culture and realistic in vitro models require greater control over cellular imaging tools.[5] Furthermore, several microfluidic approaches that utilize either horizontally integrated membrane layers or vertically defined features can benefit from a precision microscope. Often it is important to image two different parts of the sample within a brief period of time. For example, fluorescence microscopy has been used for imaging superoxide formation in live cells; however, this method becomes challenging during analysis of cells that get readily oxidized.[6] It occurs because scanning two separate chips using two microscopes does not produce accurate comparative data.

These shortcomings of conventional methods can be eliminated if whole slide/chip scan can be automated for lateral movements as well as to remove imaging artifacts. Currently, basic microscopy functions are carried out manually that incorporate human errors, and thus normalization is lost. This paper presents a simple approach to image live-cells at high resolution over a large area. A microscope has been modified to achieve 3-axis control. Hardware and software have been developed to achieve precise positioning, stepping, and imaging at submicron resolution.

Materials and Methods

A control circuit was designed and implemented for the 3-axis submicron microscope. Previously, this semi-automatic microscope used a joystick to control its movements. This included movement of stage and the lens. The stage carrying the samples to be imaged could move in lateral directions (x-axis and y-axis). The lens could move vertically (up and down). Thus, the lens and stage altogether had 3 degrees of freedom. Human involvement was required to control the joystick, making the process slow as well as prone to errors. For example, moving the stage and the lens back to the same exact relative position required impossibly precise human control as well as some sort of markers on the sample. In the upgrade reported here, a control circuit was designed to eliminate such restrictions. The circuit brought additional functionalities to the system so that it could directly communicate with a computer and could be programmed to move the microscope stage and lens on a pre-defined path. This circuit was developed using inexpensive discrete components. The modified microscope required no direct hardware intervention by the user to move the stage and the lens. For repetitive experiments, this microscope brought the flexibility by programming once and letting it process on the predefined course.

System Block Diagram

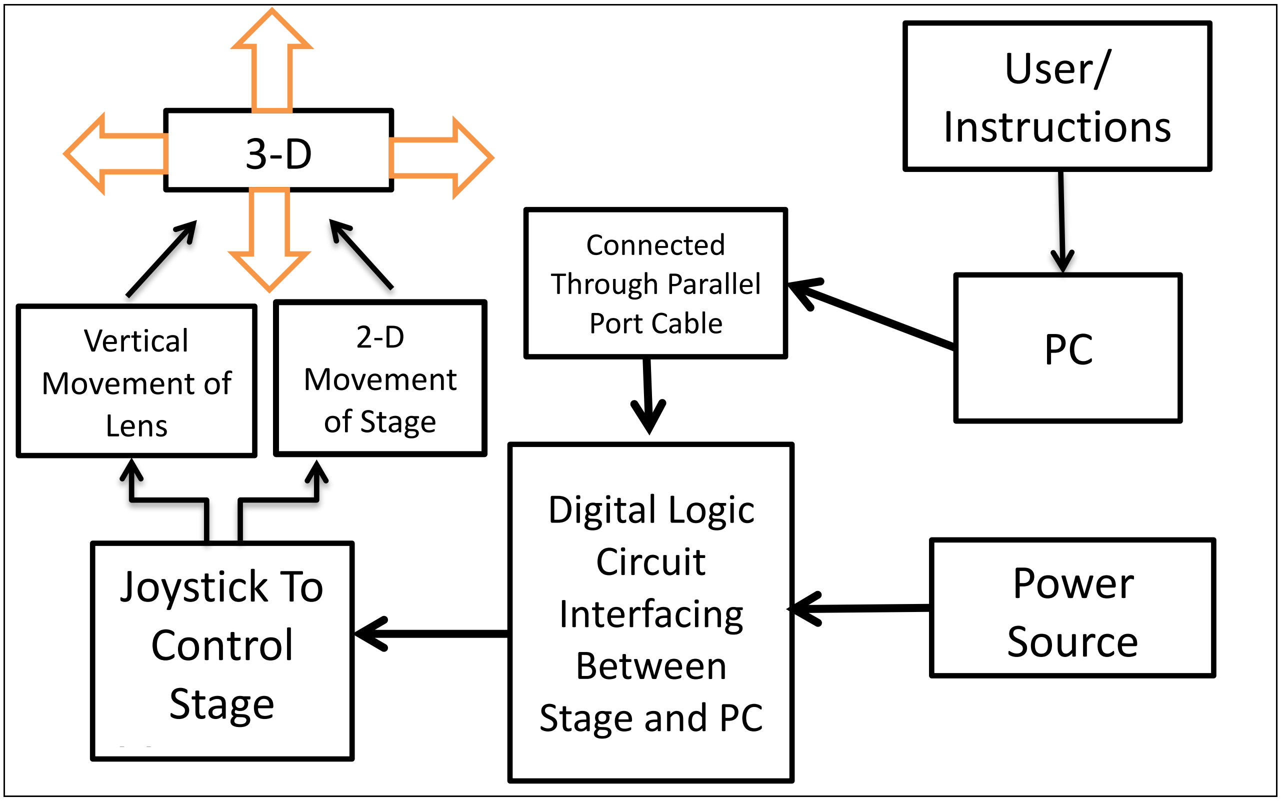


Figure 1. System hierarchy is represented in the block diagram.

A higher level system representation is given in Figure 1. To gain complete control over the movement of stage and lens, the mechanism of legacy joystick was investigated. The joystick had a complex voltage control circuitry to run the stage motors. In addition to the direction of motion of the stage and the lens, it also had a varying output voltage level that was used to control the speed of the stage motion. For our design, we eliminated the joystick variable power levels and used an external power source. We used a single voltage source to generate 3 different voltage levels using potentiometers and voltage regulators. A power source of 5 V and 0.25 mA regulated this control circuit.

Delivering the specific power from source was achieved with 2 8-1 Analog Multiplexers. These multiplexers delivered specific input power to the stepper motors of the microscope. Eight data pins of the parallel port were used for control pins of the analog multiplexer. These control pins selected the relevant power level for movement of the stage and the lens. The set of specific values was unique for all cases. These cases are given in Table 1.

Table 1. Settings of the eight data pins for specific movement of the scope.

Action	Data pins [d0 d1 d2 d3 d4 d5 d6 d7]
Stage moving towards positive y-axis	[1 1 0 1 0 1 0 0]
Stage moving towards negative y-axis	[1 0 0 1 0 1 0 0]
Stage moving towards positive x-axis	[0 1 1 0 0 1 0 0]
Stage moving towards negative x-axis	[0 1 1 1 0 1 0 0]
Lens moving towards positive z-axis	[1 1 0 1 1 0 0 0]
Lens moving towards negative z-axis	[1 0 0 1 1 0 0 0]
Both the stage and lens stationary	[0 1 0 1 0 1 0 0]

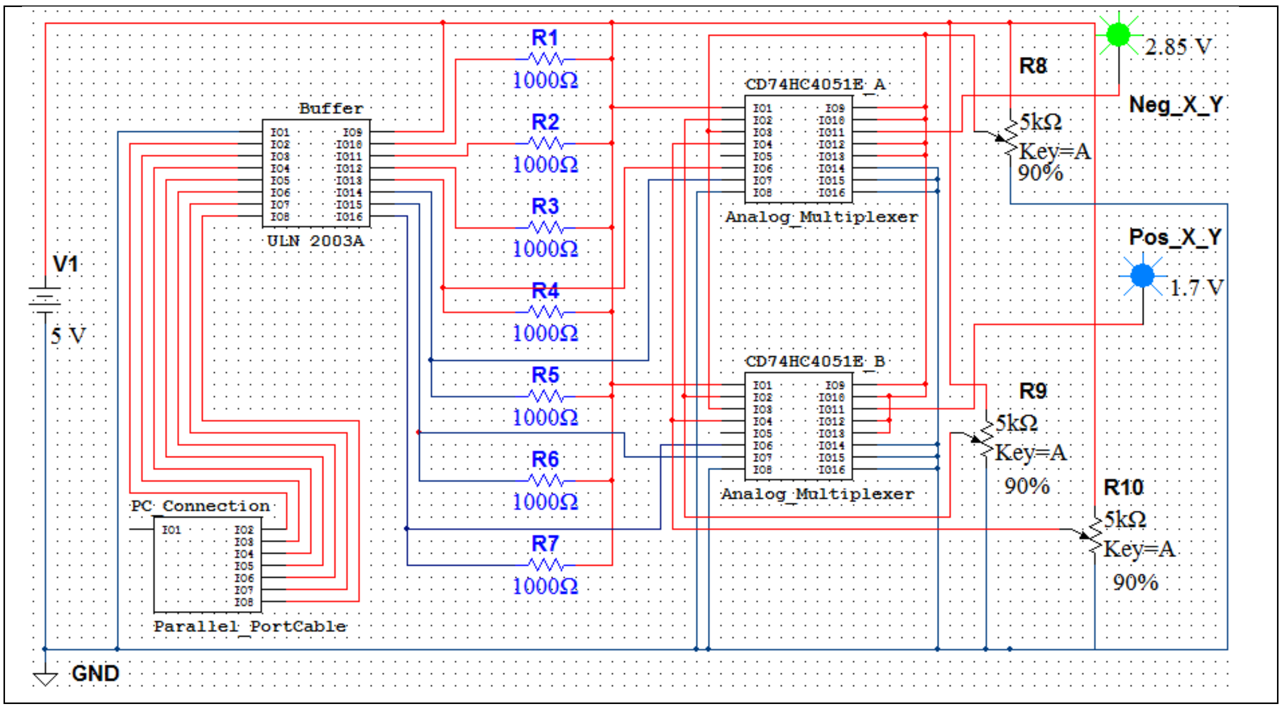
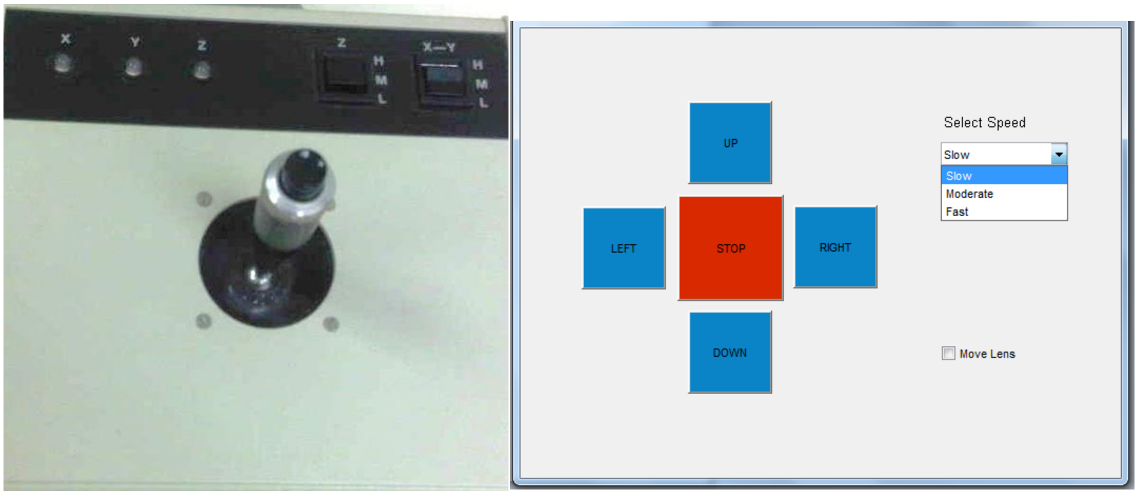


Figure 2. Input and output pin connections of individual ICs of 3-D microscope logic circuit.

Schematics

The schematic of the designed circuit is presented in Figure 2. This shows the pin-to-pin connections of integrated circuits (ICs) used in the presented work. The scheme required an operating power higher than what the parallel port of computer could provide. Thus, a buffer between the computer and the control circuit was necessary to isolate the parallel port from high current. A commercially available high voltage, high current, Darlington Array Buffer (ULN2003A) was used for this purpose. The buffer connected parallel port to the electronic circuit and acted as an electronic switch.



(a) (b)

Figure 3. (a) Mechanical joystick of the legacy system was used to control the stage and lens movement. (b) MATLAB GUI showing electronic equivalent of the joystick.

The system was controlled by routines developed in MATLAB. Figure 3 shows the legacy joystick and graphical user interface (GUI) made in the MATLAB to control the system. This integrated setup controls the three stepper motors assembled in the submicron inspection microscope. The flowchart of the software is shown in Figure 4. We can see that the 3D movement can track changes occurring in a living cell colony to observe and record specific behavior of cells. Such behavior is hallmark of cellular level diagnostics where live cell imaging can provide not only real-time data but the work presented here can increase the throughput of that data by imaging larger areas automatically. Capturing images of cells and then processing these images through image processing algorithms can provide a trajectory of cell behavior that can help physicians/researchers make quick decisions.

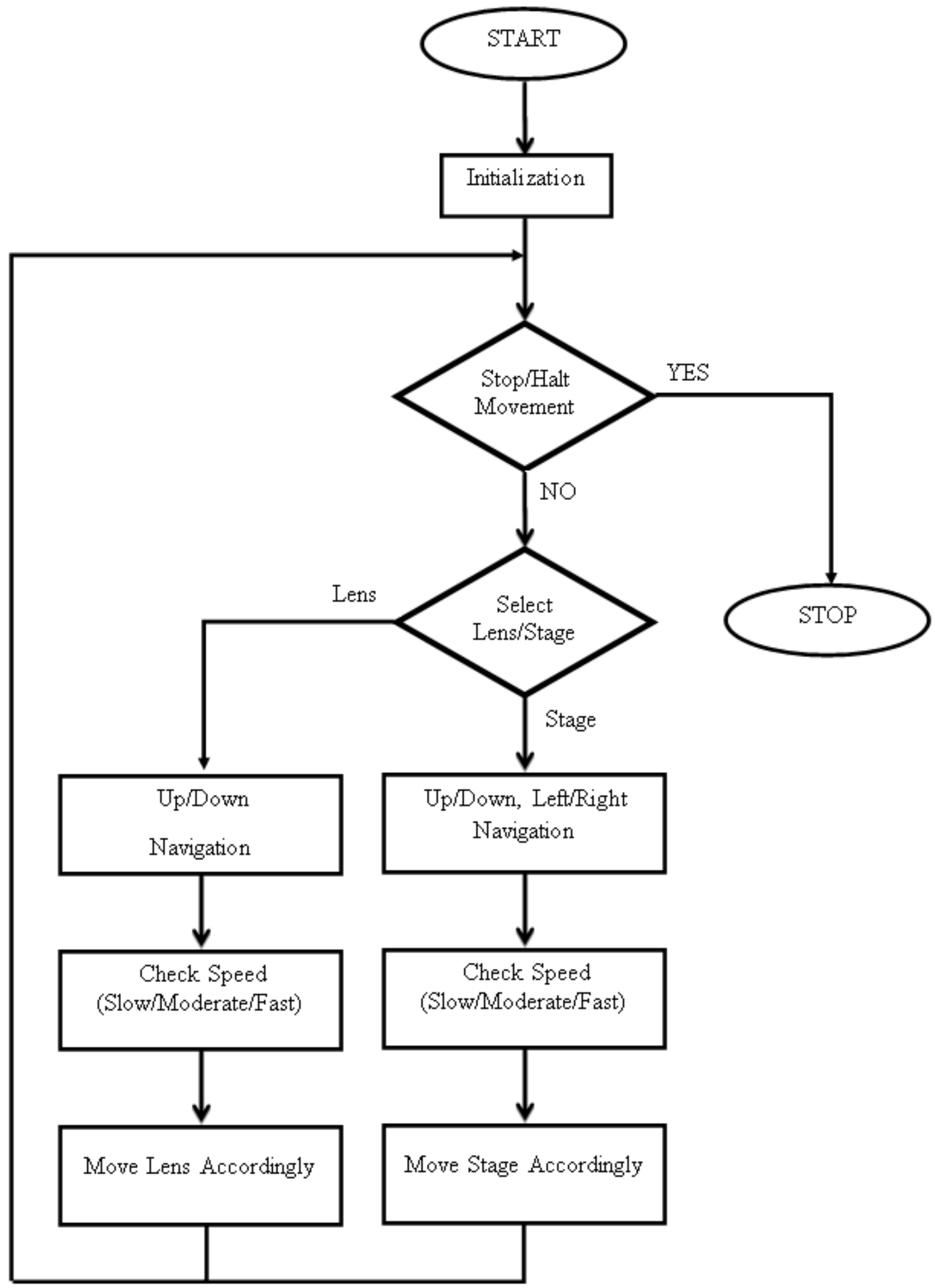


Figure 4. Flow chart of the MATLAB program shows the decision tree for the logic circuit.

Conclusions

An efficient system of auto imaging of live cells has been developed by integrating a simple logic circuit accompanied with MATLAB software. This system of live-cell imaging is fast and impervious to human artifacts. The logic circuitry can electronically move the stage and lens at submicron resolution. This approach has improved quality of work by taking less instructions and time from the operator. The electronic circuit has enabled automatic capturing of microscopic images for predefined exposure time at predefined steps. This fast and error-free method can be a special tool for biomedical researchers to extract essential information through auto imaging of live cells at high resolution. This can also lead to single-cell track imaging from a composite image for cell colony.

Acknowledgments

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Extended Abstract with Poster

Is Distance Education Distant Education?

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Extended Abstract

Distance learning engineering course offerings are increasing in popularity among institutions of higher learning. These courses are often viewed as a cost-effective mechanism to deliver engineering education to worldwide student clients. As such, distance learning (DL) initiatives such as the Massive Online Open Course (MOOC) offerings initiated at Stanford University are being adopted by an increasing number of academic institutions such as MIT, Harvard, UC-Berkeley, and more recently the University of Texas System[1]. In the wake of this rapid expansion of engineering course offerings through MOOCs and other distance delivery modes, it is imperative to address whether or not such online instructional tools are suitable substitutes for in-class learning. A perception among some engineering educators is that students taking classes by distance do not receive the same level of learning experience as the students in class[2]. As a result, the DL students' understanding of course materials is presumed to be inferior to those of in-class students.

This study sets out to test this hypothesis by comparing the grades of distance versus in-class students who took the same exams. The data covers four graduate-level courses taught by the same instructor over a period of four-years. The mode of instruction for all four courses was video-streaming the lectures for on-line viewing on a secured website. After viewing the lectures online, DL students interacted with the instructor by E-mail. All other course transactions such as submittal of homework assignments and term papers and the returned graded work were also conducted electronically. Exams were administered electronically through a third-party proctor pre-approved by the instructor. The proctors were typically a supervisor at the DL student's work place or another professional acquaintance of the instructor at the student's place of employment. The exams were E-mailed to the proctors who administered the exam at the satellite location and returned a pdf copy of the completed exams to the instructor.

Statistical analyses were conducted to examine whether there was any difference in the mean exam grades of the two groups of students over the four-year period. The exam grades are used

as a proxy for student's understanding of the course materials. Table 1 shows the mean exam grades of the two student groups in each of the four respective courses. As shown in Table 1, the mean grades of the DL students were by-and-large less than those of the in-class students. Therefore, a cursory conclusion could be that the DL students' understanding of the course materials is indeed inferior to that of the in-class students. However, the central question of this study is whether the observed differences are statistically significant. To address the above, a one-tailed hypothesis test is conducted with the null hypothesis being the exam grades are not different versus the alternate hypothesis that the DL grades are less than the in-class grades.

The group statistics for the DL and in-class grades, which formed the basis for the statistical tests, are summarized in Table 2. The results of the hypothesis tests are presented in Table 3. As shown in Table 3, the null hypothesis that the means are statistically the same cannot be rejected at either the 5% or 10% levels of significance which are typically used for these tests. In fact, the p-value corresponding to this test is 0.29, signifying that the mean grades of the two student groups (DL versus in-class) are statistically very close and that the null hypothesis cannot be rejected even at the 29% level of significance.

In conclusion, there appears to be no statistical difference in performance of the two student groups as quantified by their exam grades. It may be argued that the exam grades might not be an accurate measure of students' understanding of the course material. However, such grades have always been used by instructors as the key assessment measure for this purpose. Hence, it has been used in this study as a surrogate measure of understanding course materials. It should also be emphasized that the conclusions in this study are predicated on the specific distance learning delivery mode and student-instructor interactions described above and may not be valid for other types of delivery modes and interaction techniques. Although the majority of DL courses rely on the video streaming of lectures with web-based delivery, there is a wide variation in how the question and answer, homework assignments, project reports, and exams are handled. These latter elements may also play a significant role in the quality of instructions in DL classes.

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Table 1. Mean Exam Grades by Semester for In-Class versus DL Students in the Same Graduate Courses

Semester	In-Class Mean	DL Mean	P-value (1-tailed)
Fall 2008	88.60	88.67	0.493
Fall 2010	88.60	87.20	0.398
Fall 2011	81.00	78.75	0.394
Fall 2012	77.50	74.25	0.352
Total	84.10	82.13	0.293

Table 2. Group Statistics for Mean Grades of In-Class versus DL Students

	Groups	N	Mean	Std. Deviation	Std. Error Mean
Total Grades	In-Class	30	84.10	11.63	2.12
	DL	16	82.13	11.71	2.93

Table 3. P-Values for a 1-Tailed Hypothesis Test of Mean Grades of DL Students Being Less than Those of the In-Class Students

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	p-value Level of Sig. (1-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Total Grades	Equal variances assumed	0.138	0.712	0.547	44	0.293	1.975	3.609	-5.299	9.249
	Equal variances not assumed			0.546	30.55	0.295	1.975	3.617	-5.406	9.356

Extended Abstract with Poster

Using SPICE Schematics to Deliver the Essence of Microelectronics

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Abstract (Extended)

Microelectronics is an integral part of our fast-paced lives. Circuit designs for cutting edge devices change every day to accommodate newer innovations. For a novice designer, physical implementation of even a basic circuit requires certain expertise as well as expensive lab equipments. Fortunately, understanding the fundamental working principles of electrical circuits, starting from designing and implementing those to get some decent outputs can be done outside lab environment. Using ubiquitous computing resources it is possible to simulate simple to fairly complicated circuits. Several software are available for simulations and most of these are fairly intuitive. SPICE, Electronic Workbench, Multisim are to name a few. Softwares to carry out simulations (SPICE, NI Multisim, etc.) are used in industry as well. Most of these tools have student versions available as freeware. PSPICE is commercial software that is extensively used in industry. A student version of PSPICE is available to perform basic electronic circuit design. The freeware version allows limited number of nodes to simulate, but this is good enough to implement fairly complicated circuits. DC/AC circuits with basic understanding of voltage divider, current splitting, and Kirchhoff's laws can be constructed in SPICE environment. The working principles can be understood by investigating the outputs using probes at different nodes and branches showing the parameters of the circuit. The potential of this is not just limited here. Interested students can take their enthusiasm farther and learn advanced topics like basic high-pass, low-pass, band-pass filter design without having to do a formal engineering course. This can lead to designing of amplifiers with off the shelf components like operational amplifiers. The students can get a flavor of the analog world while understanding the basic principles of the devices used on day to day basis.

SPICE stands for *Simulation Program for Integrated Circuits Emphasis*. This simulation tool was developed by Lawrence Nagel and coworkers as a circuit simulator at Electrical Engineering and Computer Science Department of the University of California, Berkeley and was announced on April 12, 1973[1]. From there it flourished and newer device models have been added on regular basis. Many other specialized simulators have been designed subsequently; however all other design tools used for such simulations still roughly follow the format of original SPICE.

Core SPICE program is text command based. A much user friendly PSPICE was initially developed by Microsim Corporation in San Jose, CA, which was later acquired by Cadence Design System, Inc. PSPICE provides a user-friendly graphical interface for circuit design. A student version with certain number of maximum nodes is available for free that can be used by students as learning tool.

SPICE can simulate circuit operations using basic components like resistors, capacitors etc. Included library provides a pool of component models that can be built into circuits. Enthusiast and hobbyists can design and modify circuits, and test output stability before implementing with physical components. At high school level, basic circuit elements are usually introduced whereas physical implementation requires lab facilities as well as expert supervision. Introduction to SPICE can give students an easy and at-home access to the amazing world of electrical engineering without going through the cost, infrastructure and potential electrical hazards. This can bring significant amount of savings in terms of time and money. SPICE can give potential engineering students deep insights and confidence before entering to college environment. SPICE is a well documented software package with numerous, well explained and easily accessible tutorials, both in written as well as in video format [2-4]. The graphical user interface of SPICE Schematics is very intuitive and the procedures resemble closely to the real lab situations. Hence it is easy for any beginner to familiarize with the environment.

The basic steps for a successful simulation are illustrated in Figure 1. Like any design problem, a few error-corrections, adjustments of parameters or even modification of the initial circuit diagram may be required. Although not very difficult, the text-based input method can be a little intimidating for a beginner and hence it is not focused in this paper.

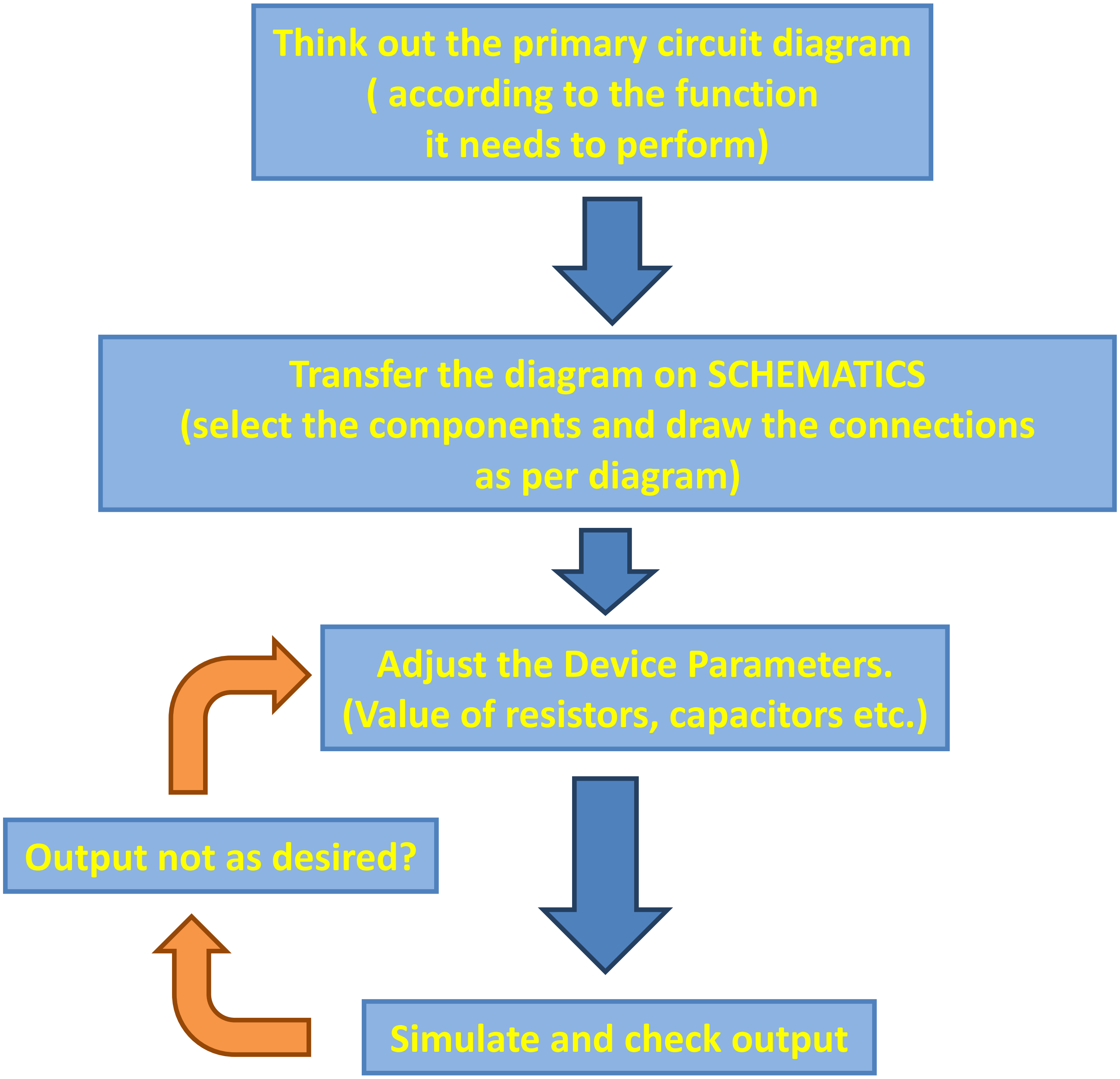


Figure 1: Basic Steps to setup a SPICE simulation.

The graphical user interface (GUI) of SPICE for circuit simulation is called SCHEMATICS. It gives a drawing area for circuit design and implementation. One can choose the components from the given pool and place it on the drawing area by selection. Components are well arranged and categorized in the SPICE library. A large number of component models are available in the default pool, ranging from resistors to commercially available integrated circuits (ICs). These models are usually provided by the component manufacturers. Dependant sources with user customizable parameters are available for advanced users and can be used towards designing modular circuits as well as device models [5, 6]. Connections between the circuit elements can be established using simple mouse click and draw. Circuit parameters can be changed with easy interface and hence provide flexibility of design and modification.

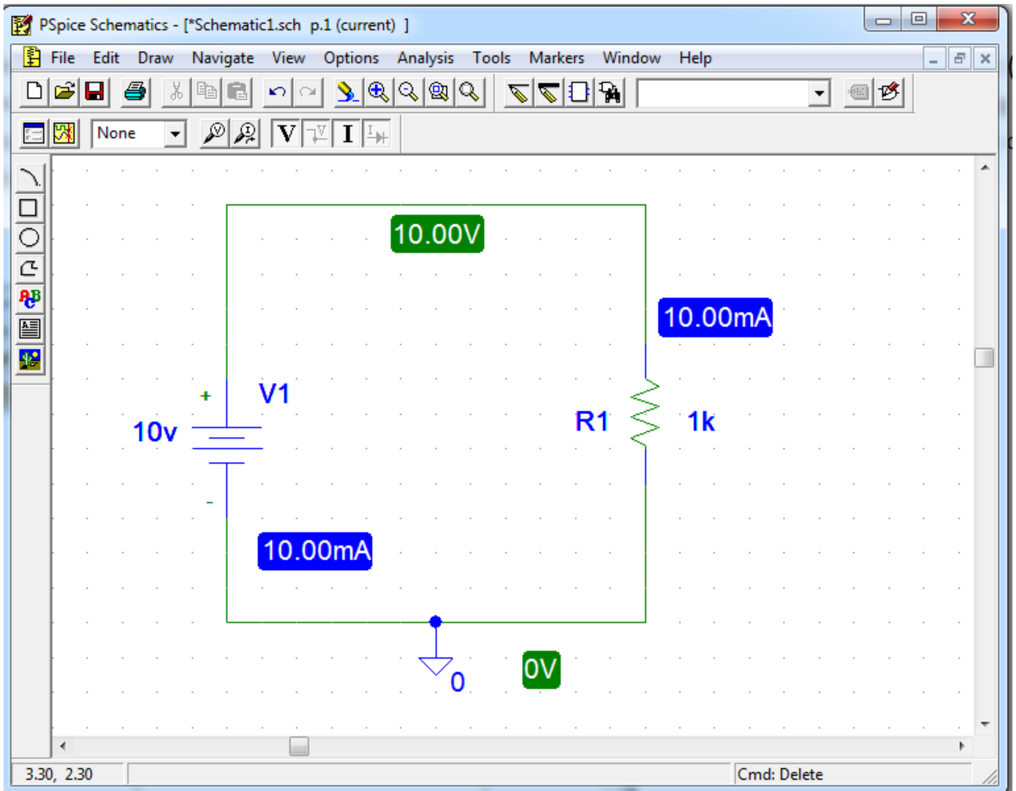
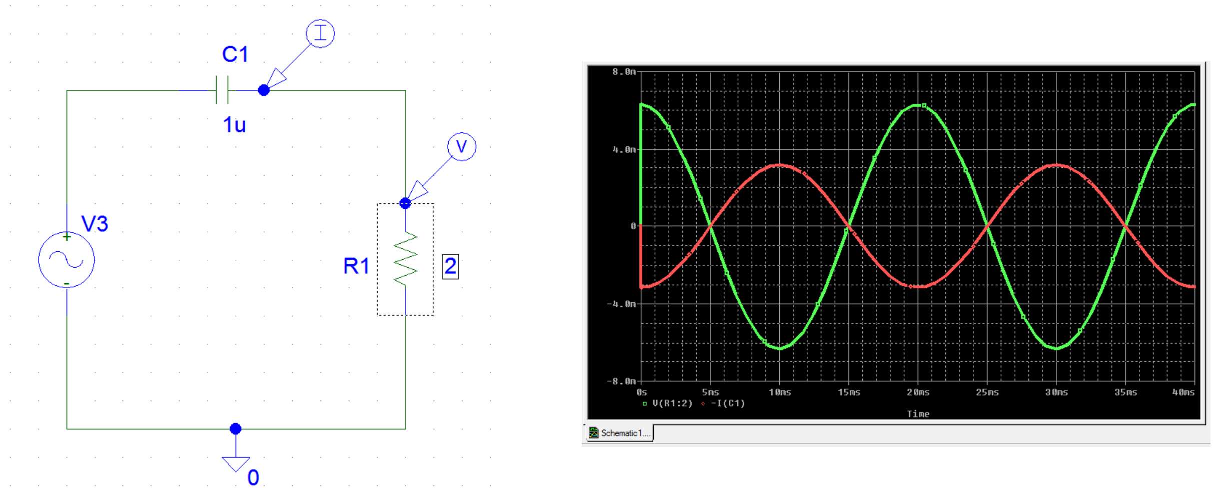


*Figure 2: Drawing space of the SCHEMATICS. Well laid out buttons provide easy access to numerous features from selection of components to one click simulation. Complex functions are also provided for advanced users. In the above figure, a 10 Volt DC source is shown connected to a 1 K**Ω** resistor. In SPICE, a reference voltage needs to be defined and hence placed here at the bottom. After simulation, the output voltage at different nodes and the current flowing in the branch (in this case 10 mA) are displayed with proper units. The outputs are similar to the result one would see using physical Voltmeter or Ammeter. One can easily observe from the output quantities how voltage and current follows Ohm's law.*

Simple DC circuits can be constructed using constant voltage sources and resistors (Figure 2). After simulation one can observe Ohm's law relationship between voltage and current in the circuit elements. Ohm’s law is the foundation of electrical engineering. The series and parallel combination principles of the electrical components can be investigated. One can also observe the voltage divider law or current divider law by simple modifications of the circuits. This gives students an intuitive idea of how electric current and potential works in the circuit. Slightly advanced users can extend these ideas using dependant sources.



(a) (b)

Figure 3: (a) A simple AC circuit connected with a capacitor and a resistor. The voltage and current "probes" are connected to the circuit. The output voltage and current are measured at these points. (b) Shows the voltage and current in the output window. The Green and Red graphs represent voltage and current, respectively. The phase difference of a typical AC circuit is noticeable in the output.This probe window closely mimics the expensive oscilloscopes commonly used in the laboratories. The output parameters can also be programmed to find, for example, voltage difference between two specific nodes etc.

AC sources are ubiquitous in our everyday life and sinusoidal AC sources are provided within the SPICE component library to manipulate as desired. Voltage amplitude, phase and frequencies of these sources can be adjusted and optimized accordingly. Root mean square (RMS) output, as well as time varying outputs can be investigated by putting "probes" at different points in the circuit (Figure 3). Probes facilitate output display in graphical format. Features like AC sweep, where amplitudes and frequencies of the sources can be varied smoothly over a range, make it easy to check device performance and optimize the design. For example, using this feature on can investigate the working principle of the very important class of circuits like "Filters". One can investigate the output with varying parameters and pick the most suitable one for the design. These features are in fact much easier to implement on SPICE environment than in physical labs, facilitating faster design and optimization of time. This alleviates need for expensive oscilloscopes, frequency generators, power supplies, etc.

A vast range of analog electronic circuit components are found in the SPICE library including diodes, bipolar junction transistors (BJTs), or metal oxide field effect transistors (MOSFETs). For curious students it is easy to build simple electronic circuits like rectifiers using diodes for AC-DC conversion and check the output as desired. Without delving into the device theory and based on the working principles one can design many such useful and everyday devices. Experiment like this with physical devices involve electrical hazard which is avoided in SPICE environment without compromising the design experience. Accomplishments like these can certainly encourage students towards pursuing an Engineering degree while making them confident towards working in a physical lab.

Many commercially available and highly customizable ICs are included in the SPICE library. For advanced users, this will provide a way towards designing many interesting circuit implementations (Figure 4). Hobbyists have been building such circuits for long and SPICE platforms can immensely increase the flexibility of their design and experiments. For example, SPICE includes several commercial versions of operational amplifiers (Op-Amp). These are fairly simple devices but can be manipulated to design a range of circuits with very useful functions like amplifiers, adders, integrators and active filters, etc. It is also possible to make modules using basic electronic devices or ICs, giving students a flavor of how to design modern ICs and a peek in the Large Scale Integration (LSI) world.

Introduction to digital logic gates and their implementation is important as first glimpse into the working of computer systems. These can be introduced without much background of the analog devices (Figure 6). SPICE environment has a pool of logic gates including AND, NAND, OR, NOR, X-OR etc. One can design simple circuit like a basic binary adder to fairly complex circuits like Arithmetic logic Unit (ALU) and even 4-bit computers using the student version of SPICE. Such playground of digital circuit design can open new horizons for young students in computer engineering.

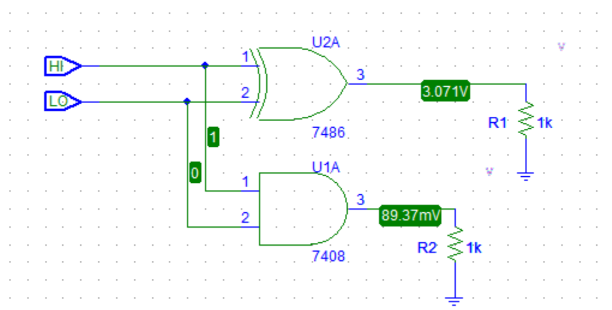


Figure 4: Binary adders take two inputs in binary form and display the output after binary addition. A binary adder circuit employing an XOR and an AND gate is shown above. With the digital inputs provided, the output is shown as analog voltage. This adder is the building block for modern central processing units. Combining this with the clock/timer circuit can give an idea of how modern computers perform binary calculations.

SPICE can provide a very effective introduction to electrical engineering and electronics for young students. They can develop simple skills related to circuits with a head start in their engineering endeavors. The student version is sufficient enough for users ranging from beginners to enthusiasts. With the vast arrays of tutorials, instructions and discussion forums available online, and with the processing power of a modest computer, one can implement decent circuits to learn the underlying principles. Minimal supervision is necessary to setup these circuits in SPICE. This in home simulation tool can be very useful for directing a new generation towards engineering.

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Extended Abstract with Poster

Study on Tube Hydroforming Process using Finite Element Analysis and Experimental Validation

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Extended Abstract

At present, tube hydroforming process has drawn increasing attention from automotive, aerospace, and shipbuilding industries because of its unique advantages over the traditional forming process. For example, it is well known that the hydroforming process can effectively reduce the overall weight of the formed part as well as the number of steps required for making complex shapes. Hence, such process keeps the tooling costs and the component production costs low. The tube hydroforming process is mainly used to make tubular products with varying cross-sectional shape along their longitudinal direction. During the process, a tube is first placed in the closed cavity of a forming die. After sealing both ends of the tube, the hydraulic fluid is then injected into the tube and the tube is formed according to the shape of the die cavity.

This study investigates the effects of material properties and frictional parameters on a hydroforming process that includes performing and crushing. The effects of flow formulation in analytical analysis of the tube hydroforming process are also discussed.

The tube material used for this study is stainless steel SUS304. The material's flow stress is defined through a power law of its equivalent strain, $\bar{\sigma} = K\,\bar{\varepsilon}^n$, where K = 1452MPa is the strength coefficient and n = 0.6 the strain-hardening exponent. Other properties of SUS 304 include: Young's modulus E = 200GPa, Poisson's ratio ν = 0.3, and density ρ = 7800kg/m^3. Material's anisotropy in longitudinal and hoop directions is evaluated through incremental ratios as:

$$r_x = \frac{d\varepsilon_{22}}{d\varepsilon_{33}} \quad , \quad r_y = \frac{d\varepsilon_{11}}{d\varepsilon_{33}} \tag{1}$$

The geometric dimensions of the tube are: outer diameter D_o = 94mm, wall thickness t = 1.28mm. The distance that side dies move during the performing step is 17mm, the distance in which upper dies move down is 17mm. The radius of the side die is 15mm, the length of the upper die is 90mm, and its width is 60mm. Fig. 1 sketches the configuration of the tooling.

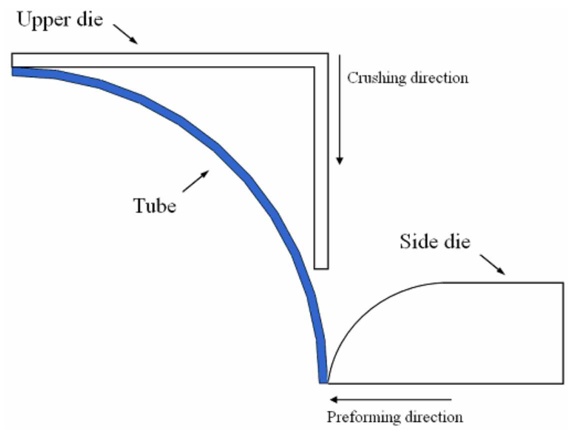

Figure 1. Configurations of the tube and dies

Pressurization curve during the expansion and crushing in this hydroforming process is displayed in Fig. 2.

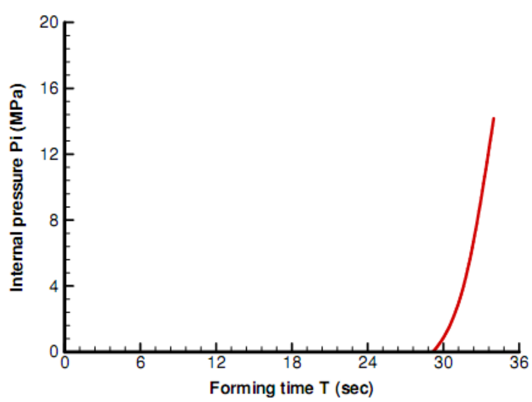

Figure 2. Pressurization curve during expansion and crushing processes

In the entire process, the first time period is from 0 to 17 seconds corresponds to the movement of the side dies during the performing step, and the second time period is from 17 to 34 seconds refers to the movement of the upper dies during the crushing step. The velocities of the side and upper dies are set to be 1mm/s, therefore the distances that both dies move during the performing and crushing steps can be precisely controlled at 17mm when the two time periods are set as 17s.

The movements of the dies are described as follows: in the performing step, the side dies move 17mm inwards during 17s and immediately move back to the original position at the end of the time period; at the same time the upper dies begin to perform the crushing operation at a total stroke of 17mm from 17s to 34s. As reflected in Fig. 1, the internal pressure of the tube appears at t = 29s, which means that the internal pressure does not appear during the performing (movement of the side dies) as well as the early stage of the crushing (from 17s to 29s). At t = 29s, when the upper dies move 12mm downwards, the internal pressure begins to be applied inside the tube and increase gradually while the upper dies continue to move down until the maximum stroke of 17mm is reached. The internal pressure is applied during the late stage of the crushing (after 29s till 34s) to prevent the performed tube from returning to its initial circular shape, thereby avoiding pinching of the tube between the upper and lower dies. The applied internal pressure will also flow the tube material into the corners of the dies as much as possible.

FEA software package ABAQUS is used to model the tube and simulate the hydroforming process. A linear 4-node element that uses reduced-integration (CPE4R with hourglass control) is used to model the tube. Fig. 3 shows the FE tube model is in contact with an upper die, which includes 705 elements and is meshed following the algorithm of advancing front.

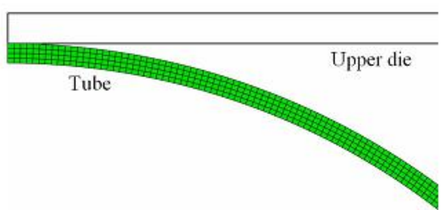

Figure 3. Finite element tube model

After implementing the flow formulation and applying appropriate boundary conditions, the presented FE model is used for numerical analysis through ABAQUS.

From the FEA results it can be observed that during the performing-crushing-hydroforming process, as the strain hardening component reduces, the strength coefficient and anisotropy in X direction increases, the material flows better through the die cavity and the relative thickness along the tube becomes more unified. The anisotropy in Y direction, however, has no obvious influence on the thickness distribution. As shown in Fig. 12, when the friction coefficient increases, the amount of material that flows into the die cavity decreases and the local thinning increases, hence the die filling also increases.

In this study, the effects of material properties and friction coefficient on a performing-crushing-hydroforming process are investigated. Important parameters discussed in this study include the strain hardening component, strength coefficient, and anisotropic in X (longitudinal) and Y (hoop) directions. The effects of those parameters on the tube's thickness distribution and corner filling are revealed. Through the numerical simulation it is found that when the value of the strength coefficient increases or the value of strain hardening component decreases, the distribution of the thickness along the tube length is more uniformed and the radius of filling of the corner decreases. Also by increasing the value of anisotropy in X direction the magnitude of tube wall thinning is decreased while the radius of filling of the corner is decreased also. It should be noted that variation of anisotropy in Y direction doesn't have any sensible effect in the thickness distribution and die filling. As the friction between tube and die increases, the local thinning along the tube increases and the flow of material through die decreases also.

Afterwards, the effect of flow formulation in the analysis of tube hydroforming process is studied by comparing the results obtained from the flow formulation to those from the solid formulation. Flow formulation is implemented in a numerical code, SPID, for an axisymmetric bulge simulation. The simulation results are compared to those obtained from ABAQUS which uses the solid formulation. The comparison shows that the results from the flow formulation in the process that undergoes large plastic strain are in good agreement with those from the solid formulation, except that the stress values in the direction perpendicular to the direction of material flow are lower than those evaluated using the solid formulation. In general it can be concluded that the flow formulation is suitable for processes that experience large deformation. For other process where the large deformation is not involved, the flow formulation will lead to considerable errors, especially in predicting the stress distribution.

Keywords: tube hydroforming process, performing-crushing processes, flow formulation, solid formulation, finite element method, numerical simulation.

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Extended Abstract with Poster

Two dimensional Maxwell Plots for a single, double, and triple Gas Electron Multiplier (GEM) X-ray fluorescence gas detector

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Southern University

Extended Abstract

We built a fluorescence gas X-ray detector using a single, double, and triple Gas Electron Multiplier (GEM) enclosed in a multiple Plexiglas flanges. The GEM is made of two thin perforated copper electrodes separated by a Kapton as an insulator [1]. The detector consists of three regions: an ionization, amplification, and collection regions placed one on top of the other separated by the Plexiglas flanges as in Figure1(a, b). All parts of the detector are held together using O-rings to provide gas leak free detector. Argon gas mixed with Carbon Dioxide in the ratio of 80/20, used as a detecting medium, is allowed to flow through the detector at a slow flowing rate. Three electric fields are created in each region of the detector, the highest electric field exits in the amplification region where the GEM is located. When a fluorescence X-ray from a test sample interacts with the flowing gas, ionization of the gas takes place. The primary ionized electrons from the ionization region are drifted by a small electric field into the GEM area where the high electric field generates more electrons by impact ionization. The perforated GEM allows the primary electrons to enter and leave after multiplication in the GEM towards the collection region. We have generated two dimensional Maxwell SV plots that were used to generate both the electric field and the equal potential lines for the three regions of the detector. These differences in magnitudes and functions of the electric fields, in each region of the detector, are made because of the variable values of the potential differences applied between the consecutive conducting electrodes. The lowest negative DC high voltage is applied at the Mylar window as in Figure 1a. The first GEM is placed below the Mylar window. Consecutive GEMs are placed below each other with respect to the Mylar window as in Figure 1a. The voltage at the top of the GEM is always lower negatively than the bottom of the GEM. This is to provide a voltage difference to create an electric field. The direction of the electric field points upward towards the Mylar to allow the negatively charged electrons to flow downwards towards the GEM and finally to the collection region. The first electric field is between the Mylar and the top of the GEM, in the drift region. The second electric field is between the top of the GEM and the bottom of the GEM in the multiplication or amplification region. The third electric field is between the lower electrode of the GEM and the printed circuit board (PCB) known as the collection region.

The intent of this extended abstract is to plot the electric field, equal potential lines [2-4], and to demonstrate how the primary electrons generated from the fluorescence X-ray of the dilute test sample are drifted in the first region of the detector, amplified in the second region of the single GEM or multiple GEMs, and then collected by the third region of the electric field towards the printed circuit board (PCB) for further electronic amplification and processing of the data. For more noise free amplification of the primary ionized electrons multiple GEM are added below the first GEM. Both the equal potential and the electric field lines for each region are plotted using Maxwell SV two dimensional plots for single, double, and triple GEM X-ray fluorescence detector. The software is a free download from the internet [5, 6].The two dimensional Maxwell software helps to provide a physical picture of the electric field and the equal potential lines in the three regions of the detector as in Figure 2 (a, b).

An enlarged and a zoom in plots of the equal potential lines and the electric field within the GEM are shown in Figure 3(a, b). This is the main region of amplification of the primary electrons generated by the fluorescence X ray emitted by the test sample.

Similar plots and results are obtained for the double and the triple GEM detector. For the double and triple GEM detector we add a second GEM below the first GEM for the double and we add a third GEM below the second GEM to form the triple GEM. Each GEM provides its own amplification that is similar to the GEM before it. However, the numbers of the electrons that are amplified in the first GEM are further amplified by the second GEM. Furthermore, the third GEM amplifies the amplified electrons from the second GEM. The intent is to obtain multiple amplifications of the primary electron signal without any noise. This improves the signal to noise (S/N) ratio that is badly needed when testing dilute elements producing very small primary electrons during X-ray absorption spectroscopy (XAS). For lack of space, in this extended abstract, the Maxwell SV plots for the single and triple GEM are not shown.

We obtained results from the actual test experiment using a single GEM X-ray fluorescence detector for a dilute sample, a leaf of tree as in Figure 4. We have used NSLS synchrotron facilities at Brookhaven National Laboratory in Long Island, New York. The single GEM provided a relatively good scan for Iron (Fe) in a dry tree leaf.

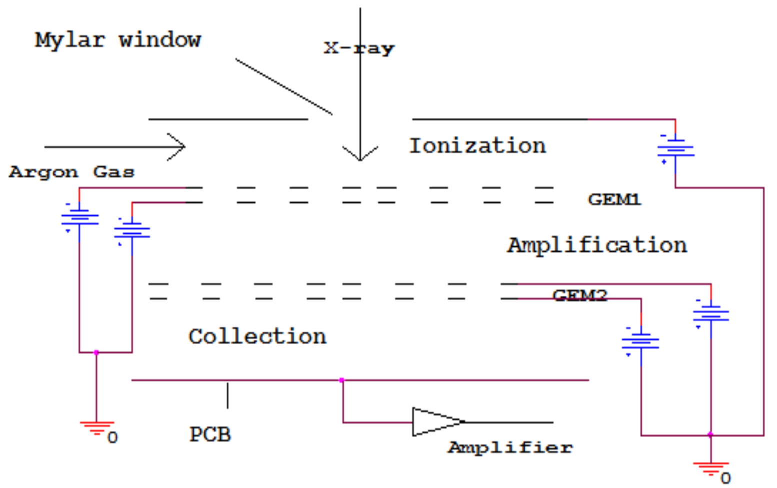

Figure 1a. The double GEM detector sketch showing the Mylar, the GEM and the PCB Board with HV DC biased sources and the electronic amplifier

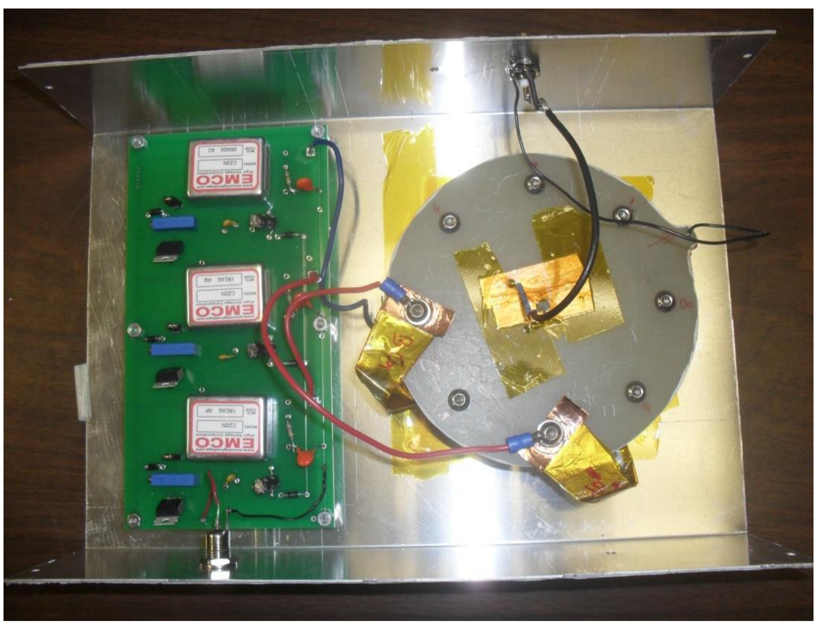

Figure 1b. The actual single Gem detector assembly with a built-in HV DC sources for the Mylar, upper and lower GEM electrodes voltages

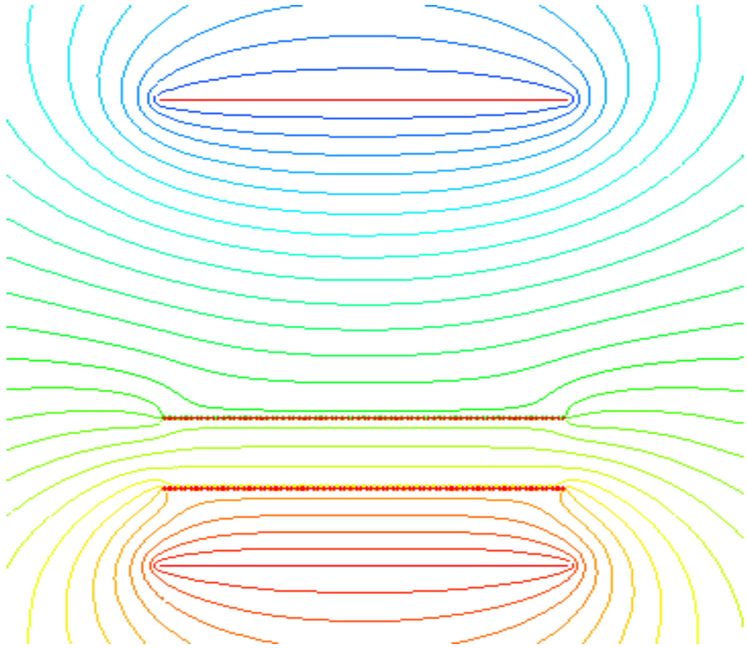

Figure 2a**.**The exact geometrical drawing of Maxwell SV for a double GEM using Maxwell SV showing the potential lines for both the drift and the collection regions.The Mylar, the GEM, and the PCB are shown as horizontal straight lines. The contour lines are the equal potential lines.

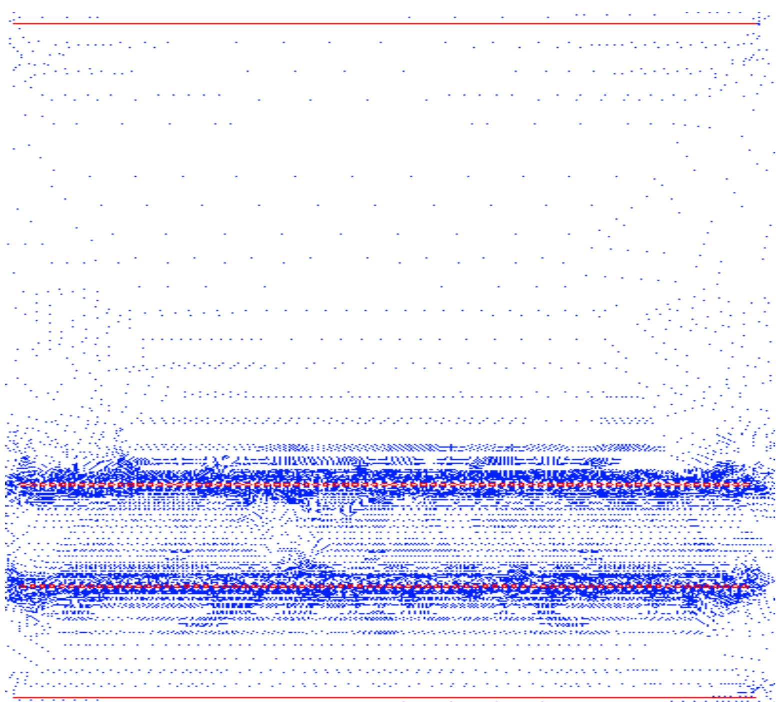

Figure 2b. The electric field lines for a double GEM showing the drift, amplification, and collection regions. Notice the concentration of the Electric field within the GEM holes. The Mylar, the GEM and the PCB are shown.

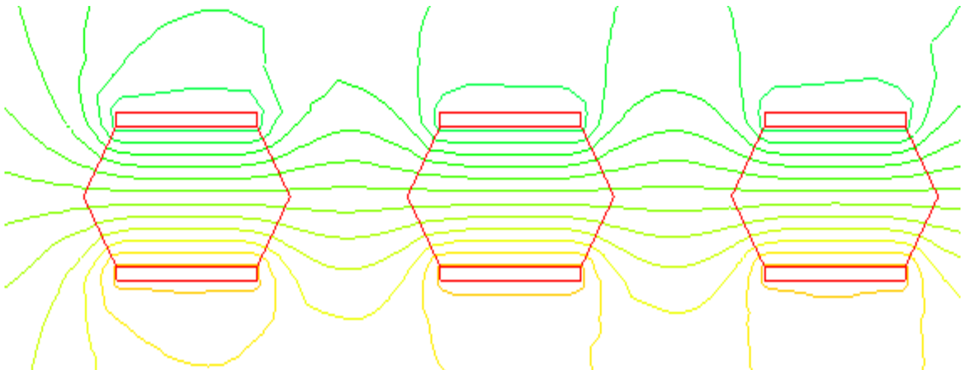

Figure 3a.The equal-potential lines within the GEM enlarged.

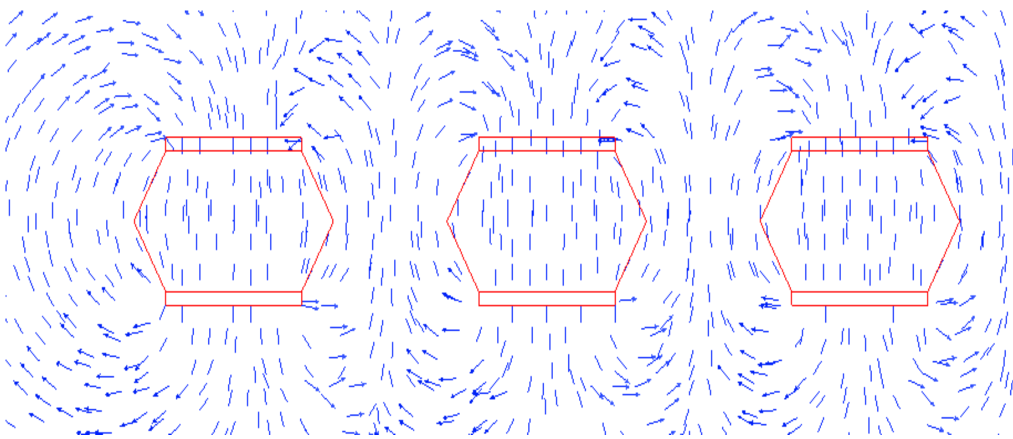

Figure 3b.The Electric field lines and direction within the holes of the GEM enlarged.

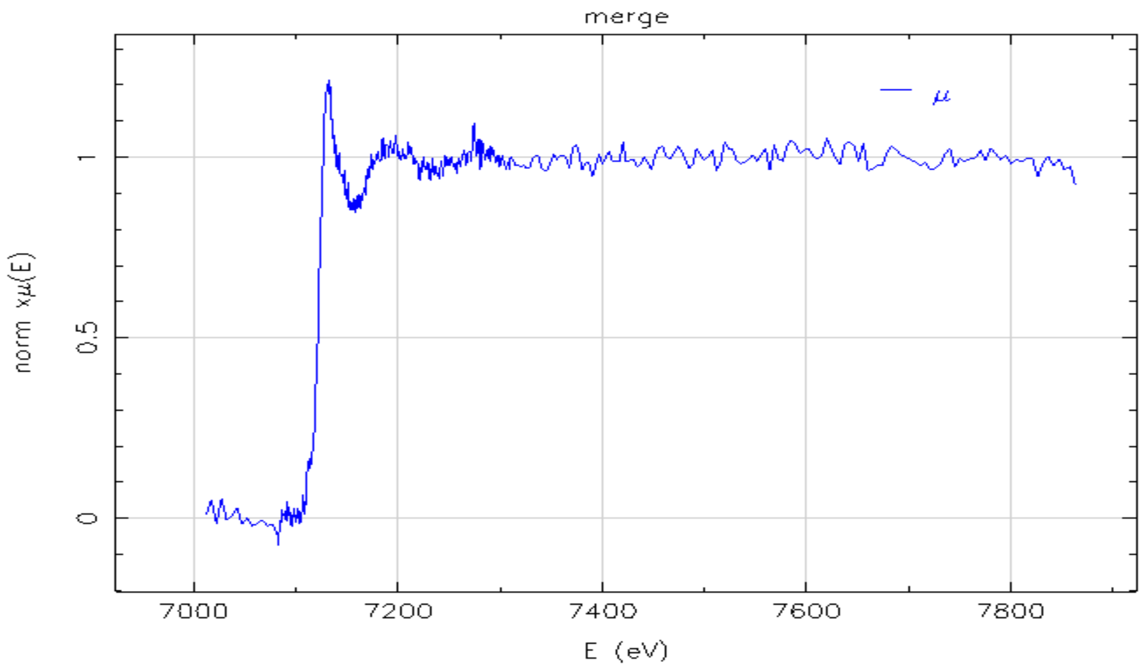

Figure 4. A single GEM 10 cm x 10 cm, X-ray fluorescence detector scan for an arbitrary leaf of a tree.

Summary and Conclusions

In this paper we have made a detailed plotting of both the electrical field distribution and the equal potential lines for a double GEM X-ray fluorescence detector using Maxwell SV software. These plots show clearly the concentration of the electric field in the amplification region within the GEM holes. Multiple GEMs allow further amplifications as the amplified electrons move from one GEM area holes to another GEM area holes. The advantage of multiple GEM is that we can decrease the magnitude of the Electric field in each GEM so as to avoid gas discharges breakdown and the creation of sparks that completely destroys the GEM and voids its use as an amplification region.

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6. Free download **ansoftkoreamaxwell**sv download Files at Software Informer - **Maxwell** Render™ is a new render engine based on the physics of real light.

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Extended Abstract with Poster

An iPhone Application Developed for Time Study Practice

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Extended Abstract

Tools developed for the engineering professional often don't work well for teaching purposes. The cost/benefit ratio is usually very high considering the limited amount of a semester in which the tool would be useful. In learning situations instructors often want students to not only gather data but also to complete calculations and evaluate the results themselves. This allows the student to understand why equations are derived in the way that they are so that they may alter those equations if the need arises. Those options are not usually available in off-the-shelf software. Professional tools are usually designed to not only gather data but to also complete the calculations for the professionals using them. For these reasons the author developed an iPhone application developed for students in an Industrial Engineering Metrics & Measurements class. The application is a data gathering and reporting tool for direct time studies. It requires the user to make all relevant calculations. This extended abstract describes the need for and the advantages of using mobile class applications developed for teaching purposes. It also describes the author's experiences in developing one such application.

Engineers are, at the core, problem solvers. Engineering educators spend a lot of time in the engineering curriculum teaching aspiring engineers the algorithms, heuristics, and methods to solve problems for a given set of data. We typically give them a problem in a nice, tight paragraph which has all of the variables needed to solve the problem. Their goal is usually to find the right method, plug in the given variables and get an answer that matches the one in the back of the book. If only the real world were so easy! Real world problems don't come with a paragraph summarizing the problem and the few variables required to solve it. The professional engineer must usually gather data in order to determine the cause of the problem as well as gather data on each of the variables needed to solve the problem. Mobile devices are a great tool for a variety of data gathering applications. There are many mobile applications on the market developed for the professional engineer. Most of the tools though are not very practical for the student engineer.

Applications developed for professional engineers are usually designed to not only gather data but also to internally manipulate the data through the required algorithms and produce an output that can then be used by the engineer. If students use these same applications they aren't given the opportunity to practice using the data. While the practice of gathering of data is important, an important goal as engineering educators is also to teach the algorithms, heuristics and methods. Students need to understand what goes on in the "black box" and why. They need to know the algorithms so that they can change them to fit a specific situation or understand the type of data that needs to be gathered and why it needs to be gathered. If an application allows the student to skip this very important step they are not learning all that they need to learn. Professional applications are also typically very expensive. We may only be teaching a topic for a week or two a year before we move on to the next topic. It's impossible to justify the cost of most professional applications for this very limited use.

Unfortunately there are very few mobile apps developed with the engineering student in mind. Amateur app development is a useful solution for engineering educators who view this absence in the market as an opportunity, as opposed to a problem.

The mobile app arena has opened up opportunities for individuals to develop and distribute software that didn't previously exist. The cost and time commitment to develop is relatively low. Amateur developers can take an app from idea to distribution in a matter of months, even without much (if any) programming experience. Developing allows the engineering educator complete control over the features that are in or are left out of an application. This allows us to teach students all aspects of the problem solving cycle. Applications can be customized to an educator's own wants, needs, experiences, formats, input types, or output types.

The author's experience in teaching an industrial engineering Metrics and Measurements class led to the development of a mobile app developed specifically for classroom use. Time & Rate is an iOS app written for students to learn and practice performing direct time studies. It was developed, because of need, to be used in the classroom and was customized as such. The app is a data collection tool only; it leaves all calculations up to the student. Prior to designing this application, the author had no C, Objective-C, or C++ programming knowledge and didn't even own a Mac. The timeline of the entire development project from purchasing the Mac to seeing the app appear on iTunes was three months working entirely after work hours and on weekends. The cost to develop the app including the computer, the developer license, and the LLC creation was around $2000.

Time & Rate has been in use for several years. The app is not required for coursework. Students who own an iOS device and want to use the app may do so. Students who do not own an iOS device or who don't want to use it are allowed to use mechanical stop watches provided in class. This increase in tools has allowed for more efficient lab work experiences without any increase in resources needed to be provided by the school. Students feel like they are getting introduced to a tool that will be useful to them after graduation while still getting a chance to practice all of the knowledge necessary in the classroom. The quick and low cost development cycle has allowed the developer/educator to provide the tool to students at a very low cost ($2.99 per student) compared to the professional tool that had previously been used which cost the department over $1000/year in licensing costs to maintain.

Engineering educators who would like to give their students a real world data gathering experience while still requiring the classroom calculation practice should consider educational mobile app development. There are endless opportunities to develop tools to prepare our students to be successful engineering professionals.

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Extended Abstract with Poster

Fall Semester Mini-Project: Reverse Engineering a WWII Fighter - The North American P-51D Mustang

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In the fall of 2012 the senior design capstone class has been assigned a semester mini-project that challenges the students to reverse engineer a high performance WWII fighter aircraft. The capstone course mini-project experience during this first semester has been initiated to teach students when and how to operate disciplinary design tools that prepare them for design trade-studies they will encounter in the second semester senior design project. The class has been divided into three groups of 14 people and assigned the Messerschmitt Bf 109, Supermarine Spitfire, and the North American P-51 Mustang. This paper is the story of the group that focuses on the North American P-51 Mustang. The engineering team first forms a methodology that parametrically reproduces the documented aircraft performance specifications; the simulation results are validated by direct comparison with historical data found in research; this validation step enables them to calibrate the tools used to achieve an appropriate accuracy. Throughout the course of the project students are able to first-hand understand why certain design choices have been made with the P-51 engineering team from the 1940's; the capstone team is in the position to offer insight on how those legacy decisions could be improved using technology from the 21st century. The first step in the project is to choose and introduce the P-51D variant through a literature review, brief history of the aircraft and also to research the design approach, technologies, mission profile and

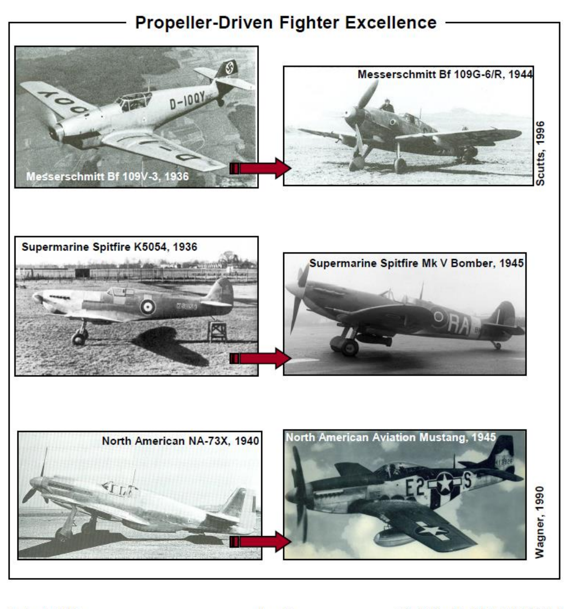

Figure 1 - WWII Fighter Aircraft[1]

various aircraft settings. The student team performs conceptual design tasks by analyzing selected mission operating point for each engineering discipline; the overall conceptual design methodology integrates the individual team efforts. Once the synthesis design tool and disciplinary analysis tools have been established and calibrated, the disciplinary teams agree on quantifying one mission profile point in the WWII B-17 bomber escort mission that highlights the long range cruise condition over a distance of about 1,100 nm. Ultimately the group has been able to reproduce the performance specifications of the 70-year-old P-51 Mustang.

Throughout this project, The UTA MAE students have been able to gain exposure to the incomprehensible knowledge and decisions made by the aeronautical engineering giants of the 1940's, an era that spawned an aircraft capable of exceeding those goals mandated by the circumstances of WWII. But perhaps most importantly, the students learned just how much of their future success rests on knowledge attained from previous generations. In summary, the student group has been experiencing the power of engineering legacy knowledge next to basic engineering understanding and tool proficiency.

In 1940 the British Purchasing Commission expressed interest in contracting North American Aviation (NAA) to convert their established assembly line (in just 120 days time) to manufacture the Curtis P-40 under special license. NAA opposed the idea and proposed to engineer an entirely new fighter plane in less than 120-days. 102 days later the NA-73X was rolled out and waited 20 days for the Allison V-1710 engine to arrive. The Royal Air Force (RAF) was the first to fly the Mustang with primary uses as a tactical-reconnaissance aircraft and fighter-bomber. The airframe was praised for its superb aerodynamic characteristics and industry first laminar flow wing, however the aircraft was not suited to long-range escort missions because of engine power limitations. By 1944 the P-51D was the defining variant powered by the more powerful V-1650-7 Rolls Royce/ Packard Merlin V-12 Engine, also featuring a new bubble style canopy and dorsal fin vertical tail. There were two production plants in the U.S. (one in Inglewood, California and one in Dallas, Texas) and during the height of WWII they were producing a new P-51 every 21 minutes. Over 15,000 Mustangs were produced at an estimated cost of just over \$50,000 (in 1945 USD). Adjusted for inflation that number is just over \$600,000 (in 2011 USD). The P-51 had an unprecedented service length from 1942 until its retirement in 1984. The retired fighters fly under the Limited Type Certification (LTC-11 Revision 5) and many of them are converted to civilian air race planes. Today incomplete project P-51's and fully restored models sell from anywhere between 400 thousand and 2.2 million dollars. The North American P-51 Mustang is considered by many to represent the highest level of refinement ever achieved by any propeller driven fighter aircraft.

In the beginning of the project, the student engineering team determined the single most important factor for success was to establish and maintain a high level of communication for information sharing. Lines of communication between group members consisted of cell phone, text message, e-mail, drop box, YouTube playlists and a private Facebook group. The next logical step was to appoint a Chief Engineer and assign the remaining group members to the various aircraft categories or teams (Modeling & Sizing, Weights & Structures, Aerodynamics, Stability & Control, Propulsion, Performance and Loftin Sanity Check). Early on the team established a mentality of parallel disciplinary methods as opposed to the more conventional trickle down or series method. This helped reduce the waiting period between team output to input exchange and induced an overall sense of urgency, obligation and team dependency. Great emphasis was placed on group communication; each team was dependant upon one another from the start. The entire process was more a melting pot of information sharing rather than a one-way flow from inputs to deliverables.

A few weeks into the project, after speaking with Amit and Dr. Chudoba, it became apparent that the team's plans were excessively ambitious. Initially the plan was to reverse engineer the P-51, produce results for 3-5 mission profile points, perform flight simulations in MATLAB for verification and create a model to fly in the X-Plane simulator. The group was advised to consolidate their efforts, make assumptions when necessary, identify and completely answer the important questions regarding the project objective. Even if the end result was to analyze just one base line cruise condition point in an oversimplified mission profile and present a closed loop result, it would hold greater value than an incomplete evaluation of multiple points. From that point on, the team's mission was to keep it simple and not get lost in the detail despite the overwhelming amount of information provided in the P-51 D Mustang literature to review. Furthermore it was brought to the team's attention that an appropriate measure of merit for their speculative results would be somewhere within 40% accuracy compared to the aircrafts historical performance deliverables. When discussing the formation of the group and team methodologies, the Chief Engineer proposed that everyone aspire to calculate results to within 25% accuracy of historical values (with the maximum acceptable error of 40% as the group's personal measure of merit).

Responsibilities of the Chief Engineer were as follows; Define the project scope and primary plan of action, guide teams in establishing individual project objectives, make group governing decisions, promote communication amongst sub-groups (teams), produce desired deliverables to team individuals, create project presentations, poster and video. Initial decisions made by the Chief Engineer that established group direction were choosing the variant & mission profile. The P-51D Mustang Variant was chosen because over 8,000 of the more than 16,000 Mustangs produced were "D" variants; it was also thought that this choice would lead to the greatest abundance of historical aircraft information and the least hassle during the group literature search. The Packard V-1650-7 (developed by Rolls-Royce Merlin) became the engine variant of choice for the same reasons as 6,325 of these engines were produced primarily for the P-51D. Students then chose to focus on the WWII B-17 bomber escort mission profile because it represented simplicity that highlighted a single point at the max-range cruise condition. It was both important and helpful to define the aircraft variant and specify one mission profile before getting too in depth with the literature search. After the variant and mission profile had been selected, it was time to apply the standard to design to this unique reverse engineering research project. The student engineering team followed these seven steps. Analyze one Mustang variant (P-51D V-1650-7) in one mission profile (B-17 bomber escort). Integrate available historical data from any point in the profile to achieve an equation to return the performance specifications of the aircraft. Iterate established method until resulting error is reduced to within appropriate accuracy. Converge on one cruise point in the mission profile for all teams to produce specifications. Screen solution space for aircraft specs at specified mission point and compare to theoretical calculations. Visualize the aircraft specifications in the solution space using the Loftin Sizing Method. Assess Risk and estimate error between specifications defined by group theoretical calculations, Loftin Sizing Method, and given Historical Values. Measure of Merit achieved if results were below or within 25%-40% of physical aircraft performance specifications.

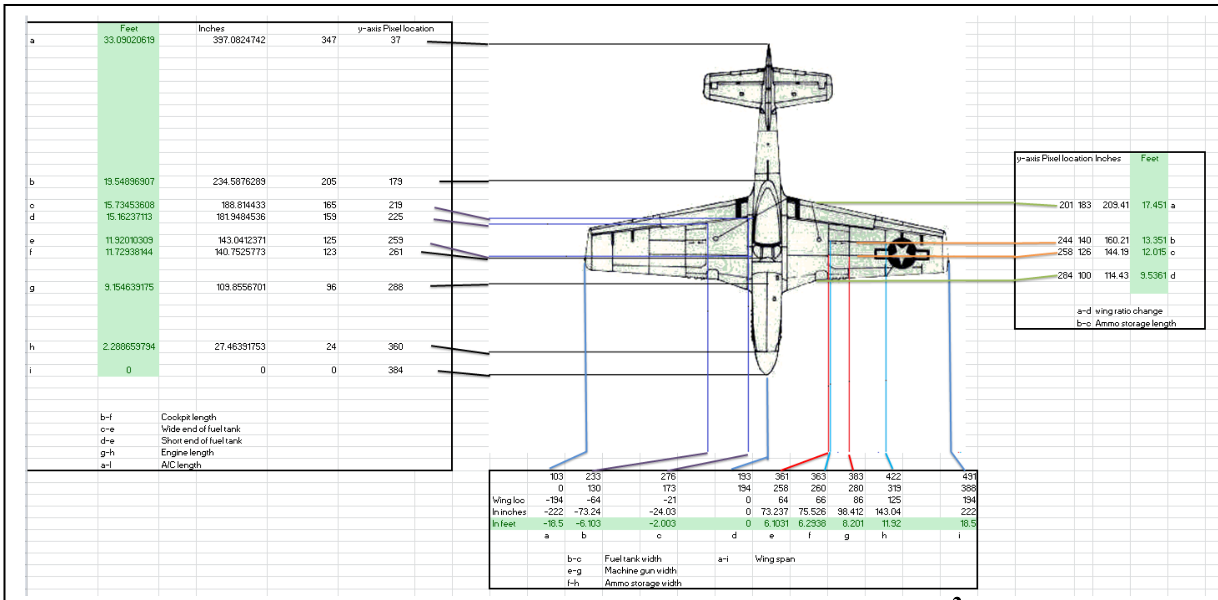

Figure 2 - Initial Aircraft pixel Sizing (Top View)[2]

Once the project mission had been established and the literature review conducted to determine the aircraft variant & mission profile, one profile point was then used for analysis (starting with given Historical Data/Inputs), which ultimately culminated in the Loftin Sanity Check where analytical results were compared to the original historical aircraft performance specifications. If the results were favorable, the methodology concluded with desired mission deliverables. If the results were not within an acceptable range of accuracy, the process re-iterated, starting all over with the aircraft sizing.

The Modeling & Sizing Team obtained initial general aircraft dimensions and airfoil dimensions from historical documentation. Then arbitrary geometry (control surfaces and trim surfaces) was calculated using pixel ratio method, scale model method, and ultimately verified by physical measurements method. A simplified beam model was created for the Structures Team, simplified wing and tail plane models were created for the Aerodynamics Team. Finally a full wing body detailed 3D model was produced with accurate aerodynamic and control surface sizes.

The Weights & Structures Team obtained weight components from historical data then combines them with component locations from the Modeling & Sizing Team to find the C.G. location for the P-51. Variation in component weights such as fuel and ammunition lead to the formation of the C.G. travel diagram. Lift distribution and drag data obtained from the Aerodynamics Team was used in conjunction with propeller torque values obtained from the Propulsion Team to calculate the stress analysis (wing loading) and safety factor of the simplified structural 3D model provided by the Modeling and Sizing Team (featuring one single I-beam as the wing spar). The Weights and Structures Team also produced a weight buildup diagram showcasing the different aircraft weights at different points throughout the mission profile (primarily used by the Performance Team and Loftin Sanity Check).

Figure 3 - Final 3D Model[3]

Table 1 – Weight Componenets & Cg Locations for Historical Aircraft Geometry[4]

Part	# Parts	Wt/Part	Comments	Total Weight (lbs)	Part Length (in)	Distance From Nose (in)	Cg From Nose (in)	Moment from Nose (lb-in)
Prop	1	450		450	28	28	14	6300
Landgear	2	200		400	27		114.433	45773.2
EnginePit	1	2250		2250	92	120	74	166500
Wing	2	850	include Fuel Cells	1700	84	188	146	248200
Wingtips	2	20		40	50	188	163	6520
Ailerons	2	25		50	18	206	197	9850
Flaps	2	35	dry	70	28	216	202	14140
Radiator	1	450	dry	450	105	282	229.5	103275
Cockpit	1	1250		1250	175	282	194.5	243125
TailFuse	1	150		150	79	361	321.5	48225
HorizTail	1	70		70	34	337	320	22400
Elevators	2	25		50	20	356	346	17300
VertTail	1	20		20	39	356	336.5	6730
Rudder	1	35		35	31	387	371.5	13002.5
Fuel Wing	2	598		1196	84	188	146	174616
Fuel Fuse	1	552.5		552.5	105	282	229.5	126798.75
Ammo	1	2080		2080	16.02	160.21	152.2	316576
Extra Fuel	2	500		1000	50	188	163	163000
Pilot	1	200	With Gear	200	175	282	194.5	38900

Empty Weight	6985	lbs	Cg of Empty Weight	136.1976664	in
Engine Weight	1715	lbs	Cg of Zero Fuel	141.0487534	in
Structure Weight	5270	lbs	Cg of Max Landing Wt	146.0236482	in
Fuel Weight	1748.5	lbs	Cg of MTOGW	147.4367545	in
Extra Fuel Weight	1000	lbs			
Payload Weight	2280	lbs			
Gross Weight	12013.5	lbs			

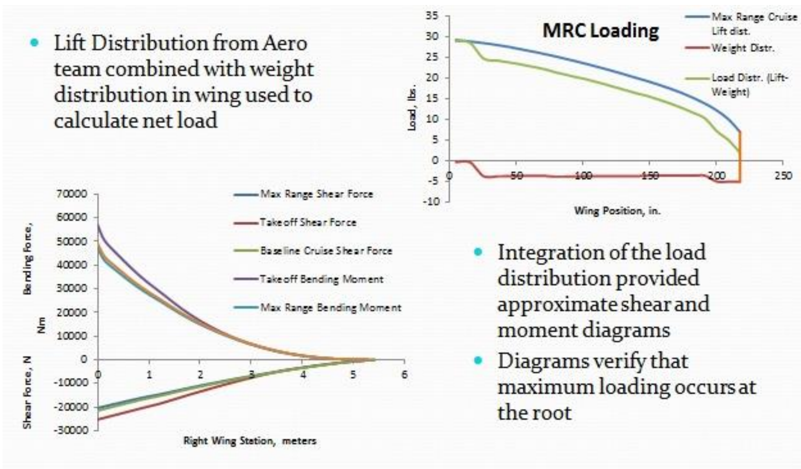

Figure 4 - Shear Moment Diagrams[3]

The Aerodynamics Team obtained major dimensions; coordinate locations of major aircraft features and airfoil section models from the Modeling & Sizing Team. C.G. location at various flight conditions was obtained from the Weights & Structures Team. And aerodynamically meaningful geometry such as chord length, taper ratio, wing sweep, aspect ratio, mean aerodynamic chord, etc. was all obtained from within the Aerodynamics Team. These inputs were then plugged into thin air foil theory, flat plate skin friction analysis, finite wing theory and wing body aerodynamics to yield the lift curve, polar, and zero lift drag. Vortex Lattice Method Tornado was used to find the aircraft stability and control derivatives and wing lift distribution.

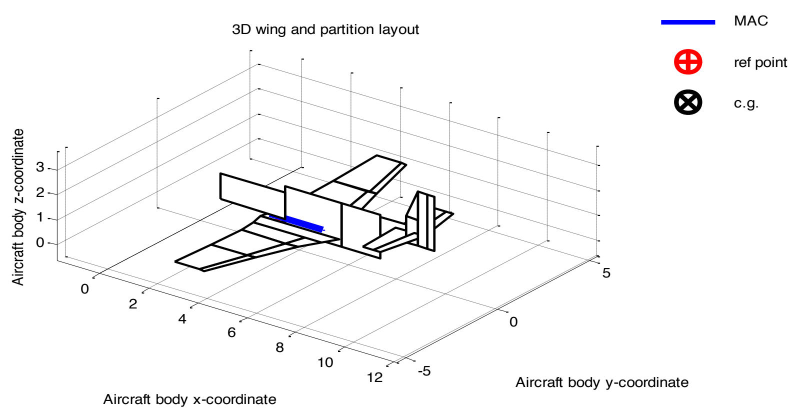

Figure 5 - Vortex Lattice Method Geometry[3]

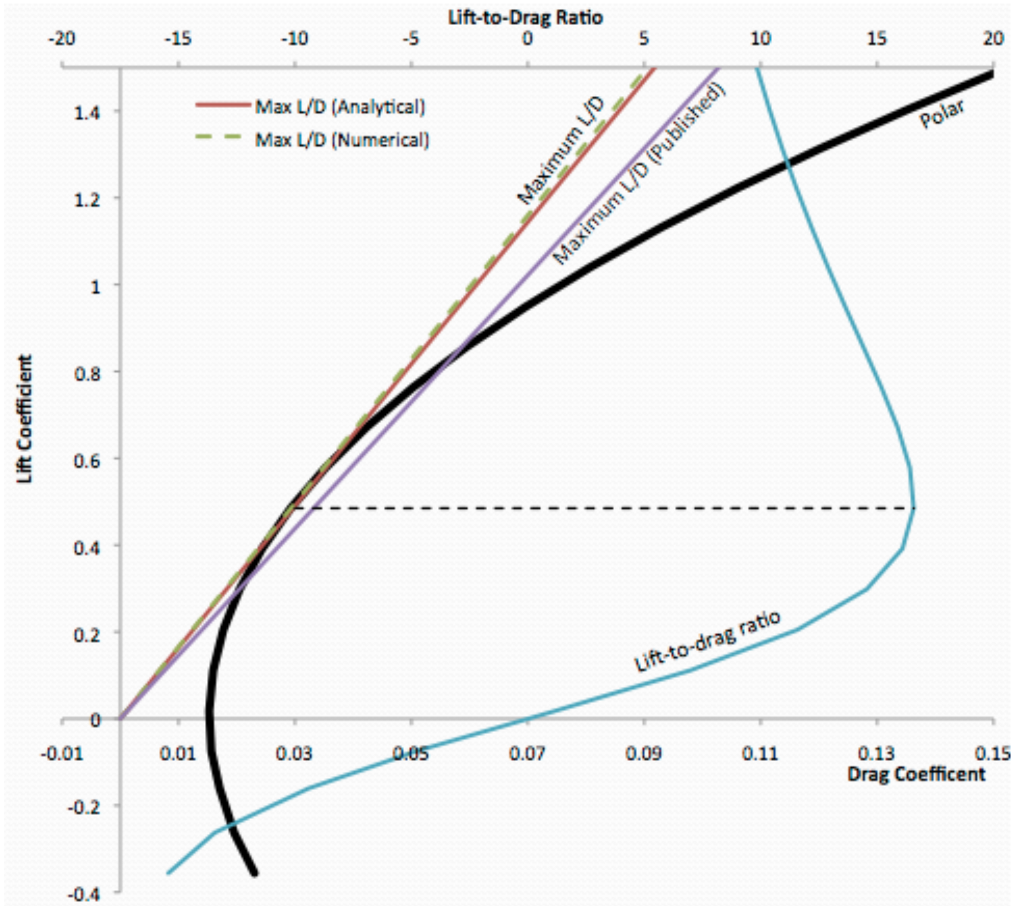

Figure 6 - Polar and L/D Ratio[3]

The Stability & Control Team needed stability derivatives, control surface sizing, propeller torque and aerodynamic coefficients from the Aerodynamics Team, Propulsion Team and Modeling & Sizing Team to calculate the static stability derivatives. If the derivatives predicted static stability then they were used to find the control surface deflections required to trim the aircraft and determine if the aircraft could be trimmed in all phases of flight. This information was used to find the total drag produced in flight at the baseline cruise condition. Minimum control airspeed was also found and

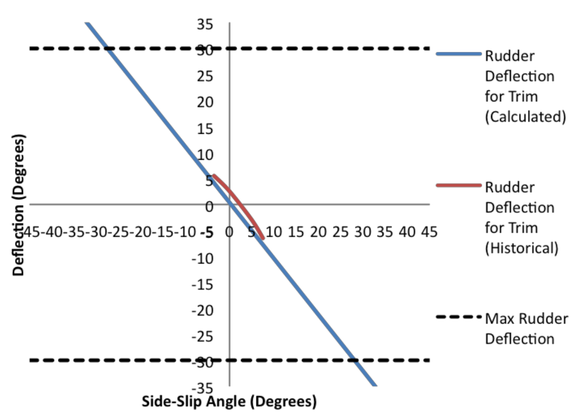

Figure 7 - Rudder Deflection for Trim Historical Comparison (Baseline Cruise Condition - Engine Operative)[3]

used to calculate the minimum power required for flight.

The Propulsion Team input values for given flight conditions, airframe drag and engine specifications into momentum theory and then subsequently output values for power, toque and optimum power/torque rpm. This information was used to calculate things like fuel consumption that were passed on to the Performance Team. Propeller geometry (airfoil section twist distribution and the number of blades) was used to determine the propeller efficiency, thrust, drag due to propeller rotation and net engine moment torque. These variables were passed onto the Performance Team, Structures Team and Stability & Control Team.

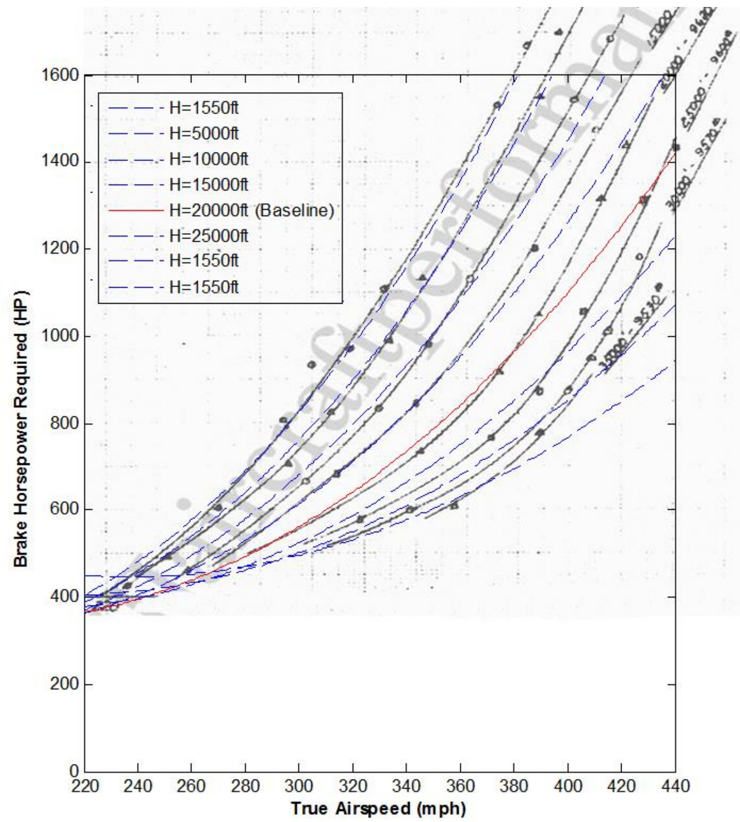

Figure 8 - Required Horsepower Historical Comparison and Validation[3]

The Performance Team was the last step in the analysis; they required input from every other team. Weight, minimum control airspeed, thrust data, wing area & aspect ratio, aerodynamic coefficients were all used to find the aircraft landing distance, runway length, liftoff velocity, climb rate, cruise range, stall velocity, max range cruise velocity, descent ratio, flight path angle (with respect to angle of attack) and vertical force ratio (withrespect to angle of attack) and the L/D maximum.

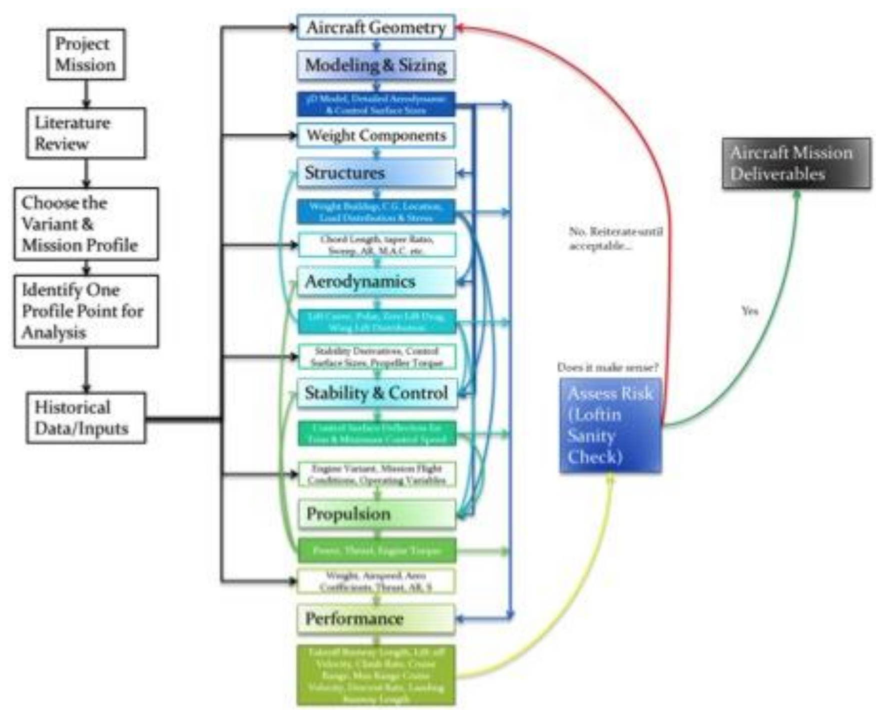

Figure 9 - Horizontally Integrated Group Methodology (Condensed Team Interaction)

When compared to historical data, all the results from the Loftin Sanity Check and Group Analysis represented fell within the desired MoM of 40% accuracy. For analytical performance calculations the students found the outlying value to be rate of climb, which was nearly 40% higher than historical values indicated. Aircraft performance results that seem too good to be true usually are, and it's not uncommon in aerospace industry to encounter this phenomenon when assumptions are made for calculations. Conceptual design engineers in industry constantly predict aircraft to be of higher performance and lower cost than what they actually end up being. The student engineering team calculated their theoretical P-51D to be larger, lighter and faster with more lift capability than historical data revealed. Common sense lead them to believe that the simplification of most conceptual design calculation methods were to blame for the apparent negligence of some negative performance effects. From a methodological standpoint this mini-project was a great success. The group as a whole was able to complete one entire iteration of their proposed methodology and achieve results within a realistic accuracy.

Table 2 - Loftin Results vs. Historical Data and Group Calculation[3]

			Loftin	Historical	Group	Calculated % Diff	Group % Diff
Structure							
Maximum Gross Weight	W_g	*lbf*	9664.90	9760	--	**0.97**	--
Empty Weight	W_e	*lbf*	7024.61	7125	6985	**1.41**	**1.96**
Fuel Weight	W_f	*lbf*	1730.29	--	1254	--	**27.53**
Payload Weight	W_P	*lbf*	910.00	--	1021	--	**10.87**
Aerodynamic Configuration							
Planform Area	S	ft^2	234.31	233	237.29	**0.56**	**1.84**
	AR		5.86	5.86	6.59	--	**11.10**
Zero-lift Drag	$C_{D,0}$		0.0161	0.0161	0.0160	--	**0.62**
Max Glide Ratio	$(L/D)_{max}$		14.04	14	16.3	**0.31**	**16.43**
Propulsion *(baseline cruise, 20kft)*							
Power Required (at Sea Level)	P_O	*hp*	1481.24	1490		**0.59**	
Military Horsepower Available		*hp*	1490				
Emergency Horsepower Available		*hp*	1720				
Airport Performance *(dry, level, hard-surface runway, and zero wind, Baseline Cruise)*							
Landign Field Length	l_L	*ft*	2845.16	2250	--	**26.45**	--
Landing Ground Run	$l_{L,g}$	*ft*	1587.97	1520	1712.9	**4.47**	**12.69**
Total Takeoff Field Length	l_T	*ft*	1584.50	1720	--	**7.88**	-
Take-off Ground Run	$l_{T,g}$	*ft*	960.31	1040	1080	**7.66**	**3.85**
Performance *(baseline cruise)*							
Rate of Climb	ROC	*ft/min*	2504.21	2925	4065.6	**14.39**	**38.99**
Stalling Speed	V_S	*mph*	85.41	100	98.09	**14.59**	**1.91**
Cruise Speed	V_C	*mph*	383.23	384	383	**0.20**	**0.06**
Maximum Airspeed (25 kft)	V_{MAX}	*mph*	436.65	437	--	**0.08**	--
Maximum Range							
Maximum Range Airspeed	V_M	*mph*	258.07	--	279.49	--	**7.66**
Maximum Range	R_M	*miles*	1471.80	1108	1188.70	**32.83**	**6.79**

Historical Data Reference from [3], [26], [38] as from Hew, Weekly Report 2012 Fall MAE 4350.

The purpose of this mini-project was to immerse students in the conceptual design environment and expose them to multidisciplinary teamwork in preparation for the spring semester capstone project. Both students and professors involved believe that this project exceeded everyone's hopes and expectations in simulating such an environment that will be explored in further detail during the spring semester of 2013. This experience has provided students with an unprecedented learning experience in a fun, competitive, low-risk setting that demanded cooperation, logical thinking and restraint towards over ambition when faced with zero tolerance deadlines. In 60 days the UTA MAE students gained perspective into the conceptual design world and a heightened respect for the engineers that left behind the legacy of a WWII fighter that was built from nothing in less than 120 days, the aerodynamically unprecedented propeller driven perfection that has remained unsurpassed for over 70 years, the North American P-51D Mustang.

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Extended Abstract with Poster

Lowering Barriers to Enhance 2 + 2 Transfer Student Success, Persistence and Retention: The Dallas STEM Gateways Collaborative

John Sibert, Matthew Goeckner
The University of Texas at Dallas

Dave Galley
Collin College

Kory Goldammer
Richland College

Abstract

The University of Texas at Dallas, Collin College, and Richland College of the Dallas County Community College District have established a joint effort, the NSF-sponsored Dallas STEM Gateways Collaborative, to significantly increase the number of undergraduate students completing degrees in Science, Technology, Engineering, and Mathematics (STEM) in the North Texas region. Building upon previous cooperation among these three institutions and the remarkable concentration of high-tech businesses in the Dallas-Fort Worth Metroplex, the Collaborative has implemented best-practice methods to bring about a cultural change that will lead to a sustained increase in the production of STEM-trained graduates. First, the Collaborative has strengthened recruitment into introductory STEM courses and expanded the use of student mentoring within those courses to encourage student selection of STEM majors and classroom success. Second, it has increased opportunities for internships and undergraduate research experiences for students early in their college career to encourage students to remain committed to the pursuit of STEM majors. Finally, a concerted effort of curriculum alignment across all STEM fields at the three participating institutions combined with a formal professional development program aimed at spreading effective pedagogical techniques across all three institutions has been designed to enhance teaching effectiveness at the critical introductory level. The Dallas STEM Gateways Collaborative program is built to enhance the number, quality, and diversity of undergraduates successfully earning STEM degrees.

Introduction

There is now ample documentation that the United States is facing an economic crisis unless it increases its production of talented science, technology, engineering and mathematics (STEM) graduates.[1,2] As described in *Rising Above the Gathering Storm*,[1] the global demand for skilled STEM workers is increasing and the number of American students pursuing STEM careers is likely to continue to decline unless the Nation intervenes. In areas like the Dallas-Fort Worth metroplex, with its concentration of high tech businesses and industry and rapidly growing population, the need is made even more apparent.

The state of Texas, recognizing the need for a scientifically and mathematically literate citizenry recently introduced a new high school graduation requirement: each student must successfully complete four years of science and four years of mathematics to earn a high school diploma. Even with this additional high school preparation, many students who have an interest in STEM careers will find the traditional undergraduate courses in STEM fields intimidating. Furthermore, many who start their undergraduate careers in community colleges find barriers to transferring to four-year colleges and universities to finish their baccalaureate degrees.

In spite of the alarming national trends, many colleges and universities have recognized that by creating programs that excite and stimulate students early in their STEM careers, many more students will successfully earn their undergraduate STEM degrees.[3,4] For example, due to wide-spread efforts in the physics community, the number of undergraduates earning degrees in physics in the U.S. increased by more than 35% from 1999-2007 with almost all of these being domestic students. Detailed data are available from the Statistical Research Division of the American Institute of Physics. The lesson here is that focused efforts that address the entire student program, not just the curriculum, can lead to significant increases in the number of STEM majors.

To address the STEM workforce problem and to increase significantly the number of students earning undergraduate STEM degrees, the University of Texas at Dallas (UTD), Collin County Community College, and Richland College of the Dallas County Community College District have formed the Dallas STEM Gateways Collaborative (referred to as the "Collaborative" in this document), a cooperative project providing a comprehensive and coordinated set of activities focusing on the gateway experiences during the first two years of the students' undergraduate experience. The activities include recruitment and retention efforts aimed at STEM students combined with a series of curricular and faculty development activities that are designed to produce significant cultural changes in the institutions' focus on undergraduate STEM education. The activities build on and significantly extend existing collaborative activities and are in alignment with and enhanced by other recent initiatives at the three institutions. We report here on progress associated with establishing a pipeline of STEM students that begins in the high schools, proceeds through the two-year institutions and finishes with graduation at the four-year institution in STEM disciplines.

Results and Discussion

The Collaborative is a partnership between three institutions (UT Dallas, Collin College and Richland College) to facilitate the recruitment and success of STEM students. Specific programs include the following with selected activities highlighted in subsequent sections. The successful 2+2 articulation program in engineering (including important curricular alignment agreements) between Collin College, Richland College and UT Dallas was expanded to all STEM disciplines at both Collin College and Richland College. Enhanced Advising has played a key role in this effort at the community college level. Direct presentations to students, parents, and counselors coupled with the offering of Technical Dual Credit coursework at local high schools has produced a collaborative recruitment effort aimed at making the 2+2 programs known to high school juniors and seniors in the diverse Dallas-Fort Worth Metroplex. Expansion of the award winning Peer-Led Team Learning (PLTL)[5-9] program in gateway STEM classes at UT Dallas has occurred and is in the process of being leveraged to Richland College and Collin College. There have been many collaborative activities among the three institutions to build a STEM student learning community. These activities have included opportunities for: undergraduate research and internships, joint student organization activities, an undergraduate research fair and STEM mentoring career workshops. A Faculty Innovation Grant Award program was created to facilitate research and education innovations across all three institutions. There has been an expanded effort at Richland College to address the Math and Science Tutoring needs of STEM students in specific higher level Math, Physics and Chemistry courses. An outreach effort at Collin College to build a pipeline of STEM students targeted to attend UT Dallas through Robotics Camps and College Robotics Competitions is bearing success. Finally, and of particular significance, a robust method for the tracking of Collin and Richland transfer students within classes and degree programs at the University of Texas at Dallas has been developed to aid the Collaborative in channeling resources to appropriately lower transfer barriers for students.

Articulation Agreements

A major early activity of the Collaborative was the development of articulation agreements between UT Dallas and, respectively, Collin College and Richland College in the STEM disciplines. Separate agreements for engineering and computer science, biology, chemistry, physics, mathematics and geosciences was the result of a series of department specific alignment-articulation meetings of professors, deans and department chairs from each of the Collaborative's member institutions. In addition to the formal agreements, survey data show that participant views of each other's institutions have grown positively through collaborative interaction. Participants reached accord on course prerequisites, course content and instructional materials with each formal agreement including a provision for an annual review. Further, a matrix of the course equivalencies for each discipline, constructed by the STEM academic advisors from the three member institutions, became an attachment to each agreement. All who participated in the development of the STEM articulation agreements have agreed that these agreements provide clear and safe paths for the Collin and Richland students who plan to earn a STEM baccalaureate degree at The University of Texas at Dallas. As these articulation agreements have been institutionalized, they now represent a platform for recurring future communication/collaboration among the STEM departments across all three campuses.

Summer Undergraduate Research Experiences for Transfer Students

Undergraduate research experiences have been shown to be an excellent opportunity for engagement and persistence within STEM degree plans.[10] Thus, the Collaborative placed twenty STEM students from Collin and Richland College in the research laboratories of UT Dallas faculty in the summers of 2011 and 2012 with an additional twelve planned for the summer of 2013. The research areas covered a wide STEM base including biology, chemistry, geosciences, applied mathematics, electrical engineering, mechanical engineering and computer science. The response from faculty and students has been overwhelmingly positive with, for example, a molecular biology student commenting that this is the best experience of her life and a faculty member sending an unsolicited e-mail report that his engineering student is outstanding and completing tasks so quickly that the faculty member is challenged to keep him occupied – a good problem to have! Most importantly, all twenty students who have participated in the program are currently or will be pursuing STEM degrees at UT Dallas.

Peer Led Team Learning (PLTL)

The integration of Peer-led Team Learning (PLTL)[9] into the UT Dallas STEM learning framework has been supported, in part, by the Collaborative. The PLTL program began in the Fall of 2008 with a pilot group of 161 students in General Chemistry I (CHEM 1311) PLTL and for whom the DFW (grade of D, F or Withdrawal) rate was less than 19% - an 18 percentage point drop from the preceding five-year historical average of over 37%. In the Fall of 2009, student enrollment in CHEM 1311 PLTL increased by 41% to 227 students and the DFW rate for that cohort was a remarkably low 9%, which provided additional encouragement for other STEM disciplines to consider PLTL support. Presently, up to twelve courses each long semester are PLTL supported including general and organic chemistry, physics and calculus with over 1000 students participating annually. Typical results show that students perform more than half of a letter grade higher simply by participating in PLTL. The PLTL program has now been institutionalized with partial support from student fees and online registration as for regular classes. The student demand is high with, for example, PLTL slots in chemistry often completely filling within an hour of being made available online. Finally, both Collin College and Richland College are now considering PLTL programs modeled after that of UT Dallas. In the former case, a faculty innovation grant (*vide infra*) from the Collaborative was awarded to Collin College biology faculty for a pilot study.

Faculty Innovation Grants

The Collaborative has introduced a faculty innovation grant program designed to facilitate faculty and student interaction across the 2 year and 4 year institutions. Thus, at least one faculty member from UT Dallas and either Collin College or Richland College are required as co-PIs on any submission. The series of recurring meetings across institutions that led to the formal articulation agreements described above have served as a critical vehicle in stimulating discussion among faculty concerning common research interests, resulting in the development of proposal ideas. This further solidified the value of regular faculty meetings involving members from all three institutions to the goals of the Collaborative. For example, Prof. Juan Gonzalez (UT Dallas) and Prof. Jonathan Lawson (Collin College) were awarded a proposal in 2012 on "Student-Directed Whole-Genome Sequencing of Enviromental Bacteria". This proposal involves both faculty members and their students interacting across institutions with Gonzalez providing a UT Dallas presence at Collin College and Lawson and Collin College students working in the UT Dallas research laboratories. Of particular note, this project connects directly to Lawson's formal biology course taught at Collin College.

Transfer Student Data Tracking

In order to benchmark and track the Collin College and Richland College transfer student population at UT Dallas, a robust, secure method is needed for accessing student data that addresses the appropriate questions relating to absolute numbers of STEM transfer students, identification of transfer student gateway courses, performance in classes and time to graduation in STEM fields. In addition, the impact of specific programs, including the summer research experience and PLTL for example, on transfer student numbers and performance hinges on such a method. One of the most significant achievements of the Collaborative has been the development of a method to track transfer students at UT Dallas. These data are providing rich information to not only assess progress, but to target interventions that will allow for greater transfer student success. Selected data are shown in Figures 1 and 2. The Collaborative objective of filling the pipeline with STEM students is shown to be working well as represented by the enrollment data in chemistry (Figure 1) over a five-year period. There is a dramatic increase in transfer students from Collin College and Richland College (as monitored by enrollment from the Dallas County Community College District, of which Richland College is a member) in the gateway chemistry courses at UT Dallas, but not in transfer students from other institutions. However, as shown in Figure 2, representative data from the same gateway chemistry courses clearly show that transfer students need intervention to be more successful as transfer student performance lags significantly behind that of native UT Dallas students. The data in both Figures 1 and 2 are consistent with data for gateway mathematics and physics courses. As we implement Collaborative interventions, the success, persistence and retention of transfer students will be tracked by our innovative data collection methodology. Conversely, specific *data driven* interventions at the three institutions can now be targeted to aid transfer students in final STEM baccalaureate success.

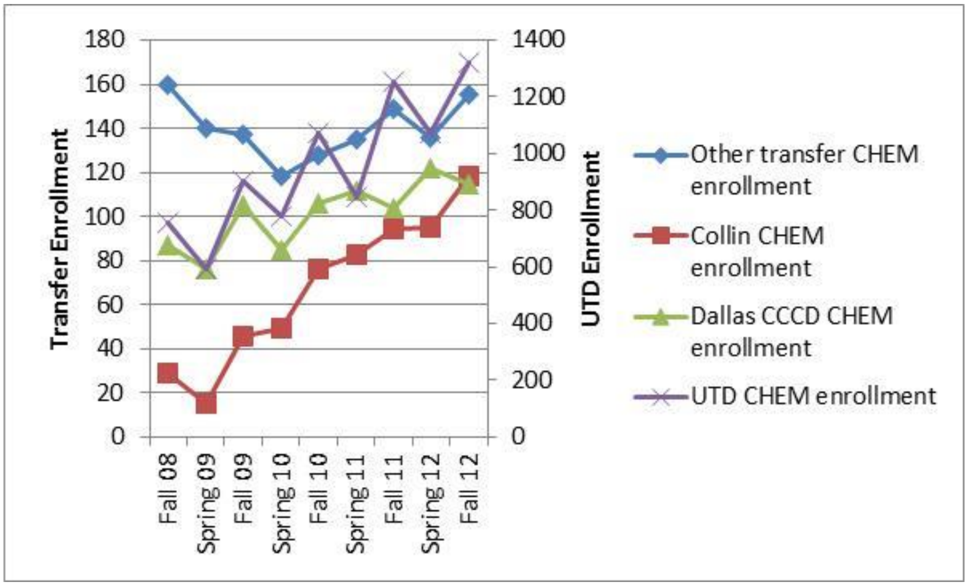

Figure 1. Enrollment data for transfer and native students in chemistry courses at UT Dallas.

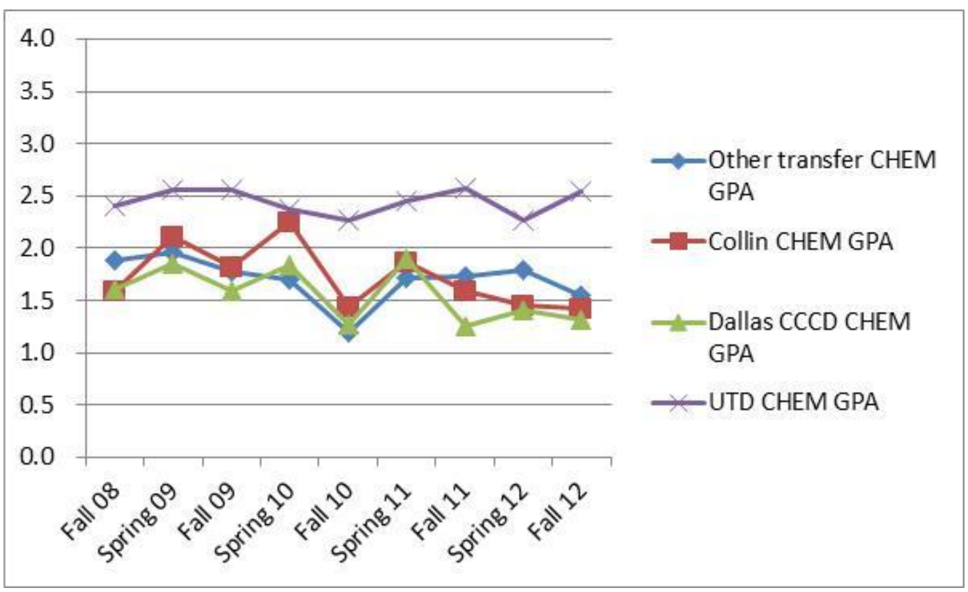

Figure 2. Average GPA of transfer and native students in chemistry courses at UT Dallas.

Summary and Conclusions

The Dallas STEM Gateways Collaborative has been established to provide a comprehensive and coordinated set of activities across three campuses (UT Dallas, Collin and Richland Colleges), focusing on the gateway experiences during the first two years of the students' undergraduate career with the ultimate goal of establishing and growing a pipeline for STEM majors from the two year institutions, Collin College and Richland College, to UT Dallas that will lead to more STEM majors in an absolute sense and greater opportunities for success and engagement as these students proceed to STEM degrees. The pipeline has been established with focus now being drawn to interventions that will facilitate transfer student success at the four-year institution.

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JOHN SIBERT

Dr. Sibert is an associate professor of chemistry at UT Dallas with research interests that lie in the area of molecular architecture, designing and building new molecules for applications that span from medicine to environmental science to advanced new materials. He has an educational emphasis on engaging learners in innovative methods centered on curiosity and discovery.

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DAVE GALLEY
Dave Galley serves as the Director of Engineering and is a member of the faculty at Collin College. He has twenty years of industrial experience working as an engineer and in management and executive capacities. His current interests focus on the recruitment and success of STEM students from high school through the university and into the workplace.

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Dr. Goldammer coordinates the Nanotechnology and Semiconductor Manufacturing program while serving on the faculty at Richland College. He has fourteen years of experience working in the semiconductor industry.

Extended Abstract with Poster

Reverse Engineering through Simulation of a Conceptual Design Process of Supermarine Spitfire

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Abstract

This paper is a report documenting the experience of participating in a Senior Design Capstone course in which the Supermarine Spitfire Mk Vb was reversed engineered. Instituting multi-disciplinary analysis, first order estimations, and calculations, the design team verified the flight capabilities of the Spitfire. The final focus of this engineering was to incorporate a synthesis of all the major disciplines through Lawrence Loftin's Subsonic Aircraft: Evolution and the Matching of Size to Performance. A brief discussion of this rapid iteration process is described below and results in a sanity check for the conceptual design and reverse engineering process by creating a solution space for a typical WWII fighter mission. Proving that the Spitfire's match point lies within the admissible range of design is confirmation for the reverse engineering tools used. Through reading this report one can begin to understand the complexity of conceptual designing an airplane and the adaptation of tools used for unconventional aircrafts. This includes the aerodynamic calculations using the United States Air Force DATCOM+ tool and the modification for an elliptical wing planform. From these results an engine analysis can be developed to measure its performance. The stability and control team took the ideology behind Loftin's method and applied it to the stability and control surfaces. Creating parameters and utilizing known stability trends, the team created a solution space for the stability and control effectors. The strong analysis of the individual disciplines is combined in the end to create a solution space for the Spitfire Mk Vb which exemplifies a joint effort and creates well rounded multi-disciplinary engineers. Overall, the skills developed through the project will allow each team member to carry on techniques and knowledge to other aircraft conceptual design.

Introduction

The Supermarine Spitfire is one of the most iconic and beloved aircraft or its era, and this semester, a group of senior students was able to participate in the active learning experience of reverse engineering this exceptional airplane as a part of the Senior Design Capstone Course. The Senior Design Capstone Course compiles the years of undergraduate studies to test and approve the student's engineering abilities. Under the direction of Dr. Bernd Chudoba the senior class was tasked to reverse engineer the famous World War II fighter planes with an emphasis on using a conceptual design process. Rather than using a purely analytical reverse engineering technique, the group implemented a simulation of the conceptual design phase of an aircraft in order to recreate the Spitfire based on its performance characteristics. By breaking into the individual disciplines involved in aircraft conceptual design, the team worked to create a solution space for the sizing based on a set of performance and geometric parameters. This paper defines the overall project goals for the team, as well as the teamwork and methodology used to reverse engineer the Spitfire, and outlines the results of the synthesis of the various disciplines' results.

The Team

The Spitfire team consisted of 14 individuals separated into five main disciplines for conceptually designing an aircraft as well as a chief engineer to oversee the project. These groups are: structures, aerodynamics, propulsions, performance, and stability & control. The small team allows quick communication and cooperation between the members. A hierarchy of leadership allows the big picture of the project to be focused on through the chief engineer and the details of the aircraft to be handled by the different disciplines. This process is common for the majority of companies and especially in engineering projects, much like designer R.J. Mitchell and his Supermarine team. His leadership and design genius is an inspiration for all engineers. He has had as many failures as he has had success stories, which is an encouraging notion when looking at our own imperfections.

Project Overview

The first steps taken by the team were to perform a literature survey to create a data base of sources to provide information concerning the project. Knowledge is the key. Through collecting a large database, we can grasp a better understanding of conceptual design, reverse engineering and the Spitfire itself. Nicolai notes that the first task for designing a vehicle is to "study, evaluate and understand..."[1] We took his wisdom to heart and tried to implement this into our entire project.

The next step taken by the team was to define each discipline's deliverables. With these variables, the teams were able to create individual methodologies in order to produce their key deliverables. When combining the groups' flows, we were able to create an overall group methodology. This flow incorporates all the disciplines but simplifies the processes to create a neat organizational hierarchy. Giving each team the responsibility to define their tasks for the semester creates a sense of ownership of the project and indicates the makings of a successful group.

No matter how hard-working a team may be they still need encouragement and pressure to complete a project by a deadline. One slip up for the team was not specifically defining a timeline for the project. Had we originally created and stuck with a detailed timeline, our analysis and results would have been more in depth. Nevertheless, in the time allotted the team performed admirably, creating unique techniques to reverse engineer the Spitfire and conceptually design a propeller driven aircraft.

Challenges

Over the course of the semester numerous problems arose and had to be resolved in order for the team to function at an effective level. The management and operation of the group is another objective of the capstone course which simulates a real world engineering team. These challenges include: information transfer between groups, parameter definition and assignment, timeline of deliverables, group dynamics and participation, and depth of project analysis.
The transfer of information between the groups was sometimes delayed, which consequently lagged the project progression. Because each group had priorities of their own, the information required by others was usually deferred until a convenient time. Problems arose when initial or new deliverables were not presented in a timely manner to fit the timeline of the project. This was one area where the chief intervened and made cross discipline information a number one priority. Also, even when the needed information was delivered, it often changed as the project progressed and values were corrected or refined. Additionally, even with revisions to these values, the updates were not necessarily transferred to the appropriate departments, creating a lapse in the information flow and overall analysis process.
When we originally set deliverables for each group, we kept in mind that they might change as the project progresses. When a controversy arose concerning what group should cover a certain scope of analysis, it had to be dealt with or else a part of the project would be incomplete.

Since our project was to incorporate Loftin's conceptual design process into our reverse engineering, we tried to perform similar analysis using parameters and historical trends to size various parts of the aircraft. However, this was sometimes complicated when incorporating it into every discipline. We realized that some of the disciplines are strictly analysis and others would require more resources given in one semester to create complex parameter analysis of the aircraft.

The two sided coin of the project was the team dynamic. There were good things and bad things that can be expected when working with a group. Over the weeks, individual work ethics and participation became a point of significant concern. The differences in the level of commitment, work rate, communication, and schedules proved to be an exasperating affair. The chief designated team leads to oversee their group's work and to assess the timely manner of the work. This meant organizing discipline meetings, delegating work, and participation of individual members. Occasionally in the middle of a project, the person in charge realizes that they are not suited for the responsibilities and need to be removed from the position. Fortunately our group never arrived at this dilemma.

In the beginning of the project our team had high hopes and aspirations, but we quickly realized the constraints of resources and time. This led to problems when determining the depth of analysis desired in this reverse engineering process. Reduced order calculations provided reasonably accurate results in a short time, while some higher order analysis was needed for correct verification of the Spitfire. The solution chosen was to employ reduced order methods where it would suffice, since these were generally less resource-intensive, and resorting to the higher order methods only when absolutely necessary for accurate production of results.

Reverse Engineering

One of the biggest challenges faced, and the running theme of this project, was the integration of a conceptual design synthesis method with a reverse engineering process. Essentially, the two concepts are polar opposites of the other. As such, generating a unified method incorporating both elements involved a prolific amount of improvisation to existing analytical tools as well as producing original methods tailored to the case-specific requirements. The methodology taken for this reverse engineering process was based on the methodologies of Loftin and Roskam for fixed-wing aircraft. Loftin and Roskam use a wide knowledge base of similar class aircrafts to create solution spaces in which the airplane design can exist. We started with the basic aircraft description and configuration, similar to Loftin, but with more detail since the geometry and specifications of the aircraft we were analyzing were already known.

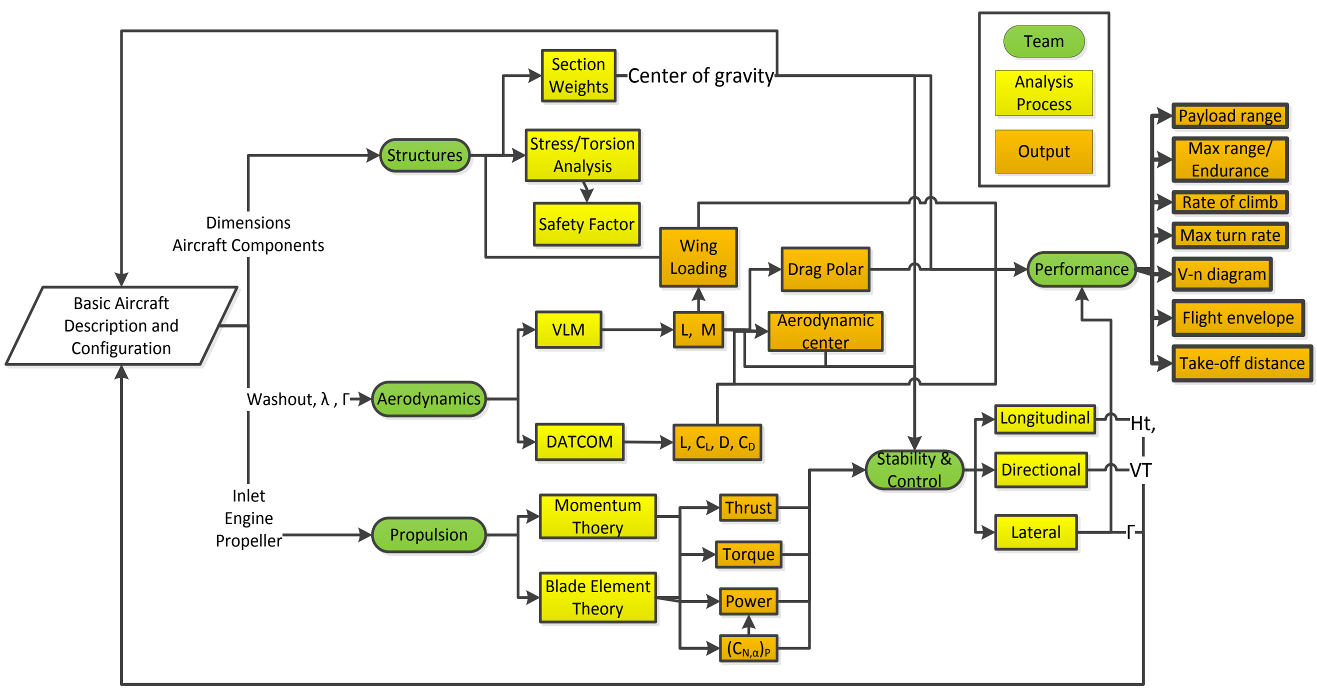

Figure 1. Group Multi-Disciplinary Analysis Methodology.

Figure 1 shows a flow chart of our designing methodology. This refined flow incorporated all the disciplines into a systematic method of iterating the aircraft design to obtain performance charts that facilitated comparison and cross-reference. This analysis involved sanity checks and then proceeded to detailed examination of the aircraft to determine if the change was beneficial or detrimental.

The group would perform optimization of the aircraft with current technology only if time permitted. Analysis of the Design Constraining Flight Conditions was our main focus and allowed us to verify the flight capabilities of the Spitfire. The successive sections detail the procedures and methods of analysis that are specific to each discipline.

Aerodynamics

The Supermarine Spitfire is known for its fighting capabilities and the Battle of Britain, but it's most notable feature is its elliptical wing. That being said, the aerodynamics team was eager to begin analysis on the aircraft and to utilize the skills gained throughout their collegiate career. The semester spent working on the project was a learning experience for the entire team because they utilized multiple aerodynamic prediction methods to determine the right aerodynamic tool that would produce accurate results. There are countless methods of calculating lift and drag on an aircraft, but all the methods have their own certain limitations. The team began to explore the various methods through a literature search. Once these methods were determined, the group of three was divided into three groups. Each person studied their designated method and improved their skillset by developing aerodynamic proficiencies while performing their analysis. The collective results of the team were used by the structures, propulsion, stability and control and performance teams, and as well in the overall Loftin analysis. Therefore, there was a great deal of pressure for the aerodynamics team to produce quick and accurate results.

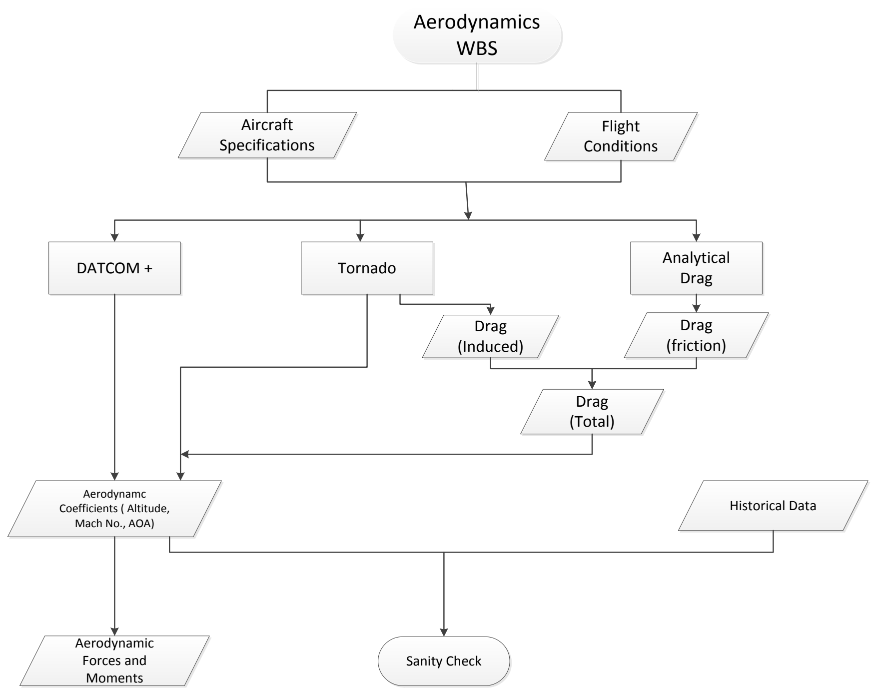

Figure 2. Aerodynamics Work Breakdown Structure.

The principal aerodynamic tool utilized for the project was DATCOM +[2], a user-friendly version of the United States Air Force Stability and Control Digital DATCOM. The program allowed for the user to define the geometry of a fixed-wing aircraft and the specifications, including the Spitfire's propeller and engine location, within an input file. The static aerodynamic and dynamic stability derivatives at various flight conditions were predicted using non-linear aerodynamics and semi-empirical calculations. A secondary method, Tornado[4], was employed to serve as a sanity check for the analysis. The program combines vortex panel method based MATLAB codes and is able to produce sufficient aerodynamic analysis to serve as a verification of the data obtained by DATCOM+. In the aerodynamics field it is often the case where engineers must perform method-switching to account for the limitations provided by the tool used. For this reason the aerodynamic team employed analytical calculations to calculate the skin friction drag, and then combined the data with the total drag obtained from Tornado to provide accurate results that could be compared with that of the primary method.

The work breakdown structure for the aerodynamics team can be seen in Figure 2. The diagram shows that the aircraft specifications and flight conditions were the inputs for the three methods used by the team, shown in the third level. The analytical drag method shows how the skin friction drag was combined with the drag results produced by Tornado to provide an accurate comparison with the results from DATCOM. The results of the tools were compared with obtained historical data to verify accuracy with actual experimental data, and then the results were exported to the other teams per specific need. The maximum lift coefficient for cruise speed was given to the Chief Engineer who used it for Loftin analysis. The aerodynamics team performed above and beyond during the project semester by generating accurate results to be used by the other design teams and by adding skills into their method's library.

Propulsion

The propulsion team was tasked with the overall analysis of the propulsion system present on the Spitfire Mk.Vb variant. The engine is sized based on power requirements for takeoff, climb rate, service ceiling and maximum speed scenarios, essentially the four main design constraining flight conditions (DCFC) for the aircraft selected. With the engine sized, the propeller geometry and aerodynamic characteristics were modeled using Reference [5]. To combine the two components of engine and propeller, the team narrowed down the analysis tools to two options; Momentum theory and Blade Element Theory.[6] The objective is to pair the engine output power and rpm with the aerodynamic characteristics of the propeller to simulate thrust production. To close the analysis loop, we had to use the aforementioned performance criteria at the DCFC to verify the feasibility and capability of the model. Essentially, the significance of this analytical and experimental data comparison is twofold; firstly it verifies that the modeled system replicates the actual system quite accurately, and secondly it shows that the overall propulsion system of the aircraft was able to achieve and surpass the performance requirements set in place by the British Air Ministry.

One of the main challenges faced by the propulsions team was the coding process whereby the blade element theory required several iteration loops to solve for required variables. This resulted in relatively long code run times thus decreasing productivity in terms of examining higher numbers of data points. The iterative process also introduced another error in the form of the propulsive efficiency being greater than unity initially, which physically is not possible. After the break tolerance for the iterations was corrected, the problem was rectified; however it remained a valid point of concern for a significant period of the project timeline.
The highlight of the educational experience specific to the propulsion analysis is the necessity an

d ability to produce a working model with the least amount of time and resources, then refining t he model to where it is feasible and ideally, optimal. To be efficient in this process, a broad base of knowledge and solid command of relevant theory is crucial, however it is hands-on experience that provides the engineer with the decisive edge.

Stability and Control

The stability and control team consisted of three members, allowing the team to be split into the three sub-disciplines of static stability and control: longitudinal, lateral, and directional. Since the three sub-disciplines are relatively independent, splitting the team allowed for a more stream-lined reverse engineering process and promoted high self-responsibility among all team members. Each group-member was responsible for getting the work done per their assigned sub-discipline. The disadvantage of the approach is that the entire team is dependent on each and every member of the stability and control group to finish their work. To ensure that appropriate progress was made, the stability and control team had weekly meetings to discuss encountered issues and progress.

The methodology for the stability and control team consisted of a Loftin-like design process, where inputs were parameterized, using additional information from Roskam's aircraft design series.[7] This approach was chosen to mimic the conceptual design phase of the Supermarine Spitfire. The final outputs for this approach were solution spaces that defined the sizing of the horizontal and vertical tail plane for longitudinal and directional stability, as well as dihedral for lateral stability. Solution spaces for the sizing of all primary control surfaces were also created. The solution spaces were created to see whether the Spitfire did indeed lie within the boundaries and therefore proving that the aircraft was stable and maneuverable.

Structures

The structures and performance teams both played important roles within the group by calculating and providing geometric and performance parameters to the other groups for their calculations. The nature of the analysis these groups performed meant that their calculations were primarily analytical as opposed to a simulation of the conceptual design process used by the other groups. The primary information provided by the structures group to the team consisted of the geometry of the Spitfire aircraft including the sizing of the aircraft structure along with estimations of the aircraft weight. From these measurements the team was also able to calculate the location of the aircraft's center of gravity, which was the most crucial geometric parameter for other groups' calculations. The structures team also created maps of the shear forces and moment acting along the Spitfire's wing and fuselage structures due to aerodynamic forces induced during flight. Based on these force calculations and the material properties of the aircraft, a factor of safety was able to be calculated to show that the Spitfire structure was capable of withstanding the forces induced during the most demanding of flight conditions.

Performance

The performance team relied heavily on the information being passed from the other groups in order to analytically quantify how well the Supermarine Spitfire performed. A payload-range calculation was created which allowed for analysis of the effect that the weight of the armament being carried would affect the range of the aircraft. Using the lowest payload possible for the aircraft, it was also possible to find the maximum range and endurance, or loitering time possible for the aircraft, which would have been a crucial parameter for a bomber escort mission. This analytical prediction for the range and endurance produced a range that was within 4% and endurance that was within 6% of the actual Spitfire's performance. The combat and maneuvering performance were also analyzed in the form of the aircraft's climb rate, minimum turn radius and maximum turn rate, and all three were shown to be well within the range typical of a fighter aircraft of the era. The takeoff and landing performance were analyzed by creating a V-n (velocity versus load factor) diagram which showed the load factors the aircraft could withstand over the possible range of flight velocities. Finally, the most important output of the performance team was the formation of the flight envelope which predicted all the combinations of flight velocity and altitude at which the Spitfire was capable of flying. Again this flight envelope was shown to correlate well with historical data, thus verifying that the analysis from all of the teams produced results which matched the actual Spitfire.

Loftin Verification

After the reverse engineering analysis the team was then able to simulate the sizing of an aircraft using Loftin's parametric sizing technique.[8] Any conceptual design consists of parametric sizing, configuration layout, and configuration evaluation. The parametric sizing method laid out by Lawrence Loftin gives a rapid sizing method based on existing correlations of well-known aircraft design parameters. In order to stick with the reverse engineering theme of the project, the outputs from the performance and structures groups were used in place of the empirical data that Loftin's design process generally relies on. Using Loftin's design method allows for the creation of a solution space which constrains the design's total weight, engine power and wing area.

The typical conceptual design sizing phase consists of seven distinct steps: analyze, integrate, iterate, converge, screen, visualize, and assess risk. The analysis begins with evaluating the properties, characteristics, and performance objectives with known equations from a basic engineering undergraduate degree. Many of these relations are defined by Loftin, but through our literature research and built up database we were able to verify the equations used. Next, one should build up a system of equations integrating them so major aircraft performance can be evaluated. Once the integration of parameters has been created, the following step is to iterate the method until it can converge on a specific desired value. This convergence is accomplished by constraining the combination of engine power and wing area using several performance requirements set within the design objectives.

The constraining curves used by Loftin for first order conceptual design are defined by the required velocity characteristics as well as the aircraft's takeoff/landing field performance. The resulting figure represents the screening step and leads to a visualization of the aircraft. The overall objective of the Loftin sizing method is to choose a configuration which yields the best combination of high wing loading and high power loading. Crossing these constraining curves increases the risk of flying the vehicle and is a measure of the safety of the aircraft.

As stated, the overall goal of this project involved creating valid methods for performing a revers
e engineering, as well as simulating the sizing portion of the conceptual design phase of an aircra
ft. The successful completion of the solution space using the disciplinary results serves to fulfill
both of these goals. After implementing the values obtained by the disciplines throughout the pro
ject, the solution space seen in Figure 3 was created. The solution space indicates that the actual
Spitfire Mk-Vb fell within the admissible section of the matching chart, thus verifying the metho
ds used by the individual disciplines, as well as the sizing method.

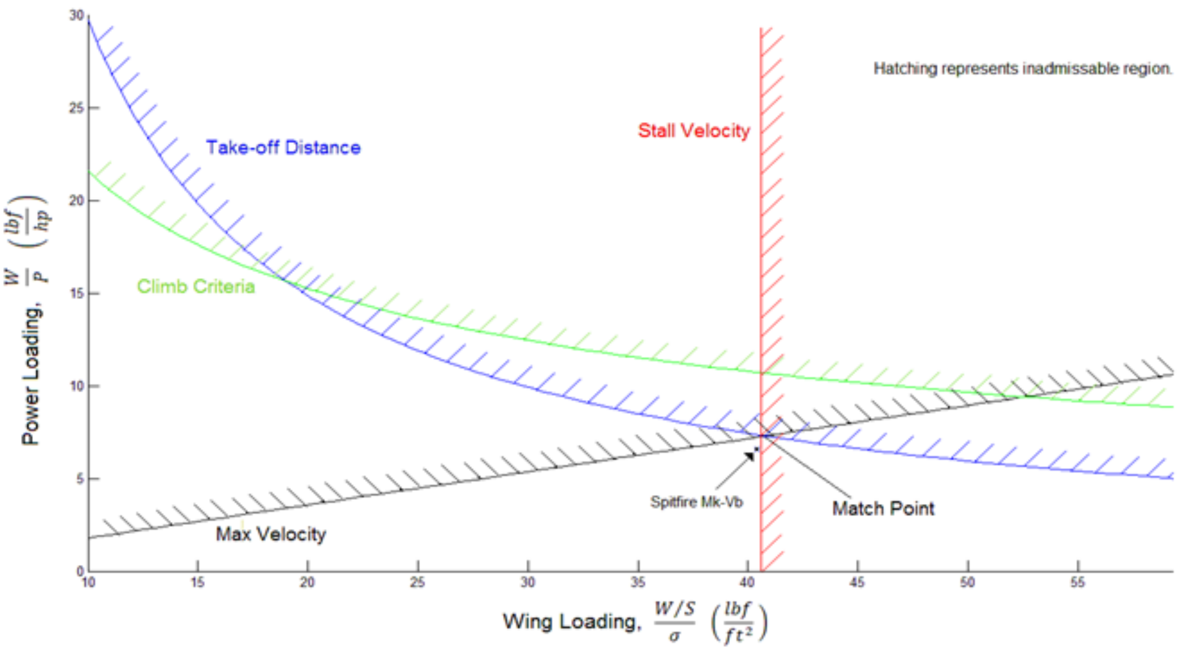

Figure 2. Visualized match point of the Supermarine Spitfire.

Summary and Conclusions

The biggest takeaway from this project has been the level of complexity involved in analyzing or designing an aircraft, even if this aircraft has been sitting in museums for over 50 years. The methodology employed by the group has allowed for not only a better understanding of the reverse engineering of an aircraft, but has also given insight into the conceptual design phase commonly employed in industry. Though working as a large group consisted of many challenges, the teamwork allowed for a truly cooperative learning experience which helped the growth of each individual member. The group was able to break up into the various disciplines involved in aircraft design and successfully reverse engineer the aircraft to show that the Supermarine Spitfire flew. Using the results from each of these disciplines, a basic conceptual design of the Spitfire was recreated using the parametric sizing method of Lawrence Loftin. This conceptual design simulation resulted in an accurate and realistic solution space for the sizing of an aircraft with the Spitfire's performance capabilities, and it has been shown that the Spitfire's sizing is within this acceptable space and very near the match point created. The combination of the reverse engineering and conceptual design of an aircraft has been both interesting and engaging, and has truly given an insight into the genius of the aircraft designers of the past.

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Extended Abstract with Poster

Obtaining ABET Accreditation: Identifying Challenges, Problem and Prospects for BUET: A Case Study

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Extended Abstract

Bangladesh University of Engineering and Technology (BUET) is the premier engineering and technology university of Bangladesh. It has a strong undergraduate program with highly competitive entrance requirements. As the top ranked engineering university of the country, BUET attracts the best and brightest of the country. Eventually, a small number get the opportunity to be admitted to BUET due to limitation of available places. For example, the total number of students admitted in the undergraduate level in BUET was 855, from about 70,000 eligible students, who successfully completed higher secondary level of education in science group in 2007 (Ahmed, 2008). Graduates from BUET are working in all sectors of Bangladesh as faculty members, government officials, policy makers, entrepreneurs and so on. BUET graduates have spread all over the world and have been employed in various countries in the public and private sectors as well as in education and research. Every year a good number of BUET graduates seek opportunities in countries in North America, particularly in the United States for graduate education and research. Though the course curricula of BUET was developed following the US system with the active help and assistance of a US University, BUET till now did not apply for nor seek formal ABET accreditation.

According to Rugarcia et al. (2000), future engineers will have to face and cope with seven particular challenges: information expansion, diminishing boundaries between the disciplines, globalization of the economy, endangered environment, resource constraints, emerging social responsibilities and rapid changes in technology. These changes are already taking place, and with the rapidly changing global scenario, including its political and socio-economic structures, the role of engineers is changing rapidly in this highly competitive environment. Therefore, the quality and standard of education of any engineering institution is important for their students to

enter either in the job market directly as professionals or to go for further higher studies around the world. To accommodate these requirements for future engineers, all the departments of BUET have been updating and modifying their respective curricula. Moreover, there has been an increasing concern among the majority of faculty members at BUET that ABET accreditation should be sought to enhance and streamline its academic curricula, educational administration and management processes.

In view of this, The Civil Engineering Department of BUET had recently taken several steps through a program called Higher Education Quality Enhancement Program (HEQEP) funded by the University Grant Commission (UGC) of Bangladesh. As a first step of the program, several courses are being evaluated according to the criteria used for ABET accreditation. The objective of this paper is to identify the obstacles to achieving ABET accreditation and various ways to overcome these problems. The summary of a particular case study is presented which was conducted by one of the authors. The findings of the case study provide necessary data which may assist BUET policy makers in focusing on the appropriate problem areas and opportunities for Civil Engineering Department with regard to ABET accreditation processes and requirements.

The undergraduate curricula at BUET are based on the course system. There are two terms in an academic year and the duration of each term is eighteen weeks. Thirteen weeks are assigned for classes and five weeks are allowed for preparation and study for an intensive end of semester exam for each course. In addition to the professional courses pertaining to each discipline, emphasis is also given on acquiring knowledge in the basic and social sciences. A student needs to complete a total of 160 credit hours to obtain an undergraduate degree in Civil Engineering degree. The total credit requirement is higher than the standard requirement for a University in North America. The grading system and marks distribution are as follows. Distribution of marks is fixed irrespective of course, instructor and needs of students. 10 % marks is assigned to class attendance, 20% is assigned to home works and quizzes, and the remaining 70% is for the term final exam. Course offerings and planning are decided by Board of Undergraduate Studies (BUGS). There is also provision for employing teaching assistants (TAs) depending on the number of registered students.

One of the major drawbacks of the current undergraduate teaching method in BUET is the widespread use of the deductive method by a significant majority. In this approach, students are taught theories and governing laws with the assumption that once the principles are well understood, students will be able to apply them to particular situations and cases as needed. Induction is the natural way of learning and most engineering students are inductive learners (Felder et al., 1988). Classroom evaluation is important to assess and eventually to bring out the best of the students potential abilities. The evaluation method should be carefully designed to enhance the learning capacity of students. As has been already mentioned, most engineering students learn more naturally by the inductive process; therefore, class tests and assignments need to be compatible with this learning style of students. The classroom assessment process needs to improve students' understanding of engineering tools and concepts, as well as his/her ability to apply his understanding to practical problems. In many cases, classroom evaluation methods commonly followed in BUET fail to significantly and appropriately address these issues.

Failure to provide regular feedback to students about their progress in the course due to the grading scheme (end-of-term exam only, rather than periodic exams) is another major drawback of the BUET undergraduate education system.

It is also observed that a good number of engineering students in BUET gradually lose interest in engineering courses. This is due to inability or inherent weakness of the course design which fails to communicate to the students effectively the overall mission, vision, objective of the engineering profession and the means by which these objectives are to be actually realized by a practicing engineer. It is a struggle for most students to correlate theories taught in the classroom to real-life engineering. In such cases, courses or seminars may be structured within the curricula to achieve such an understanding. These seminars or courses if offered by an experienced engineer from the industry could be of great help. Various workshops may be arranged where experienced engineers and professionals from industry can share real-life experience and practical and challenging situations and problems with the students. Such workshops are generally absent in BUET, particularly in the undergraduate program.

Lack of availability of modern teaching equipment and logistic support is another area of major concern. Due to budget constraints, it is not possible to provide computing facilities for all students.

Multidimensional competition among students is generally not common in BUET. These types of competition ensure participation of students having different skills in a team environment which allows quick and easy exchange of skills and concepts. The current practice among undergraduate students of BUET is to focus primarily on course work and chase hard for a better grade. There are limited opportunities for undergraduate research in BUET. Research experience is useful and helpful for undergraduate students to become independent, interdependent and lifelong learners.

A survey was conducted among students of the course titled "Structural Analysis and Design Sessional III" under the HEQEP project. It is a final year design-based course in which students have the opportunity to utilize commercially available structural analysis and design software packages to analyze and design various types of structures, including reinforced concrete buildings, water tanks, and folded plates. The course was designed and conducted following the ABET general criteria for baccalaureate level programs. Students were updated on a regular basis about their progress. Well defined course objectives were set following ABET student outcomes criterion (Criterion 3). A term project based on real-life data was introduced for the first time to address course outcome and students were encouraged to go beyond the classroom for successful completion of the project.

Feedback from students was collected through various surveys. Survey data were compiled and provided a more objective view of current problems associated with the existing undergraduate program in Civil Engineering. In one query of the survey, students were asked to evaluate the inclusion of term project in the course. There were six ratings with highly appreciated or vital being the highest and negative impact being the lowest. More than 50% of students highly appreciated the inclusion of the term project. About 25% of students found introduction of a term project to be very important (the second highest rating) in context of the course. From another response it has been found that 65% of students found hands-on training on software to be important, very important or vital. Inadequacy of computing facilities was considered by most students as one of the major constraints of the program. The pilot study under HEQEP thus provided important initial data regarding the approaches that may be considered for improvement of the course curriculum and related facilities that are necessary for future ABET accreditation.

Rapid economic changes are continuously increasing and broadening the scope of work, responsibility and role of engineers in their respective communities. The new generation of engineers needs to be globally competitive with strong communication skills to perform effectively in a multidisciplinary working environment. Redesigning and improving engineering education to achieve accreditation of professional associations like ABET is a necessary first step in that direction. The Department of Civil Engineering of BUET is now re-evaluating its courses and implementing policies and processes with the objective of seeking ABET accreditation. The outcome of the pilot study is expected to assist the Department ing clearly identifying the areas that need to be improved to achieve that objective.

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Extended Abstract with Poster

Evaluating Effects of the Arlington Undergraduate Research-based Achievement for STEM (AURAS) Program on the Performance of Engineering Students in Chemistry Courses

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Abstract

The current study was designed to evaluate the effect of supplemental instruction on academic achievement and to develop credible research to assess the learning of students in general chemistry courses. At The University of Texas at Arlington, completion of general chemistry is a core requirement of the engineering curriculum, and the Chemistry for Engineers course effectively combines traditional first and second semester general chemistry courses into a one semester course. Similar to other institutions, our students face obstacles to learning chemistry. These are evident from the low passing rates that are reported in literature and seen in our classrooms. The university has instituted the Arlington Undergraduate Research-based Achievement for STEM (AURAS), a National Science Foundation-funded program to promote success in general chemistry, and ultimately increase retention and graduation rates of engineering students.

General chemistry is identified as a "high-risk" class because it impacts both retention and graduation rates. In general chemistry, students are taught basic science principles and they acquire academic skills that are necessary to solve engineering problems in subsequent classes[1,2]. A thorough understanding of the material is associated with a positive outcome for the student in the engineering program. The University of Purdue reported an average graduation rate of 57 percent over a period of 15 years for engineering-bound students[2]. The percentage of engineering graduates increased to 89 percent when calculated among students who had successfully completed "high-risk" courses. Unfortunately this average does not take into account the nearly 50 percent of unsuccessful students commonly found in introductory chemistry courses[3,4].

Through the AURAS program, sessions of supplemental instructional were offered to students enrolled in the Chemistry for Engineers course for the fall 2011 semester. Only one class section was offered, therefore, all students compared in this study attended the same lecture taught by one instructor. One ESP section with a capacity of forty students was available. It was led by two

teaching assistants (TAs) and two undergraduate Peer Academic Leaders (PAL) that were present at all times and stayed constant throughout the program. Subjects were recruited by advisors and registered for the program prior to the first session. Separately from regular classroom and laboratory sessions, students attended four hour sessions of supplemental instruction scheduled once a week, in which material was reinforced using the model of a Treisman-style Emerging Scholars Program (ESP)[5,6]. In ESP, an emphasis is placed on building community among the students through active learning and fostering collective efforts aimed to solve challenging problems.

Students enrolled in ESP, henceforth the ESP group, received the benefits of the AURAS program while the comparison non-ESP group did not. Our hypotheses were that the experimental group would attain higher marks on examinations and a higher percentage of students would pass the course (attaining marks of A, B, or C), compared to non-ESP students. The first hypothesis was proven. As shown in **Figure 1**, ESP students had statistically higher grades in the Exam 1, Exam 2, Exam 3, and the final exam ($p < 0.05$). ESP students retained a higher average for Exam 4, which approximated significant value ($p = 0.06$). Due to a holiday break mid-week, only one ESP session was administered to prepare students for Exam 4 and the exam covered two chapters in the textbook. This could be the reason that no significance was found on Exam 4. The second hypothesis was proven by comparing the passing rates in each group. The ESP group had a higher passing rate than the non-ESP group (85% versus 57%) From Pearsons' chi-square test we can say there is a minimal probability (0.5%) that the difference in grades is a result of random chance. Data on demographics and academic background variables (SAT/ACT scores) is currently being analyzed to decipher if the groups come from the same population. If the groups are comparable, we can safely say that attending AURAS and success in chemistry are dependent on one another ($\chi^2(1)_{.005} = 7.88$, $\chi^2_{calc} = 10.57$, $p < 0.005$).

Both summative and formative assessments were used throughout the AURAS program to promote a thorough understanding of the material taught in class. For this purpose, a list of learning outcomes was distilled from the learning objectives provided for each chapter of the textbook *Chemistry for Engineering Students*, Second Edition, by Brown and Holme[7]. Learning outcomes were statements of the knowledge and skills students were expected to master. At the beginning of each session, students were administered short quizzes or extended test review packets, depending on the date proximity of the formal examination. All questions administered to the students were coded with the learning objective/outcome that was being tested. The performance of the class was computed for each test by averaging the grades over the questions coding one objective. This average is termed class mastery. Class mastery is a measure of how well the class understood the concepts, and could apply the skills, outlined in a given outcome. Content validity on of the learning outcomes was established by the course instructor who reviewed and modified the list.

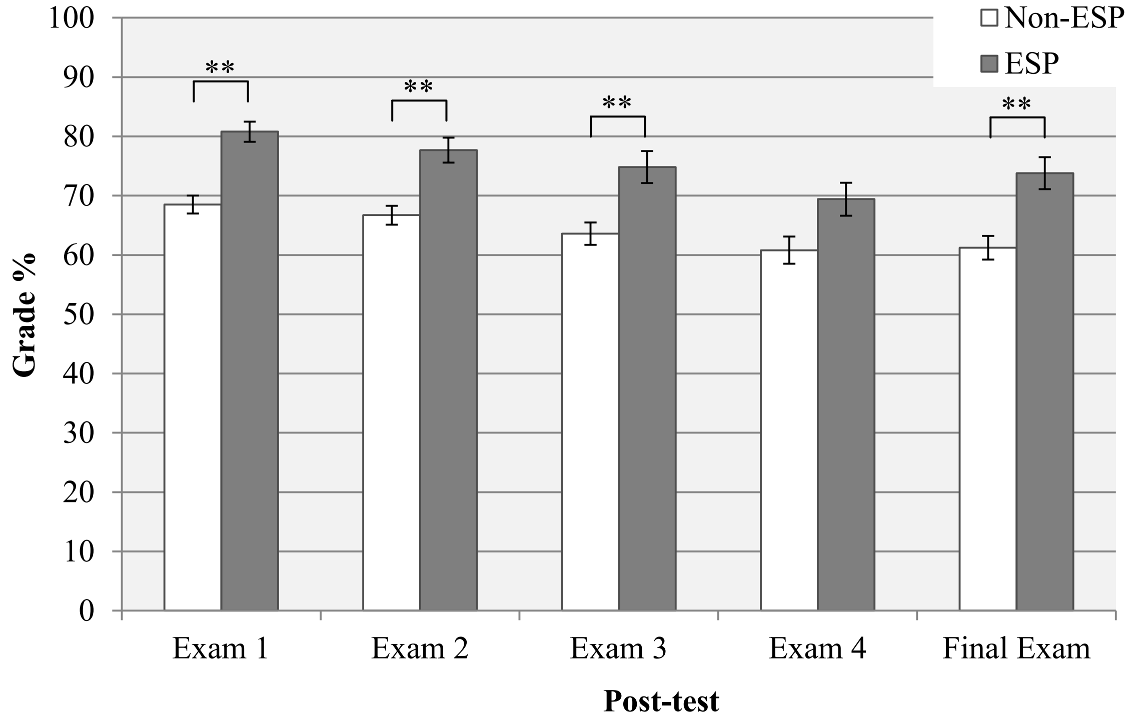

Figure 1. Mean scores for each of the five post tests: T-statistics were used to test for significance (*p < 0.05; **p < 0.005). Standard error bars shown.

The scores obtained from the learning outcomes were used to evaluate the combined ability of the traditional course and the ESP instruction to effectively deliver course themes (summative evaluation), while the scores obtained from the detailed learning objectives were used to monitor students learning and to provide ongoing feedback to the students and ESP instructors (formative assessment). TAs developed lesson plans with integrated activities, such as Process Oriented Guided Inquiry Learning (POGIL) real world problems to foster collaborative learning, while emphasizing challenging concepts. PAL students tutored individual students or groups, based on their discretion, and regularly updated TAs to ensure ESP lessons transitioned at the same pace as that of the course. It was hypothesized learning would increase over time, which would in turn result in a continuous increase of class mastery from test to test.

On average, students had a mastery of 59.1% (SD = 14.0) when the outcome was originally tested in AURAS (pre-test). Mastery of chemistry content increased to 78.6% (SD = 7.8) on the formal examination given in class (non-comprehensive/immediate post-test). When the outcomes were tested in the comprehensive final examination, the average class mastery was 74.8% (SD = 13.9). Repeated analysis of variance (ANOVA) was used to test the effect ESP- supplemental instruction had on class mastery of chemistry content. A significant increase in content mastery was found for the range of learning outcomes, $F(2,16) = 12.45$, $p = 0.00001$. *Post hoc* comparisons revealed significant differences between the pre-test and imidiate post-test and the pre-test and the final post-test. The results indicate that the class had a significant increase in understanding prior to being tested in class. We can confidently say that the program enhanced the course and resulted in improved student attainment of the material. This is evident from both the learning outcomes assessment and the comparison of exams grades between the ESP and non-ESP group. We further postulate that in addition to enhanced learning, ESP instruction resulted in learning retention, which is shown by the significantly higher mastery of chemistry content between the pre-test and final post-test. No significant differences were noted between the initial and final post-test scores. This could be interpreted in two ways: (1) knowledge increase was not continuous from immediate to final post-test or (2) knowledge decay was insignificant. Future research using learning outcomes based assessment would benefit from an analysis testing the effect of repeated assessment on the learn–forget curve model [8,9].

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Extended Abstract with Poster

Case Study: Course Access Habits of Online Graduate Students that are Working Professionals

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Abstract

The objective of this extended abstract is to present a case-study providing insight into the course access habits of online students, specifically those that are working professionals pursuing a graduate degree. The case study involved a small class of nine working professionals pursuing an online graduate degree in mechanical engineering. While these results will vary with student population, this work provides a fascinating insight into how online engineering students approach their coursework. Data such as this can aid faculty into selecting appropriate deadlines for assignments and setting aside virtual office hours that best meet the needs of the working professional online student.

Introduction

More and more working professionals are turning to online learning to further their careers and remain competitive in the modern workforce, often with both the approval and support of their employers [1]. How their educational needs may differ from those of the classical on-campus graduate students is worthy of attention. As a first step, this extended abstract looks at the use patterns of student professionals taking an online graduate course through a learning management system. This has been done in the past for investigating student learning styles and web use patterns for undergraduate students [2].

Fully online courses present their own set of challenges. Modern online courses are more than merely recording a faculty member lecturing to an on-campus class, but rather include a variety of media and formats to present information to the students. When such a course is taught for the first time online, it is important to be able to look back at the course and determine what material the students accessed the most and what material could be replaced or eliminated.

Another issue is online presence: when is the best time to be available to answer questions for online students? One of the frustrations faced by online students is the time it takes for a faculty member to answer their questions. Being able to setup times for "virtual" office hours that match the times students are working on their assignments would not only increase student learning but improve their level of satisfaction with the course.

Course Setup for Case Study

The University of Texas at Tyler has recently begun offering a fully online master's degree program in mechanical engineering or civil engineering. What makes this program unusual is its compressed format: all courses are offered over seven weeks, rather than sixteen weeks, to make it possible for students to complete their degree more quickly.

This case study focuses on a seven-week fully online finite element analysis course with nine students enrolled. All nine students were full-time working professionals holding either an engineering or technical position. The students included an officer in the Civil Engineer Corps, a mechanical engineer working in research and development for a major biomedical company, a civil engineer at a local firm, an independent design and engineering graphics consultant, a structural engineer with 30+ years' experience, a petroleum engineer, and a mechanical engineer working in heat transfer. All students lived and worked in North America. The students included both civil and mechanical engineering graduate students, all with undergraduate degrees in engineering.

The course was presented to the students using the learning management system *Blackboard Learn*, which allows faculty to monitor student activity even without enabling statistics tracking on particular items [3].

All course materials were made available through *Blackboard* in form of video lectures, video demonstrations, handouts, and discussion forums. The midterm was a "take-home" exam and the final consisted of several finite element analysis problems to be solved using software tools. The students primarily accessed content, tools, announcements, discussion boards (which were assigned), and grades. By contrast, they made little to no use of email through the learning management system, calendars (only two students out of nine), or task lists available through Blackboard.

Course Material Access Statistics

Using Course Reports in *Blackboard*, it is possible to determine what content areas have been used the most, how many hours a student has spent actually logged into the course, and what days of the week and times of day the course is being accessed. Blackboard also records hits, where a hit is defined as every time a request is sent to the Blackboard learning system (basically, every mouse click) [3].

Homework assignments were due on Mondays or Wednesdays, and new material posted each Monday. Figure 1 illustrates that students accessed the course material primarily on Mondays and Thursdays. Weekends, it would seem, were not the primary time that the working students were accessing course material. The day of the week students most often accessed the course corresponded with assignment due dates, and surprisingly most students did not access the course material very much on Sunday.

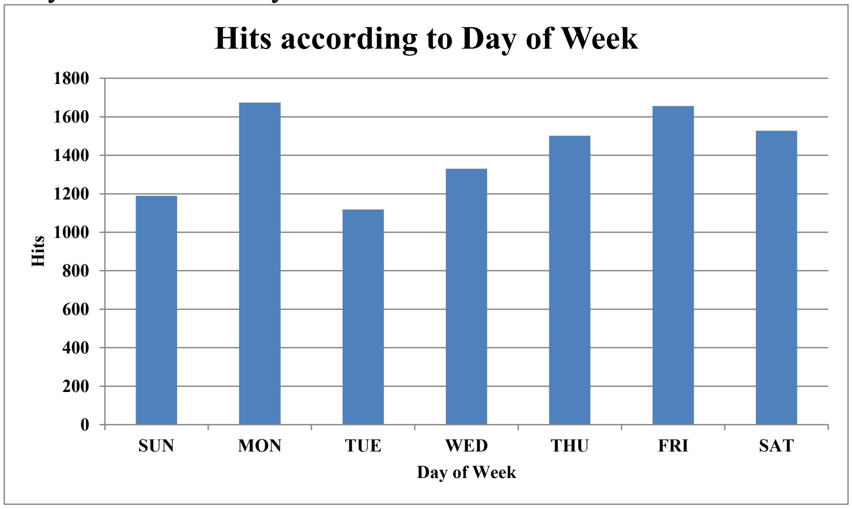

Figure 1. Chart illustrating online course activity during the week

The amount of information obtained about the time of day students accessed the course is extremely revealing, demonstrating that the professional students enrolled in this course had regular study habits and were not as likely to need help in the early hours of the morning (midnight to 6 am). This is illustrated by Figure 2, showing the total hits over the length of the course. The data indicates that the students accessed course materials the most at 10 AM, 4 PM, and 9 PM. This is similar to findings regarding the use of online tools for teaching electricity principles from 1996, where students were also found to access tools at consistent times [3].

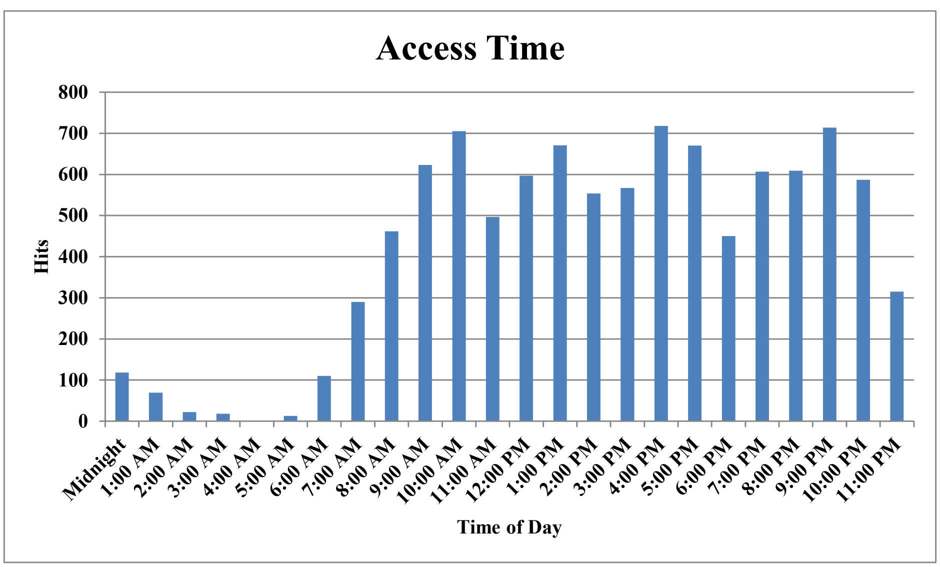

Figure 2. Chart illustrating online course activity versus time of day.

The data in Figure 2, however, is based on US Central Time, but not all students lived in the same time zone. However, the data remains important for a faculty member working to ensure that students have access to course materials when they need them.

The final fascinating statistic focuses on the hours spent logged into the learning management system. On average, the students spent 217 hours logged into the course, with the minimum number of hours being 44 and the maximum being 515.

Conclusions

The number of hours students were actively logged into the learning management system varied greatly, but could be explained in part by students downloading course materials to access offline at a later time. Variation in study time, however, is to be expected for any population of students whether online or traditional.

In spite of time zone differences for students located across the United States and Canada, this data indicates that there are common blocks of time where students actively engage in the coursework through the online learning management system. Very little time was spent working with online course materials during the early morning hours, with primary times of access being 10 am, 4 pm, and 9 pm CST. This could indicate that a morning office hour when the professor could be accessed via phone or Skype might be appropriate for this demographic of student, and could be convenient for both student and faculty.

Because these results were limited to only one course, there is not enough information to determine if there was truly an increase in activity immediately prior to the due date for an assignment. However, it seems logical that Monday, the beginning of the work week and of the academic week, was the most active day for the students.

Future Work

This case study is currently being followed up by a second online course, with a similar format, for which both overall course access statistics and individual course material statistics are being gathered. A comparison will be made between results of this research and the new results, as well as a look into what course materials the students actually use and which they may be ignoring.

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Extended Abstract with Poster

Using Turning Technology (response system) in Teaching Statics

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Abstract

Statics is one of the early challenging courses for sophomore-level students at The University of Tennessee at Martin (UTM). In Statics, students are challenged to solve and analyze real life engineering-mechanics problems. On the other hand, instructors' challenge is to get the students to participate, focus, and understand the material during class periods. Turning Technology, LLC offers a response system that can get immediate students' participation and feedback. This interactive system is used along with PowerPoint slides to facilitate and try to improve students' learning experience in Statics at the Department of Engineering at UTM. The used technology was found to be useful, effective, simple to use and inexpensive tool. This response system was implemented in teaching Statics as an auxiliary tool along with multiple-choice questions on various topics each class time. The course-textbook supplementary material was used in class as the source of multiple-choice questions. The use of the response system was found to be effective in the following areas: students learning and understanding, Subject weakness points identification, students' preparedness for tests, and in students' interaction and collaboration. Also the response system helped in the evaluation of students' performance and in checking attendance. The use of Turningpoint 2008 Software generated instantaneous useful results for students' responses. The use of the response system technology was an exciting experience for both students and instructor and it helped students enhance the level of understanding for Statics. This paper shows some work on the implementation of the Turning Technology response system in teaching Statics.

Introduction

One of the main challenges that instructors face is having students to interact and participate in classes. Students' engagement requires an effort from both students and instructors. Class interaction and engagement bring a spectrum of benefits to the students and to the learning process in general. It is thought that it will keep the students in an alert and focused mode, stimulate their thinking, and give some motivation. There are different ways and tools that are implemented in the educational area that try to get the students in the interaction environment. One of these methods is the response card system (clickers) that Turning Technologies, LLC developed. It has a variety of applications but share the same concept: open discussions, get feed back, and analyze the results. Audience can vary from K-12 to higher education and even businesses. This paper presents the utilization of this technology in the teaching process of a general engineering course-Statics as an interactive tool. Statics is offered at the Department of Engineering at The University of Tennessee at Martin as a required sophomore-level course. Most students view the Statics course as a challenging course. The authors attempted to test and utilize the response system hoping that it will ease and help in the learning process in a collaborative and dynamic approach.

Turning Technology Response System

The applied technology is developed by Turning Technologies, LLC. The three main components of this system are: the handheld response card (Clicker), receiver, and Turningpoint 2008 software (Figure 1).

Response card Receiver Software

Figure 1: The main components of the turning point technology

The response card has different buttons that can be used as needed. Cards have alpha/numeric buttons to answer questions appropriately[1]. The cards communicate with the computer via a receiver that is plugged into the computer using a USB connection and uses a preset channel.

The software component of this system is the tool that collects, organizes, and presents the data and results. Two main types of software exist: Turningpoint 2008 and Turningpoint anywhere. The latter is a more generic program that offers the basic polling needs. Turningpoint 2008 is the latest software used that offers more features and components than Turningpoint anywhere. The setup and usage of the system is not difficult. More about the features of the system is presented in other sections of this paper.

Implementation

Each student is required to get his/her own response card that can be purchased from the bookstore on campus. Each card has a unique code that is assigned to it and therefore, each student info will be linked to that card. The University of Tennessee at Martin adopted the usage of this system and therefore got the full services provided by the manufacturer. One of the interesting features of the system is that it can be linked to Blackboard[2] used on campus. Blackboard offers an on line system for both instructors and students to interact and communicate. Course materials, discussions, and grades can be uploaded/downloaded from Blackboard. The response system was implemented in ENGR121-Statics class for the main objectives of getting students to better understand the difficult topics. The instruction strategy was to get the students involved, collaborative, dynamic, and all in an exciting environment. The form of multiple-choice questions (MCQ) in a PowerPoint environment was the main methodology of the implementation. The course-textbook supplementary material[3] was used in class as the source of multiple-choice questions. An example of the questions given is shown in figure 2.

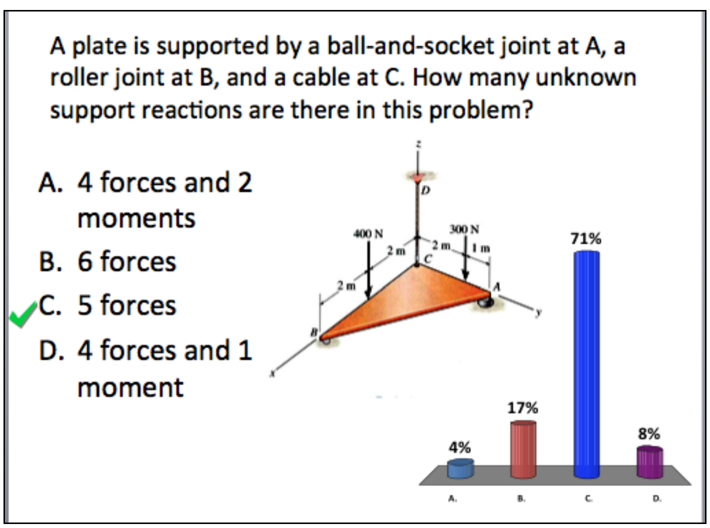

Figure 2 example of the MCQ with answers results

Each question is presented to the students and then a preset timer starts where all students can see. Once the time is up, the results as a percentage for each answered choice in the MCQ is shown as well as the correct answer. The questions covered the important concepts and topics in the material.

Results and Analysis

The results of the collected data can be exported to excel as seen in figure 3. Each answered question and responded answers are presented as a percentage from the total responders. It is also shown as a pie chart with the different answers. A unique feature of the software is that it can show the difficulty index for the questions given. The difficulty index is an assessment tool used by the software to determine the difficulty level of the problems given at a test. The difficulty index is the calculated based on the proportion of the students who answered the question correctly.

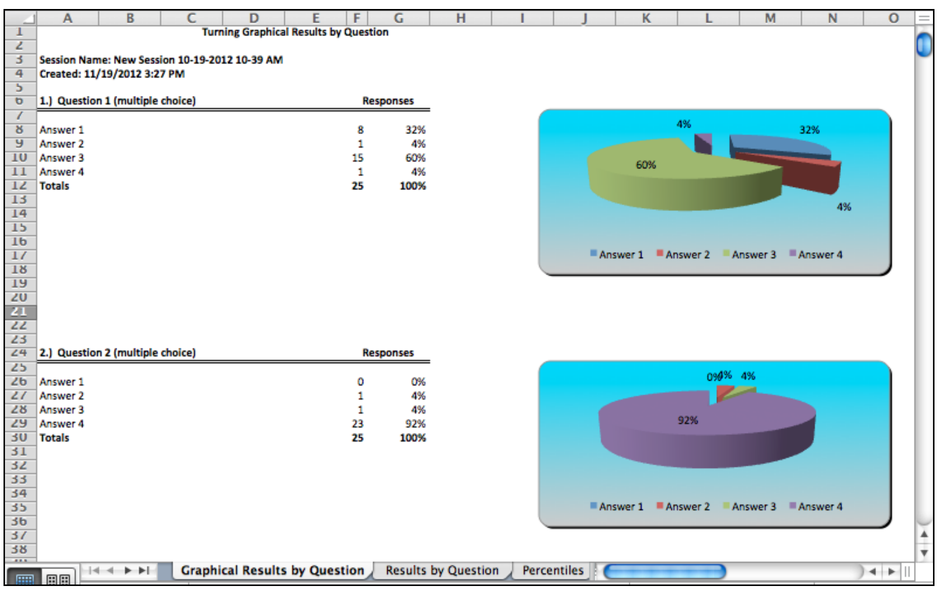

Figure 3 Results of answered MCQ’s exported to excel

Screenshots of the questions and the student’s answers can also be viewed as seen in figure 4. That feature is helpful for the instructor to identify the weak points or hard topics that students are having difficulty with.

Session Name: New Session 10-19-2012 10-39 AM.tpz
Created: 10/23/12 11:57 AM

1.) Question 1

	Responses (percent)	(count)
Answer 1	32%	8
Answer 2	4%	1
Answer 3	60%	15
Answer 4	4%	1
Totals	100%	25

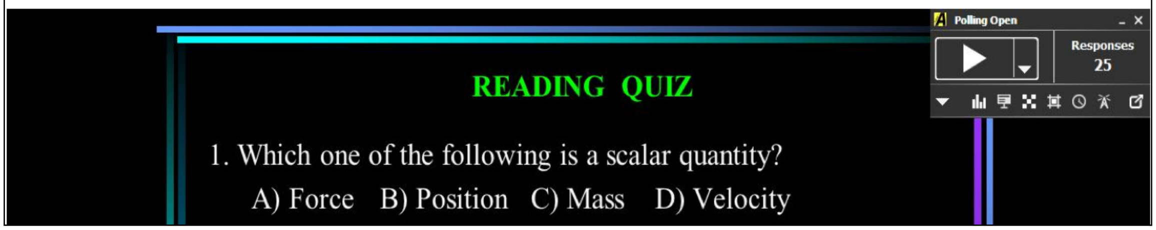

Figure 4 Results by question with screenshot

Individual students' answers can also be presented and summarized as seen in figure 5. Each answered question and the time for response are summarized. The answers can be graded instantly and a final grade can be given based on the correct answer.

Session Name: New Session 10-24-2012 10-57 AM.tpz
Created: 1/7/13 11:49 AM

Device ID: 2EA34C **First Name:** **Last Name:** **User Data:**

Response	Time (in seconds)	Question
3	7.20	1) Question 1
4	11.65	2) Question 2
3	26.45	3) Question 3
2	31.32	4) Question 4
3	14.70	5) Question 5
2	19.24	6) Question 6
4	15.65	7) Question 7
3	14.54	8) Question 8
3	8.34	9) Question 9
2	6.18	10) Question 10
4	11.15	11) Question 11
2	9.89	12) Question 12
2	17.19	13) Question 13
-	-	14) Question 14
4	2.82	15) Question 15
5	4.50	16) Question 16
3	6.8	17) Question 17
4	7.95	18) Question 18
2	7.67	19) Question 19
3	5.90	20) Question 20
3	44.87	21) Question 21
2	11.55	22) Question 22
4	14.18	23) Question 23
2	11.45	24) Question 24
2	6.78	25) Question 25
4	18.84	26) Question 26
1	10.46	27) Question 27
3	23.9	28) Question 28
2	12.62	29) Question 29
3	4.86	30) Question 30

Figure 5 Individual results for the answered questions

The answered results using the response system where utilized in different ways. The required info reached the students and the message was delivered in a style that got their attention. Students recognized correct answers and identified their possible errors and weak points. Students where corrected immediately for the mistakes they have made in approaching problems. Results where also used for checking students' attendance. All of the above conclusions were based on authors' observations in classroom and based on the students' feedback as described in the next section.

Students' Survey

A survey was used to get students' feedback on the implementation of the response system used in the course. Twenty-six students participated in the survey out of a total of thirty students in total. The ten questions asked in the survey are shown below. The answers with (yes or no) format along with students' responses are shown next to the questions as seen below. Students added notes and they are also shown at the end of the survey results.

1. Were the clickers hard to use?
   Yes__0___ No___26___
2. Do you believe that clickers encouraged you to participate in class?
   Yes___21__ No___5___
3. Was the time given to answer the questions (quizzes) given in class enough?
   Yes___21__ No___5___
4. Did the statistics presented after each answered class tell you something about where you stand in class?
   Yes__23___ No__3____
5. Did the (clickers) questions cover most of the important topics and concepts in class?
   Yes___21__ No___5___
6. Did clickers' questions help you identify your weak points in the subjects?
   Yes___21__ No___5___
7. Did clickers' questions help you prepare for tests?
   Yes___13__ No___13___
8. Do you believe that it is fair if clickers are used to check your attendance?
   Yes___23__ No___3___
9. Do you recommend the use of clickers in future classes?
   Yes___24__ No___2___
10. Overall, Do you believe that clickers are useful interactive participation tool?
   Yes__25___ No__1____

Figure 6 Students' survey for the use of the response system

The results of the survey showed a unanimous agreement that the adopted response technology was easy to use, encouraged participation in class, indicated student's stand in class, helped identifying weak points in subjects, fair tool to be used for attendance checking, and as a useful interactive participation tool.

Conclusion

The use of Turning Technology was an interesting experience that brought a new perspective for teaching Statics. This response-based system encouraged students' participation in a fun and dynamic environment. Students' found the tool helpful in clearing difficult definitions, and in pointing out their weak points in the subjects taught. Clickers results helped the instructor focus more on the topics that the students where challenged with. It gave an opportunity for the students to prepare for tests. The use of the response system was found to be helpful for student's interaction and collaboration in the classroom. Also it helped in the evaluation of students' performance and in checking attendance. Overall, The use of this response system might improve students' learning and understanding of Statics.

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Extended Abstract with Poster

AURAS: Increasing Retention in High-loss Mathematics and Chemistry Courses

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Abstract

The University of Texas at Arlington (UTA) is implementing AURAS, the “Arlington Undergraduate Research-based Achievement for STEM collaboration”, as a combined effort of the Colleges of Science and Engineering to increase retention of incoming first-semester freshmen in these colleges. The goal of AURAS is to use research-based approaches and best practices to increase the retention of science, technology, engineering and math (STEM) majors, particularly women and other students underrepresented in STEM. Specific objectives dovetail to meet this goal, with program components linked to one or more of these objectives. Program components include (1) implementation of the recognized best-practice “Emerging Scholars” program in high-loss courses in mathematics (specifically, Pre-calculus and Calculus I & II) and chemistry (Chemistry for Engineers and General Chemistry) courses, and (2) undergraduate research opportunities (“authentic experiences”) pairing first- and second-year undergraduates with faculty mentors for the purpose of providing research experiences. The authentic experiences component began in Spring 2010 and the first Emerging Scholars programs in mathematics and chemistry began in Fall 2010.

Once data from three semesters of implementation of the Emerging Scholars courses was collected and analyzed, it was apparent that this model of instruction was effective in improving

success rates in high-loss courses. Current efforts are devoted to exploration of ways to make the project more sustainable. The paper will document the success of the program and discuss current efforts toward sustainability. The project is supported by National Science Foundation grant #0856796.

Introduction

The Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP) is a congressionally-mandated program administered by the National Science Foundation (NSF). The STEP program has as its goal increasing the number of students (U.S. citizens or permanent residents) receiving associate or baccalaureate degrees in established or emerging fields in science, technology, engineering and mathematics (STEM) in the United States.

UT Arlington's STEP grant #0856796 began in Fall 2009. It is called AURAS, the Arlington Undergraduate Research-based Achievement for STEM collaboration. The way in which AURAS is intended to increase the number of graduates in the STEM fields is to increase the pass rates in a set of courses which were identified as high-loss courses for students intending to major in Biochemistry, Chemistry, Mathematics, Physics or one of the 8 undergraduate engineering majors. Note: a 9^{th} engineering undergraduate major in Bioengineering was added in Fall 2012. The identified courses were Pre-Calculus II, Calculus I, Calculus II, General Chemistry I, and Chemistry for Engineers.

The designed interventions intended to produce a change in pass rates for these courses were modeled after the Emerging Scholars Program (ESP) implementations [1]. The ESP model requires increased student time in a seminar/workshop setting to promote key features and to "learn how to learn" mathematics or chemistry. The ESP model has been adapted at over one hundred campuses across the nation and has been broadened to include a variety of introductory science and engineering courses as well as those in the introductory mathematics sequence. Research studies show that the ESP model positively impacts retention in a STEM-based major.

The AURAS program

The AURAS program at UT Arlington is a combined effort of the Colleges of Science and Engineering. It has as its specific goal to increase retention of incoming first-semester freshmen in these colleges. At the time this effort was proposed, the first-year retention rates in the colleges were approximately 69%, meaning that for students beginning as first-time first semester freshmen in the Fall of 2008, only 69% of this group of students returned to UT Arlington in the Fall of 2009. Specific objectives of the AURAS program designed to increase the retention rates are:

Objective #1: Pedagogical reform in high-loss courses to provide intensive intervention to target students.
Objective #2: Authentic learning experiences to increase STEM interest and offer financial support.
Objective #3: Discipline-based research and evaluation to verify results and foster long-term change.

Implementation of AURAS

In Fall 2010 the first courses under the ESP model were begun, with approximately 25 students in AURAS sections of Pre-calculus II, Calculus I, General Chemistry I and Chemistry for Engineers. In each case, the lecture sections for the AURAS students were the same sections open to non-AURAS students, lab sections (where required) were the same as those for non-AURAS students, but an additional "AURAS seminar" was added for the AURAS students. The AURAS seminar was a 4-hour unit designed not only to help students master course material by providing help and additional challenging content but also to provide a sense of community and engagement to those involved. The program was modeled after successful Emerging Scholars Programs at other schools (e.g., UT Austin), but also included elements of the Learning Assistant Model (e.g., University of Colorado at Boulder) to provide additional study and college career skills to the students.

Additionally, undergraduate research experiences were available to those who successfully completed the AURAS coursework. In these cases, interested students were matched with faculty in the College of Engineering and College of Science. Students received a stipend for up to 10 hours of work per week, over the period of one semester, renewable when both the mentor and mentee requested it.

Discipline-based research focused on conducting educational research in the areas of Physics (spatial intelligence), Mathematics (understanding of continuity and derivatives) and Chemistry (methods for effective instruction of stoichiometry and learning outcomes-based assessment strategies).

Results

In Spring 2012, at time of the project's 3rd year review, results of the AURAS ESP classes were seen to be very promising.

As shown in Table 1, four classes with high drop and failure rates were targeted during each of the semesters Fall '10, Spring '11 and Fall '11. For each of the two fall semesters, there is data from Math 1323, Precalculus II. The table shows the pass rate for those two fall classes combined: for the students in the AURAS seminar for Precalculus, the pass rate was 56%, compared with the pass rates of 35% for students in the same lecture section but not in the AURAS seminar, and the pass rate of 42% for students in all Precalculus lecture sections but not in the AURAS seminar. At the same time, the drop rates for students in the AURAS seminar in either semester was 21% as compared to the drop rate of 35% for students in the same lecture section but not in the AURAS seminar, and a drop rate of 27% for students in all lecture sections but not in the AURAS seminars. The results for the Chemistry for Engineers (Chem 1465) class have been more dramatic. There was a Chem 1465 class during each of the three semesters shown in this table. Students in the AURAS seminar for Chem 1465 have an 80% pass rate compared to a 51% pass rate for students not in the AURAS seminar, and have a drop rate of 0% compared to a drop rate of 18% for students not in the AURAS seminar.

Fall 2010, Spring 2011 & Fall 2011 composite												
Course		A	B	C	**Pass**	D	F	I	Q	W	**Drop**	Total
Math 1323*	ESP	5	16	6	**56%**	3	8	0	0	10	**21%**	48
Math 1323*	non-ESP (1)	13	14	24	**35%**	10	34	0	3	48	**35%**	146
Math 1323*	non-ESP (2)	57	84	96	**42%**	62	108	1	8	146	**27%**	562
Math 1426	ESP	15	14	12	**80%**	8	0	0	0	2	**4%**	51
Math 1426	non-ESP (1)	17	34	37	**56%**	19	17	0	2	31	**21%**	157
Math 1426	non-ESP (2)	85	218	206	**48%**	156	147	2	6	239	**23%**	1059
Math 2425#	ESP	5	4	9	**72%**	2	2	0	0	3	**12%**	25
Math 2425#	non-ESP (1)	12	11	12	**65%**	1	7	0	1	10	**20%**	54
Math 2425#	non-ESP (2)	32	52	47	**52%**	14	39	1	4	64	**27%**	253
Chem 1441	ESP	15	15	15	**71%**	8	6	0	1	3	**6%**	63
Chem 1441	non-ESP (2)	166	176	226	**48%**	134	225	4	8	238	**21%**	1177
Chem 1465	ESP	13	15	19	**80%**	5	7	0	0	0	**0%**	59
Chem 1465	non-ESP (2)	19	54	89	**51%**	45	49	2	4	53	**18%**	315
(1) non-ESP same section					*** Math 1323 Fall 2010 & Fall 2011 only**							
(2) non-ESP all sections					**# Math 2425 Spring 2011 only**							

Table 1. ESP vs. non-ESP composite class performance results over the first 3 semesters

Additional semesters' results are being analyzed at this time and will be available at the time of the presentation.

The Future

A tenet of the STEP program is to create institutional change which will remain after the life of the grant funding. After the first year's result were available, it became clear to the Department of Chemistry & Biochemistry that the AURAS seminar was making a meaningful difference in the success rates of its majors. The department took the step of requiring that its chemistry majors and biochemistry majors enroll in the AURAS section on General Chemistry I. At the urging of the Internal Advisory Committee for AURAS, the sustainability of the AURAS efforts have been under consideration even during the 2nd year of implementation of the ESP courses. Efforts toward sustainability are focused on making less labor-intensive the instructional interventions. With this in mind, the AURAS seminar for Chemistry for Engineering was reduced to a 2-hour seminar in Fall '12. The results of this modification are not yet available, but student satisfaction appears to be increased. The sustainability of these efforts continue to be front and center in the planning for the remaining years of this grant and for the continuation of components of this successful project beyond the grant period.

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Extended Abstract with Poster

Bringing MEMS technology Closer to Undergraduate Education via the Mobile Microrobotics Challenge

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Abstract

The Robocup initiative has emerged as a platform for fostering robotics research by providing a set of standard problems categorized into leagues. During the first Robocup event, almost two decades ago, robots could not perform many of the required tasks; however, they have since improved dramatically in both reliability and performance. Recognizing the value of such events, the US NIST has proposed a similar robot competition at the microscale (the Mobile Microrobotics Challenge – MMC). The UT Arlington Microrobotics team has successfully competed twice in these event, with broad participation from both undergraduate and graduate students. Microrobots utilize Micro Electro Mechanical System (MEMS) technology, and are actuated using real-time control systems. As a result, the competition is an excellent vehicle for undergraduate student education, and an important introduction to engineering problems at the micro and nano scales.

Introduction

The first MMC competition was held in 2007 with the name Robocup Nanogram [1]. A dozen teams designed and fabricated micrometer scale robots that can be powered and controlled without wires. During the International Conference on Robotics and Automation (ICRA 2010, 2011, 2012), the event (Mobile Microrobotics Challenge - MMC) called for competition with untethered microrobots that must fit within a 600 μm diameter sphere [2]. On a controlled setup under a microscope, microrobots race along a distance of 2 mm, push micropegs, and insert them into holes, or they demonstrate a freely selected style of operation. In 2013, NIST delegated responsibility for the organization of the MMC to the IEEE Robotics and Automation Society, and the next challenge will be held at ICRA 2013 in Karlsruhe, Germany by a committee representing the Micro-Nano Robotics TC of IEEE-RAS [3].

At the present time, qualifying for the challenge proves to be an incredibly difficult feat, which suggests that much research in this field is needed. Many of the finalists who competed in 2010-2012 used magnetic fields to power their microrobots. At present, the competition is dominated by European teams, for instance ET Zurich using the Octomag magnetic drive, although several US teams (CMU, U. Hawaii) have also been strong contenders. All participants directly credit the MMC competition for channeling their research efforts toward demonstrable and robust microrobotic technology, as opposed to impractical lab curiosities. Popa lead a team of students from UT-Arlington to the 2011 and 2012 challenges [4-5]. Our microrobots used vibration and laser energy for power and motion control.

Approach

For the 2013 competition in Karslruhe, Germany, the UTA Microrobotics Team is sponsored by the UTA Research Institute (UTARI), and plans to participate using magnetic field-powered microrobots with increased maneuverability (Figure 1). Both graduate and undergraduate students are part of our teams, and share multiple team responsibilities including microrobot modeling, fabrication, control, and system integration. Sub-mm scratch drive robots are powered and controlled through wireless transmission of magnetic energy by a magnetic field drive system that we will bring to the competition.

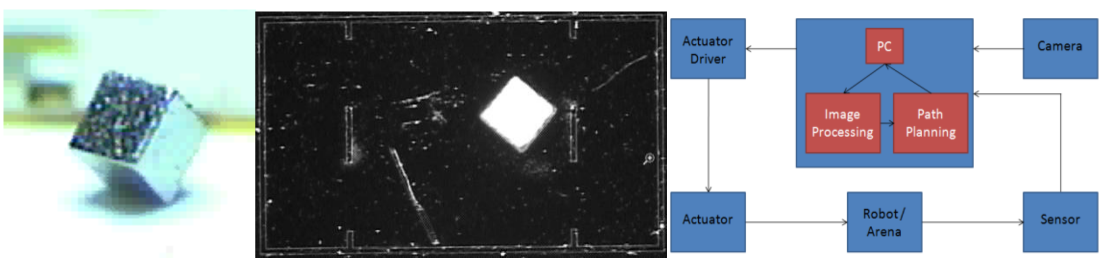

Figure 1: (Left) 3D Photo of a 500 μm cube microrobot, MAGBOT. (Center) Top view of microrobot on the 3x2 mm arena, (Right) Control system diagram.

This system consists of a computer running National Instruments Labview, robot actuators and driver from Newport Corporation, robot arena and microrobot, and a high speed FPGA camera microscope. A new operator interface for teleoperation of the microassembly task is being set up using a Microsoft Kinect®. This sensor captures the human/operator's body position, in specific the hand, which will be used to control the mobility of the microrobotic platform giving the operator a more intuitive control over the system. And the mobility challenge consists of automated microrobot motion control, without operator intervention. For this task, students must close the control loop from the microscope to the precision positioning stages to make the robot follow a figure "8" trajectory on the microrobot arena.

Conclusion

The IEEE MMC brings students in all engineering disciplines closer to the micro-nano world through an exciting type of competition, which requires both theoretical and practical know-how in microfabrication, metrology, control, and system integration. At UTA, this endeavor has been combined with Undergraduate Electrical Engineering education through independent study projects, Senior Design projects, and is an excellent bridge to follow-up micro-nanoscale instruction in graduate school. Furthermore, it presents an opportunity for engineering students to interact with sponsor companies, and engage in other outreach activities. Future papers will describe more detailed competition, including research technology and educational outcomes of MMC.

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DAN O. POPA

Dr. Popa currently serves as an Associate Professor of Electrical Engineering at the University of Texas at Arlington. His research interests include robotics and control systems, including micro and nano robotics, assistive robotics, advanced real time control, and human-robot interaction. In addition to teaching duties in the EE department, Dr. Popa is affiliated faculty at UT Arlington's Research Institute, where he plays an active role in research and commercialization activities.

NAHUM TORRES-ARENAS

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Extended Abstract with Poster

STEM High School Teaching Enhancement Through Collaborative Engineering Research on Extreme Winds

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Abstract

The Research Experience for Teachers (RET) project on Hazard Mitigation at UT Arlington was funded by the National Science Foundation (NSF). The project had the important intellectual focus of educating high school STEM teachers in inquiry-based research learning, research design, execution and implementation, and in solving real-world hazard-related engineering problems with open-ended solutions. The RET program brought together 27 high school STEM teachers from 10 high schools in the Arlington, Texas, and five other school districts from surrounding areas. A total of seven summer research projects with the common theme of hazard mitigation were identified and conducted. In the six week summer extreme wind RET project, the STEM teachers were provided with hands on research experience with the International Building Code (IBC) wind load provisions, analysis of existing structures for wind loads, determining shortcomings (if any) of the analyzed structures, and designing upgrades and retrofits for the structures for complying with the building code provisions. Potential ethical issues arising out of deliberately or negligently using faulty design, inferior material selection and/or sub-standard construction practice, and the effect of such practice on wind integrity of structures were also covered.

A total of 12 comprehensive classroom lectures were given to the participating teachers on the RET project on Extreme Winds. A description of the various types of extreme winds and their effects on structures were shown through the use of mathematics and statistics. They could then relate the wind loads to the appropriate mathematical and physical formulations. Lectures on basic mechanics of structures were also provided. Knowledge on the analysis of structures for wind load was very helpful to the teachers for designing small classroom projects in their classes. The teachers were provided with the knowledge of calculating forces in simple structural members like roof trusses, as they are one of the most important parts of residential homes and are very common. The teachers were given the opportunity to explore

structural analysis and the design software RISA 3D. The structures were then analyzed and responses were evaluated in terms of stress and deflection. The analyses were done by the teachers under the supervision of the faculty mentor and the graduate research assistant. A field trip was undertaken to a local truss production facility in Ft. Worth, Texas. The field trip provided a clear concept to the teachers about the fabrication process of different parts of a truss and how these parts are assembled. The field trips helped the teachers in building their prototype class projects with balsa wood pieces which were connected to each other resembling actual connections.

At the initiation of the summer RET program, each teacher was asked to produce the current lesson plan that they were using in their classrooms. At the end of the summer program, each teacher produced a modified and enhanced lesson plan, based on their acquired knowledge from the RET project. At one High School, a modified post-RET lesson plan was developed as a project for the Honors or Pre-Advanced Placement (pre-AP) Physics students. Using the concept of forces, students develop roof trusses that withstand the greatest amount of force with a limited amount of materials. Once the maximum load is determined, the students evaluate the truss members in solving two dimensional components of the forces that satisfy the condition for static equilibrium. After the RET project experience, one Teacher modified her teaching approach for the AP Physics class as follows. Students were asked to research and report on recent failures in engineering infrastructure and how ethics may have played a role. The AP students also complete the roof truss exercise, similar to the pre-AP Physics students, extending the application into the building walls. Students are given a construction budget, simulating real life projects. In the first two years of the RET project, students were able to take various field trips to UT Arlington. Students took the first trip to understand how various materials are tested in the laboratory. During the second visit, students were able to explore the same areas plus the manufacturing and robotics laboratory, 3D engineering design lab in aerospace engineering, and the projects in computer engineering and smart robotics. Student groups also were able to make modifications to their projects to determine what could be added or removed from their designs to improve the performance of their structure in the wind loads provided in the simulation. Building a structure that is strong enough and balances cost, strength, and time required to build, as learned by the students through the RET project, is sound engineering practice. Overall, the students had generally positive comments about the RET lesson experience. Of the 20 junior and senior students surveyed after the field trips in 2008 and 2009, six are currently studying engineering.

From the teacher's perspective, it is important to help students see real life applications to the lessons that are taught in the classroom. It is apparent that the exposure to real life examples helped students understand why they needed to learn the material; it also helped motivate their interest in career fields (such as engineering, sciences, mathematics and technology). The teacher benefits in other ways, such as the ability to gain knowledge outside their area of expertise, create new educational and professional relationships between the high schools and the university, better understand career fields in relation to material in the classroom, acquire professional development hours and the financial assistance in terms of a summer stipend. Through the RET project, teachers began to view themselves as researchers, not in the traditional way of performing experiments in a laboratory and gathering data, but in gathering new engineering and educational information. They were able to develop real life scenarios for lesson plans that students could find relevant and experience a small part of engineering. Fifteen teachers were able to present their RET experiences at various conferences.

Additionally, three teachers were awarded a scholarship for graduate school, earning a Master of Education degree in Curriculum and Instruction. Teachers felt that the RET experience was one of the most rewarding teacher development programs for them.

DANIELLE REYNOLDS
Danielle Reynolds has 15 years of teaching experience, currently teaching high school Physics at John A. Dubiski Career High School in Grand Prairie, Texas. She earned her Master of Education in Curriculum and Instruction in 2011, and her Bachelor of Science in Physics in 1993, both from the University of Texas at Arlington. She was elected by her peers as Campus Teacher of the Year in 2011-2012 school year.

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Extended Abstract with Poster

Longhorns Face the Grand Challenges with I-Engineers: Interdisciplinary, International, Innovative, & Inspir(ed)(ing) Engineering Education

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Abstract

As Scholars face the 21st Century Engineering Grand Challenges, it provides opportunities in higher education to: a) honor the multiple ways of knowing and communicating in engineering (STEM literacy); b) connect socially and culturally to engineering; and c) find solutions to the world's most pressing societal and technical issues. These experiences will be described with examples of interdisciplinary and design-based teaching at The University Texas at Austin. The Grand Challenges Scholars' reflections and survey results will represent ways that they engaged in and responded to international and interdisciplinary engineering education projects. Specifically, the experiences of the design and launch of an enterprise in Ghana will create a thick and rich description about interdisciplinary, international, service-learning, and entrepreneurial components of engineering designs framed within the 21st Century Engineering Grand Challenges. This mixed methods study includes details about the factors that inspire and retain Scholars' engagement and success in engineering designs.

Keywords: Grand Challenges, design-based learning, interdisciplinary, service-learning, entrepreneurship.

Introduction & Inspiration

In October 2011, when we welcomed our seven billionth citizen, the world became more crowded, increasingly complicated, and better connected than ever before in history. As society grows more global and interconnected, the problems that must be solved by the next generations are becoming more complex in scale. Meanwhile, the demographics and engineering needs for our nation are shifting in unprecedented ways. Texas is in a unique position to serve as a research model for ways that we can identify, impact, and evaluate innovative engineering education especially with under-represented populations. Such research will provide insight into ways to shape landscapes of learning and successfully prepare 21st century students as leaders in innovation and entrepreneurship with engineering.

From natural disasters to overcrowded cities, from pandemics to more than a billion people without access to safe water, ours is a world filled with affliction and catastrophe – yet it is a world of possibilities and opportunities for hope and solutions. Our community is comprised of international scholars striving with hope in this challenging time. We do more than hope for a better, safer, and more accessible world for our global citizens because, as agents of change, we put that hope into action with the work and research that we conduct. Margaret Mead once wisely advised, "Never doubt that a small group of people can change the world. Indeed, it is the only thing that ever has." Commensurate with her notion we face the 21st Century Engineering Grand Challenges locally with student-facilitated projects and globally as a network of activists.

Teachers, students, community members, policy makers, and industry are working together to take steps in effecting change to systematically enrich the field of engineering education Recently, the National Academy of Engineers (NAE) explored broad realms of human concern – sustainability, health, vulnerability, and joy of living – and generated 14 specific 21st Century Grand Challenges that await innovative engineering solutions. The NAE solicited research and educational leaders to face these 21st Century issues by establishing the Grand Challenges Scholars Program (GCSP) to prepare college students to solve the Grand Challenges. The NAE GCSP provides a framework for curricular enhancements that will motivate students to address the Grand Challenges through five components: (1) a **research experience** related to a Grand Challenge; (2) **interdisciplinary curriculum** that integrates engineering, public policy, business, and ethics, and more; (3) **entrepreneurship** to turn creative ideas into inventions and innovations; (4) **global dimension**s necessary to navigate our modern economy; and (5) **service-learning** to deepen the social consciousness of the Scholars. The GCSPs are in part, a response to national innovation-focused policies such as *Educate to Innovate* and *Innovation Strategy for Economic Development*, which have inspired new ideas and research in engineering education.

Throughout human history, imagination has come to fruition in many ways, notably through engineering which drives immense advances in civilization. These advances can be seen with significant engineering feats that drastically changed societies – ships that created innovative channels for trade and travel; sanitation systems for improved health and quality of life; widespread development and distribution of electricity and water; automobiles and airplanes; telephones; computers; space exploration; and internet are but a few of the most salient.

Upon reflection of the 20th century and forward looking in our first decade of the new millennium, the NAE sought innovative ways to identify formidable challenges as the population grows and its needs and desires expand [2]. The NAE garnered a team of thought leaders with a wide range of experiences that show dedication to improving the quality of life around the globe. This team explored broad realms of human concern – sustainability, health, vulnerability, and joy of living – and generated 14 specific Grand Challenges [3] that await engineering solutions.

The NAE is leading engineering communities to make momentous paradigm shifts in research focus and discourse to indicate explicit inclusion of multiple, shifting, and dynamic societal contexts. This paradigm shift is evident in salient research and practice that distinctly explores interplays between contexts such as cultures and geo-politics as key factors in engineering. To face these Grand Challenges, we must integrate ideas and voices from many people, including traditionally underrepresented groups, and diverse perspectives to embrace our global ecology.

As Scholars face the 21st Century Engineering Grand Challenges, it provides opportunities in higher education to: a) honor the multiple ways of knowing and communicating in engineering (STEM literacy); b) connect socially and culturally to engineering; and c) find solutions to the world's most pressing societal and technical issues. These experiences will be described with examples of interdisciplinary and design-based teaching at a The University Texas at Austin

(UT). The undergraduate Scholars' reflections and survey results will represent ways that they engaged in and responded to interdisciplinary engineering education projects that have global perspective. Since there are a wide range of projects GC Scholars are working on, this paper will create a vignette about how our GCSP works by including specific examples of a project in Ghana. The experiences of the design and launch of an enterprise in Ghana will create a thick and rich description about interdisciplinary, international, service-learning, and entrepreneurial components in engineering designs framed within the 21st Century Engineering Grand Challenges. This mixed methods case study includes details about the factors that inspire and retain Scholars' engagement and success in engineering designs.

With this study, portions of the fundamental scaffolding to connect the Grand Challenges to engineering education that builds bridges to close those global divisions are provided. The theoretical framework of this study offers critical feminist lens through which to view the Grand Challenges [3-9]. This can create images of shifting gazes on engineering design in a new era. It prompts discourses of power structures, ways to include and interpret multiple perspectives, and considerations of implications and consequences with shifting contexts – all important in community development as global citizens in engineering design. Finally, by indicating factors for all members including underrepresented groups to pursue and persist in engineering, we may be better prepared to engage and keep diverse groups to join in helping address the Grand Challenges. The GCSPs are access avenues to engineering that are framed much differently than traditional engineering courses or experiences that may focus more on fundamental engineering concepts without layered contextualization and connections. These engineering challenges will take many decades of imaginative ideas and dynamic design teams.

Imagining I-Engineers

A metaphor illustrates multifarious ideas in a way that creates and connects understanding by constructing a symbol. In recent engineering education discourse, there is vast discussion of the T-shaped engineer to provide a metaphor for describing an ideal engineer; broadly learning and weaving across disciplines (top of the T) and going deeply into understanding engineering concepts (vertical branch of the T). Engineering educators and others are aware that the I-beam transformed design and is a critical component in sustainable and strong building. This new metaphor is introduced in response to the T-shaped engineer [10] that is inspired by the unique strengths of the I-beam to share my vision of an I-shaped engineer [11]. I-beams are integral parts of sustainable, strong designs because of the interactions between the parallel flanges and connecting web. Imagine the I-shaped engineer [Fig. 1] whose strength is built on interdisciplinary connections.

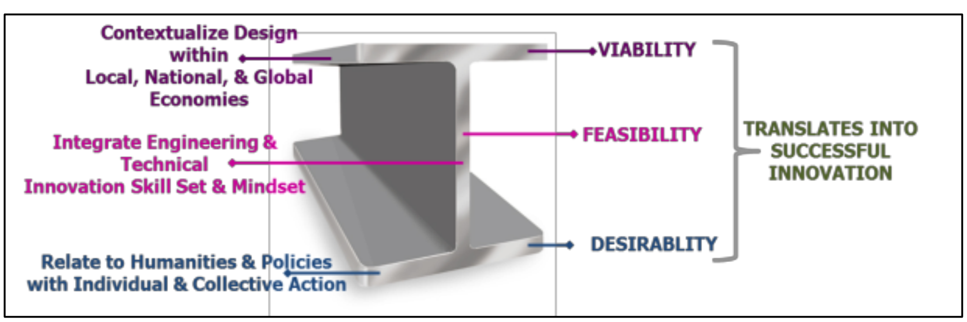

Figure 1. Interdisciplinary Strengths of the I-Engineer.

GCSPs develop designers with an innovative skillset and mind set needed to address the most pressing societal issues of the 21st century with engineering solutions. GC Scholars: a) **contextualize engineering design and entrepreneurship within local, national, and global economies**, b) **integrate engineering and technical innovation skills**, and c) **relate to humanities and policies prompting individual and collective action**. The 21st Century Engineering Grand Challenges are calls to action and serve as focal points for society's attention to opportunities and challenges effecting our quality of life. GC Scholars are agents of positive change in their research, service-learning, and entrepreneurship. They exhibit technical and leadership skills required in making significant strides towards solving these complex issues by acting locally with potential to scale globally. Each Scholar engages in rigorous research and design within the Grand Challenges that directly translates into strong and dynamic skills for the global workforce. GC Scholars analyze and incorporate strategies *viability*, *feasibility*, and *desirability* into design that translates into *successful innovation* [12].

Interdisciplinary Teaching & Design-Based Learning with the 21st Century Engineering Grand Challenges

The newly founded Grand Challenges Scholars & K12 Partners Program (GCSP & K12) is an interdisciplinary, university-wide program, housed in the Cockrell School of Engineering which is affiliated with the National Academy of Engineering. The University Texas at Austin is the first in the nation to be a university-wide program. The GCSP is a certificate program designed to be complementary, not additive, to the student's traditional academic path. GC Scholars will complete courses, research projects, community projects, a comprehensive reflective report, and a final design that specifically addresses each of the five components of all GCSPs as designated by the NAE [Fig. 2]. The GCSP certificate program is designed to offer students from all majors an introduction to the program through one new course, an array of university-wide course connections, and mentorship to complete rigorous interdisciplinary research and innovative design prototypes. This certificate program will provide students with the scholarship network and formal recognition from the NAE for their efforts, while typically requiring only one course beyond their standard degree program.

The five key components of our GCSP and Incubator include facing the 21st Century Engineering Grand Challenges with
(1) entrepreneurship and
(2) service-learning by
(3) understanding global dimensions through
(4) research and
(5) interdisciplinary curriculum.

Figure 2. Five Components of GCSP

There is a strong infrastructure at UT Austin is comprised of professors, courses, and programs that support Scholars in facing the Grand Challenges. Because of this wide array of opportunities, we are able to design the GCSP to be a "light footprint" and complementary to a student's educational plan. Projects for Underserved Communities (PUC) is one of the programs at our university that connects clearly with the GCSP. It provides students with an interdisciplinary, international, multi-semester engineering design project. This paper will zoom in to describe a specific example of how teams of PUC students some of whom are GC Scholars engaged in the five components with a community in Ghana. It will then zoom out to show broad perspectives of the GCSP with survey results.

Investigating impacts of our GCSP in Ghana

In starting the GCSP, we attracted students that are also in PUC which is a leading program in providing students with the opportunity to implement an international, interdisciplinary project. Our GC Scholars who choose to do international projects in underserved communities will go through the PUC courses to learn effective ways to implement international design projects that are culturally relevant and sustainable. As we initially launched the GCSP, we joined our new GC Scholars and other PUC student teams for implementation of their projects in Ghana where we worked alongside them as advisors. We collaborated with the Ghanaian community on the fresh water and alternative energy projects and developing a business model. This was our first chance to see and learn about the five key components of the GCSP in action.

The design team members conducted rigorous research to prototype designs for fresh water and alternative energy. They developed as I-engineers by integrating engineering and technical innovation skills to incorporate strategies for *feasibility* into their designs. When the summer 2011 team arrived in Ghana, the well from the previous year's project was not functional. The team thoroughly assessed the well equipment and found significant issues. The team decided to make all necessary changes in repairing and improving the water system. These changes included new submersible pumps, relocation of electrical source, voltage protector, low level float switches, corrective plumbing, and the installation of safe features in the electrical subsystem. These repairs and improvements restored the well to an operational and sustainable state. Additionally, the team undertook work toward a sachet packaging center and repurposing initiative. Complementary to doing rigorous research and design to face these global Grand Challenges in Ghana, these interdisciplinary teams of Scholars also engaged in the other key components of service-learning and entrepreneurship described in the following sections.

International Engineering Service-Learning

Service-learning is a pillar of the program because of the very nature of the GCSP is to design innovative solutions to the society's most pressing issues. Indeed, engineering is not done in a vacuum and so there must be many diverse community members involved in all aspects of the design process. For a design to be successful and sustainable, the community needs to be engaged in identifying their own needs and also learning about ways to make it effective and long-lasting. One of the ways to develop as I-engineers and ensure *desirability* into innovative design is through service-learning as people work individually and collectively as agents of positive change. Service-learning is a teaching and learning strategy that integrates meaningful community service with instruction and reflection to enrich the learning experience, teach civic responsibility, and strengthen communities [13]. There were many ways that the Ghanaian community engaged in the engineering projects. To promote excitement and interest in the project and facilitate understanding of the projects' rationale, the team conducted educational outreach experiences, as illustrated in Figure 3. To help promote the creation of the repurposing enterprise and address litter from used sachets in the village, the team led a community wide pick-up collaborating with each of the local schools. The next phase of this education will include placement of used sachet receptacles at schools and other parts of the village for community recycling.

Figure 3. Service-learning with a Ghanaian community.

Innovative Entrepreneurships

Entrepreneurship is a pillar of the GCSPs because it is vital to translate invention to innovation and develop market ventures that scale to global solutions. Indeed, engineering education is the innovation engine that drives the global economy. When our GC Scholars engage in entrepreneurial activities, they contextualize engineering design and entrepreneurship within local, national, and global economies. Through these experiences, the GC Scholars develop as I-engineers who analyze and incorporate strategies for *viability* into design that translates into successful innovation.

For the entrepreneurial component of this project, UT Austin, Kwame Nkrumah University for Science and Technology in Ghana, and local leaders and community members collaborated to establish an enterprise as a long-term business venture with specific goals [Fig. 4]. This enterprise's first entrepreneurial venture is to produce clean water sachets and begin an initiative to repurpose used sachet packages into merchandise. The second business-in-development that will be part of the enterprise is to create and sell alternative energy briquettes and briquette press kits. Both of the innovative engineering entrepreneurships are described next. The description begins with the administrative sustainability plan. Then the details of the water engineering entrepreneurship in the enterprise will complete this section of the paper. The Board of Directors will oversee the completion of the two projects and the operations of the enterprise long term in collaboration with the universities. The complete board will be representative of the entire community through community leaders, community members, men and women, as well as school and church representatives.

Figure 4. 2011-2012 Project goals for sachet packaging center and repurposing initiative.

The essential components for the enterprise, focusing on the sachet packaging center and repurposing initiative are illustrated in Figure 5. Key aspects of these components include building construction, equipment installation, and employee hiring for the sachet production; training, initial set-up and installation of equipment, and market identification for the repurposing initiative; and business registration, certification by the FDB, and creation of the Board of Directors for this new enterprise as part of the enterprise.

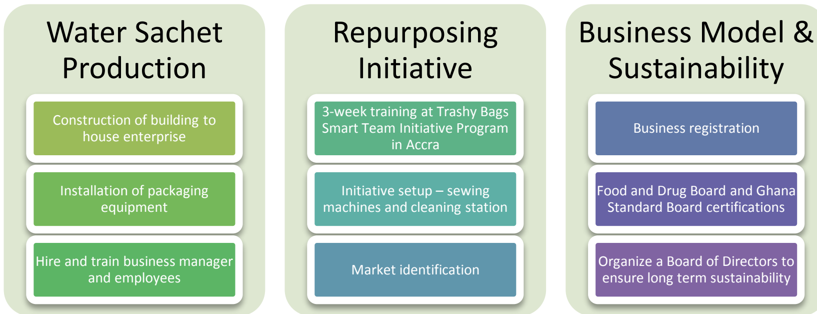

Figure 5. Components as part of the enterprise.

To address the essential components described in Figure 5 and implement the administrative sustainability plan that includes: a) maintenance and repair of all equipment to ensure *technical sustainability*; b) accurate accounting records and tracking of revenue and expenses will ensure *financial sustainability*; c) daily operations & administrative oversight will ensure *production & performance sustainability*; and d) effective communication between all collaborators ensures *relational sustainability***.** Now that a detailed example of the GCSP components in action in Ghana has been presented, the next section will present findings from this mixed methods study about the GCSP five key components.

Inquiries and Insights

This mixed methods study is conducted in an effort to create thick and rich descriptions of the experiences of GC Scholars. Since the GCSPs are new initiatives by the National Academy of Engineering and educational institutions, it is vital that we glean information about the teaching and learning experiences. The research inquiries were posed to identify factors that inspired GC Scholars and indicate ways that they are developing as I-engineers. The data indicate: a) ways that Scholars perceive aspects of the five pillars, b) the significance of each of the Grand Challenges in driving job creation, c) ranking of the most important Grand Challenges to solve, and d) capable bodies of facing the Grand Challenges. The data are collected through a short, online survey and though written reflections. Eighteen GC Scholars participated in this study, some of whom are on the PUC implementation teams and others who are doing different GCS projects. The Scholars range from Freshmen through Seniors and one Master's student and also have chosen a variety of degree majors including engineering to business to social work. One-third of the Scholars are female and 53% are non-White. The quantitative results gleaned from the survey and the qualitative results from the written reflections include multiple perspectives on the aforementioned topics. The insights from this research illuminate factors that inspired and informed the I-engineers. The quantitative data analysis is included in this section whereas the last section of the paper includes qualitative data and analysis so that the final voices are those of the Scholars speaking of their inspiration in their own words in an effort to be inspiring to others.

To understand perspectives about the interdisciplinary curriculum pillar that is needed in addressing the Grand Challenges, Scholars ranked the significance of disciplines that they believe relate to engineering [Fig. 6]. These weighted results indicate that Technology, Business, and Economics are all considered very significant to include in their education.

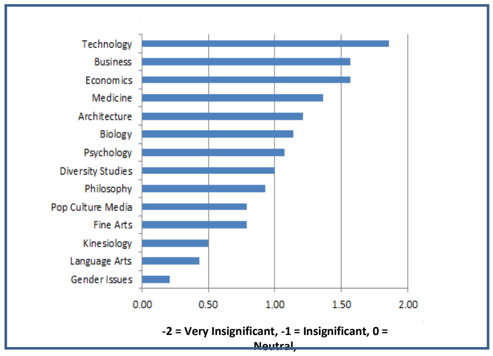

Figure 6. Perceived Importance of Interdisciplinary Curriculum.

Medicine, Architecture, Biology, Psychology, and Diversity Studies are all perceived as being significant topics to integrate into engineering education. Although not all topics were found to be significant or very significant, none were perceived to be insignificant.

Some of the survey questions were modeled after the international, longitudinal study of the students' perceptions of the GCs (14). In a future study, the results of these GC Scholars can be compared with broader international population. The Scholars indicate that the top GCs to drive job creation are 1) economical solar energy, 2) urban infrastructure, and 3) engineering tools of scientific discovery. They perceive the most pressing GCs to solve are 1) clean water, 2) economical solar energy, and 3) urban infrastructure. The most capable bodies rank private businesses, international organizations, educational institutions, medical professions, Non-Governmental Organizations, urban planners, and governments as all capable.

As agents of positive change and capable bodies, the Scholars ranked skills as being vital in addressing the GCs [Fig. 7]. These weighted results indicate that creativity, teamwork, up-to-date knowledge, responsibility and ethics, and being a risk-taker are all very significant skills to hone. All other skills were found to be significant for the GCs. These results can also be compared in the future to the results of the international survey.

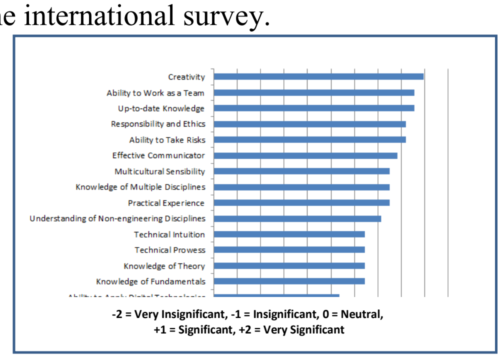

Figure 7. Important Skills for GC Scholars.

GC Scholars indicate the factors that influence them in choosing to pursue and persist in the GCSP [Fig 8]. The most influential factors that when weighted rank very significant are: interest and application of imagination. Self-concept of ability, task utility, being hands-on, and financial opportunities are all significant factors influencing the Scholars in their engineering endeavors.

Findings show that spirituality and military involvement are insignificant in Scholars' choices to pursue and persist in the GCSP.

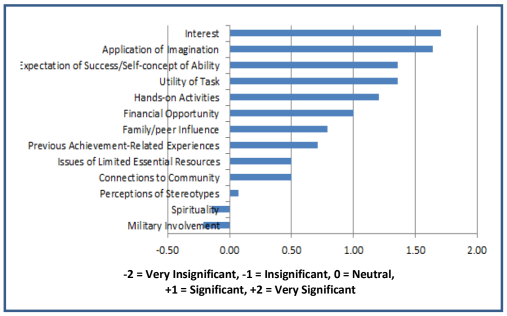

Figure 8. Influential Factors in Pursing and Persisting.

The survey responses are quantitative and provide insight into rankings of importance and can help in considering ways to develop interdisciplinary curriculum with a focus on key topics to include. The quantitative results provide insight about broad topics across the five GCSP components. To provide a breadth and depth, the quantitative data is complemented by qualitative data for this mixed methods study. The last section helps provide qualitative insight about what inspired these GC Scholars and how they are inspiring actions to improve the world through innovative, international, interdisciplinary engineering. Listen to the GCSP pillars in action.

Inspir(ed)(ing) I-Engineers

*"The **experience** gained from stepping out of the classroom and into the real world was invaluable. To be given the opportunity to get hands on and see the results were more than any textbook or lecture could ever teach me."* **Design-based, rigorous research**

"This international development project expanded my perspective of the world and the need to step out and do something about the dire circumstances it houses. I saw with my own eyes how engineers, social workers, economists, and businessmen can make a difference in the world, and the desperate need for them to respond. It was a beautiful picture of interdisciplinary work that would not have been possible without the experience." **Interdisciplinary Curriculum and Entrepreneurship**

*"I think that the experience showed me that life should be joyful and vibrant, and that proceeding through challenges with a joyous attitude can do wonders for the success of a project. After seeing the beauty and vibrancy of the locals, it was difficult **not** to succeed with that joy, which in turn greatly helped the success of our projects."* **Global Perspectives**

"The key to success in any project, especially service-learning projects, is building relationships—with your team, with the locals, with your advisors. Not only are these relationships crucial to the success of a project, but they are also priceless experiences to cherish and learn from for the rest of your life." **Service-learning**

"I am continuing to come back to a state of amazement at how beautifully interwoven our lives are with everyone else's. We do not live in this world to get lost in our own heads, but to work with one another, such as we did as a team in Ghana, to join with those further away to meet one

goal. Alone we can accomplish quite a bit, but when we come together, we can utilize our talents to their full abilities and share with one another things we may not have had individually, allowing for an increase in growth in every aspect. We have been given these things not so we may achieve alone, but so we may extend a hand to pull others up, so they can extend the other one to us when the opportunity comes." **Grand Challenges Scholars as I-Engineers.**

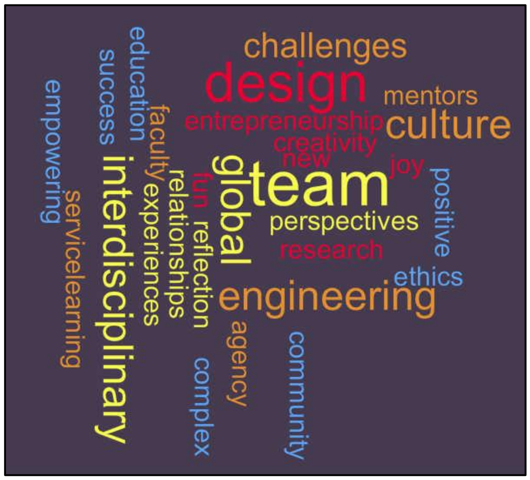

Figure 9. Themes from Scholars' Speaking.

In conclusion, this research aids in understanding the skills that must be nurtured for Scholars to be effective as 21st century learners and leaders in a global workforce [15]. This research aims to provide insight into understanding the impacts and inspirations that the GCSPs have on engineering education. These are new programs and have many aspects to be explored to determine effective practices for our diverse Scholars. In future papers, there will be disaggregation of data for gender and also comparisons to the international community. There will also be deeper analysis of the themes that arise from the qualitative data in the last section. For our Scholars, findings indicate that interdisciplinary curriculum is vital, clear rankings of GCs in terms of importance to solve and perception of job creation, as well as the most capable bodies to implement those solutions. By identifying factors influencing Scholars and the skillsets they believe are needed to solve these GCs, we now have some insight into ways to recruit and support future engineers in their educational paths. Finally, by viewing Figure 9, we are able to see the most important themes that arise from the Scholars' reflections about the key components of facing the Grand Challenges which beacons us to include these topics as we continue the conversation within our global community of engineering education.

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Extended Abstract with Poster

A Labview Project: Design of an Automated Water Heating System

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Abstract

The task to attract students to science, technology, engineering and mathematics (STEM) fields is becoming more challenging. There is a need to introduce students to one important function that most engineers and technologists are involved in, which is system design process.

In this paper, a student project to design a complete automated water heating system is presented. Both software simulations and hardware implementation are shown. This application serves as a tool to introduce freshman engineers, and technologists to systems design starting from conceptual ideas to final implementation. The advantages of using Labview as a graphical language to develop this type of applications and its use as a tool to attract students to STEM fields are discussed.

Introduction

As the engineering, science, and technology fields become more challenging, there is a need to introduce design projects in the freshman year curriculum and even in high school curriculum. This process will help students to understand what they can accomplish by enrolling in STEM (Science, Technology, Engineering and Mathematics) fields, and more importantly is to equip them with tools that will make learning STEM subjects more interesting.

One of the tools that are widely used in the academia and industry is National Instrument's Labview data acquisition hardware and software to acquire data, process and control [1]. These integrated hardware-software tools use computers increased computational capabilities to assist the user in the design, development, and control of complex systems in a much shorter time [2-10]. As a result, STEM fields are under pressure to incorporate the use of advanced tools into their curriculum so their graduates can be well trained in the use and application development to serve the needs of the industrial community.

In a typical Engineering curriculum, hands-on and real world problem-solving approaches are an integral part of the design learning process. Such a process can be broadly described and categorized into defining a need, background research, design criteria and constraints, building and testing a prototype, redesign and retest if necessary. To implement such a process, students usually work in teams to design and develop an idea as a solution to a valid existing open-ended technical problem through application of the engineering design process. Before starting any design project, the team must answer a set of questions which include: (1) Is there a need for the product? (2) Is a new version of an existing product with a solution already available? (3) What are the advantages of the redesigned product [11]? Once the project team realizes a solution to the technical problem is not available or not convincing, then a decision to develop a solution to the problem and eventually build the final product is made.

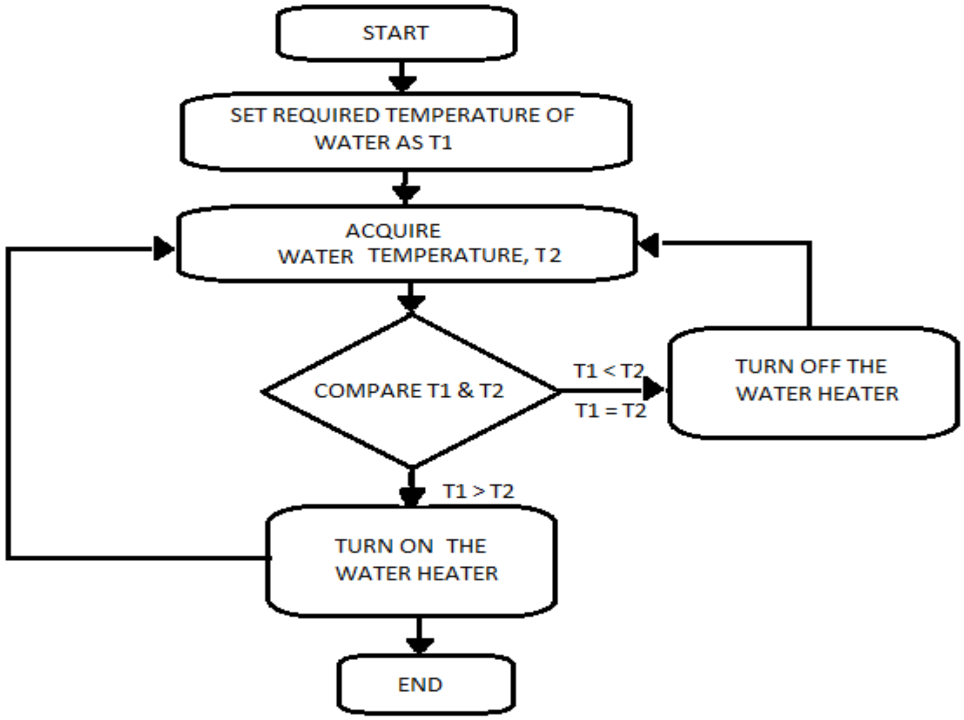
Good engineers look at a variety of different possible designs before moving forward. Once the design is made, it is build and the prototype is tested repeatedly for flaws that require a rectification. Validating, rectifying and justifying are prime attributes to solve a technical problem. This entire process will teach students all the steps that are required to obtain the best design that meets all specifications.

This project is a control system that could be included in an engineering/technologist curriculum to demonstrate the process of converting theoretical knowledge into practical implementation. This will boost the confidence in the engineering students and encourage them to come up with new ideas and solutions [12]. It has the strength to inspire students to be more interested in STEM fields by knowing the process that an engineer/technologist follows to develop new products, and solve challenging problems.

It is worthwhile to mention that the learning experience that students gain in an environment that integrates team oriented, hands-on learning and engaging them in the design and analysis process, is a must in today's technological needs. In this paper, a student project to design a complete automated water heating system is presented.

Principles of designing an automated water heater

The ultimate aim of this project is to help the reader to design a water heater that heats up the water to a certain temperature and regulates it according to the user willingness, depending upon a threshold temperature being set up. The complete design flowchart is shown below. The design consists of three basic steps to be followed: (1) reading the input data, (2) processing the data, and (3) generating a variable corresponding to the DC output to control the actuator (i.e. a relay).



This design uses a temperature sensor shown in figure 1 to sense the temperature of the water and generates a signal in volts corresponding to the heat.

Figure 1: Temperature sensor

The acquired voltage v is converted to temperature in terms of Celsius using the equation shown below, where v is the voltage variable and C is the Celsius temperature.

```
C=106.0*v-270.9;
```

As the LCD of the sensor displays temperature in Fahrenheit, the temperature sensed is converted from Celsius scale to Fahrenheit scale to increase the user-friendliness of the design. This conversion is based on the following equation.

```
F=(9/5)*C+32;
```

Labview is the core of the measurement systems. The signal from the DAQ card is processed. The software is composed of two parts: the front panel and the block diagram. The front panel shown in figure 2 is designed with the primary aim of making it user friendly as it acts as an interface between the human and the system.

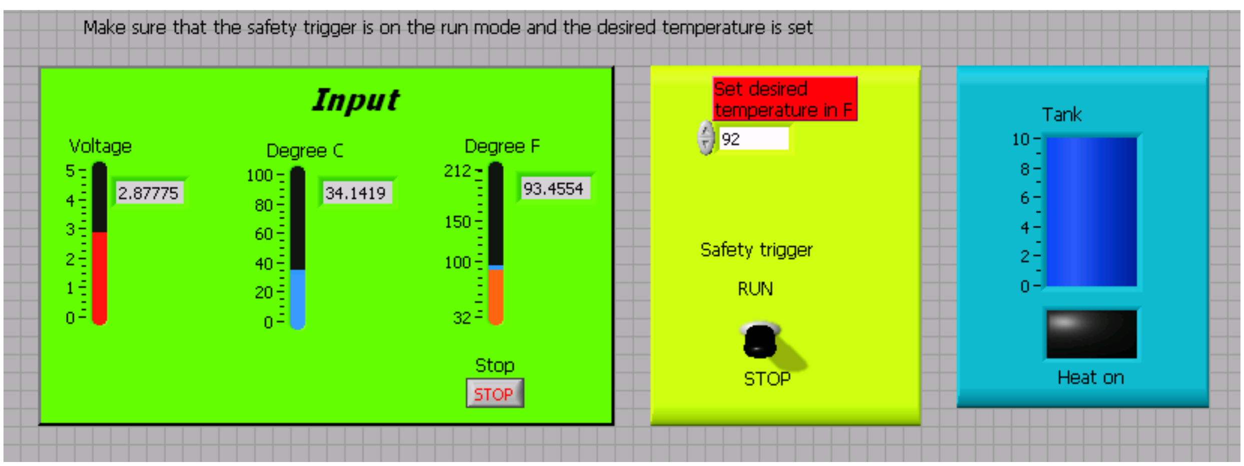


Figure 2: Front panel of the Application

The input parameters to the system are provided through the control modules.

The block diagram shown in figure 3 has three main blocks that are responsible for (a) relating the voltage to the corresponding temperature in Celsius (b) conversion of Celsius into

Fahrenheit to improve the user friendliness and (c) comparison of the water temperature with the required temperature.

The output of every conversion is displayed on the front panel. A safety trigger has been installed to halt the system to ensure safety of the user in case the system runs out of control. The system uses two data acquisition assistants for input and output of the system, the input DAQ is set and connected to the first input pin and the output DAQ is connected to provide the output voltage as per the requirement.

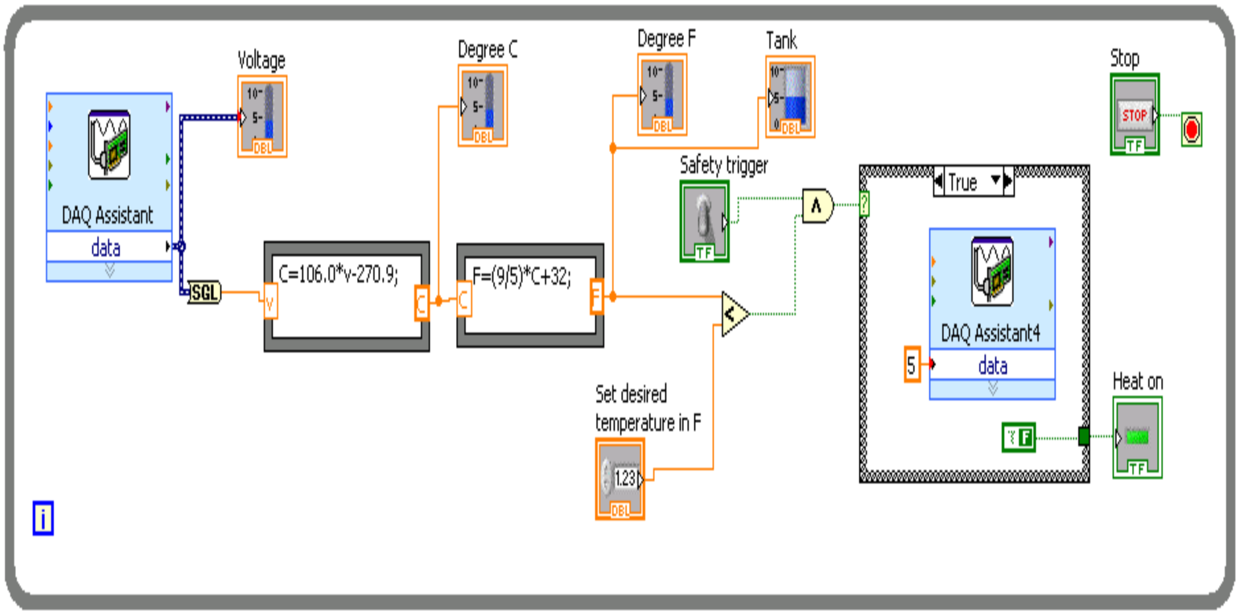


Figure 3 : Block Diagram of the system

Discussions

Initially, the block diagram is fabricated and the connections are made. The required temperature of the water is set in the front panel. By running the application, the temperature sensor acquires the temperature of the water, if the temperature of the water is lower, the water heater is turned on. Any increase in the temperature of the water is detected by the sensor and is exhibited on the front panel. When the required temperature is attained, the water heater turns off while the sensor acquires the temperature of the water continuously and maintains it at the desired temperature. It should be clear that the water heater does not have to remain in ON state continuously and thus the power consumption is reduced.

Conclusions

In this paper, a student project to design a complete automated water heating system was presented. Both software simulations and hardware implementation were shown. The advantages of using Labview as a graphical language to develop this type of applications have been discussed. This simple project can be used as a teaching tool to attract students to STEM fields and inspires them to come up with new ideas and solutions to challenging problems.

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Introducing Chaotic Circuits in Analog Systems Course

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Abstract

For decades, the engineering undergraduate education in the area of systems design has been mainly focused in linear models. Today, it is important for students to be exposed to chaos phenomena which exist in electrical, mechanical, biological and other systems. In this paper, we focus in electrical chaotic systems with the understanding that similar systems exist in other fields of study. We present two autonomous and two nonautonomous circuits that behave chaotically. We have selected simple circuits, such as the Colpitts oscillator, that are actually taught to students in electronics courses. Multisim is used to simulate circuits and show the presence of chaos. Complete circuits implementation and oscilloscope plots are all given. Student's first time experience with these phenomena is discussed.

Introduction

One of the reasons that engineering undergraduate education in the area of circuit and design has been mainly focused in linear models is that linear system theory has been thoroughly developed, and mathematical tools are available to analyze such systems. This philosophy has led many scientists and experimentalists to disregard many observed phenomena because linear system theory can not explain them. In the last decade, there is a strong interest in exploring systems that display unusual complicated waveforms, commonly known as strange attractors. These attractors have been increasingly observed in several nonlinear deterministic systems.

Therefore, it is important for today's students to be exposed to these complex chaos phenomena. From the educational aspect, students need to learn not only how to control and avoid chaos but also how to design chaotic circuits and develop applications, which explore these phenomena. Realizing the educational value to introduce undergraduate students to the phenomena of chaos, Lonngren [1] describes an interesting electronics experiment to illustrate the existence of chaos. The described laboratory experiment with the accompanying theory is a good start for the student to grasp and understand chaos. As a continuation of this goal and to enhance students understanding of chaos, Hamill [2] presented a collection of ten chaotic circuits simulated using PSpice. These circuits, some are quite simple, illustrate how chaos can be generated.

This paper can be viewed as a logical follow up on the progress made to understand chaos. It is a continuation to strengthen the student understanding not only on how chaos is simulated but also how to implement it. It is worthwhile to mention that some of the presented circuits, such as the Colpitts oscillator, are taught to students in electronics courses. Yet, there is no mention that chaotic behavior may occur. We have chosen to stay away from circuits that require a degree of mathematical sophistication beyond the undergraduate level. Although the paper uses electronics circuits to illustrate the existence of chaotic behavior, and will benefit instructors in the electrical/electronics field, it can also be used in other fields of study to present similar chaotic system such as the "pendulum." For the reader, who would like to experiment for more complex circuits, references are given [3-9]

In this paper, several chaotic circuits are presented for the student and the practicing engineer to study and experiment with. We have selected to use Multisim [10] to simulate circuits since it provides an interface as close as to the real implementation environment. In addition, complete circuits implementation and oscilloscope graphical plots are all presented.

Examples of autonomous chaotic circuits

Chua's circuit: The first example we present is the Chua's circuit (a third-order autonomous, dissipative electrical circuit). It has been investigated thoroughly at the experimental, numerical and analytical levels [11-15]. This circuit, known for its rich repertoire of nonlinear dynamical phenomena, has become a universal paradigm for chaos. Fig. 1(a) shows the Chua's circuit which includes two capacitors, a resistor, an inductor and a nonlinear resistor NR. Applying KCL and KVL, the Chua's circuit is described by three differential equations:

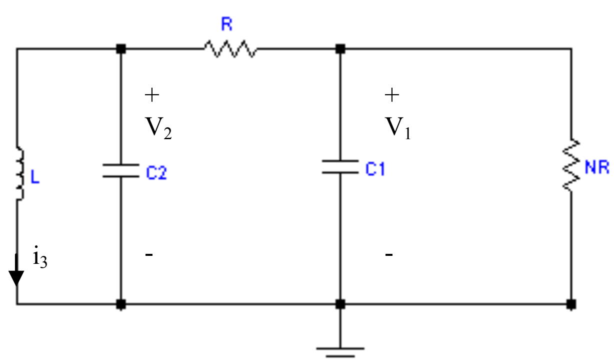

Fig 1. (a) The unfolded Chua's circuit

$$
\begin{aligned}
C_1 \frac{dv_1}{dt} &= \frac{1}{R}(v_1 - v_2) - f(v_1) \\
C_2 \frac{dv_2}{dt} &= \frac{1}{R}(v_1 - v_2) + i_3 \\
L \frac{di_3}{dt} &= -v_2
\end{aligned}
\qquad (1)
$$

Where the nonlinear Chua's function, shown in Fig. 1(b), is described by

$$
f(v_R) = m_o v_R + \frac{1}{2}(m_1 - m_o)\left\{\left|v_R + B_p\right| - \left|v_R - B_p\right|\right\} \qquad (2)
$$

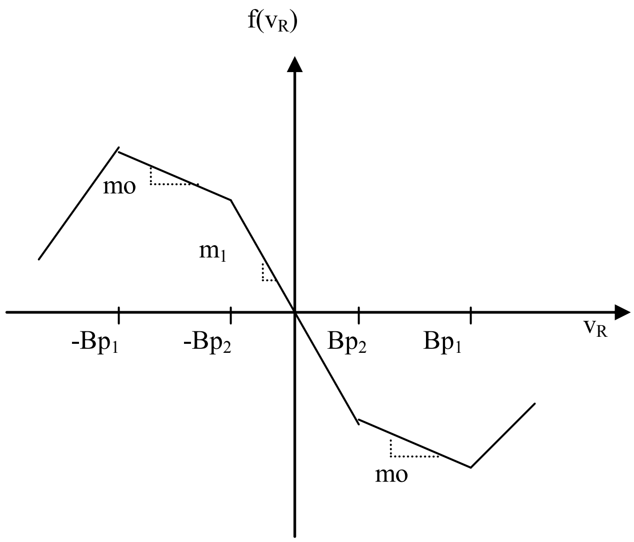

Fig.1(b) Chua's nonlinear function

The realization of the Chua's circuit is shown in Fig 1.(c). The constant m_o , m_1, and B_p can be easily computed.

$$
\left(m_1 = -\frac{R_2}{R_1 R_3} - \frac{R_5}{R_4 R_6},\; m_o = -\frac{R_2}{R_1 R_3} + \frac{1}{R_4},\; B_{p_1} = \frac{R_3}{R_2 + R_3} E_{sat},\; B_{p_2} = \frac{R_6}{R_5 + R_6} \right)
$$

Where, E_{sat} is the saturation voltage of the operational amplifier. The complete implementation of the Chua's circuit is shown in Fig. 1(c).

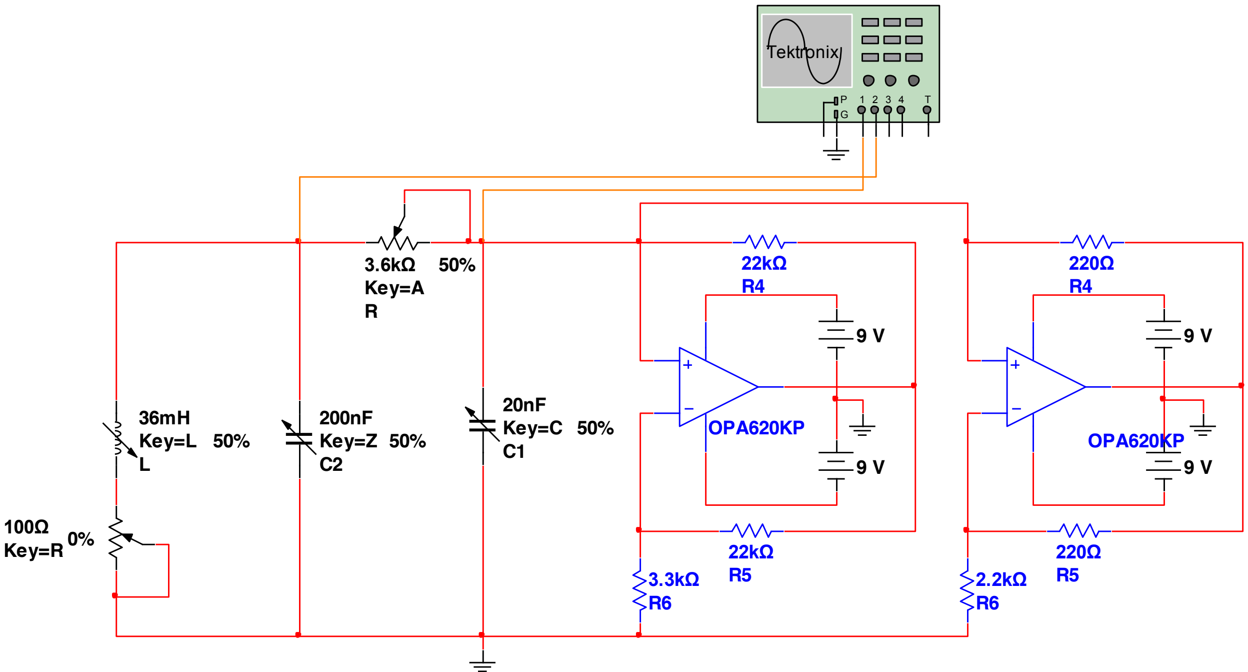

Fig 1.(c) The realization of the Chua's circuit [1]

The results of Multisim simulation show the phase portrait of the probed signals in fig. 1(d).

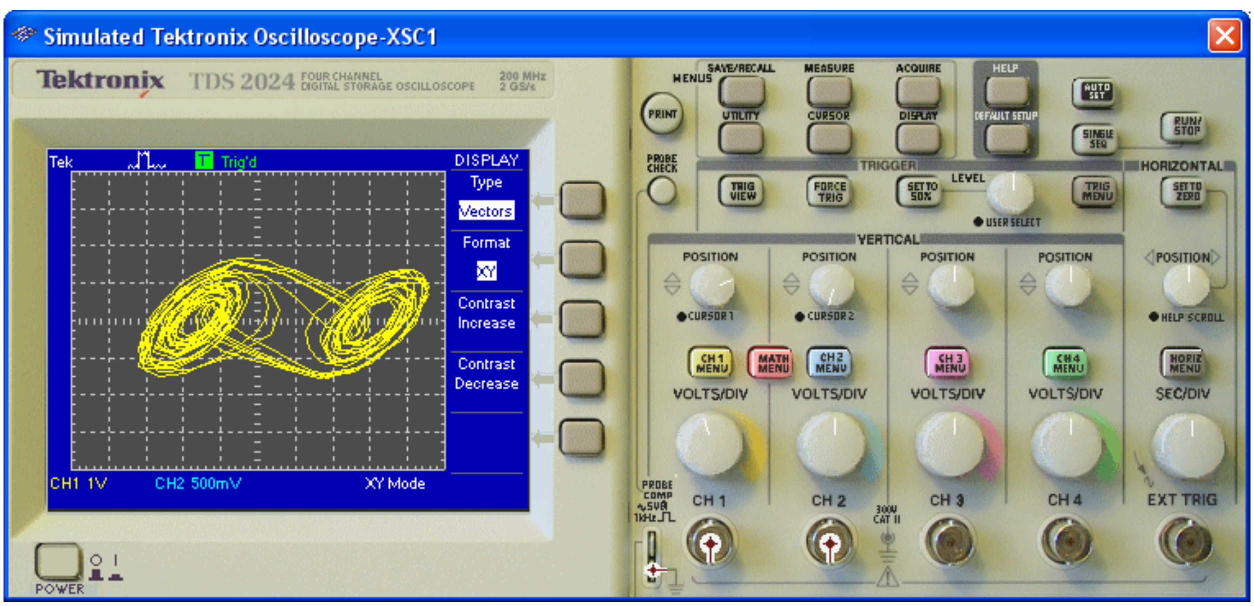

Fig. 1(d). Phase portrait Vc_2 versus Vc_1.

The Chua's circuit was implemented using the TL082 operational amplifier. The double scroll is shown in fig. 1(e) and the voltage $v_{c1}(t)$ as well as its spectrum are shown in fig.1(f). The reader is encouraged to experiment with this circuit by connecting a variable resistor in series with the inductor L.

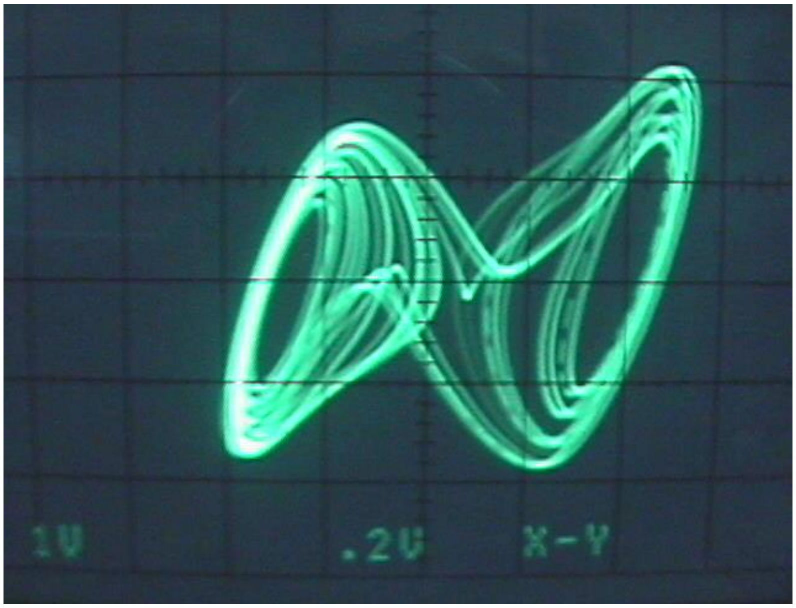

Fig.1(e). double scroll Vc2 versus Vc1 for R=1.53KΩ

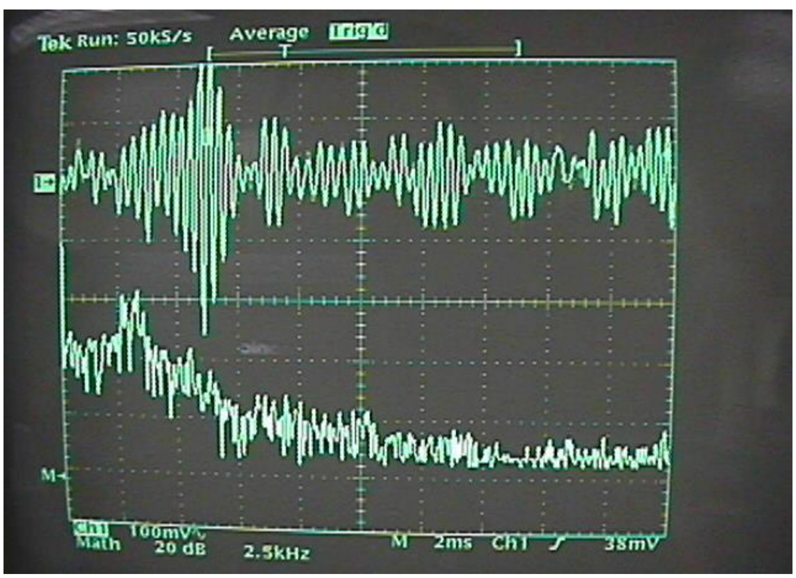

Fig.1(f). Top: $V_{c1}(t)$. Bottom: Its corresponding Spectrum

Colpitts oscillator: The second example is the Colpitts oscillator [16] shown in Fig. 2(a).

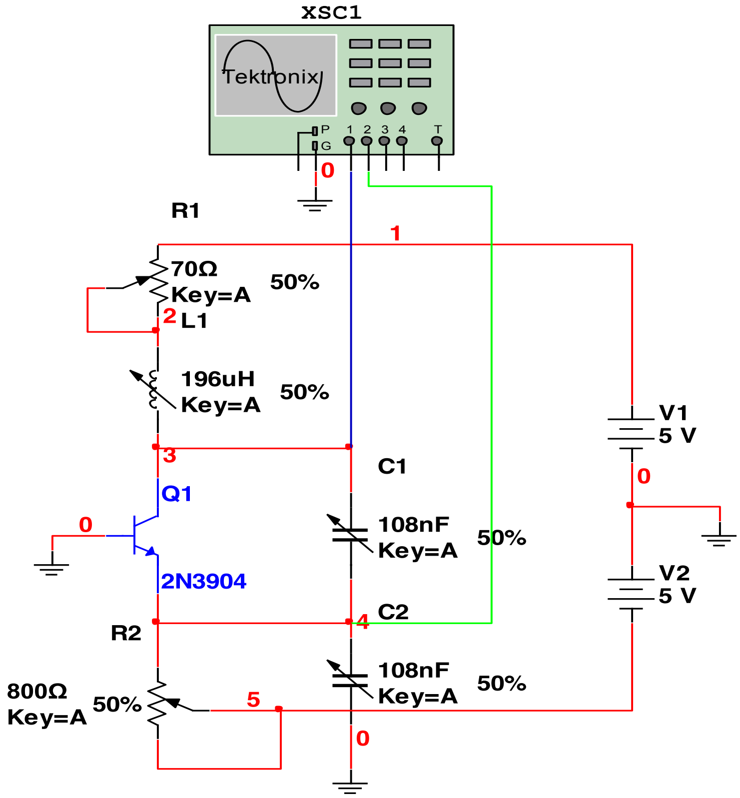

Fig. 2(a). Colpitts oscillator.

It is described by a system of three state equations:

$$
\begin{aligned}
C_1 \frac{dV_{CE}}{dt} &= i_L - i_C \\
C_2 \frac{dV_{BE}}{dt} &= -\frac{V_{EE} + V_{BE}}{R_{EE}} - i_L - i_B \\
L \frac{di_L}{dt} &= V_{CC} - V_{CE} + V_{BE} - i_L R_L
\end{aligned}
\qquad (3)
$$

The transistor is modeled as follows

$$
i_B = \begin{cases} 0 & \text{if} \quad V_{BE} \le V_{TH} \\ \dfrac{V_{BE} - V_{TH}}{R_{ON}} & \text{if} \quad V_{BE} > V_{TH} \end{cases}
$$

$$
i_C = \beta_F i_B
$$

Where, V_{TH} is the threshold voltage (≈0.75V), R_{ON} is the small signal on-resistance of the base-emitter junction, and β_F is the forward current gain of the device. In most undergraduate electronics books, this circuit is shown to oscillate but yet it can be driven to chaos. Fig. 2(b) shows the chaotic phase portrait. By changing the value of resistance R_L we obtain different trajectories.

Fig. 2(b). Phase portrait of V_C versus V_E

The Colpitts oscillator was implemented and its phase portrait scroll is shown in Fig. 2(c). The voltage $V_C(t)$ and its spectrum are shown in Fig. 2(d)

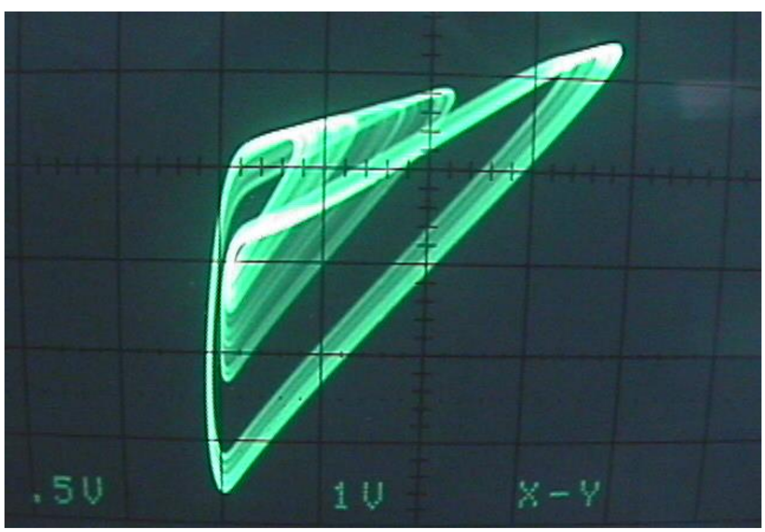

Fig.2(c). Phase portrait of V_C versus V_E for R_{EE}=466Ω

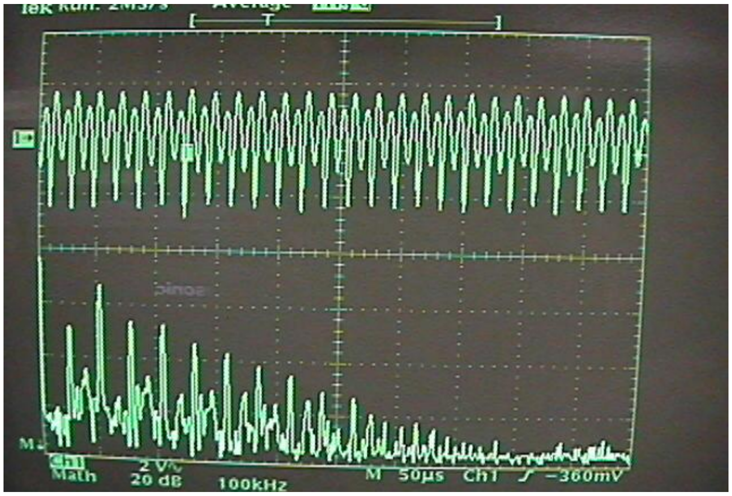

Fig.2(d). Top: $V_C(t)$. Bottom: its corresponding spectrum

Examples of nonautonomous chaotic circuits

RL-Diode circuit: The first example of nonautonomous chaotic circuit is the driven RL-diode circuit [17-18] shown in Fig 3(a).

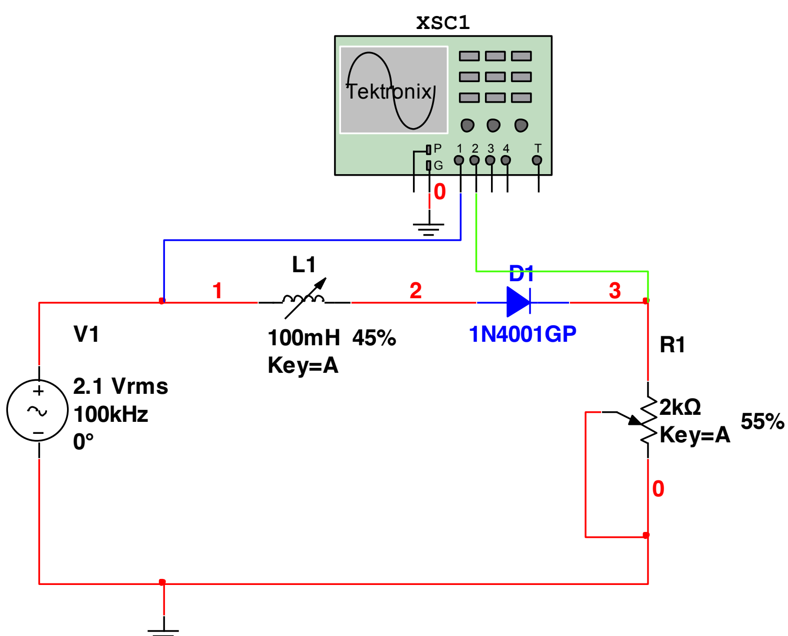

Fig. 3(a). RL-Diode chaotic circuit

It consists of a series connection of an ac-voltage source, a linear resistor, a linear inductor and a diode which is the only nonlinear circuit element. The state equations describing this circuit are

$$
\begin{aligned}
V_{in} &= Ri + L\frac{di}{dt} + V_D \\
i &= I_S\left(e^{\frac{V_D}{nV_T}} - 1\right)
\end{aligned}
$$

Where V_D is the voltage across the diode, I_S is the diode saturation current, n is a constant which has a value between 1 and 2 depending on the material and the physical structure of the diode, and V_T is the thermal voltage. The i-v characteristic of a diode is shown in Fig. 3(b).

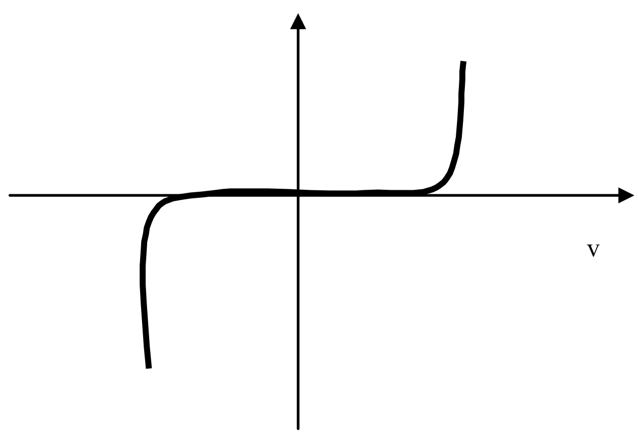

Fig. 3(b). I-V diode characteristic.

An important feature of this circuit is that the current i (or the voltage across the resistor R) can be chaotic although the input voltage V_{in} is nonchaotic. The results of the Multisim simulation, are shown in Fig. 3(c) for R=1kΩ.

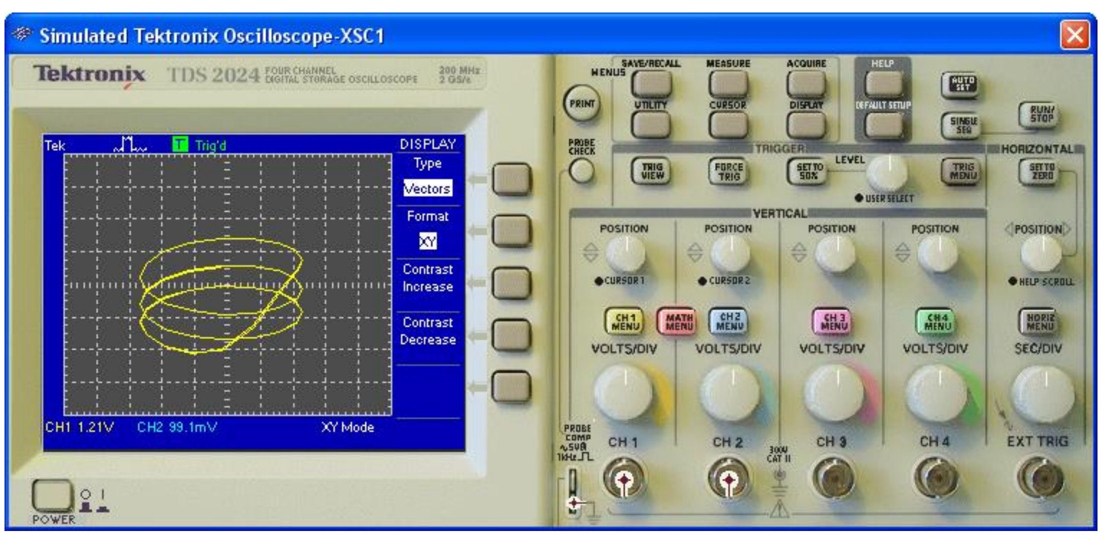

Fig. 3(c). Phase portrait of Vin versus V_R

The RL-diode was implemented and its phase portrait is shown in fig. 3(d). The voltage across the resistance R and its spectrum are shown in fig. 3(e). The reader is encouraged to experiment with different values of R to obtain different phase portraits.

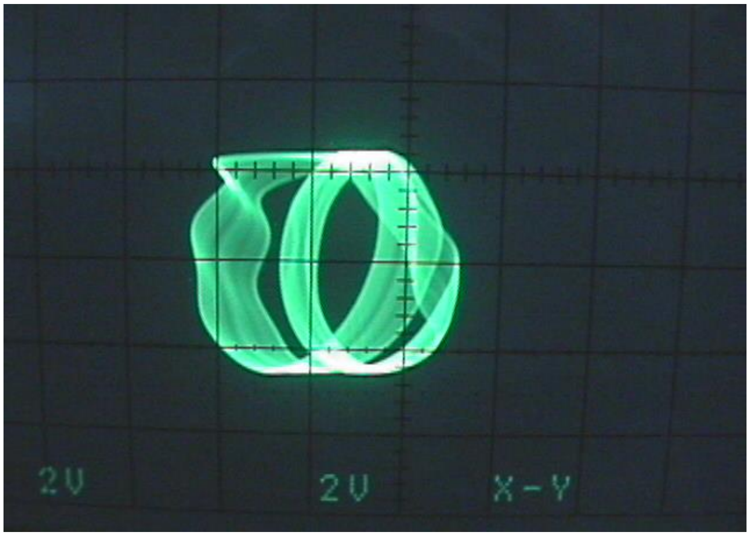

Fig.3(d) Plot of Vin versus VR for the input frequency = 130KHz
Vin peak-peak=6.5V and R=26KΩ.

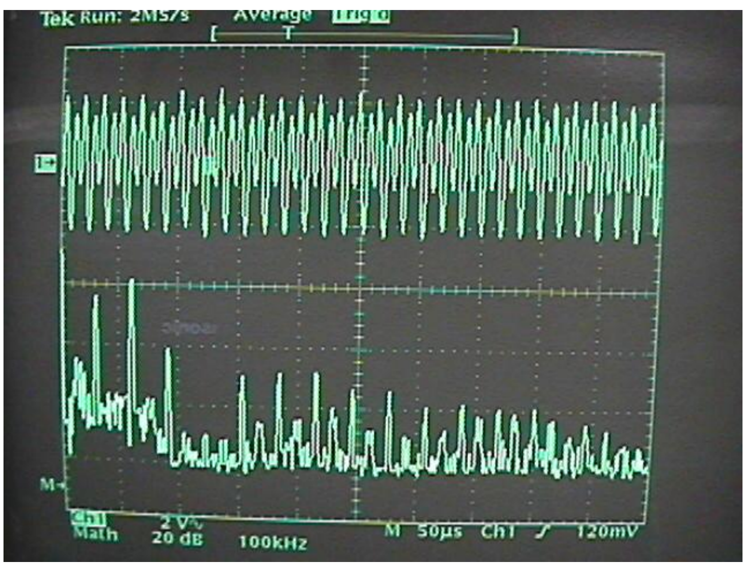

Fig.3(f). Top:V_R(t). Bottom: Its corresponding spectrum

Nonautonomous Chua's family circuit: The second example is a simple sinusoidal driven circuit shown in Fig.4(a) [19].

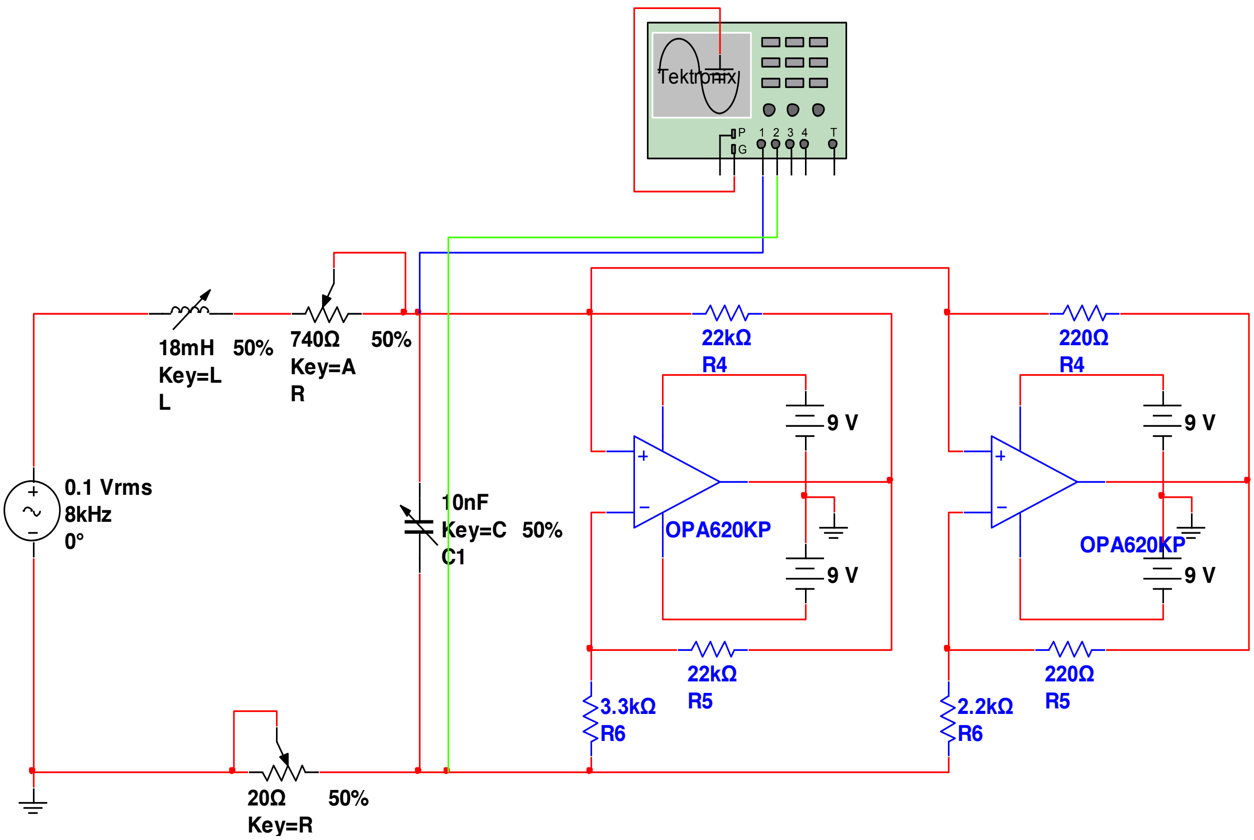

Fig. 4(a). Dissipative nautonomous chaotic circuit

It consists of an external periodic source, a linear resistor, an inductor, a capacitor and the nonlinear Chua's function NR. By applying Kirchoff's laws, the resultant state equations are:

$$C\frac{dv_1}{dt} = i_L - f(v_1)$$

$$L\frac{di_L}{dt} = -Ri_L - v_1 + a\sin(\omega t)$$

Where, the nonlinear Chua's function, shown previously in Fig. 1(b), is described by equation (2). In addition to the implementation of the Chua's function, a small resistor, connected in series with the external source, is added to the circuit in order to probe the current i_L. The results of Multisim simulation show the phase portrait of the probed signal in Fig.4(b).

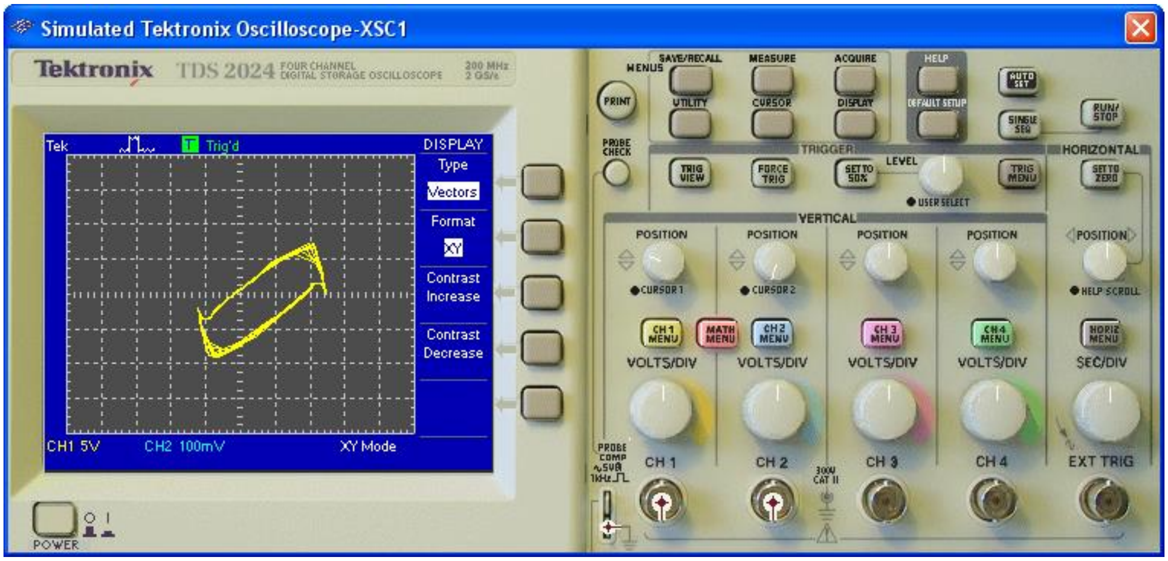

Fig. 4(b). Phase portrait of the probed signals Vc_1 versus Vr

This circuit was implemented and the phase portrait is shown in fig. 4(c). The voltage $v_{C1}(t)$ and its spectrum are shown in fig. 4(d). The reader is encouraged to experiment with this circuit by changing the amplitude of the external source as well as the frequency.

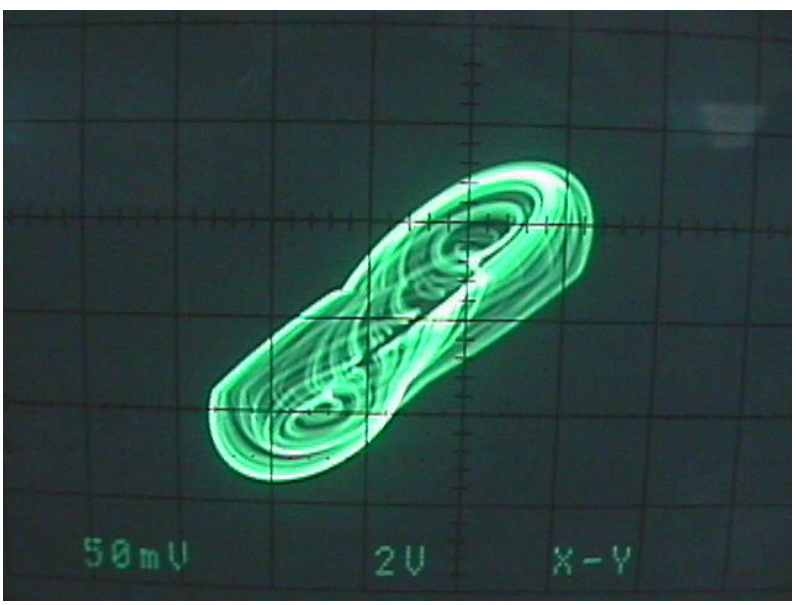

Fig.4(c): V_{C1} versus V_r for R=740Ω. For frequency = 15KHz and Vin-peak-peak=2V

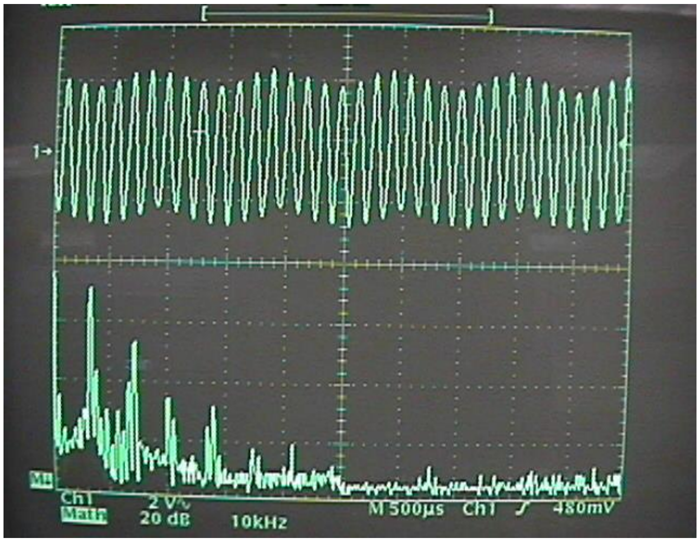

Fig.4(d): Top: $V_{C1}(t)$. Bottom: its corresponding spectrum

Conclusions and Discussions

Introducing the phenomena of chaos to students and practicing engineers is very important not only to investigate its existence even in simple nonlinear circuits but also to explore it and build some sophisticated applications. The circuits presented here are selected because of their simplicity from the mathematical point of view. Multisim simulation provides a virtual electronic lab environment to experiment with chaos. This will enhance the learning process by being able to make all circuit changes before purchasing any component to implement actual circuits. Complete circuits implementations are presented to show the existence of chaos behavior.

At the end of semester, students were definitely fascinated by the existence of this chaos phenomenon. They understood that the linear model that describes the device is a simplified version of a complex real one. They spent hours in trying to find other parameters to obtain other attractors. Finally some of their questions that remained unanswered are (1) how to set the parameter to guarantee the display of attractors and (2) has anyone developed a commercialized product that takes advantage of this phenomenon. It is our hope that this paper will entice the reader to experiment with this nonlinear phenomenon.

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Harvesting Energy using Piezoelectric Materials for a Pacemaker

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Abstract

A pacemaker is a small sophisticated unit that helps to regulate heart's rhythm. This is performed by sending a small electric stimulation to the heart. The doctor places the pacemaker under the skin on patient's chest, just below the collarbone. It's connected to the heart with tiny wires. Pacemakers' main purpose is to keep the heart beating properly by maintaining the heartbeats, which helps the body get blood, oxygen and food that it needs. Pacemakers are useful in many cardiac conditions which can disrupt the heart's normal electrical system. They are mostly used for patients who may have slower heart rates caused by sinus syndrome or heart blocks. They usually eliminate the symptoms often caused by bradycardia including weakness, fatigue, lightheadedness, dizziness, or loss of consciousness. Pacemakers do not take over the work of the heart as it's responsible to function on its own. Rather, the pacemaker merely helps to regulate the timing and sequence of the heartbeat.

The replacement of a pacemaker has some negative effects on the patients, such as the cost of a surgery to replace a pacemaker is $45,000. There are complications that may be caused during the surgery or during the recovery time such as infection, and mainly the trauma of going through a surgery itself such as patients who have phobia of needles, anesthesia, or hospitals. The additional cost of the procedure with associated medical care varies greatly depending on the hospital that the patient receives the pacemaker. In an outpatient setting, where the procedure is done on the same day of discharge or the day prior to discharge, the average cost is over $2,000 plus the cost of the pacemaker. However, for the inpatient setting, where the patients are admitted to the hospital, the average cost can be over $60,000. If the surgery is repeated there is a risk of damage to the blood vessels or the nerves near where the pacemaker is implanted, according to MayoClinic.com. There is also a risk that a lung may collapse during the procedure if it is punctured or that the heart may be punctured, according to MedlinePlus. Sometimes the surgery can cause an abnormal heart rhythm. Other side effects of the surgery include a risk of infection, swelling, bruising, bleeding or an allergic reaction to the anesthesia given during the procedure.

Our goal is to eliminate the need for this extra surgery for such crucial device and the risks that are involved for doing so. Our idea is simple: Covert mechanical energy into electrical energy and use it as a power source for the pacemaker instead of a battery. We will capture the vibrations of the human heart using the piezoelectric energy harvesters and convert it into electrical energy and provide a power source for the pacemaker, thus eliminating the need for an extra surgery in order to replace a battery.

Introduction

Pacemakers are very important and crucial medical device that stimulates the heart by electrical impulses in order to keep it beating at a healthy rate. The pacemaker is inserted through a surgery that can take up to 90 minutes. The pacemaker is made up of three parts. First is the generator, this is the computer and battery. Second is the connector, this is where the leads are attached. Lastly is the leads, these are the wires that link the heart with the pacemaker.

Our Self-Powered Pacemaker is a device that functions just like any Pacemaker in the market, but instead it creates power independently from the battery using piezoelectric harvesters, which uses the vibrations from the heartbeats and converts them into electrical energy and harvests them into the capacitors. The stored energy is utilized as a power source for the pacemaker.

Background

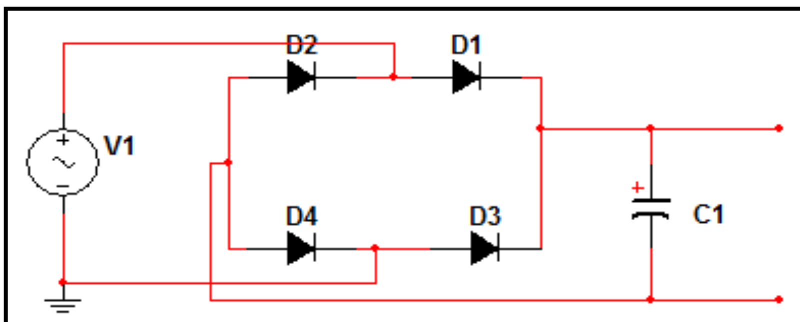
Our interest in energy harvesting led us to believe that we can take apart a complex device such as a pacemaker and eliminate it's battery as the primary power source. We introduced this idea to few medical professionals such as Dr. Macknojia, a cardiologist, and Dr. Curran, PHD in Neurology. Their enthusiasm and inputs for this topic gave us motivation to design a complete product for demonstration. The main complexity of this project dealt with the piezoelectric sensors since our application needs sufficient power to work. Since we cannot use an actual human heart to test our theory, we created a mimic heartbeat model using Arduino microcontroller. This required us to create a complex C code which is listed in Appendences of this paper. Our project's primary goal is the cost reduction for patients. The replacement surgery and the risks associated can be an alarming factor for patients' health.

Product Requirements

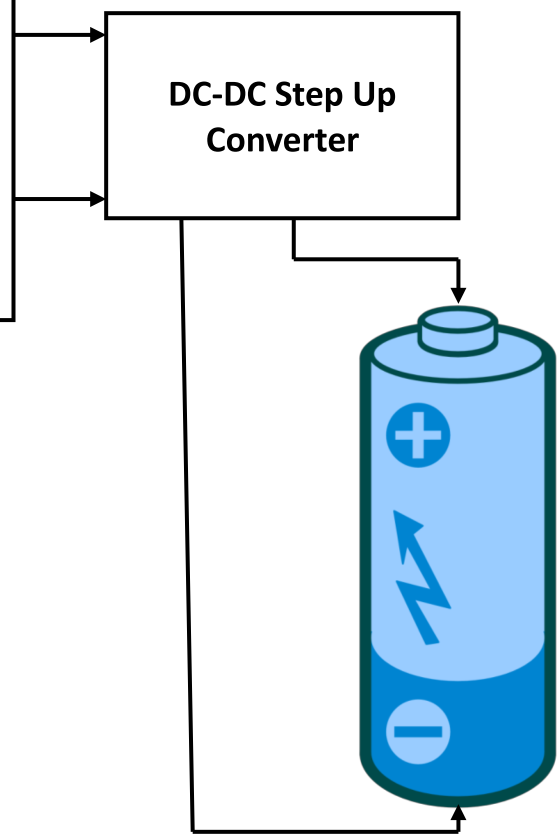
- Breadboard – For testing purposes.
- Capacitors – To store the energy.
- Arduino UNO – To create a heartbeat model
- Oscilloscope – To get our energy readings.
- Vibration Motors – To mimic the heart vibrations.
- LTC3588-1 chip – To mount it onto the heart.
- Aluminum enclosure – To place the circuit inside.
- Fake Heart Prop – To mimic the actual heart with a motor inside
- Piezoelectric Energy Harvesters – To convert vibrations into electrical energy

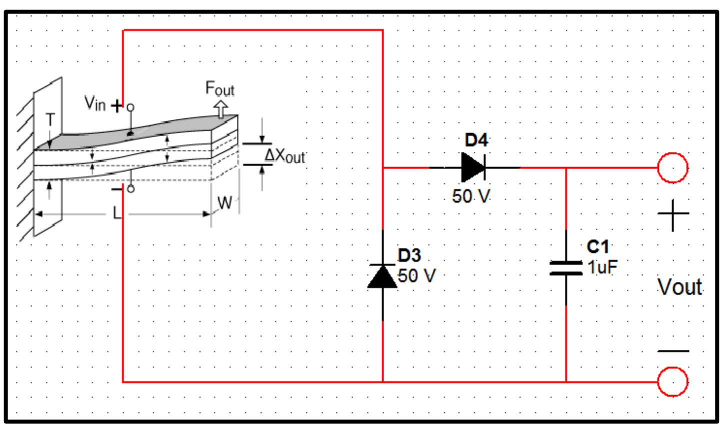
Design Alternatives

Designing a pacemaker's circuit was not complicated. We were given an actual pacemaker donated by Hall Garcia Medical facility for testing purposes. We used the dremel tool to pry open the titanium covering. Our original goal was to use the actual circuit from that pacemaker. Unfortunately the manufactures had a tamper protection liquid inside the pacemaker which destroys the circuit if anyone cuts open the pacemaker. Although, the circuit was useless, it gave a great picture of how we can build a pacemaker from scratch. Any pacemaker's circuit is a full-wave bridge rectifier consisting of four diodes in series with capacitors to hold the charge into.

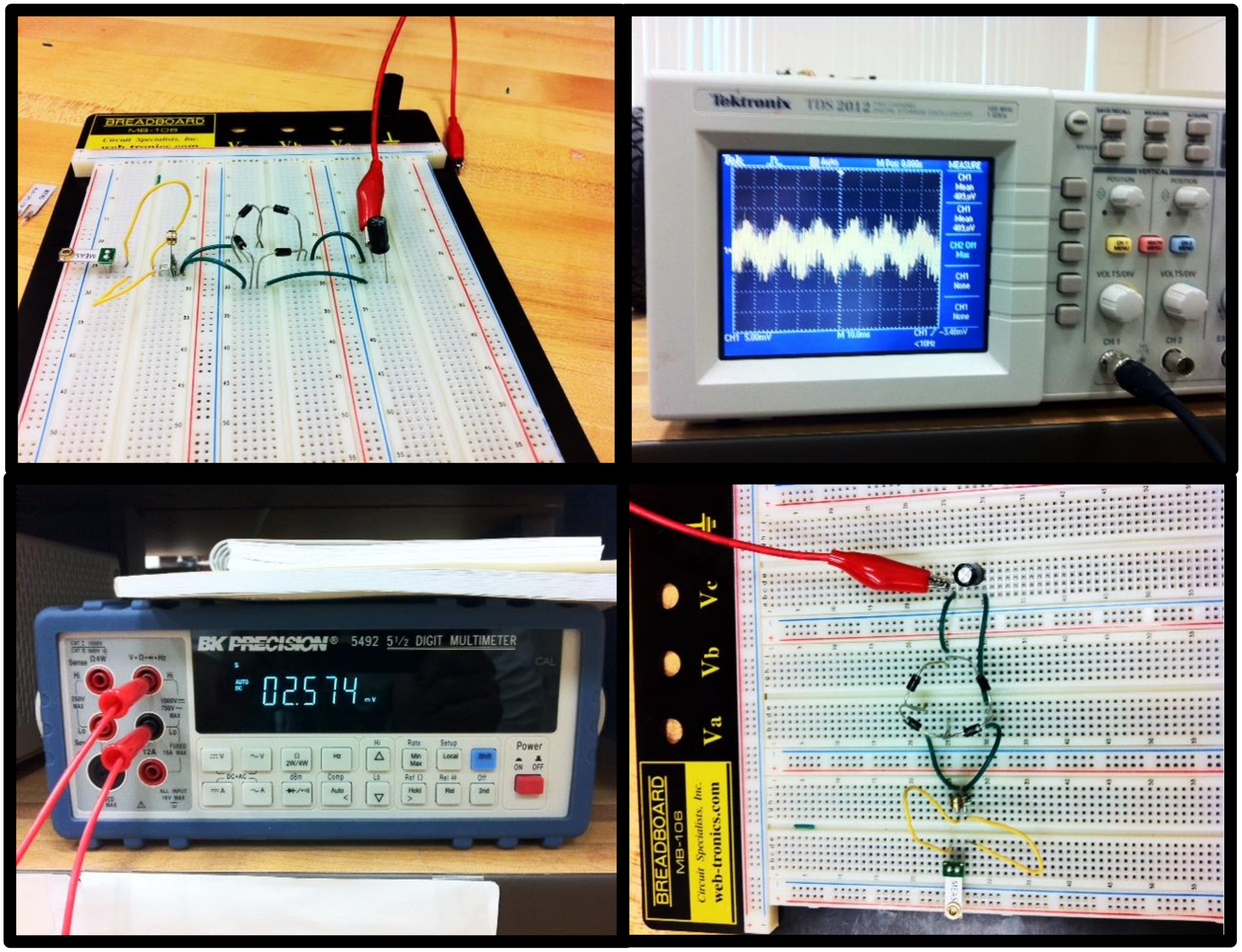


Full-wave bridge rectifier Pacemaker Circuit



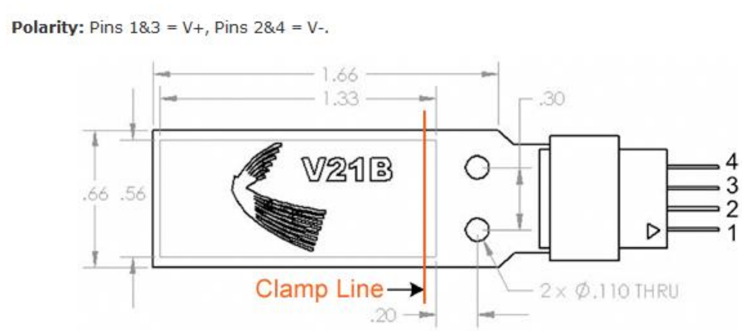


Piezoelectric Sensor used as a Power Source



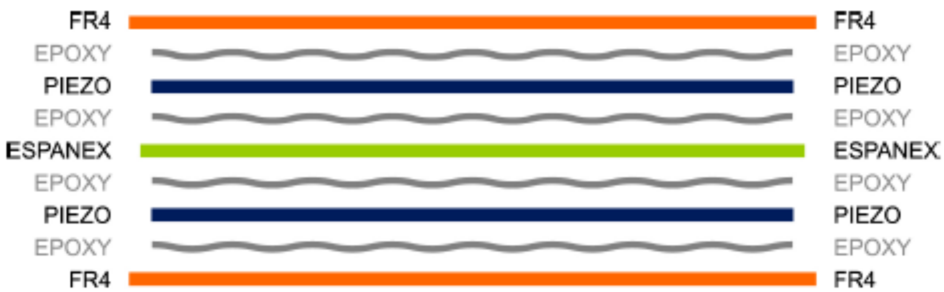
Piezoelectric Energy Harvesting Rectifier Pacemaker Circuit with Piezoelectric Minisense100 Vibration Sensors

While conducting our research, we came across Volture Vibration Energy harvesters that are created by MIDE Engineering group. The Volture Piezoelectric Energy Harvester uses the piezoelectric effect to convert normally wasted mechanical energy in the form of vibrations into useable electrical energy. Any application where sensing is needed and there is a consistent vibration to harvest from can benefit from the Volture. This harvester was clamped at its base to allow for resonant frequency energy harvesting. This ensures that the clamp line (front of the clamp) is around) 0.2" over the edge of the piezoelectric ceramic is efficient and safe operation.

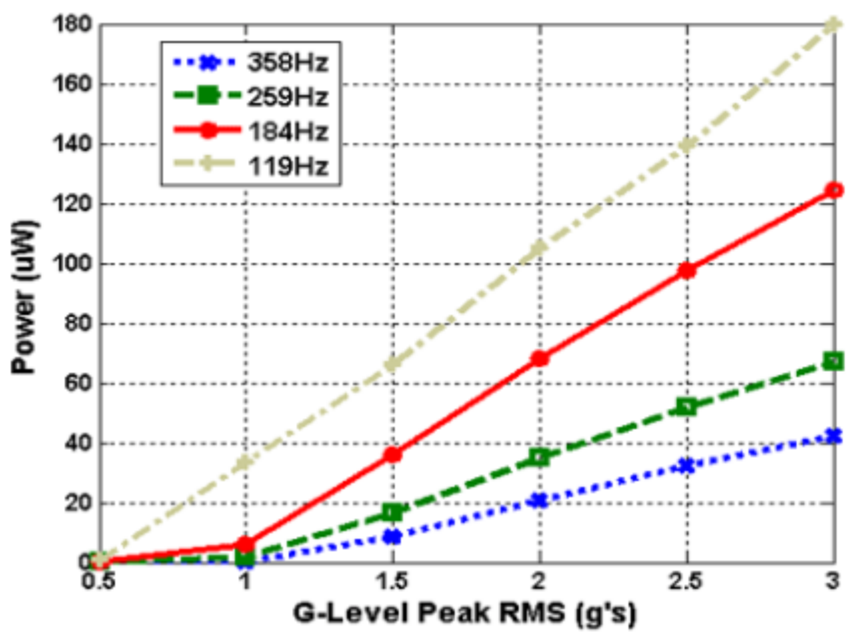


Volture Piezoelectric Energy Harvester

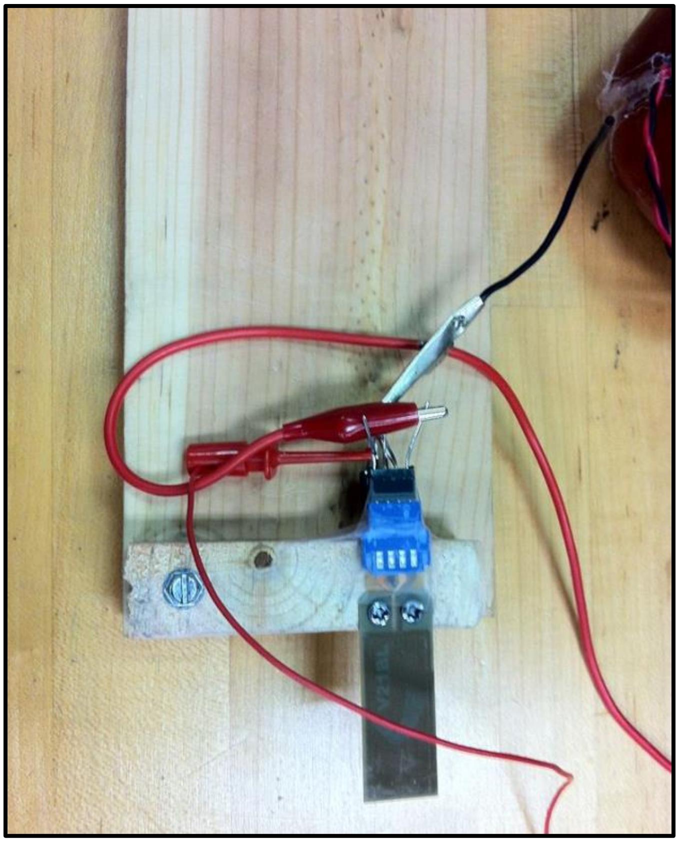
Product Layers

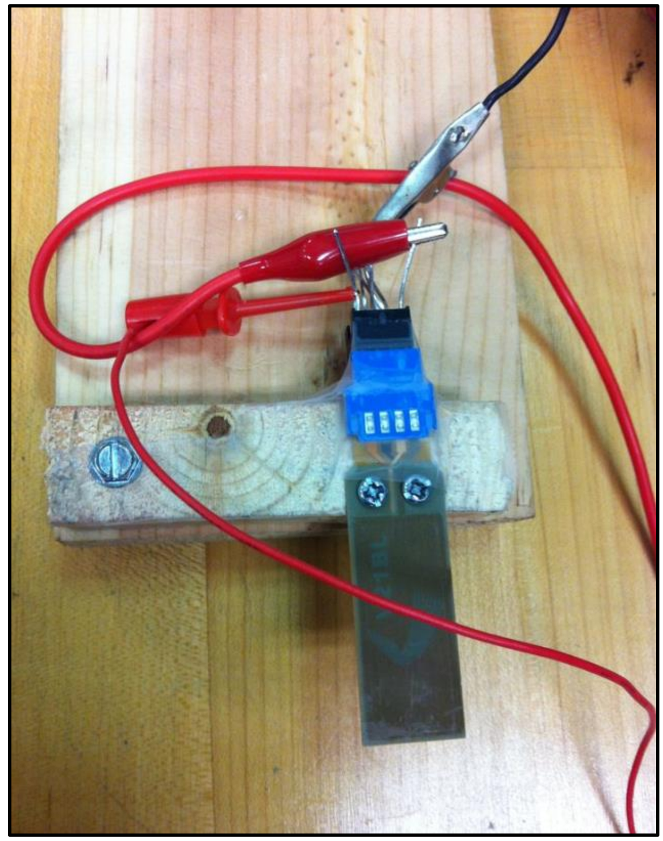


Specifications - v22b	
Application type:	energy harvesting
Frequency Range (Hz):	120 - 360
Harvesting Bandwidth (Hz):	2
Device size (in):	1.4 x 0.24 x 0.025
Device weight (oz):	0.045
Active elements:	1 stack of 2 piezos
Piezo wafer size (in):	1.00 x 0.15 x 0.01
Device capacitance (nF):	nominal: 10.2, maximum: 14.2



Energy Harvesting using Piezoelectric Materials for a Pacemaker,
University of Houston College of Technology, March 8, 2013.



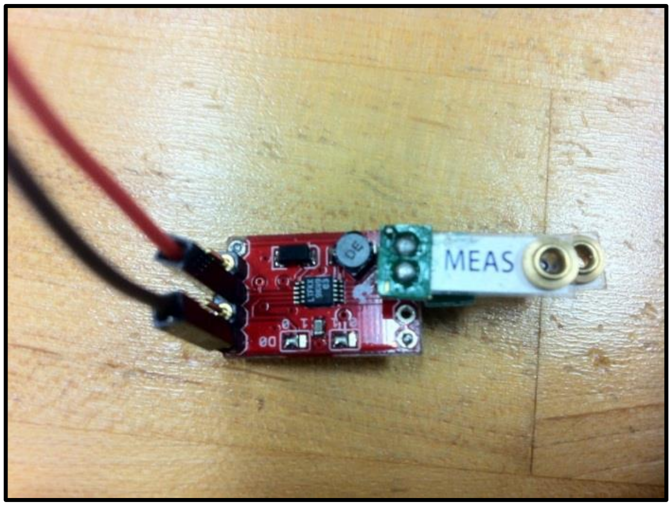


Volture Energy Harvesters connected with our Pacemaker Circuit

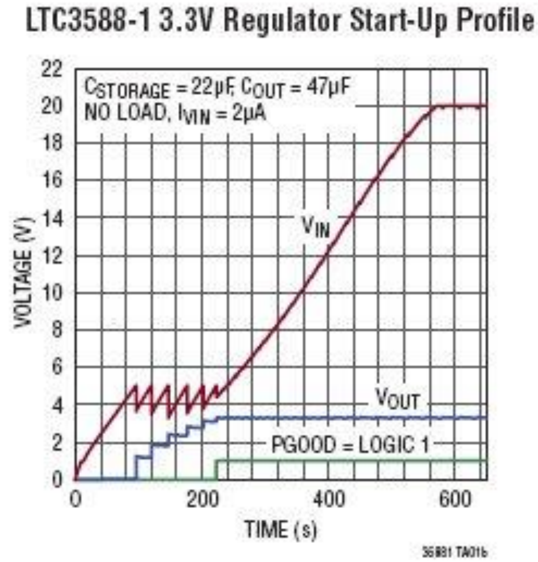
Unfortunately, after vigorous testing, we concluded these harvesters were not what we are trying to accomplish in our project. They were designed mainly for higher frequency applications and since pacemaker's frequency is very low, these harvesters were not ideal and dropped from our design. Going back to our original design of full-wave bridge rectifier circuit, we came across a problem: The capacitors we had were leaking the charge really fast, and were not sufficient to hold for a longer period. After doing more research we found a LTC3588-1 chip which was perfect for our project. Therefore, we finalized our circuit using The Minisense100 piezoelectric Vibration sensor mounted parallel onto LTC3588-1 chip.

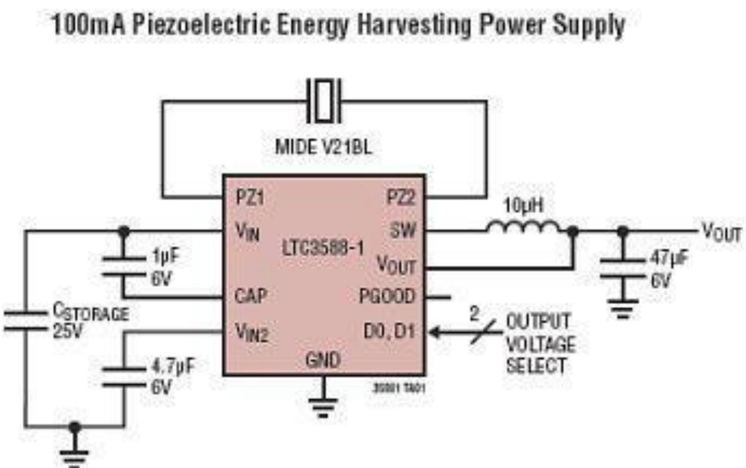
Design Specifications

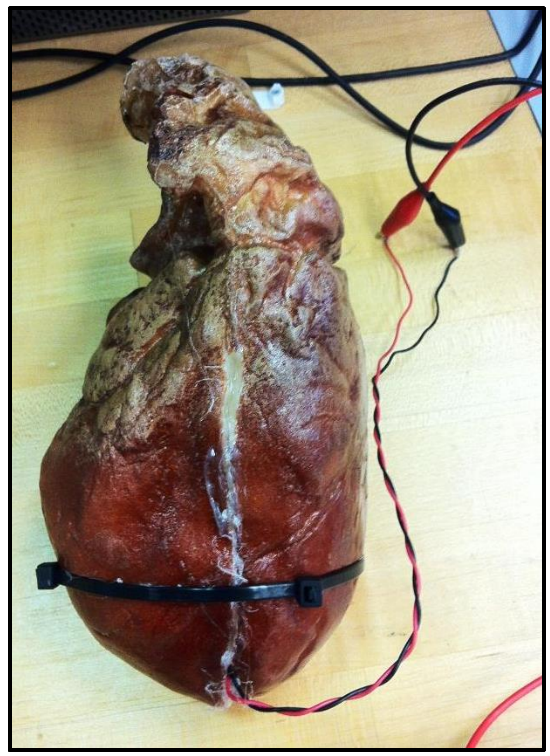
The LTC3588-1 integrates a low-loss full-wave bridge rectifier with a high efficiency buck converter to form a complete energy harvesting solution optimized for high output impedance energy sources such as piezoelectric transducers. An ultralow quiescent current under-voltage lockout (UVLO) mode with a wide hysteresis window allows charge to accumulate on an input capacitor until the buck converter can efficiently transfer a portion of the stored charge to the output. In regulation, the LTC3588-1 enters a sleep state in which both input and output quiescent currents are minimal. The buck converter turns on and off as needed to maintain regulation.



LTC3588-1 Chip with Minisense100 piezoelectric Vibration sensors mounted parallel

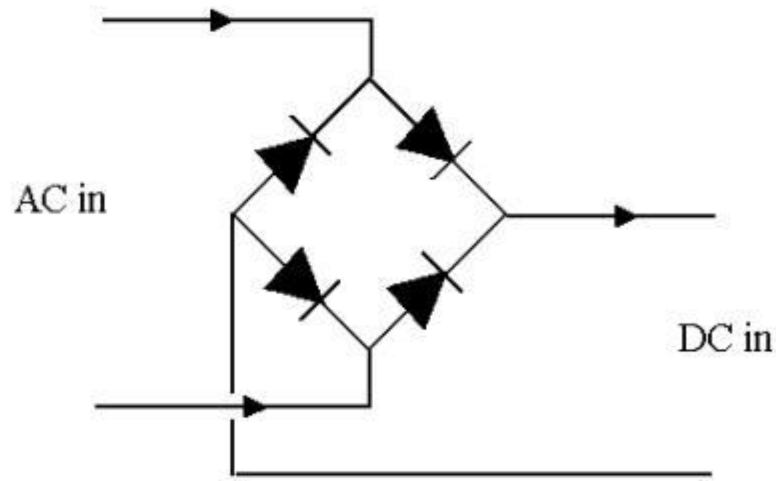




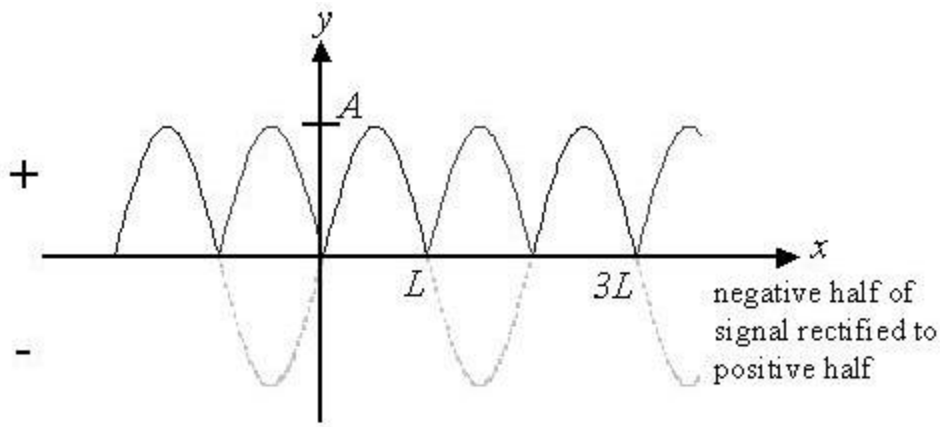


Foam Modeled Heart with DC Motor mounted inside

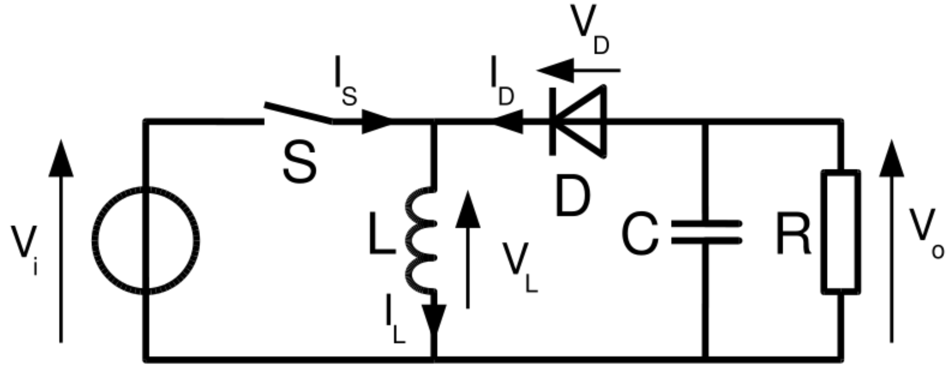
The piezoelectric material is an AC voltage source which means that the voltage will shift from positive to negative as it is moving up and down. To convert the AC voltage to DC voltage, a diode bridge rectifier is implemented in the circuit design.



The conversion from AC to DC occurs as only the positive input remains on the upper path of the diode rectifier and the negative input remains in the lower diodes. By using this process, all of negative waves are converted to positive as shown in figure above. The capacitor across the output terminals is required to smooth the ripples as the flow of current is rectified.



Once the AC input has been rectified to DC output, the output then goes through a buck-boost converter circuit. The circuit consists of a reversed biased diode, inductor, capacitor and a switch. The buck-boost converter is a type of DC to DC converter that has an output voltage that is greater or less than the input voltage. One of the most noticeable characteristic of the buck-boost converter is that it changes the polarity of the output voltage opposed to that of the input.



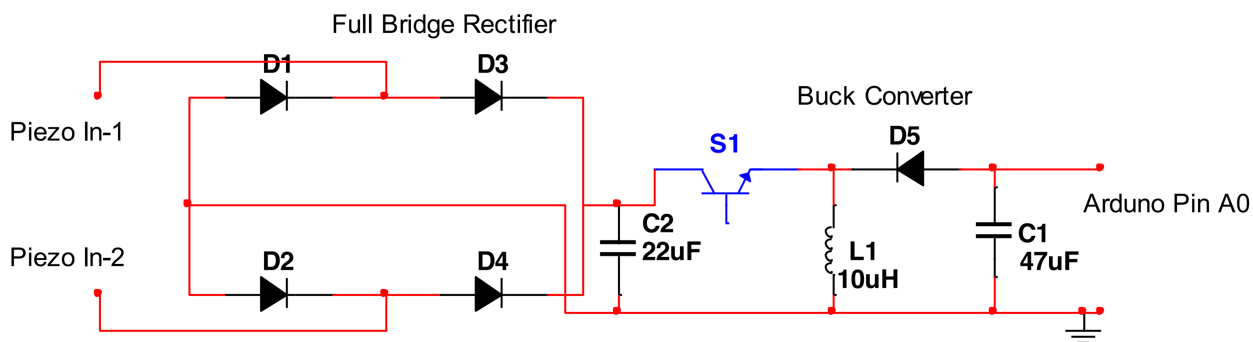
When the switch is in the on/closed state, the input voltage source is directly connected to the inductor (L). This results in the inductor storing the energy. In this state the capacitor is used to supply energy to the output load. When the switch moves to off/open state, the inductor is connected to the output load and capacitor in which the energy is transferred from the inductor to the capacitor and the load. The rate of change in the inductor current I_L in the on state is given by the following equation (eq 1):

$$\Delta I_{L_{On}} = \int_0^{DT} d\, I_L = \int_0^{DT} \frac{V_i}{L}\, dt = \frac{V_i DT}{L} \qquad \text{eq (1)}$$

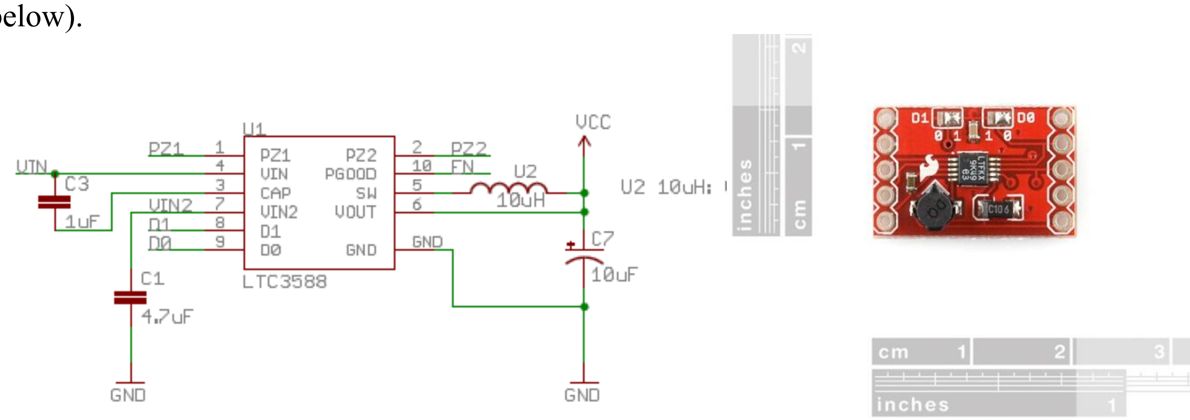
D is the duty cycle. It represents the fraction of the commutation period T during which the switch is on. Therefore D ranges between 0 (S is never on) and 1 (S is always on). During the off state, the switch is open so the inductor current flows through the load and this can be expressed by the following equation (eq 2).

$$\Delta I_{L_{On}} = \int_0^{(1-D)T} d\, I_L = \int_0^{(1-D)T} \frac{V_o}{L}\, dt = \frac{V_o(1-D)T}{L} \qquad \text{eq (2)}$$

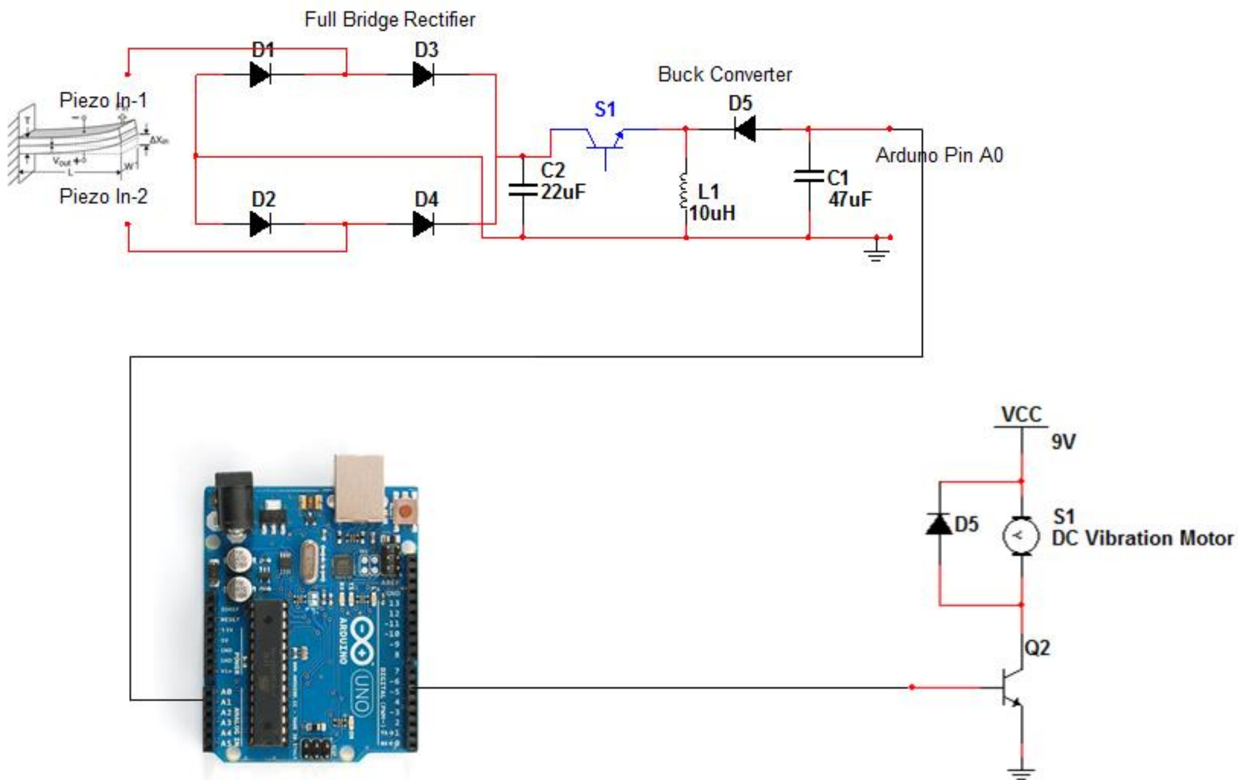
After finalizing all the components a simulation of the circuit was created in Multisim software (see figure below). The circuit was fully designed on the software with parts, diode rectifier circuit and the buck-boost converter circuit.



A LTC3588 breakout board was acquired for this project as it had all the necessary components required. The size of the prototype was essential to the design as this entire circuitry will be placed in a human body. With the limited tool and hardware, a prototype was prepared. Following image shows the LTC3588 pin outs and components attached to the chip (figure below).



Once the prototype was completed a graphical user interface (GUI) was developed to show the harvested energy from the piezo-electrical material. The gui consists of two separate programs. The first program is used to feed the analog signal (voltage) to the Arduino microcontroller to convert the value from analog to digital format. This task is achieved using the Analog to Digital Converter chip that is on board of the microcontroller. Once a signal is received by the microcontroller, the process of converting the analog signal to digital signal takes place at which point the microcontroller sends the collected data to the serial port of the Arduino.

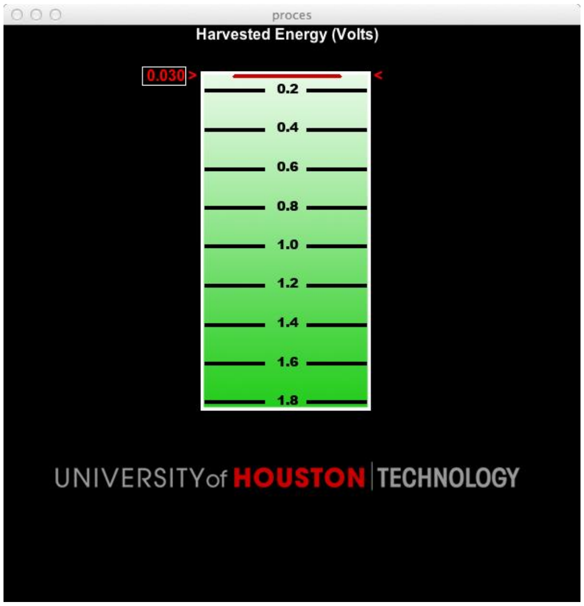


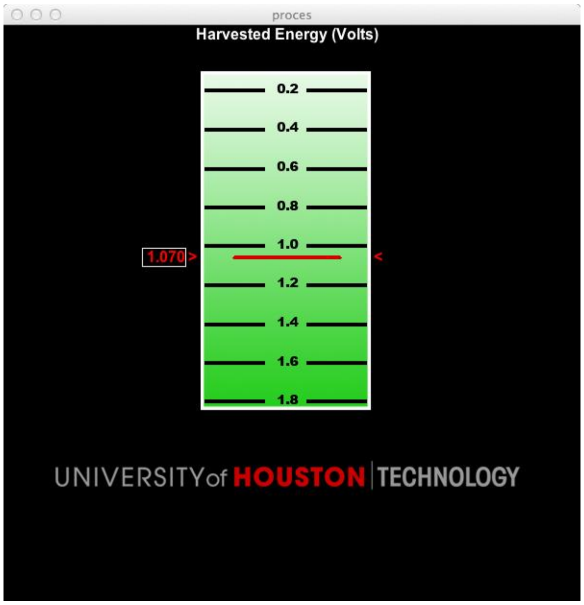
LTC3588-1 - Piezoelectric Energy Harvesting Power Supply

Features

- **950nA Input Quiescent Current (Output in Regulation – No Load)**
- **450nA Input Quiescent Current in UVLO**
- **2.7V to 20V Input Operating Range**
- **Integrated Low-Loss Full-Wave Bridge Rectifier**
- **Up to 100mA of Output Current**
- **Selectable Output Voltages of 1.8V, 2.5V, 3.3V, 3.6V**
- High Efficiency Integrated Hysteretic Buck DC/DC
- Input Protective Shunt – Up to 25mA Pull-Down at VIN ≥ 20V
- Wide Input Undervoltage Lockout (UVLO) Range
- Available in 10-Lead MSE and 3mm × 3mm DFN
- Packages

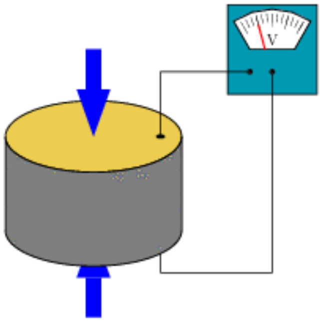
The next phase of the gui involves processing the data the is collected from the serial port of the Arduino. The gui is developed using the Processing IDE software. Processing uses combination of java and C++ programming language. The gui shows the level of voltage that is being stored in the capacitor that is harvested from the piezoelectric material. Below are the gui screenshots:





Design Description

The basic principle behind a piezoelectric material is that it takes the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry. The first thing that needs to be understood is the piezoelectric effect which describes the relationship between a mechanical stress and an electrical voltage in solids.



Piezoelectric properties

Figure above shows the relationship between the mechanical and electrical state in which when the material is stressed, it results in a voltage as an output.

This project involves the use of piezoelectric material to take the vibration that are caused by the heartbeat and convert it into a power source which will charge the battery of the pacemaker.

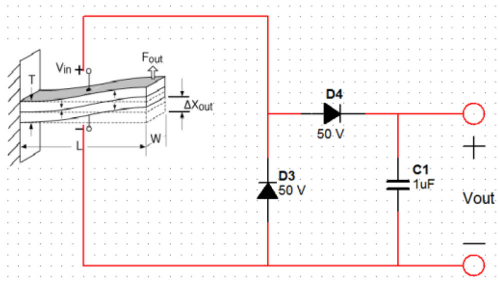


Figure 1: Sensor Circuit

This effect of piezoelectric material is achieved by creating voltage through vibration is reversible. This means that an applied mechanical stress will generate a voltage and an applied voltage will change the shape of the solid by a small amount.

There are two main groups of piezoelectric materials which are crystals such as quartz and ceramics such as PZT. Piezoelectric materials can be used as power sources, sensors, and actuators. However, the main focus of this project will revolve around the use piezoelectric material as a power source.

One of the most important aspects of this project was to be to harvest maximum power. This was done when both, piezoelectric circuit and pacemaker circuit, were impedance matched (can be seen in Design Alternatives section). When two circuits are impedance matched, this allows for the maximum power transfer to take place. This also ensures that no power is being wasted or lost.

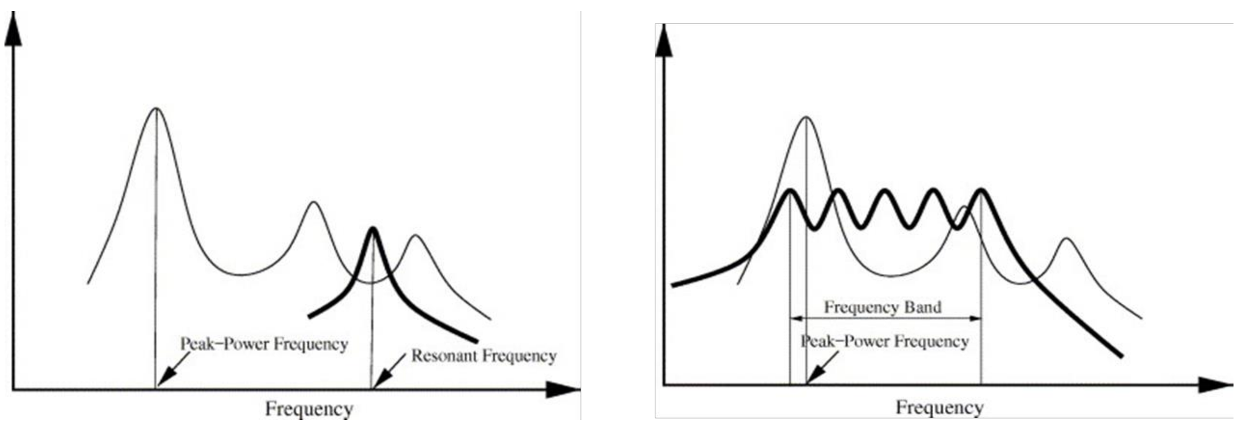


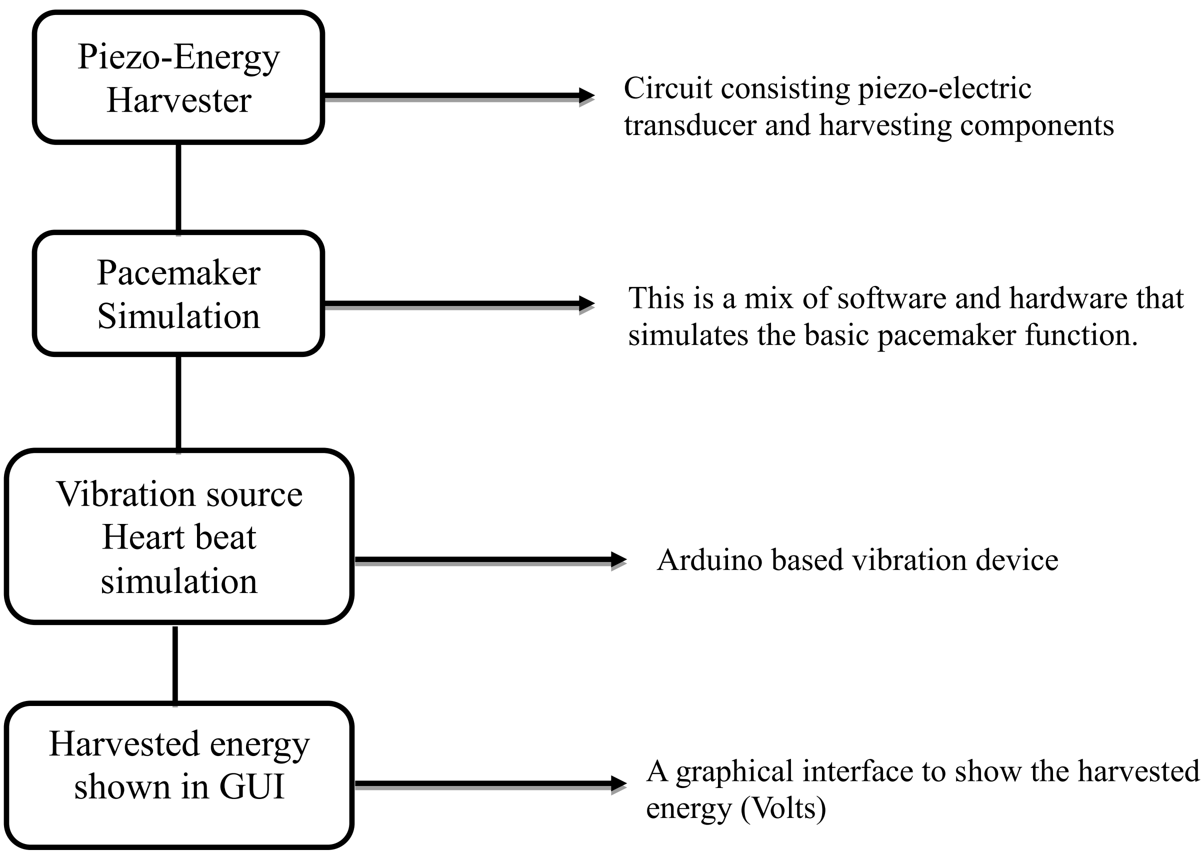
Figure 2: Maximum Power Transfer

As the figure 3 above show, that both parts of the circuits, the sensor and the pacemaker circuits, must have the same resonant frequency as well as the impedance for there to be maximum power transfer.

Another aspect of the project focused on was the human anatomy as it tends to reject foreign materials. To correct this issue we protected our circuit with titanium cover so that the body does not cause the device to be rejected.

Construction Details

In order to fabricate this project, you would need to buy an LTC3588-1 with two Minisense100 piezoelectric Vibration sensors showed in design specifications. Then you would need to mount these sensors in parallel by soldering them with each of its pin. You would also need a DC motor which will mimic the heartbeat connected to the Arduino microcontroller as showed in Design Specifications. You would need to buy a modeled heart to place the motors inside of it and you would need to find the spot with most accurate vibrations.



Cost Analysis

Financial usage reporting		
Item	**Est. Cost**	**Actual Cost**
PS3 Controller for Motors	$59.00	Free
Minisense100 Piezoelectric harvesters	$4.00	$4.00
Arduino mini	$39.00	$39.00
Heart Model	$50.00	$110.00
LTC3588 Chip	$30.00	$40.00
Totals	$182.00	$193.00

Ultimately this project will cost in the range of $10,000 - $12,000 in the market, which includes an actual pacemaker, labor, tools and equipment, and sensors. Although our actual cost was $350, this cost is mainly based on a conceptual project. Our goal was to have a demonstrative project which can be implemented using sufficient industry tools and can be sent for human trail.

Conclusion

We were successfully able to complete our goal for harvesting the energy using heart vibrations model. Although originally we had planned to work with an actual pacemaker, but unfortunately the manufacture had a tampering protection liquid on it which destroys the circuit if opened. After doing a bit more research we came across Volture energy harvesters, but after vigorous testing we concluded that those harvesters were for higher frequency devices instead of a pacemaker. Hence, we designed our own way of harvesting energy using miniSense100 piezoelectric sensors that converts the heart's vibrations and converts them into electrical energy mounted parallel with LTC3588-1 that integrates a low-loss full-wave bridge rectifier with a high efficiency buck converter to form a complete energy harvesting solution optimized for high output impedance energy sources such as piezoelectric transducers.

User Instructions

In order to use our product a person needs to be licensed as a medical surgeon capable of performing pacemaker surgeries. It is not meant to be tampered with by the patients or any other medical professionals.

Appendices

- **C Program for GUI, which shows the output voltage whenever the heart vibrates, combined with the heartbeat model:**

```
const int analogInPin = A0;  // Analog input pin that the potentiometer is attached to
const int analogOutPin = 9; // Analog output pin that the LED is attached to
int sensorValue = 0;        // value read from the pot
float outputValue = 0;        // value output to the PWM (analog out)

void setup()
{
  Serial.begin(9600);
}

void loop()
{

  sensorValue = analogRead(analogInPin);
  outputValue = fmap(sensorValue, 0, 1023, 0.0, 5.0);
  //map the adc values to 0-5v
```

```
  // print the results to the serial monitor:
  Serial.println(outputValue);
  delay(100);
  heartBeat(0.6);

}

float fmap(float x, float in_min, float in_max, float out_min, float out_max)
{
  return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
}

void heartBeat(float tempo){
    if ((millis() - prevMillis) > (long)(heartBeatArray[hbeatIndex]* tempo)){
        hbeatIndex++;
        if (hbeatIndex > 3) hbeatIndex = 0;

        if ((hbeatIndex % 2) == 0){
            digitalWrite(LEDpin, HIGH);
            delay((int)heartBeatArray[hbeatIndex]) ;
            digitalWrite(LEDpin, LOW);
        }
        hbeatIndex++;
        //Serial.println(hbeatIndex);
        prevMillis = millis();

    }
```

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M-Model: A High-Fidelity On-Line Homework System for Engineering Mechanics

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Abstract

Students solve problems by developing mental models of the problem. Although these models are many and diverse, a common one used in engineering education consists of identifying the known and unknown variables, construction of a graphical problem representation, and developing a mathematical model derived from the preceding steps. This is particularly the case for courses in physics, mechanics, and electrical circuits. M-MODEL is a computer-based implementation of this approach to problem-solving. It requires users to build the known/unknown, graphical (free-body diagram in this paper), and mathematical models of a problem. Once the student creates a complete model, M-MODEL checks it for errors such as proper number of graphical elements, naming of variables, and equation formatting. These checks also provide users with feedback that can be used to correct or improve their models. Once users are satisfied with their models, M-MODEL proceeds to solve their equations, at the instructor's discretion, as well as display the correct solution for users to compare to their models. M-MODEL also provides tools that individual authors can use to prepare problem models.

This paper discusses the features of M-MODEL as applied to a solid mechanics course. It also discusses how it may be used to encourage students to develop mental model approaches to problem solving. A student assessment of M-MODEL is also presented.

Introduction

Students solve problems by constructing mental representations the problem. These models take many forms such as graphical, mathematical, flow charts, process steps, and schematics to mention a few. As pointed out by Norman[1], these models can be contradictory, incomplete, superstitious, erroneous, and unstable, while varying in time. It is the task of the educator to help students learn how to form accurate and useful mental models and apply them to knowledge domain problems. M-MODEL is a computer-based tool that permits engineering educators to develop problems using the principle mental models of the discipline in a consistent and flexible manner. This paper describes the user environments, the philosophy behind M-MODEL, and some of the pedagogues embedded in it.

Several engineering problem solving models or schema have been reported recently. These include the Wankat and Oreovicz[2] problem solving strategy, McMaster problem solving program of Woods[3] and Woods, et al.[4], Gray and Costonzo[5] structured approach to problem solving, Mettes and associates[6] Systematic Approach to Solving Problems, and Litzenger, et al.'s[7] Integrated Problem Solving Model. The Wankat and Oreovicz strategy divides problem solving into definite steps including motivation, exploration, and reflection as well as the more common define, plan, execute and check steps. The McMaster problem solving program uses a structure similar to that of Wankat and Oreovicz and implements it across entire curricula. Gray's structured approach emphasizes pattern-matching that starts with a small number of general equations that students reduce to fit a given situation. The Mettes problem solving schema is based upon a flow chart of problem solving steps and a constructionist approach to learning. Litzinger's integrated model emphasizes problem representation and the conversion from one representation (say problem statement) to another (say graphical).

The define, plan, and execute steps are the common thread among these various models. In mechanics disciplines, these steps take the form of free-body diagram (FBD) development, listing of the given (known) and identifying (unknown) variables, creating a mathematical model consistent with the FBD, and final answer production. As pointed out by Gray and Costanzo, the current trend in mechanics is to deemphasize the final answer production step and leave this to computational software. Four mental models are commonly used to build problem solutions. These are: problem statement, graphical representation such as a FBD, given/find representation typically in the form of lists, and a system of equations that will produce the final answers. These four mental models represent the core of engineering mechanics problem solving, have a long standing tradition in engineering mechanics, and are consistent with current trends in engineering mechanics education.

The newest trend in engineering mechanics education is the application of computer technology to teach students, engage them in the learning process, and to help them understand mechanics concepts and principles. These are many and varied. They are perhaps best illustrated by the works of Gramoll[8,9], Dollar and Stief[10], Stief and Dollar[11,12], Philpot[13,14], Stanley[15], and Gray and Costanzo[16] to list a few. Many of these are similar to traditional textbook presentations with exceptions such as interactive examples, audio/video lectures, homework sets with immediate feedback, virtual experiments, and interactive animations to develop conceptual understanding. This approach to learning problem solving is based upon examples and homework problem sets and is fairly traditional. Problem interactivity has been added to keep the student engaged with the problem. Hints, intelligent coaching, instantaneous feedback, and intelligent correcting have been incorporated by many of these authors. But, they rely upon click-on-object, drop and drag, pair matching, multi-choice answers, and short answers (usually numerical) for user input and traversing the basic problem structure. They tend to be somewhat inflexible in that users must use notations, axis systems, vector directions, equation ordering and etc. as prescribed by the problem designer rather than allowing students to make choices and decisions on their own.

The Andes problem solving system for classical physics developed by VanLehn, et al.[17] and implemented at the United States Naval Academy by Schultz, et al.[17] is based upon a Baysian network representation of a problem. This system allows considerable flexibility and generates solutions, immediate feedback, and help comments based upon the path traversed by the user through this network. Hence, the user who elects to use one set of notations will be coached through the problem and produce a correct answer for that notation set just as the user who chooses to use some other notation system. This approach encourages students to think through the solution, plan their approach, and develop in-depth problem solving skills rather than charging directly and often blindly into and through the problem solution. Andes utilizes four mental models; problem statement, graphic representation, variables lists, and mathematical model, and requires users to develop each of these mental models (graphical representation is optional). Andes includes an equation solving tool although users can also solve the equations off-line. A research project conducted on some 330 students approximately one-half of whom were in a control group, resulted in a 3% (1/3 letter grade) student performance improvement on departmental pencil and paper examinations by students who did Andes homework rather than traditional homework. Anecdotal results from Andes users (Schulze, et al.[18]) indicate that students are initially reluctant to carefully define their variables, some students ask for help on almost every step of a problem solution, giving effective hints and help is very difficult, and analysis of action logs reveal that students do not understand physics as well as might be thought.

M-MODEL utilizes the same four mental models as Andes and requires users to fully develop their graphical, variables, and mathematical representations from the problem statement. Although most users will develop their representations in this order, it is not required and students can proceed however they deem appropriate. But, all user representations must be completed before a correct solution is possible. Users have complete freedom in naming their variables, orienting their FBD vectors and coordinate systems, selecting their units, and etc. as they set up their solution. These choices are graded against the problem designer’s expectations and final answers. M-MODEL is therefore an extremely versatile system that gives students considerable freedom in developing their problem solution and encourages them to utilize in-depth problem solving skills and high-order cognitions.

M-MODEL Philosophy

M-MODEL was conceived as a tool students can use to practice and develop their problem solving skills as well as to allow sufficient flexibility that varied, but correct, problem solution paths are possible. This latter objective is important in that mechanics courses are typically those courses that begin the transition from well-framed problems to the more ill-defined engineering and design problems. It is also important that students learn how to formulate problems and that correct, but possibly different, answers depend upon that formulation.

M-MODEL was also designed to require users to use all four mental models common to the current problem solving practices in the engineering educational literature. These mental models have a long standing tradition in engineering mechanics education and are familiar to engineering educators. M-MODEL also focuses on the model building process and leaves the computational details to an optional embedded equation solver. This feature is intended to channel students away from the rush to simply write equations, substitute values, and produce answers. Rather, students must carefully build complete models before a final solution is possible. Focusing on model building is also the current trend in engineering and engineering mechanics education.

M-MODEL is also intended to give problem developers tools that they can use to develop their own problems and homework sets. It is also designed to reduce the task of grading student solutions. It evaluates many student mistakes and misconceptions, assigns a grade based upon mistakes and misconceptions, and records these grades when implemented on a database and active page server. The software also records user activities, sequences, and time-on-task for research and verification purposes.

M-MODEL User Interface

The initial user screen is shown in Figure 1. This screen is divided into 5 different areas: problem statement, graphical representation, variables listing, pre- and post-calculations, and equation system. The problem statement is presented in the upper, left portion of the screen. Problems can contain up to two random parameters. This example contains two, the forces $\mathbf{F}_1$ and $\mathbf{F}_2$. Users are encouraged to select a free-body from the problem statement diagram by clicking on the appropriate object. Users are not required to do this at the beginning, but ultimately they must select a free-body and develop a FBD. Points are deducted from a student's score and an error message appears if an incorrect free-body is selected. Students can complete their FBD once the correct free-body has been selected with the tools on the graphical toolbox.

Once a user selects the correct free-body, it appears in the graphics representation window of the upper, right-hand screen where the user can use the tools in the toolbox to complete the FBD. These tools include: lines, arrows, clockwise and counter-clockwise moments, two- and three-dimension axis, points, circles, vector (bold) labels, plain labels, screen clearing, and object deleting. Any time a tool is selected by the user, a pop-up screen with user instructions appears. Some of the objects produced by the tools (e.g., axis and moments) can also be rotated as appropriate for the problem. Users click the "Check" button below the tool box to determine if their FBD is complete. An example of a completed FBD is shown in Figure 2.

Problem designers set the minimum number of graphical objects users must add to the FBD. This determines the detail that is expected for correctly completing a FBD. This may be as simple as 6-arrows, 2-moment symbols, 8-bold labels, 6-labels, and 1-two-dimensional axis for the example of Figure 2.

The graphical mental model window includes a grade display and three help buttons. Users begin with 100 points. This number is reduced whenever the user makes a mistake. This reduction depends upon the significance of the mistake. The deduction is set to be higher for a major error like selecting an incorrect free-body and less for a minor mistake like indistinct labels. The magnitude of the deducted points is at the discretion of the problem designer. The "U" button in the upper right-hand of this window activates a pop-up list of the unit symbols in M-MODEL. The "I" button activates another pop-up with an abbreviated set of instructions as a quick reference for users. Full user instructions are available in a separate file.

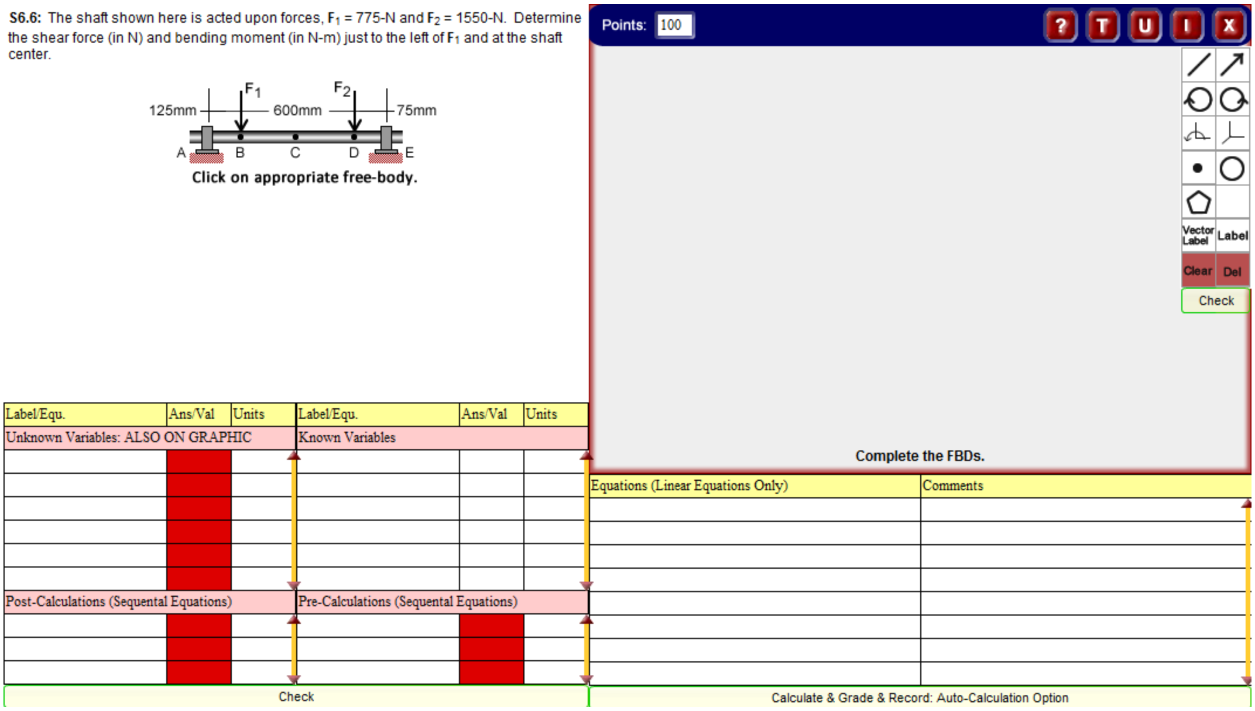

Figure 1: Initial User Interface

Two different coaches are contained in M-MODEL. The first coach is a set of problem specific tips created by the problem author. They can be individually authored or selected from a file of standard tips. A circular stack is used to display the problem specific tips. The second coach, which is accessed with the "?" button, is an intelligent tutor based upon a prioritized stack of procedural tasks. When a user requests help from the intelligent tutor, the tutor identifies where the user is in the prioritized procedure stack. If the next lowest procedure has not been done, the tutor suggests that the user proceed with that task. If it has been done, the tutor suggests that the user proceed with the highest undone task in the stack.

The left-hand side of the user interface also contains a variables list, pre-calculation, and post-calculation section in the lower quadrant as shown in Figure 2. The variables list is divided into lists of the unknown variables and known variables. These are completed by entering the labels and units for the known and unknown variables. The value of the known variables must also be entered by the user. The calculated value of the unknown variables is displayed once the user completes her model and clicks the "Calculate" button to the right. Once this "Check" button is clicked, the unknown variable labels are checked against those on the FBD (the FBD can contain more labels than those on the unknown variable list), checks all labels to insure they are distinctly named, and checks all units for internal consistency. Error messages are displayed and points deducted if any of these errors occur. These error messages provide immediate feedback and give the user the opportunity to make corrections prior to completing the full solution.

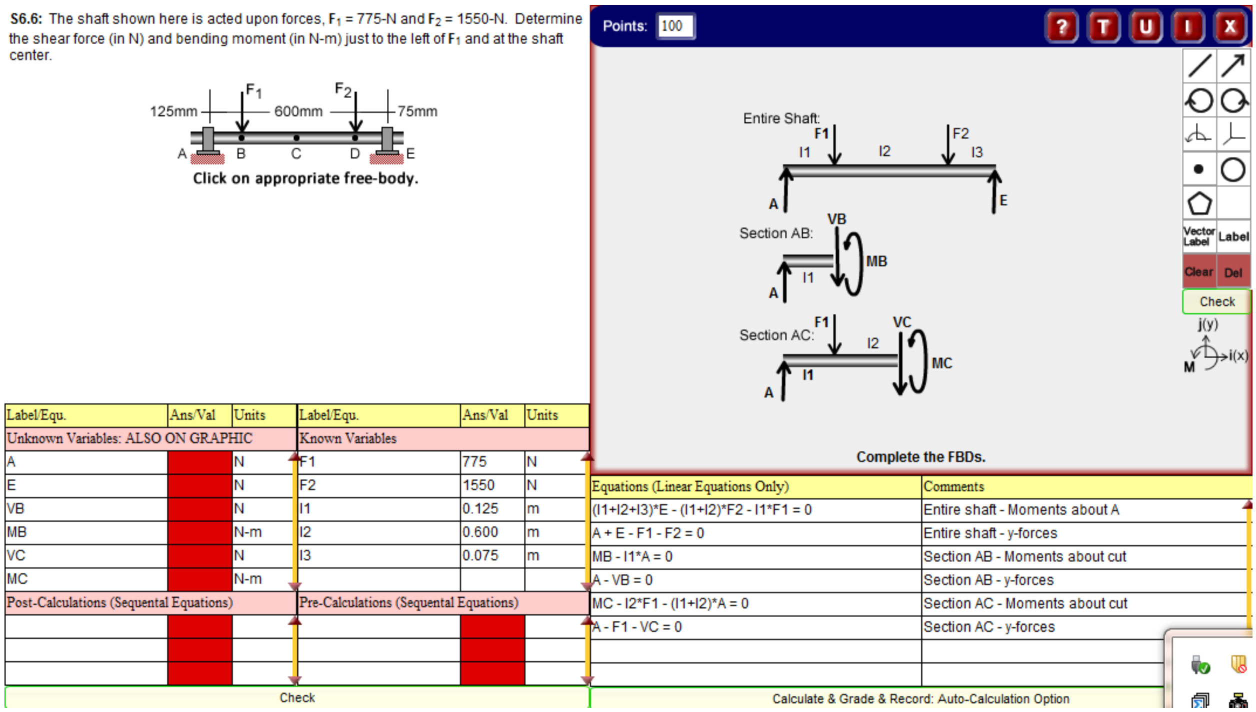

Figure 2: User screen prior to completing calculations

Pre-calculation equations and units of the resulting pre-calculation variables are entered in the "Pre-Calculations" list. Only constants and known variables can be used to build the pre-calculation equations. These are entered in equation form with the pre-calculation variable label on the left-hand side of the equation. Typical examples of pre-calculations are items like moments of inertia and areas. The pre-calculation equations are also sequentially evaluated. That is, any equation can use the known values or variables of any pre-calculation equations above it. The pre-calculation equations are the first to be evaluated when the "Calculate" or "Check" button is clicked. The results of these equations are displayed at this time and the pre-calculation variables become available for the subsequent evaluation of the equation system in the lower, right-hand section of the user interface and the post-calculation equations. The final user screen illustrating the result of these calculations is shown in Figure 3.

The "Post-Calculations" section is organized in the same manner as the "Pre-Calculations" section. The only difference is that post-calculations are done once the unknown variables have been determined by solving the pre-calculation and equation system equations. At this point all variables are available for the post-calculation equations and they may be evaluated. These equations are also sequential. A typical example of a post-calculation is an axial stress calculated from an unknown internal force (from the "Equations" section) and section area (from the "Pre-Calculation" section).

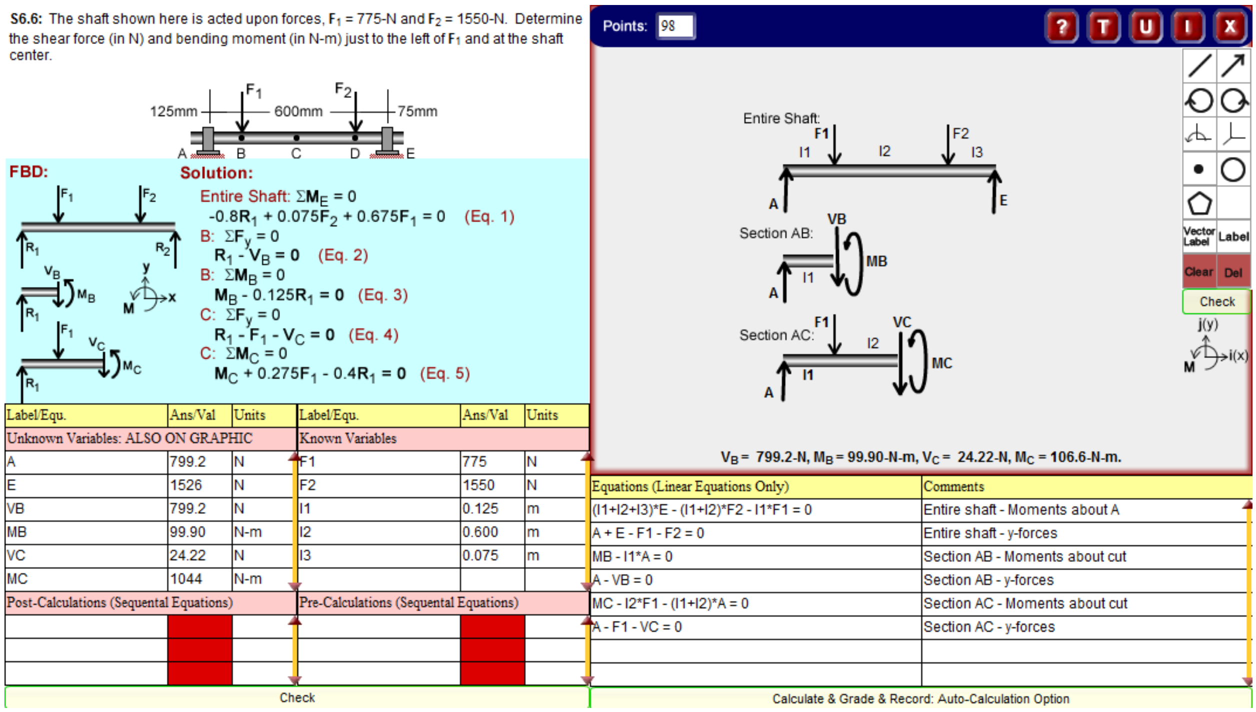

Figure 3: Final User Screen

The last section to be completed by the user prior to calculating final answers is the “Equations” section in the lower, right-hand quadrant of Figure 2. This system of equations is commonly, but not necessarily, the equations of force and moment equilibrium. This is divided into two lists: equations and comments. Comments are optional. Equation entry is intuitive and subject to very few rules.

Terms involving only constants, known variables, and pre-calculation variables are entered into these equations as appropriate. The equation solver includes the ^,*, /, +, and – operators. The equation solver also includes the following functions: sin, cos, tan, asin, acos, atan, pow (x^y), and ln (natural logarithm). These operators and functions are used to build the terms and coefficients of the pre-calculation, post-calculation, and equation system equations.

Equations entered in this section must be independent, linear equations with the number of equations matching the number of unknown variables. Any non-linear calculations (e.g., diameter of a circle given the area) must be done in the “Pre- or Post-Calculation” sections. When the “Calculate” button is clicked, several equation format checks are done, error messages displayed, and points deducted if appropriate. The system of equations is also checked at this time to insure that they are independent. The system of equation and post-calculation equations are then solved. Next, the values of the unknown variables and post-calculation variables are compared against the answers produced from a set of correct answer equations provided by the problem designer. If the problem statement includes random parameters, the problem designer must provide correct answer equations for the unknown and post-calculation variables that only include constants and the random variables. User answers are considered incorrect if they are not within +/- 1% (at the discretion of the designer) of the designer's answers. Incorrect user answers are highlighted and the user can proceed to edit any item on the screen and recalculate their answers. The user's opportunity to revise a solution based upon feedback is known to achieve deep, lasting learning (Suskie[19]).

M-MODEL Authoring Tool

The first step in creating an M-MODEL problem is drawing the problem statement, free-body, and solution graphics shown in Figure 3. The free-body graphic is normally a copy of the problem statement graphic with all but the free-body object removed or erased. Any graphics editor that produces jpg, gif, or png graphic files can be used for this purpose. Authors save these graphic files in a folder or directory of their choice. The authoring tool shown in Fig. 4 can then be used to create a new M-MODEL problem or edit an existing problem.

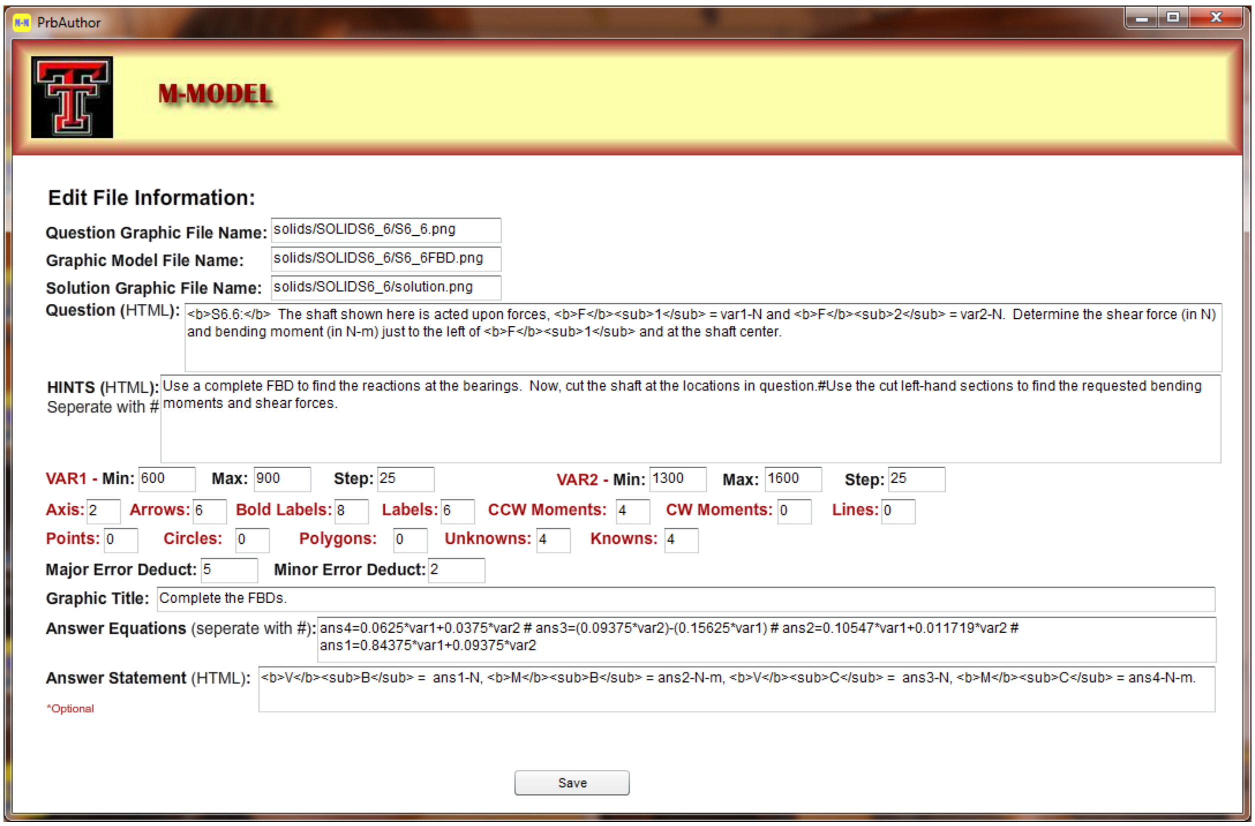

Figure 4: Problem Authors Form

The first items on this form are the names and locations of the three graphics files. The problem statement is then entered in the Question field using HTML-like markup tags for formatting. These tags are: <b> - bold font, <i> - italic font, <sub> - subscript, <sup> - superscript, <p> - paragraph break, and <g> - symbol font. Up to two random variables named var1 and var2 may be inserted anywhere in the question statement. Author hints or standard hints separated by the "#" character are entered in the Hints: field. The random variable minimum value, maximum value, and step size dictate the range and division of the random variables and are entered in the appropriate fields of Figure 4. The axis system (2- or 3-dimensional) is determined by entering 2 or 3, respectively, in the Axis field. The minimum acceptable number of the various graphical objects is then entered into each object's field. Point deductions for major and minor errors are entered into their respective fields. The title for the graphic construction panel is entered into the Graphic Title field. Correct answer equations for all the unknown and post-calculation variables, separated by #'s, are entered in the Answer Equations field. These answers are given labels, such as ans1 and ans2, using standard equation notation. These equations can only use expressions involving constants and any random variables in the question statement. The correct answers statement, including any correct answers from the "Answer Equations" field, is entered in the last field. These correct answers are denoted by their label. This form is saved as an xml file in the same directory and with the same file name as the problem statement graphic file.

M-MODEL Pedagogues

M-MODEL is a non-sequential problem solving tool that encourages students to build their own problem mental models with as few restrictions as possible. Although users must complete four of the six models (pre- and post-calculations are optional), they can be completed in any order. They can also be altered before final solution as one model provides further insight into another model. For example, users often add or remove variables as they are writing their equations or refining their graphic model. These cognitions fall under the Analyze (breaking down material or tasks into constituent elements) and Evaluate (making judgments using standards and criteria) classifications of Bloom's taxonomy (Bloom[20]). Both are at the higher-order cognitions end of Bloom's taxonomy.

M-MODEL allows users to set up and solve a problem in their own terms using solution procedures of their own creation. For example, the problem of Figures 1-3 can be correctly solved by considering **A** and **E** as pre-calculation variables or as unknown variables. In the latter case, the user must include an additional equation in the equation section and the **A** and **E** labels in the graphics panel. Users may also elect to not use **A** at all, but rather to replace it with the appropriate moment equation. Other users may elect to use some or all numerical values in lieu of variable labels and values. All of these choices are correct as long as they are consistent and will produce correct answers. Users must then "Create" (Producing alternatives or reorganizing materials in new ways) solutions which is the highest-order cognition in Bloom's taxonomy.

Although M-MODEL promotes procedural and higher-order cognitions, it is not without its penalties. First, students cannot produce correct answers without a through and detailed set of models, and often they need to refine or rebuild their models as their understanding of the problem deepens. This entails additional work on the part of the student which frequently meets with objection. Users need to solve 2-3 problems to become comfortable with the interface. This learning curve can interfere with their learning the content material and may frustrate them. Some of this extra effort is recovered by the equations solver which saves some time. The automatic solving of the equations and lack of computational practice can be problematic during examinations if numerical answers are heavily weighted although the work of VanLehn[18] suggests that this may not be an issue.

Assessment

An experiment was conducted at the US Air Force Academy during the 2010 spring semester to measure changes in student performance attributable to M-MODEL and student attitudes about M-MODEL. This experiment involved 120 students registered in 6 sections taught by 5 instructors of a solid mechanics course. This course is taken during the fourth semester of the Mechanical Engineer/Engineering Mechanics curriculum. Three of the sections (57 students) did one-third of the required homework problems using M-MODEL and the remaining two-thirds using traditional pencil-paper methods. The other three sections only used traditional homework methods. This was done up to the first common departmental examination of the semester; approximately one-third of the semester.

Individual student grades earned on the first examination and individual GPAs were analyzed for changes in student performance. First, a linear-regression analysis of the entire population examination grades as a function of student GPA was done. This regression was then used to predict each student's examination grade given their GPA. Statistical analysis was then done on the difference between the actual examination grade and their GPA predicted grade (DELTA score). When the DELTA score is positive, the student exceeds what one would expect based on their GPA. Averages and standard deviations were then calculated for the treated and untreated students. On a 125 point scale, the treated student DELTA statistics were N = 57, mean = 2.02 and SD =11.01 and for the untreated students they were N = 73, mean = -1.38 and SD = 13.54. Treated students scored on the average about 2 points more than one might expect and the untreated students underperformed by 1.38 points. The treated group then scored 3.4 points (2.7%) better than the untreated students on the average. At the host institution, this equates to about one-third of a letter grade.

Verbal comments were also collected from the students. These can be categorized in five groups:

- It takes time to learn the interface
  - M-Model version 9 addressed these comments by making the interface more intuitive
- It takes more time to solve homework problems this way
  - Embedded elapsed time data were measured. A typical problem required 10-12 minutes to complete with a grade ranging from 86% to 95%.
- I got lost
  - Hints and tips have been added to address this issue
- M-Model requires too much detail
  - The author can only presume that students have been missing some of the important details required to understand a problem
- I learned more because of feedback and opportunity to immediately correct my mistakes
  - Suggests a better understanding of model building in Engineering Mechanics

Mastering the interface of early versions of M-MODEL was the biggest problem that students reported. Some students elected to go through the optional practice problem for training and some didn't. Most students had no problems with the interface after completing 2-3 problems.

This is not atypical of new software interfaces. Current version 9 has addressed the majority of the issues raised by the students.

Conclusions

M-MODEL is a flexible, computer-based problem solving tool based on the problem statement, graphical, given/find, pre-calculations, post-calculations and equations mental representations of a problem. It is consistent with the model building pedagogue of current mechanics education. Individual problem creators can program their own problems with minimal effort using the M-MODEL authoring tool.

Its design encourages higher-order cognitions required to bridge from linear, simple problems to more ill-defined problems on the engineering intellectual development spectrum. The flexibility of its problem solving procedure challenges students to think more deeply about problems and helps them develop the confidence they need to apply their own approach to a problem. This tool also removes the burden of computational procedures so that learners can focus upon model building which is so critical to solving mechanics problems.

A student assessment of M-Model has been conducted. This experiment demonstrated a gain in student performance on course examinations that is consistent with that measured by VanLehn[18]. Several interface issues were raised by student users. These issues have been addressed in the current version 9 of M-MODEL. Interested readers may visit a demonstration version of M-MODEL at http://aln.coe.ttu.edu/anderson/premier/default.swf.

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Alignment, Stepping, Control and Measurements of Micro/Nanoscale Junctions with Automated Micropositioners

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Abstract

With the evolution of technology, the automation of repetitive processes has helped free up human capabilities to do activities of greater value. Similar was the goal in automating micropositioners used in probe stations to test micro and nanoscale junctions. Manually positioning the probe arm from terminal to terminal on the device under test was both tedious and time consuming. In order to eliminate this extraneous work, the 3-axis movement of the micropositioner was achieved through servo motors which allowed a digital override to the manually controlled analog system. All the continuous rotation servo motors were connected to a microcontroller which communicated to personal computer (PC) workstation. The PC was used to record the measurements from the device under test through universal asynchronous receiver/transmitter protocol. The driver software allowed the servo motors to position the probe arm at the required position for each test terminal without consuming precious time and wasting needless effort. This system can also be evolved to do remote monitoring of the devices as well.

Introduction

Many micro and nanoscale devices need to be probed one device at a time. The probing often requires making two or three terminal contacts to the device under test (DUT). The

characteristics of DUT are then measured before probe tips are manually moved to the next DUT. The probe is moved manually to make connections and to measure properties of DUT. This requires a lot of human time as the user has to peer through the microscope while trying to fiddle with the dials and knobs on micropositioner to move the probe arm so the it can be placed at the desired location. The automation of micropositioners of the probe arm has allowed a great increase in the efficiency of the test procedures.

Figure 1. Singatone H150 probe station modified with automated probes.

Setup

A typical probe station houses a stage with a microscope that allows magnified viewing of the DUT. For this setup, a Singatone H150 Probe Station was used, as shown in Fig. 1.[1] The micropositioner was placed on the steel plate around the stage. It was used to position the probe to make connections and to measure properties of DUT. A Singatone S-725 micropositioner was automated in this setup. An unmodified micropositioner is shown in Fig. 2.[2]

There were three basic controls on the micropositioner to control the position of the probe in three dimensions as highlighted with arrowed lines in Figure 2. The first control, *X*, was for the lateral position of the probe tips. This was a linear control which moved the tip directly proportional to the amount of turns of the knob attached to it. The other two controls for the position, *Y* and *Z*, were not linear. These moved the probe tip in a circular manner following an arc path. The arc radii for the movements were related to the lateral position of the probe arm's tip.

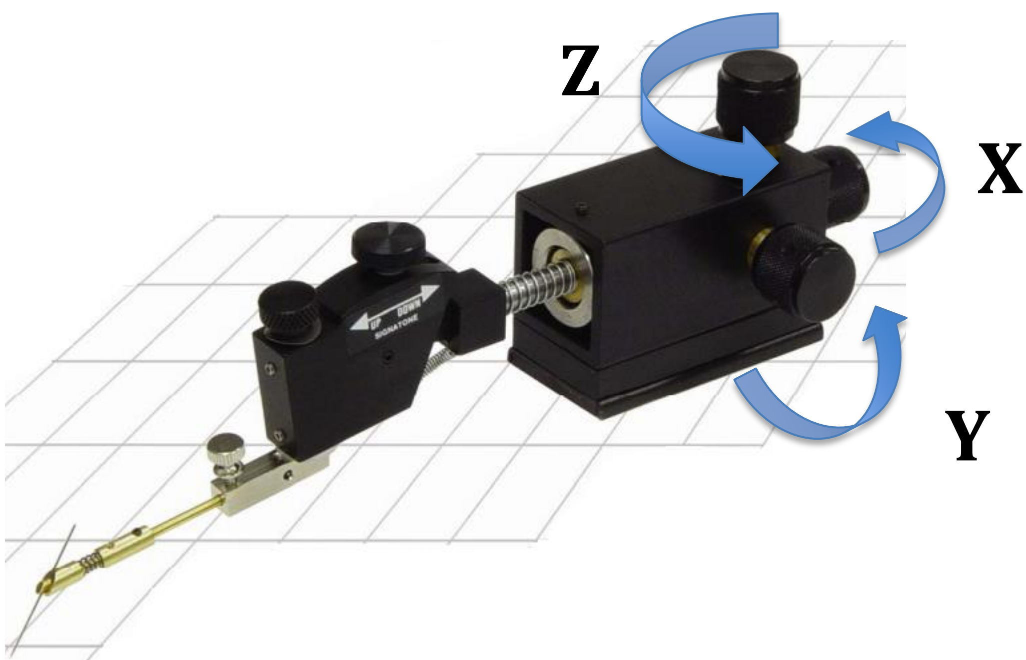

Figure 2. Unmodified Singatone S-725 micropositioner

For complete automation, each of the three control knobs was directly connected to a continuous rotating servo motor. Hitec robotics continuous rotation servos, HSR-1425CR, were used that allowed easy control of the rate of turn through pulse-width modulation (PWM).[3] All the servo motors were connected to a microcontroller which was programmed to communicate via universal asynchronous receiver/transmitter (UART) protocol. The microcontroller was connected via USB to a PC workstation which had the driver software installed to control the probe arm via the servo motors and microcontroller.

Microcontroller

The microcontroller used was an 8-bit ATmega640 microcontroller onboard an Axon II board (Figure 3).[4, 5] This processor allowed multiple PWM ports and UART through USB. It also had a series of analog inputs which could be used for tracking the position of the probe arm. There were twelve events that the microcontroller performed: four events for each servo. One commanded the motor to turn clockwise at a high speed while the other commanded a clockwise turn at low speed. The other two events turned the motor counter-clockwise. The speed allowed for fine and coarse tuning to optimize the time it took for the probe to position itself correctly.

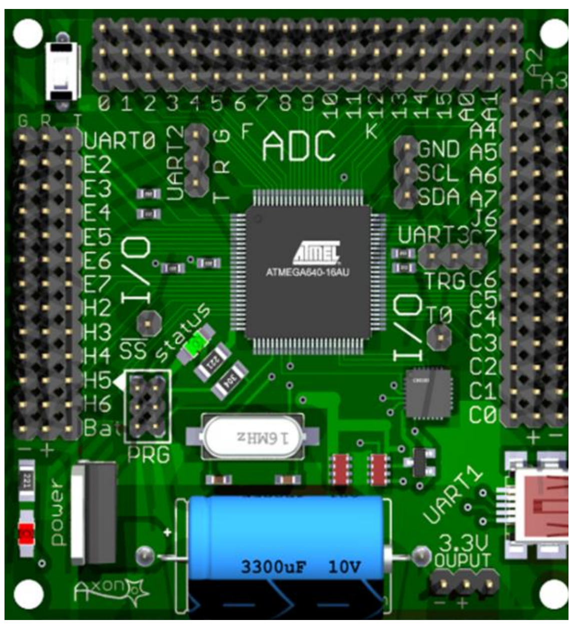

Figure 3. Axon II Board with ATmega640 microcontroller

The microcontroller waited for inputs in a series of nine characters. The first character specified the commanded position as a relative or an absolute position. The characters 2-5 and

6-9 specified the desired location's coordinates in terms of *X* and *Y* position respectively. The characters 2 and 6 were direction indicators of positive or negative movement. The microcontroller divided the string of 9 characters to decipher what it needed to do. It ran an automated sequence from the twelve events to move the probe arm's tip to the desired location. First, the controller computed the amount of motion required. If the command was for relative position, then there was no computation required. However, if it was an absolute position, then the microcontroller used its tally of the current position of probe arm's tip to calculate the relative motion required to obtain the absolute position commanded. The motion sequences were then initiated. All the sequences started with lifting the probe arm in the *Z*-direction to avoid dragging the probe tip on the DUT. Depending on the amount of motion required, the microcontroller sent pulses of varying widths to rotate the servo motors at either a low or a high speed. This positioned the probe in the *X* and then the *Y*-direction. Finally, the probe tip was lowered in the *Z*-direction to make contact with the DUT and the microcontroller updated its tally of the current position of the tip.

Driver Software

The microcontroller was connected to a PC workstation. A driver software was written to operate the microcontroller to control micropositioner. A screenshot of the main screen graphical user interface (GUI) of the software is shown in Figure 4. The software allowed automated as well as manual positioning. The manual positioning part used either buttons of the screen or the number pad of the keyboard to move the probe arm in the desired location at either a fast or slow speed depending on coarse or fine tuning.

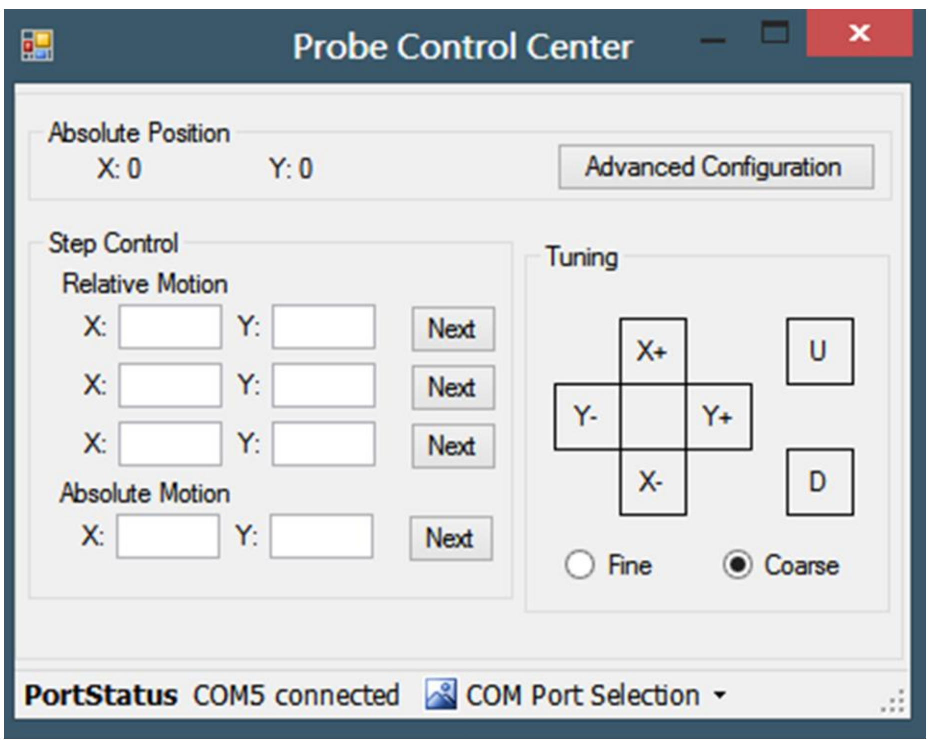

Figure 4. GUI for the micropositioner driver software.

The automatic positioning allowed an input for either a relative or an absolute X and Y coordinate for the probe to move to. Three relative motions could be stored, and with advanced configurations, a pattern could be assigned on how to execute these relative motions. A typical break-junction chip like the one in Figure 5 could have a "10-2-4" pattern configured. The first relative motion specifies the distance between two consecutive junctions. The second and third number specified the distance between each array set. In a "10-2-4" pattern, the 10 would then specify the number of junctions in each array while the 2 and 4 depict the number of rows and columns of the arrays. With this pattern specified along with the time to be spent at each DUT, the driver software generates all the locations the probe tip needs to move to and commands the microcontroller to move the servo motors to do so. The tip moves to all the locations and pause at each DUT long enough to record the readings.

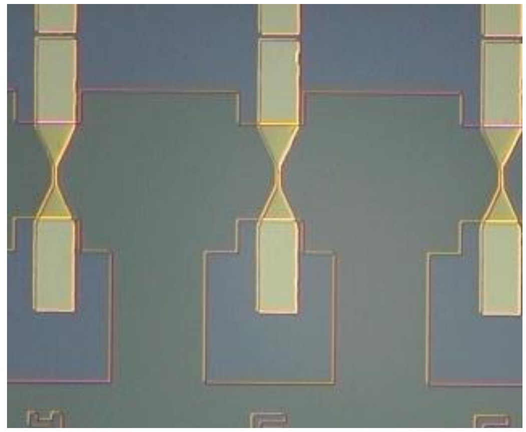

Figure 5 Break-junction chip with gold metal pads. The probe arm has to move from pad to pad for measurements.

Conclusions and Recommendations

The probe arm automation has been implemented successfully. It has been designed to be modular and allows expansion. The software and microcontroller board can control up to 3 different micropositioners and have the capability to take in analog inputs. The current version does not have any feedback. The microcontroller and the software have to track the actual location of the probe tip. In future versions, potentiometers can be used to gain analog input to measure and communicate the tip position in real-time. Also the driver software can be incorporated in LabVIEW to allow complete automation of measuring and logging of the DUT.

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Preparing for an ABET Accreditation Visit

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Abstract

Engineering faculty must prepare for an ABET accreditation visit every six years. Since the ABET process involves demonstration of continuous assessment and improvement, one must have a plan that begins the process several years before the visit. Many faculty struggle to determine the best way to prepare for ABET. This is due, in part, to both the complexity of accreditation requirements and the lack of clear guidelines. This paper proposes a unique way to plan for the ABET accreditation visit by looking at it from the viewpoint of the ABET Program Evaluator (PEV). This viewpoint starts with the on-site visit, and reviews the various activities and reports that the PEV must complete by the end of the site visit. This, in turn, can help reveal the desired results needed to achieve successful accreditation. ABET currently has nine criteria that one must address. However, recent experiences suggest that the majority of the ABET shortcomings cited during visits are associated with criterion 2 (Program Educational Objectives), criterion 3 (Student Outcomes), and criteria 4 (Continuous Improvement). This paper is an update from a previous presentation by the author. It touches on all nine criteria briefly, but then focuses on the three most troubling criteria 2, 3, and 4. By looking at the ABET process from PEV's viewpoint, faculty can first see the desirable results they need to achieve during the site visit, and then start planning backwards to be prepared for a successful ABET accreditation result.

The ABET Site Visit

The ABET site visit usually last 2-1/2 days and the schedule is very standardized as depicted in Figure 1. The ABET team consists of the team chair (who is an ABET commissioner) and one program evaluator (PEV) for each program at the school seeking accreditation. Sometimes there is a team co-chair, and also sometimes there are guest PEVs who are on a training visit. The team members are expected to arrive on the Saturday before the visit, or at least in time for the Sunday brunch and initial team meeting at 11:00 am. Before the visit, it is expected that the PEV has read the program self-study, completed a pre-visit evaluation, and audited student transcripts.

On the Sunday afternoon, the ABET team proceeds to the campus and initiates visits with the various program facilities starting around 1:30 pm and lasting until about 5:00 pm. This is the time set aside for meeting program administrators, visiting laboratory facilities, and reviewing the program outcome and course notebooks. Any clarification of the materials will be initiated during this first visit to the program. The ABET team then reassembles for a Sunday evening dinner and discussions about report preparation.

Saturday	Sunday	Monday	Tuesday
PEV Reads the Self-Study and Audits Transcripts in Advance of Travel.		**7:00 – 8:30 AM** ABET Team Breakfast and Meeting. Travel to Site Visit.	**7:00 – 8:30 AM** ABET Team Breakfast and Meeting. Travel to Site Visit.
		8:30 – 9:00 AM Dean's Presentation.	**8:30-11:00 AM** PEV Prepares Final Report and Seeks Clarifications as Needed.
		9:00-11:30 AM Visit to Program. Meet with Faculty, Staff, and Administration as Needed.	**11:00 - 11:30 PM** PEV Reports Out to Program Chair.
ABET Team Members Travel and Arrival Day.	**11:00 AM – 1:30 PM** ABET Team Brunch and Preliminary Meeting. Travel to Site Visit.	**11:30 AM – 1:30 PM** Luncheon with Faculty, Alumni, and Students.	**11:30 – 1:30 PM** ABET Team Working Lunch (Closed Session).
↓	**1:30 – 5:00 PM** Visit Program Facilities. Meet Faculty Leadership. Tour Labs and Review Course/Outcome Notebooks.	**1:30 -5:00 PM** Visit to Program. Meet with Faculty and Students as Needed. Review Course/Outcome Notebooks as Needed.	**1:30 – 2:30 PM** ABET Team Meets with University President and Delivers Program Audit Forms.
Team Evening Dinner Sometimes Planned for Those Members Available.	**5:00 – 8:00 PM** ABET Team Meeting and Dinner. Work on Report.	**5:00 – 8:00 PM** ABET Team Meeting and Dinner. Work on Report.	Team Leaves the Site.

Figure 1: Typical Schedule for ABET Site Visit.

The Monday visit starts with a presentation by the engineering dean, who overviews data about the college. The PEVs then travel back to the program facilities to interview faculty and staff. The noontime luncheon on Monday includes alumni and student invitees, as well as program administrators. This is an important luncheon since it gives the PEV one-on-one opportunities to discuss the program with alumni and students. The PEV then returns to the program and continues interviews with faculty and student groups, often senior capstone design teams. The ABET team then re-assembles for Monday evening dinner, discussions, and report writing.

By Tuesday morning, most PEVs have a good draft of their final report, which is called the program audit form (PAF). On Tuesday morning, the PEV has a brief meeting with the program chair to discuss the findings of the visit. If any shortcomings will be cited, the PEV usually wants the program chair to know about it here, rather than to hear it for the first time in front of the university president later that day. The Tuesday lunch is a closed working lunch for the ABET team, in which the final PAFs are printed to give to the university president. The last official meeting of the ABET site visit is the Tuesday afternoon meeting with the university president. Also present are the engineering dean, associate deans, all program chairs, and the full ABET team. Each PEV takes time to read aloud the PAF report for their program. This is when the PEV will cite any shortcomings about the program. After all PAFs are read aloud, the ABET team thanks the host institution and leaves the meeting with no further discussion.

The ABET Evaluation Forms

The key to understanding a successful ABET site visit is to understand what the PEV must report in the evaluation forms. The main goal of the PEV is to determine if all nine ABET criteria have been met to some level of satisfaction, and to report any misgivings on the ABET PEV forms.

Program Evaluator Worksheet

The program evaluator worksheet is used to check-off whether there are any concerns (C), weaknesses (W), or deficiencies (D) in the program, based on the expectations of each of the nine ABET criteria. These shortcomings (C, W, D) are defined by ABET as shown in Figure 2. The goal of the program faculty is to receive no weaknesses (W) or deficiencies (D) on the final PAF, which historically results in a Next General Review (NGR) grade, which means re-accreditation for another six years. In the past, a concern (C) did not require a response, but recently ABET has also expected some response to concerns as well. It is not clear yet if no response to a concern will prevent receiving an NGR.

Concern: A concern indicates that a program currently satisfies a criterion, policy, or procedure; however, the potential exists for the situation to change such that the criterion, policy, or procedure may not be satisfied.

Weakness: A weakness indicates that a program lacks the strength of compliance with a criterion, policy, or procedure to ensure that the quality of the program will not be compromised. Therefore, remedial action is required to strengthen compliance with the criterion, policy, or procedure prior to the next evaluation.

Deficiency: A deficiency indicates that a criterion, policy, or procedure is not satisfied. Therefore, the program is not in compliance with the criterion, policy, or procedure.

Figure 2: ABET Definitions of the Three Shortcomings.

As part of the visit timeframe, the PEV can check off any shortcomings at several different stages of the review process: pre-visit, day 0, day 1, and exit. The goal is to not receive any shortcomings at the exit statement. However, it is likely that some shortcomings will be cited before then. The PEV is instructed to read the program self-study before the site visit, and any shortcomings thought to exist in the self-study will be checked in the pre-visit column. Then on each day of the site visit, the PEV has the opportunity to change the rating and to supply comments that will later be incorporated into the formal PAF report.

Program Audit Form

The program audit form is the official report that the PEV leaves with the institution before leaving the site visit on Tuesday. The PAF has two parts. The first part is the edit history page that shows the level of shortcomings as the program review transits through the various stages of the ABET accreditation process: exit interview, 7-day response, editor 1, editor 2, due process, and final decision. This first part shows the various opportunities available for the program to respond to W and D shortcomings which may ultimately earn an NGR. It also shows that ABET views fairness as a serious matter.

The second part of the PAF is where the PEV provides detailed information on the reasons for giving a C, W, or D ranking for the various criteria. If a program receives a shortcoming during the ABET review, this is the page that the program chair and faculty will have to address.

The ABET Criteria

ABET annually publishes a document called "Criteria for Accrediting Engineering Programs," which can be downloaded from the ABET website: http://www.abet.org/ [1]. This document lists the wordings for all nine criteria, and also includes a few definitions where appropriate. Meeting the nine criteria is what is expected for NGR accreditation. However, interpretation of the criteria is somewhat open to the reader. So, one way to view what is expected, is to look at the PEV checklist (Appendix A) for each criterion, one-by-one.

Criterion 1: Students

The first ABET criterion 1 focuses on students. As shown in Table 1, the PEV will be looking for evidence about faculty evaluation of student performance, advising, transfer credits, and checks for students fulfilling all graduation requirements. Some points of emphasis are: 1. What are the admission standards? 2. What is the faculty advising protocol in the program for both academic and career matters? and 3. Do all students meet the same graduation standard that is enforced for both regular and transfer students? One could also link the transcript evaluation requirement with this criterion 1. Also, the PEV will want to talk to some undergraduate students during the site visit, and some of these questions in Table 1 might be addressed during these on-site interviews.

Table 1: PEV Checklist for Criterion 1

1. STUDENTS	**Check C, W, D or None**
Evaluate student performance	
Monitor student progress	
Advise students regarding curricular and career matters	
Policies for acceptance of new and transfer students in place and enforced	
Policies for awarding transfer credits and work in lieu of courses taken at the institution	
Have and enforce procedure to ensure and document that students who graduate meet all graduation requirements	

Criterion 2: Program Educational Objectives

The second ABET criterion 2 focuses on the Program Educational Objectives (PEOs). ABET defines PEOs as broad statements that describe what graduates are expected to attain within a few years of graduation.[2] As shown in Table 2, the PEV will be focusing on whether the PEO's are published, for example in the university catalog. They also should be consistent with university, college and department mission statements. Hence it is imperative to review mission statements as part of criterion 2 and to include them in the self-study. The PEV will also be looking for evidence that the PEOs have periodic review that involves both faculty and constituents. So some alumni input is needed for criterion 2.

Table 2: PEV Checklist for Criterion 2

2. PROGRAM EDUCATIONAL OBJECTIVES	**Check C, W, D or None**
Published and consistent with mission, the needs of the constituencies, and these criteria	
Documented and effective process, involving program constituencies, for the periodic review and revision of PEO's	

Criterion 3: Student Outcomes

The third ABET criterion 3 focuses on Student Outcomes (SOs). ABET defines SOs as narrower statements that describe what students are expected to know and be able to do by the time of graduation.[2] These relate to the skills, knowledge, and behaviors that students acquire in their matriculation through the program. Table 3 shows the PEV checklist for criterion 3. As can be seen, the main objective is for the PEV to determine if the students have achieved the eleven ABET outcomes, namely a-k. How this is demonstrated is up to the program. But, some factual assessment data and samples of student work demonstrating achievement of these outcomes will be needed. Programs are free to define their own SOs, but they must be mapped to the ABET a-k. In addition, there should be a clear relationship shown between the program SOs and the program PEOs. The PEV will be paying close attention to the assessment and evaluation procedures used to document that the SOs are being achieved. This is probably the most critical aspect of the entire ABET review process.

Table 3: PEV Checklist for Criterion 3

3. STUDENT OUTCOMES	**Check C, W, D or None**
Program has documented student outcomes that prepare graduates to attain the program educational objectives	
(a) ability to apply knowledge of math, engineering, and science	
(b) ability to design and conduct experiments, as well as to analyze and interpret data	
(c) ability to design system, component or process to meet needs within realistic constraints	
(d) ability to function on multi-disciplinary teams	
(e) ability to identify, formulate, and solve engineering problems	
(f) understanding of professional and ethical responsibility	
(g) ability to communicate effectively	
(h) broad education	
(i) recognition of need by an ability to engage in life-long learning	
(j) knowledge of contemporary issues	
(k) ability to use techniques, skills, and tools in engineering practice	
Additional outcomes articulated by the program	

Criterion 4: Continuous Improvement

The fourth ABET criterion 4 pertains to continuous improvement.[3,4] As shown in Table 4, programs are expected to gather assessment data pertaining to the PEOs and SOs, to evaluate that data, and then to make changes in the program based on that evaluation. Thus, the PEV will want to know what improvements have been made to the curriculum and supporting resources, based on this ABET model. Feedback from students, alumni, and faculty will be useful in satisfying criterion 4. Highlighting new courses, laboratories, and other facilities will help demonstrate that criterion 4 is being met.

Criterion 5: Curriculum

ABET criterion 5 is devoted to the program curriculum. The PEV needs to determine whether there is one year of mathematics and science in the curriculum. This usually means about 30-32 credit hours devoted to math and science courses that are typically taught outside of engineering. The PEV also needs to determine if there is one and one-half years of engineering topics (45-48 credit hours) in the curriculum. This later requirement is usually taught inside the program by engineering faculty. In some cases, a program can argue for some math and science content inside of the engineering domain, but only a few of the required credits will be accepted.

In addition, the PEV must assess the capstone design course(s) in the program and how well they incorporate student experiences in earlier courses. And of course, the entire required curriculum should be adequately mapped to the program SOs in some manner.

Criterion 6: Faculty

The sixth ABET criterion 6 deals with the program faculty. The PEV needs to determine if there is sufficient number of faculty and if the faculty members possess the competencies needed to cover all curricular areas in the program. The PEV needs to assess faculty interaction with students in the areas of advising and career counseling. The faculty accomplishments need to be presented in the self-study. The faculty development plan must be outlined in the self-study, including conference attendance and other faculty enrichment opportunities. The level of faculty interaction with industrial practitioners and employers should be included. If the program is large, the organization of faculty into smaller domain groups and the authority structure in the program must be clearly outlined in the self-study.

Table 4: PEV Checklist for Criterion 4

4. CONTINUOUS IMPROVEMENT	**Check C, W, D or None**
Regular use of appropriate, documented processes for assessing and evaluating the extent to which the program educational objectives are being attained	
Regular use of appropriate, documented processes for assessing and evaluating the extent to which the student outcomes are being attained	
Results of evaluations systematically utilized as input for the continuous improvement of the program	
Other information, if available, used to assist in improvement	

Table 5: PEV Checklist for Criterion 5

5. CURRICULUM	**Check C, W, D or None**
Devotes adequate attention and time to each component, consistent with the outcomes/objectives of the program/institution	
One year of college-level mathematics and basic (biological, chemical, and physical) sciences	
One and one-half years of engineering topics (See criterion statement)	
General education component consistent with program and institutional objectives	
Culminates in a major design experience based on knowledge and skills acquired in earlier course work and incorporates appropriate engineering standards and realistic constraints	

Table 6: PEV Checklist for Criterion 6

6. FACULTY	**Check C, W, D or None**
Sufficient number and competencies to cover all curricular areas	
Adequate levels of student-faculty interaction	
Adequate levels of student advising and counseling	
Adequate levels of university service activities	
Adequate levels of professional development	
Adequate levels of interaction with practitioners and employers	
Appropriate qualifications	
Sufficient authority for program guidance, evaluation, assessment, and improvement	
Overall competence	

Criterion 7: Facilities

ABET criterion 7 pertains to the program facilities. The PEV will want to tour the classrooms, laboratories, offices, and computing facilities. The PEV may want to review the program information technology (IT) support. The PEV may also want to view a few laboratory equipment set-ups, and will also be looking at the safety regulations that are in place within the program facilities. As many U.S. engineering programs are aging, safety in the laboratory has become a important focus on the ABET visits.

Criterion 8: Support

ABET criterion 8 relates to the program financial resources for faculty, staff, and facilities. Are there sufficient resources to support the teaching laboratories and to replace aging lab equipment? What level of support does the program receive from the college and the home institution?

Criterion 9: Program Criteria

In addition to the ABET criteria 1 to 8, there is a criterion 9 that pertains to the professional society criteria that represents the program's discipline. For example, a mechanical engineering program would correspond to the ASME criteria. These society criteria are included in the ABET document "Criteria for Accrediting Engineering Programs." There are approximately 28 member engineering societies that offer program criteria.

Table 9: PEV Checklist for Criterion 9

9. PROGRAM CRITERIA	**Check C, W, D or None**
Curricular topics	
Faculty qualifications	

Table 7: PEV Checklist for Criterion 7

7. FACILITIES	**Check C, W, D or None**
Adequate to support attainment of student outcomes and provide an atmosphere conducive to learning:	
Classrooms	
Offices	
Laboratories	
Associated equipment	
Modern tools, equipment , computing resources and laboratories are available, accessible, and systematically maintained and upgraded	
Students provided appropriate guidance regarding the use of the tools, equipment, computing resources, and laboratories	
Adequate library services, computing infrastructure, and information infrastructure	

Table 8: PEV Checklist for Criterion 8

8. SUPPORT	**Check C, W, D or None**
Institutional support and leadership sufficient to assure quality and continuity of the program	
Institutional services, financial support, and staff adequate to meet program needs	
Sufficient to attract and retain a well-qualified faculty and provide for their professional development	
Sufficient to acquire, maintain, and operate infrastructure, facilities, and equipment	
Sufficient to provide an environment to attain student outcomes	

A Closer Look at ABET Criteria 2, 3, and 4

While program faculty should pay attention to all nine criteria, recent observations suggest that criteria 2, 3, and 4 are receiving the closest attention by PEVs and the bulk of the shortcomings cited at the end of the site visit. Thus a closer look at these three criteria is warranted.

A Closer Look at Criterion 2: PEOs

Criterion 2 deals with the Program Educational Objectives (PEOs). Lack of attainment of criterion 2 could be attributed to a number of failures. Among the most frequent are:

a. Incorrect wording of the PEO statements,
b. Lack of alumni involvement in defining PEOs,
c. Lack of measureable data that PEOs are being achieved,
d. No mappings of PEOs to Mission Statement and SOs,
e. Insufficient posting/publishing of PEOs.

Incorrect Wording of the PEO Statements

Since PEOs represent the expected professional accomplishments of recent graduates, they should be written with active verbs that illustrate general achievements that can be proven. Table 10 shows some examples of poor and good ways to make PEO statements. Most notably, programs sometime write PEOs that sound more like SOs.

Table 10: Writing Program Educational Objective (PEO) Statements

Poor	**Good**
Graduates are prepared to work in the engineering fields of manufacturing and design	Graduates practice engineering in the fields of manufacturing and design in industry
Graduates have the educational background to go to graduate school and do research	Graduates pursue advanced education, research, and development in science and engineering.
Graduates have leadership and teamwork skills	Graduates participate as leaders on team projects
Graduates are aware of ethics and professional responsibility in the workplace	Graduates conduct themselves in a professional and ethical manner in the workplace

Lack of Alumni Involvement in Defining PEOs

Since the PEOs pertain to achievements by recent graduates, the program alumni should be involved in writing and reviewing them from time-to-time. Most programs have an external advisory committee (EAC) that has some members who are program alumni. Hence using the EAC to define and review the PEOs is a logical exercise, one that should be documented in the self-study, and is expected by the PEV.

Lack of Measureable Data That the PEOs are Being Achieved

Because of the generality of PEOs, and because they apply to alumni already several years removed from the program, there are less opportunities available to prove their attainment than the SOs. However, there are three possible venues for assessing PEO achievement:

a. One could directly survey the EAC on occasion, and ask them to rate the achievement of each PEO using a direct ranking form.
b. One can also send out alumni surveys every year, and compile the survey results as they pertain to each PEO.
c. Employer data and surveys can sometimes be massaged into meaningful data that support achievement of the PEOs by program graduates.

No Mappings of PEOs to Mission Statement and SOs

The PEV will expect to see two types of mappings. First, the PEOs should be mapped to the institutional mission statement, such as shown in Table 11. Secondly, the PEV will expect the PEOs to be mapped to the SOs (see later table 12).

Table 11: Mapping PEOs to Institution Mission

Institution Core Values	PEO 1 (Practice Engineering)	PEO 2 (Advanced Education and Research)	PEO 3 (Leadership, Communication, and Teamwork)	PEO 4 (Professional and Ethical)
1. Learning	√	√		
2. Discovery	√	√		
3. Freedom			√	
4. Leadership			√	
5. Individual Opportunity				√
6. Responsibility				√

Insufficient Posting/Publishing of PEOs

The PEOs represent a public document and commitment to the larger community. Hence, they should be published and posted in several places:

a. In the university catalog within the description of the program (mandatory),
b. On the program's website using a clearly visible link,
c. Posted on conspicuous bulletin boards within the program's building and facilities,
d. In alumni newsletters and other correspondence.

A Closer Look at Criterion 3: SOs

Criterion 3 deals with the Student Outcomes (SOs). Lack of attainment of criterion 3 could be attributed to a number of failures. Among the most frequent are:

a. Improper wording of the SO statements,
b. Insufficient data that all SOs are being achieved,
c. No mappings of SOs to PEOs,
d. Insufficient posting/publishing of SOs.

Improper Wording of the SO Statements

Unlike the definition of PEOs, which are left to the program to define, ABET has clearly articulated the expected SO statements. Namely, ABET has defined eleven program outcomes using the well-known a-k standard, as shown earlier in Table 3. In the past, programs were encouraged to define their own SOs, based on the needs of their constituencies. This led to some extreme examples of SOs that many PEVs felt were incorrect. Thus, the program can either simply use the ABET a-k as their SOs; or define their own SOs. If the program uses its own SOs, then it must show a correct and complete mapping of their own SOs with a-k.

Insufficient Data That All SOs Are Being Achieved

The outcomes expected in ABET a-k range from hard technical skills to soft professional skills. For most programs, the hard skills like problem solving and laboratory skills are easy to assess quantitatively. However, the soft skills like teamwork, ethics, communication, and life-long learning are harder to quantify.[5] Faculty will need to devise more subtle methods to evaluate these professional outcomes. Some possible recommendations would include:

a. Assessing "teamwork" includes both the product of teamwork, such as senior design reports, as well the interaction that occurs amongst team members. One idea is to video tape teams in action, such as working on projects, and then to assess the video for the interpersonal and leadership skills demonstrated by the students. Both the video and assessment results are then available for the PEV during the on-site visit.
b. Assessing "ethics" could include faculty reviewing a student ethics assignment in the technical communication course. One could also develop a student honor code and promote the honor code in the program, perhaps through a seminar or posting it on conspicuous bulletin boards in the building. There is also an ethics unit in the FE exam.
c. Assessing "communication" includes written, oral, and graphical communication skills. Written communication skills can be assessed by faculty reviewing documents such as senior project reports or papers from the technical communication course. Graphical communication skills can be assessed by faculty reviewing materials from the graphics or drawing course in the program, as well as illustrations in the reports and papers. For oral communication, one idea is to video tape the senior project oral presentations, and then to assess the video for the oral skills demonstrated by the students. Both the video and assessment results are then available for the PEV during the on-site visit.
d. For the "life-long learning" outcome, one can use examples of undergraduate research projects and examples of library literature searches found in project reports. Some programs also put forth the number of students who apply to graduate school.

No Mappings of SOs to PEOs,

No matter how the PEOs and SOs are defined by the program, the PEV will expect to see a mapping of the PEOs to the SOs in the self-study. One example of such a mapping is shown in Table 12.

Insufficient Posting/Publishing of SOs

The SOs represent a commitment to the learning experiences of the students in the program, and thus should be clearly conveyed to all constituents by adequate posting and publishing the SOs, such as:

a. In the university catalog within the description of the program (mandatory),
b. On the program's website using a clearly visible link,
c. Posted on conspicuous bulletin boards within the program's building and facilities,

Some programs may also include presentations of the SOs in introductory courses or at special events, such as undergraduate seminars, job fairs, and student organization events.

Table 12: Mapping of Student Outcomes to Program Objectives				
Student Outcomes	**PEO 1:** Practice Engineering	**PEO 2:** Advanced Education and Research	**PEO 3:** Leadership, Communication, and Teamwork	**PEO 4:** Professional and Ethical
(a) an ability to apply knowledge of mathematics, science, and engineering	√			
(b) an ability to design and conduct experiments, as well as to analyze and interpret data	√	√		
(c) an ability to design a system, component, or process to meet desired needs	√			
(d) an ability to function on multi-disciplinary teams	√		√	
(e) an ability to identify, formulate, and solve engineering problems	√	√		
(f) an understanding of professional and ethical responsibility			√	√
(g) an ability to communicate effectively	√	√	√	
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context			√	√
(i) a recognition of the need for, and an ability to engage in life-long learning		√		
(j) a knowledge of contemporary issues			√	√
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	√	√		

A Closer Look at Criterion 4: Continuous Improvement

Probably the most critical phase of the ABET review is demonstrating a continuous process is in place to gather and assess information that shows the SOs are being achieved by the students in the program.[6] At the heart of this process are the measures chosen to prove this achievement. Recent discussion has centered around direct versus indirect measures. Table 13 shows some examples of measures that can be used for ABET assessment, classified as either direct or indirect.[7] Experience suggests that the program should not rely on one sole method to assess the SOs, but instead should select several measures that are combinations of both direct and indirect. One example combination could be:

a. Senior exit outcomes surveys that ask specific attainment levels of a-k (indirect),
b. Evaluation of student course work by faculty committee (direct),
c. Oral exit interviews of seniors by program chair (indirect),
d. Compiled results of FE exam (direct).

Table 13: Examples of Direct and Indirect Measures for ABET Assessment.[7]		
Method	**Direct**	**Indirect**
Oral Exit Interviews of Graduating Seniors		√
Embedded Test Questions Pertaining to Specific Outcomes	√	
Evaluation of Student Portfolios Pertaining to Outcomes	√	
Senior Exit Outcomes Surveys		√
Student Outcomes Focus Groups		√
Classroom Observations of Student Performance by Faculty	√	
Evaluation of Student Course Work by Faculty Committee	√	
Compiled Results from FE Exam	√	
Employer Surveys of Student Performance During Co-op or Internship Cycles		√
Starting Salary, FE Exam Rates, Graduate School Attendance, and Other Senior Exit Data		√
External Advisory Committee (EAC) Student Outcomes Surveys		√

One thing that must be clear in the Self-Study is that the results of all these measures are systematically utilized as input for the continuous improvement of the program. If the PEV sees the data is obtained, but is not being used to improve the program, then there is a shortcoming in Criterion 4.

The ABET Self Study

The ABET self-study is a detailed document that articulates the programs response to fulfilling the ABET criteria. It actually starts with a template document supplied by ABET, in which the program responds by answering a series of questions or requests for certain types of information. It is the document that will be sent to the PEV in advance of the site visit and it will set the tone for the PEV's first impression of the program. Thus, it is important that the program starts writing the self-study early, perhaps one year before the actual visit, since it is due to ABET headquarters in June before the Fall site visit. Table 14 shows the recommended table of contents for the self-study. As can be seen, the ABET self-study chapters are divided into the nine criteria. It is the role of the program to show that all nine criteria have been attained. Inside the chapters are also some important tables, for example, demonstrating that the program curriculum content meets ABET requirements and that show faculty background information. There are also some appendices that show course syllabi, faculty resumes, and list laboratory equipment. Then there is the institutional summary appendix.

Table 14: Table of Contents for the ABET Self-Study
Background Information
Criterion 1. Students
Criterion 2. Program Educational Objectives
Criterion 3. Student Outcomes
Criterion 4. Continuous Improvement
Criterion 5. Curriculum
Criterion 6. Faculty
Criterion 7. Facilities
Criterion 8. Support
Criterion 9. Program Criteria
Appendix A. Course Syllabi
Appendix B. Faculty Resumes
Appendix C. Laboratory Equipment
Appendix D. Institutional Summary

Course and Outcome Notebooks

During the site visit, the PEV will expect to see a cabinet (see Figure 3) with notebooks that show samples of student work for each course offered in the curriculum. The course notebooks could include samples of homework, tests, reports, and other documents. The program needs to be aware that some courses are not offered every semester, or maybe not even every year. So the program needs to start this collection process well in-advance of the site visit, probably at least 3-4 semesters before the scheduled visit. In addition to the course notebooks, the PEV will be pleased if the program also assembles a set of outcome notebooks, one for each SO claimed by the program. The outcome notebooks should have the following information for each SO:

a. The SO statement
b. The list of performance criteria for the SO
c. Full results of the assessment processes for the SO
d. Mapping of the SO to courses that support the SO
e. Course syllabi for the courses that support the SO
f. A list of recommended course notebooks to review for the SO.

Figure 3: The ABET Notebooks Cabinet.

Time Table

ABET accreditation is a six-year cycle, and program faculty need to be cognizant about the processes needed for a successful ABET visit from one year to the next during this cycle. However, most programs will tend to “gear up” for ABET as the visit nears, rather than maintain constant vigilance. Experience suggests that a period of three years before the visit should be sufficient to have adequate time to prepare for the ABET visit. Table 15 shows a detailed timeline for a three-year preparation plan for ABET. This plan assumes that the program has defined the PEOs and SOs, and that the program’s previous ABET visit had resulted in an NGR.

Table 15. A Three-Year Timetable for ABET Preparation.								
Activity	**Frequency of Review**	**Sem 1***	**Sem 2**	**Sem 3**	**Sem 4**	**Sem 5**	**Sem 6**	**Sem 7**
Review PEO's	Every Three Years	√				√		
Review SO's	Every Three Years	√				√		
Interact With Program EAC	Every Three Years	√				√		**S**
Student Outcomes Survey	Each Semester	√	√	√	√	√	√	**I**
Senior Exit Oral Interviews	Each Semester	√	√	√	√	√	√	**T**
Direct Measures of Student Work	Each Semester	√	√	√	√	√	√	**E**
Review of Student Portfolios	Annually		√		√		√	
Results of FE Exam	Annually		√		√		√	**V**
Senior Exit/Achievement Data	Annually		√		√		√	**I**
Alumni Survey	Annually		√		√		√	**S**
Review Past Site Visit Report	Once Per Visit Cycle					√		**I**
Prepare Course Notebooks	Once Per Visit Cycle				√	√	√	**T**
Prepare Outcome Notebooks	Once Per Visit Cycle				√	√	√	
Write Self-Study	Once Per Visit Cycle					√	√	
Mock Site Visit	Once Per Visit Cycle					√		

* Semester 1 is the Fall semester 3-years before the ABET on-site visit.

The first main task is for the program to review the PEOs and SOs, and together with input from appropriate constituents, the PEOs and SOs are updated as needed. The various assessment processes are then instigated, using either a semester or annual time frame. These would include both the direct and indirect measures discussed in Table 13, as well student and alumni surveys. During evaluation of student work, both the evaluation results and the work itself should be saved for inclusion in the course and outcomes notebooks. About 18 months before the site visit, the program faculty will start to get involved in earnest. The self-study needs to be started and the course notebooks need to be compiled. Every course offered in the program needs its own notebook. Some programs might also try to have a mock site visit the Fall semester before the ABET visit. Someone from outside the program who is an ABET PEV, could be asked to come in and evaluate the program's preparedness, using the current ABET evaluation forms.

Conclusions

This paper has overviewed the ABET accreditation and review cycle from a program evaluator's perspective.[8] By looking at the desired results coming from the ABET on-site visit, the program faculty can then trace backwards in time the processes and activities needed to be prepared for a successful ABET review. Using the suggested processes espoused in this paper, however, will certainly not guarantee a successful visit. The result of the ABET visit is still a function of the PEV assigned to the program and his/her own personal interpretation of the ABET criteria.

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Design Innovation for Electric Aircraft

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Abstract

In spring 2012 the University of Texas at Arlington (UTA) aerospace engineering senior design capstone class was challenged to design an electric experimental aircraft that adopts the Spirit of the *Spirit of St Louis*. The mission for this next-generation electric aircraft is to fly along the historic Route 66. The *spirit* of this modern *Spirit of St. Louis* will be not to follow the same flight plan as the original Ryan NYP, but it rather retains the path-finding long-range design-challenge. Decades apart, the electric aircraft will generate new ideas that can alter the course of aviation, just as the Spirit of St. Louis. The Ryan NYP had unique design features that allowed it to cross the Atlantic Ocean in a non-stop flight. In analogy, a unique long-range electric aircraft will challenge the development of electric propulsion and its integration into modern aircraft. This paper documents the conceptual design performed by UTA's senior design capstone class based on a preceding research forecasting study by the AVD Laboratory, overall identifying a feasible electric aircraft mission for the capstone class. This project consists of a dedicated literature search generating a pertinent database and knowledge base. In addition, a design methodology is developed leading to a parametric sizing tool capable of visualizing the available solution for long-range electric aircraft. Central to this project is a study by NASA, who started contracting major corporations (i.e. Boeing, Northrop Grumman, Cessna, etc.) to address about 30 years (N+3) of future technologies concerning the use of hybrid electric aircraft for commercial use by 2030-2035. The mission, identified by the AVD Laboratory, is along the Route 66 highway, from Chicago to L.A., a distance of roughly 1,660 nm. This experimental-type aircraft will be electric with no hybrid systems on board, overall capable of flying non-stop along seven waypoints through eight states. Overall, the senior design capstone proposes an aircraft design that carries the potential to sway future electric aircraft.

Introduction

The National Aerospace and Space Administration (NASA), has started contracting major corporations (i.e. Boeing, Northrop Grumman, Cessna, etc.) to address about 30 years (N+3) of future technologies concerning the use of hybrid electric aircraft for commercial use by 2030-2035. In response to the to this green aircraft challenge, by the Aerospace Vehicular Design (AVD) Laboratory has identified a mission for the University of Texas at Arlington (UTA) aerospace engineering senior design capstone class. The mission identified is along the Route 66 highway, from Chicago to L.A., a distance of roughly 1,660 nautical miles. This route is shown in Figure 1 below.

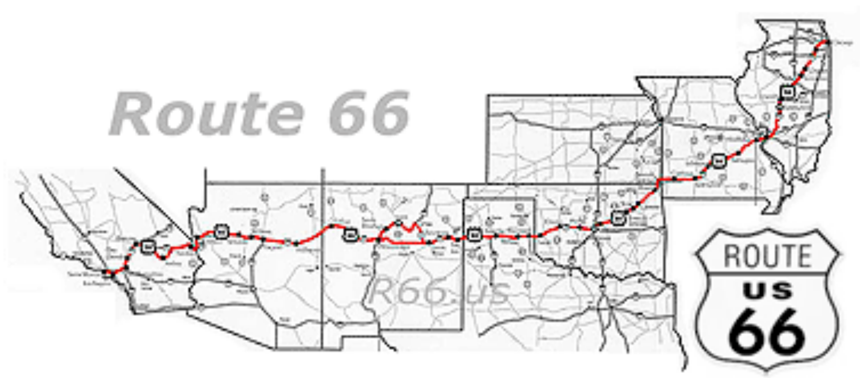


Figure 1 Historic Route 665

The conceptual design of an experimental-type aircraft is electric with no hybrid systems on board, overall capable of flying non-stop along seven waypoints through eight states. This paper documents the methods employed by both the team as a whole while emphasizing the propulsion disciplinary group as the main example. The results gained from this conceptual aircraft design study are also presented in this paper.

Educational Value

Aerospace engineering is a complex field where there is not a specific way to function or produce solutions. The senior design capstone project allows the class as a whole experience a small piece of this before entering industry. The objective of Senior Design capstone project is the analysis and design of an aerospace system such that a conceptual flight vehicle is produced. This includes a propulsion system, a structural system, or a control system, market analysis, operating studies, mission specification, civil and military certification requirements, design process, methods and tools, configuration concept selection, harmonization of individual design disciplines[12]. The capstone project challenges the engineering students to apply disciplinary analysis in the context of a multi-disciplinary design methodology to an open-ended design problem[12]. This project serves as partial fulfillment of the Accreditation Board for Engineering and Technology (ABET) and UTA's Mechanical and Aerospace Engineering Department (MAE) requirements. For more information regarding the course information or ABET requirements, please refer to reference 12. In addition, the senior design capstone project reinforces material learned in previous coursework and allows the student to explore a particular discipline of interest, which may serve later as experience in industry.

Project Overview/Mission

In the spring semester of 2012, UTA's, Aerospace Engineering Capstone Senior Design class has the challenge to design an experimental electric aircraft that adopts the Spirit of the *Spirit of St Louis*. The *spirit* of this modern *Spirit of St. Louis* will be not follow the same flight plan as the original Ryan NYP, but it rather retains the path finding long-range design-challenge of the original *Spirit of St Louis*. Although these missions are decades apart, both have and will generate new ideas that might alter the course of aviation, again.

The goal of this project is to complete the range with the minimum energy stored at take-off. This metric will measure the overall efficiency of the aircraft to perform its mission. In the beginning of the semester, the capstone class was divided into two groups, consisting of 22 and 21 students, to stir competition. If no discernible difference exists then the team to complete the mission the fastest will be ruled victorious. The rules of this competition are as follows,

- No Landing to recharge
- In flight regeneration is allowed
- Compliance with FAR 23 Take-off, Climb, and Landing requirements
- Compliance with Visual Flight Rules (VFR)
- Cruise speed of no less than 100 knots
- Future technology assumptions must:
  - Come from credible sources
  - must be forecasted to become available within the next 10 - 20 years
- Unassisted Take-off
- No dropping batteries or disintegrated batteries
- Fully self-contained

Even with the set competition requirements, the perceived measure of merit (MoM) must remain paramount. MoM being the ability to convene the investor, Dr. Chudoba, the Capstone Class Instructor, and the AVD Laboratory that the design is reliable, safe, and sound.

Project Scope

In an effort to provide a starting point and prove mission feasibility, the AVD Laboratory, conducted an in-house parametric sizing study for electric aircraft. It should be noted that the results of this study were not a conceptual design and only provides a starting data for the capstone students. A summary of the starting data provided is available in the table below.

Table 1 AVD Sizing Results5

Initial Design Summary			
Geometry		**Performance Summary**	
Spln (ft^2)	132.18	Vso (kts)	60
AR	9.29	Va (kts)	146
b (ft)	35.04	Vne (kts)	198
d prop (ft)	7.38	Vmsl (kts)	208
rpm prop (rpm)	2310	Vcr_max (kts)	191
		Vcr_Design (kts)	158
Weight		hcr (ft)	24000
TOGW (lbs)	3305	Range Max Payload (nm)	977
Wbatteries (lbs)	1212	Sto (ft)	1785
Wpay (lbs)	250	hto (ft)	0
OEW (lbs)	1843	Sl (ft)	1877
		RCsl (fpm)	1154
Performance Matching		RCce (fpm)	937
Range (nm)	1660		
Energy (kWh)	824		
ff	0.000		
bf	0.37		
L/D	19.70		
np (cruise)	0.82		
hp motor max (hp)	237	**Energy Cost**	
hp motor cont (hp)	95	electricity ($/kWh)	0.12
w/s (lbs/f^2)	25.00	wh/kg	1500
w/p (lbs/hp)	13.92	total ($)	123.66

For more information regarding the initial starting data or the AVD Sizing results, please refer to reference 5.

Team Skybrid Aeronautics

In the beginning of the semester, the class instructor encouraged the students to pick a name for their respective team. The name chosen that represents the documented project in this paper is Skybrid Aeronautics. This section simply explores how the team functions during the semester.

Management and Team Layout

The Structure of the team is broken into seven main groups, consisting of chief engineering/cost analysis, aerodynamics, propulsion, stability and control, systems, structures and performance team; this can be seen below in Figure 2

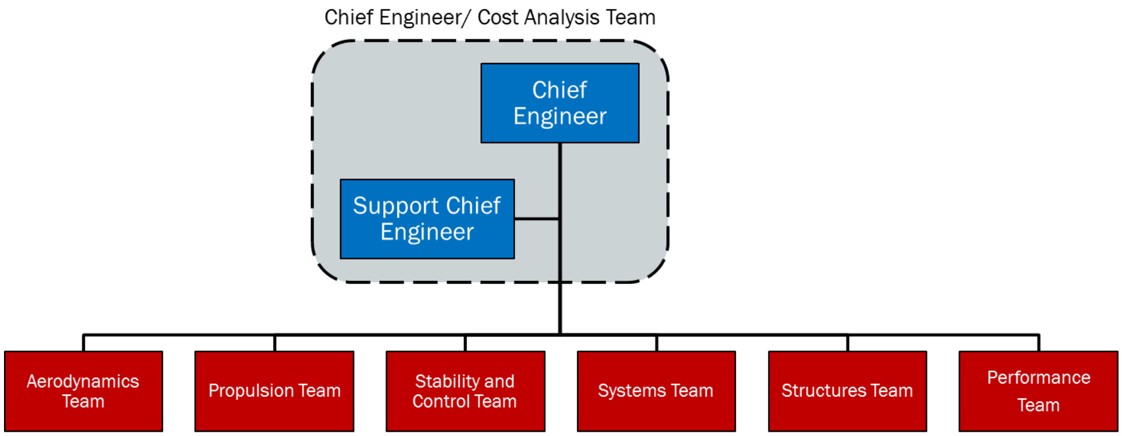


Figure 2 Skybrid Team Layout

Each of the seven disciplines was decided upon as the proper separation of groups in order to complete the design project. Both of the main two teams must follow the same team structure as Figure 2. The flow of delegation starts with the chief engineering group, consisting of the chief engineer and the support chief engineer to each team leader, with each team having roughly 3-4 people. From there the delegation is left to the team leads, who would then distribute responsibilities down to the rest of their team. This layout structure is necessary so if everyone is unable to decide on an engineering decision then the chief engineering group can make the final say for the entire team. The same can be done with each individual group and there team leads. The structure of the team is meant so that there is a proper amount of work spread evenly between each team in order to complete the tasks.

Multi-Disciplinary Analysis

As per the requirements, it is the focus of this project to use a multi-disciplinary analysis (MDA) approach for designing an electric aircraft. This will use all of our knowledge from the aerospace engineering degree plan and new knowledge acquired from the literature search, database and knowledge base (described below) performed. MDA links mathematical models from more than one discipline1. The team can then fashion a solution using the multi-disciplined approach. MDA allows the entire team, with the individual disciplines and their different modes of analysis, to work coherently in a synergistic form. From MDA we can develop a robust design methodology and from there build a parametric sizing tool to ultimately produce a practical solution.

AVD Design Process

The AVD design process is the main aircraft design method used for this project. The AVD process is a multi-disciplinary parametric approach to aircraft design, which employs carefully crafted tools to simulate the entire life cycle of an aircraft starting with conceptual design[13]. This method uses for the entire conceptual phase the buildup of a database (DB), knowledge base (KB), and parametric process (PP) as a foundation. The Skybrid Aeronautic's design process emulates the AVD design process heavily and will be revealed throughout this paper.

Literature Research

The main objective of the literature survey is to provide a strong foundation in which all decisions are based upon. In the effort to perform quality research, a database (DB), and knowledge base (KB) are constructed in parallel with the survey of literature. With respect to the Propulsion team, this foundation will support the conceptual design of the all-electric powertrain. In order to make the process of starting this year's capstone project with a quickened pace, each team was allowed access to all previous senior design capstone project team reports, literature search, databases, and knowledge bases built up. The importance of being able to look at, compare, and have an idea of where to start is for the team benefit of not starting at an initial point of zero. Figure 3 shows the method employed in the population of DB/KB Excel files.

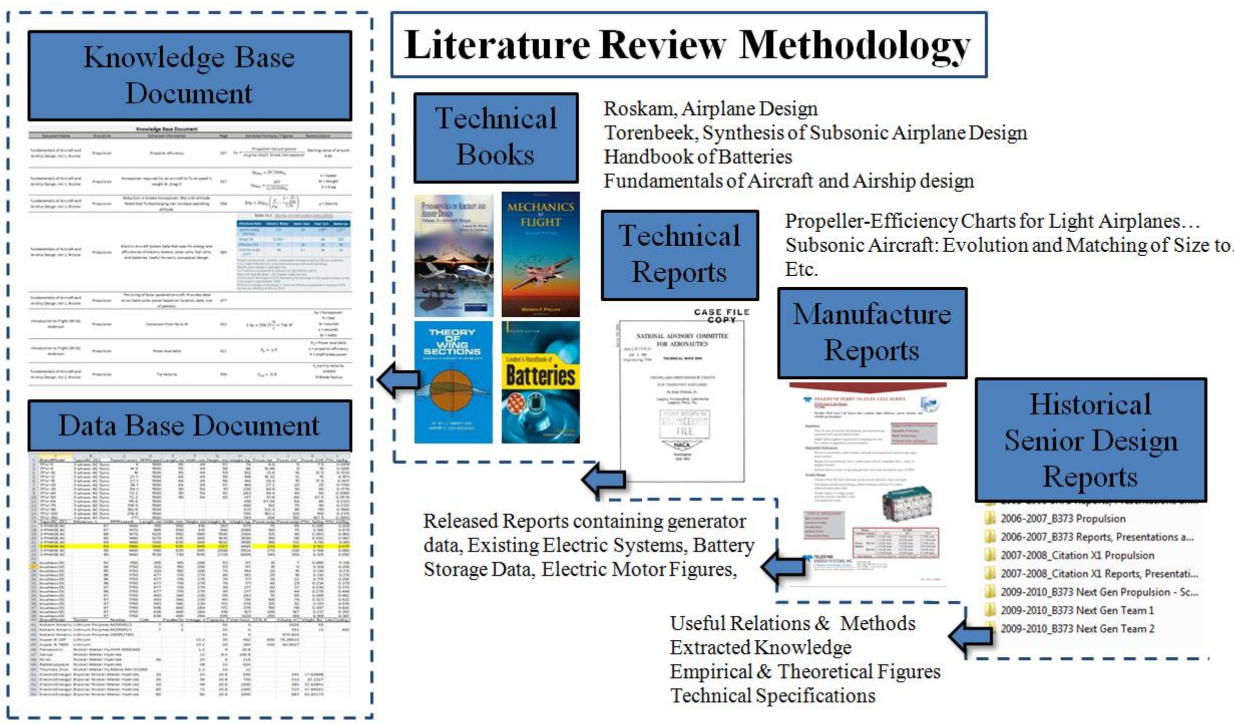


Figure 3 Literature Review Methodology

Figure 3 shows the collection of information from research, documented in the form on lessons learned into a KB and the data extracted of powertrain components into a DB. This information is screened from multiple sources. For the purposes of illustrating the method used, these documents are organized into four distinct categories, technical books, technical reports, manufacture reports, and historical, senior design reports. The outline of the KB document contains the book or report the information is cited in, including page number, extracted information and/or relations and figures. In another section of the KB are visualizations and comparisons of output data from the analysis tool. These visualizations aid in the development of presentation and report material. The DB was constructed in a different manner that contains raw numerical data of available powertrain components. For example, due to the effort to develop a "rubber" electric powertrain, one possible goal of the DB is to allow the engineer to create a regression analysis of electric motors with allowance for the estimation of engine weight and volume, based on the power available.

Propulsion System

As this paper walks through the conceptual design process of an all-electric aircraft, emphasis is placed on the propulsion department to illustrate the method and work performed across Skybrid Aeronautics. This department serves as an example as at the core of this project, the all-electric propulsion system is a major driving variable. Meeting the project requirements test the abilities of the student engineers and is a true engineering challenge in aircraft design.

Powertrain Fundamentals

With respect to the propulsion system of the aircraft, three main variables contribute to the demand and desire of electric propulsion in aviation.

- Less maintenance
- Higher reliability
- Less environmental and noise pollution

Of these advantages for electric propulsion listed above, not listed is the rising cost of aviation grade fuel. This reality is one of the strongest forces driving the development of electric powered aircraft. In order to provide a strong foundation on which to base the research of electric propulsion, a survey of current electric aircraft is performed.

Electric Flight

One of the major problems facing electric flight is that electric aircraft do not lose weight as it consumes its energy supply and in some energy storage mediums, can even gain weight. The large take-off gross weight remains relatively unchanged upon landing. This also means that the aircraft cannot cruise climb, the ability to climb while cruising due to the loss of mass. The problem is compounded due to the inefficient energy storage medium that electrochemical batteries exhibit. Table 2 represents the differences between several energy sources with respect to specific energy, the major metric for comparison in the design of electric flight. This is metric is important to electrification of flight based on its weight integration into aircraft design.

Table 2 Specific Energy of Several[4]

Energy source	Specific energy (Wh/kg)
Gasoline	12 500
Natural gas	9350
Methanol	6050
Hydrogen	33 000
Coal	8200
Lead acid battery	35
Nickel metal hydride battery	50
Lithium-polymer battery	200
Lithium-ion battery	120
Flywheel (carbon fiber)	30
Ultracapacitor	3.3

From Table 2, gasoline is a much more efficient method to store energy than the best electric battery technology at market. In the case of batteries this means for the same percentage of mass devoted to fuel, there is less extractable energy. This is one of the major design challenges for electric aircraft.

Propulsion Team Research Responsibilities

From the research of current electric aircraft, the powertrain of an all-electric airplane can be simplified down to six main components: propeller, gearbox, electric motor, power electronics, energy regeneration, and energy storage. The Propulsion group has been broken down into four subgroups. This method of sectioning out the powertrain is in effect enhancing the quality of powertrain as a whole by producing specialist within the respective disciplines. Each engineer is responsible to produce quality literature research to build defendable DB, KB, methodology, and sizing code modules for their respective topic. The organization and nature of study within the Propulsion group is in effect, multi-disciplinary analysis. The propeller research is predominantly related to aerodynamics, gearbox and electric motor to mechanics and physics, battery to chemistry and electricity, and power controllers to electronics.

Individual Area of Focus

To emphasize the process "Foundation Buildup" to develop robust and defendable research, a portion of the energy storage system research is presented in this section. The research begins with the development of basic operation of electrochemical batteries. The next step is an in-depth study of all current battery technology. This step provides a top-level view of what technology is available at market. With this knowledge, the identification and selection of an ideal energy storage medium can be rationalized. One valuable metric that is used as a tool for comparison is the specific energy of a battery. Shown in Figure 4 is a list of 20-year attainable and theoretical specific energy of several batteries.

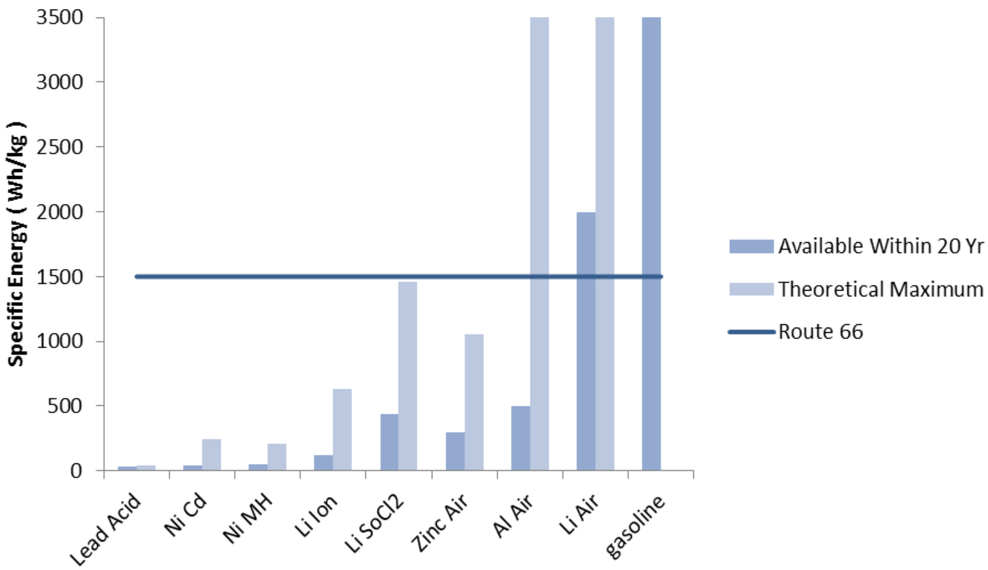


Figure 4 Comparison of Electrochemical Batteries5,[4]

According to data provided in Reference 5, the horizontal line represents the benchmark that must be met in order to complete the mission requirements for this competition. The theoretical energy density is somewhat of an unattainable goal research strives to reach. This value comes from the available energy that exists in the chemical reaction that takes place within the oxidation reduction process of the battery. A specific energy of around 1500 Wh/kg is required to perform the required range of the mission5. The literature search led to the selection of lithium battery technology for the focus of further research. The last step of the foundation buildup is to reveal the current state of the selected energy storage medium. According to Reference 5, the current level of battery technology is not capable of performing the mission of this project. This means that future battery technology will have to be considered to satisfy the requirements of the energy storage system. The use of air breathing batteries presents the best option for the electrification of flight for extended ranges5. An IBM-led coalition involving four US national laboratories and commercial partners hopes to have a full-scale prototype of a lithium-air battery ready for 2013 with commercial batteries ready for market around 20206. This places the battery within the time-period of the competition requirements. The result of the foundation buildup is the selection of lithium-air battery technology.

The research process shown in the section above illustrates the buildup of a research foundation. Further research into the lithium-air battery as an aircraft, energy storage system is performed but is not expressed in this paper because it would not enhance the objective to illustrate the research process of a foundation buildup. This example provides the reader an idea of how each engineer of the multi-disciplinary Skybrid Aeronautics team utilizes this approach to research with the goal of building a defendable product.

Design Process

The Design Process

The design process for this project has evolved over the semester into a very systematic approach at how to complete a conceptual design of an electric aircraft. The process begins with creating an initial design space of purely conceptual sketches, called Ideation. The next step in the design process is the qualitative down-select; this is the process of eliminating most of the sketches without knowing any measureable data involved (i.e. range, velocity, thrust and so on). Once this is complete the initial design space will be brought down to a manageable number of sketches. The quantitative down-select is the process of analysing the sketches to produce the first measurable data that can be compared. Once the sketches can be compared quantitatively a more refined design space is achieved. The goal eventually is to be able to choose one sketch that will ultimately become the fixed conceptual design. The design process described above can be seen in Figure 5.

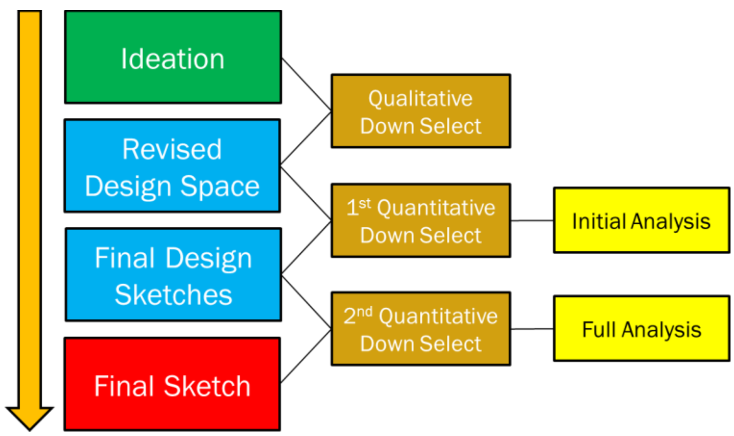


Figure 5 Skybrid Design Process

The purpose of breaking the design process down is so the design team can be tasked with the appropriate amount of work in a timely manner. The main work involved with the Skybrid design process is in the initial analysis and full analysis where most of the aircraft sketches are measured to see if they are feasible for the project requirements.

Methodology

Knowing the design process for this project the overall methodology of how the information will flow is able to take shape. The purpose of creating a methodology is to know where the flow of information is, how far it is from completion and to be able to make decisions on what needs to be done next. A basic methodology consists of seven steps, analyze, integrate, iterate, converge, screen, visualize, and assess risk1. Some examples of methodologies used by aircraft designers in the past, which were used as an initial starting point for this project, were design texts by Roskam8, Raymer[16], Nicolai7 and Torenbeek[15]. The methodology produced by each designer represents a final refined methodology that took years of experience before a true aircraft design methodology was fashioned. After comparing all methodologies, a combination of Raymer's[16] and Torenbeek's[15] methodology is used to develop Skybrid Aeronautics methodology.

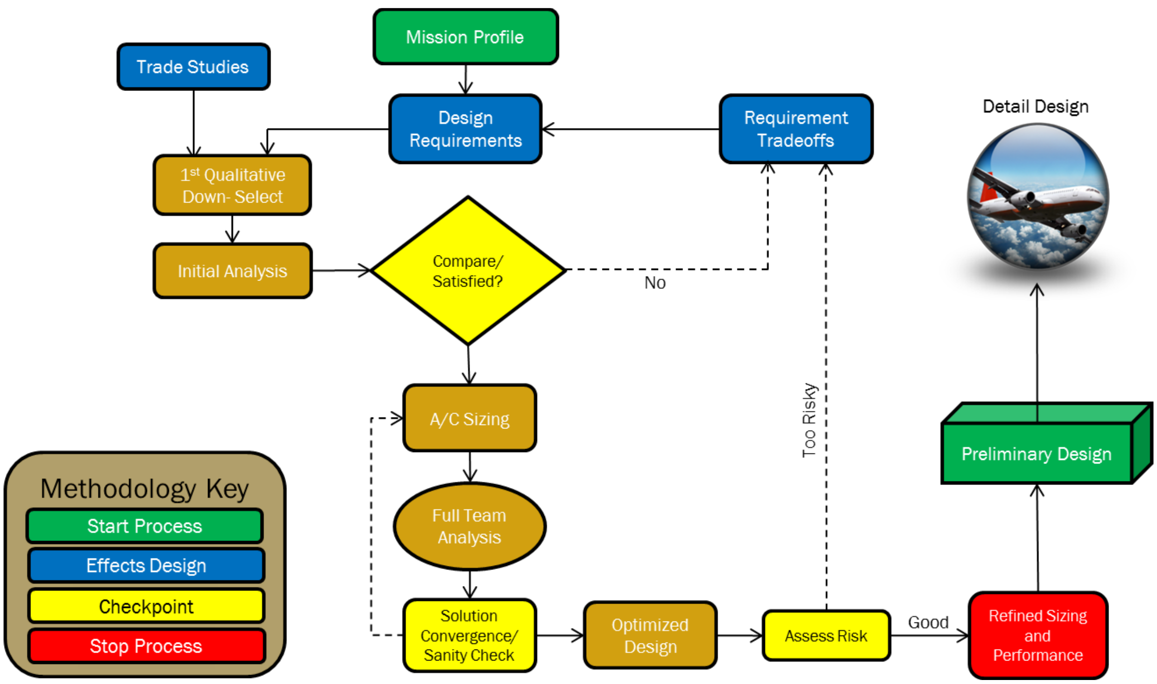


Figure 6 Overall Methodology

The flow of information is also visualized from the methodology in Figure 6. When compared to the design process figure (Figure 5), Figure 6 provides a more detailed layout of the flow of information. The information has strict paths it must follow before it can move on to the next phase. This overall integrated methodology has three main sections, 1) section that affects design and the qualitative down select, 2) the initial analysis section and 3) the full analysis section. The parts in blue affect the design and they include the design requirements, trade studies and requirement tradeoffs. The design requirements come from the mission profile designated by the Professor and the AVD lab. Trade studies are performed by each disciplinary team that will allow this design to complete its mission with the constraints proposed and are integrated into the sketches used for the qualitative down-select. Some example trade studies from each teams are, battery type (Li-air, Al-air), number of propeller blades, wing location, ducted propeller, pusher/puller, struts, boundary layer control, and body types.

Next, requirement tradeoffs come from failed design iterations that have partially gone through the integrated methodology. The next section is initial analysis, which will reduce the number of designs to just a few; explained later in detail. After the initial analysis the compare/satisfied checkpoint is reached where the design must pass to move on. Once the checkpoint is passed, the full analysis section of the integrated methodology is reached. The full analysis section will reduce the designs from initial analysis to a final design; explained later in detail. After the full analysis, an optimum design is chosen. Finally, a last sizing and performance of the optimum design will be done, ending this project, just before preliminary and detail design is reached.

IDEATION

As explained before, Ideation[14] is the creation of new ideas and for this approach the team will design and create conceptual sketches that could be added to the pool for the initial design space. For the approach in this case, a total of 18 sketches were drawn up by the different members of each disciplinary team, and then collected and categorized. To categorize each sketch meant to differentiate between if it is a tail aft configuration, three surface configuration and so on, the number of engines/propellers, high/low wing and so on. The process of categorizing each sketch would later be used to properly understand what is being designed and if it is feasible.

Qualitative Down Select

The revised design space is the process of eliminating most of the sketches from the Ideation[14] design process to just a handful that then could be further analysed. Next in order to take the initial design space and break it down to a smaller more manageable number (revised design space) a simple analysis would be performed, called the qualitative down-select. For the purpose of eliminating sketches quickly and efficiently it was determined a simple design grading would be done on a sketch by each group, systematically eliminating some of the sketches. The design grading involved simple questions that could be answered by each group, who should be knowledgeable at this point by researching their disciplines areas and completing the literature and database. Some of the questions included are,

- Was the sketch feasible? Why or why not? Explain?
- Did the sketch have growth or derivative potential? Explain?
- How much difficulty is involved with analysing the sketch?
- Each group come up with some reasons why or why not the aircraft will be our final design?

Each question was associated with a numerical scale that was from 1-10, 10 being the highest, which would be tallied later to find the plausible sketches.

Once qualitative down-select was complete, six aircraft designs, seen in Figure 7, were selected. The next step in the design process is quantitative down-select, where each design will be further analyzed for actual performance data that can be used to screen the sketches.

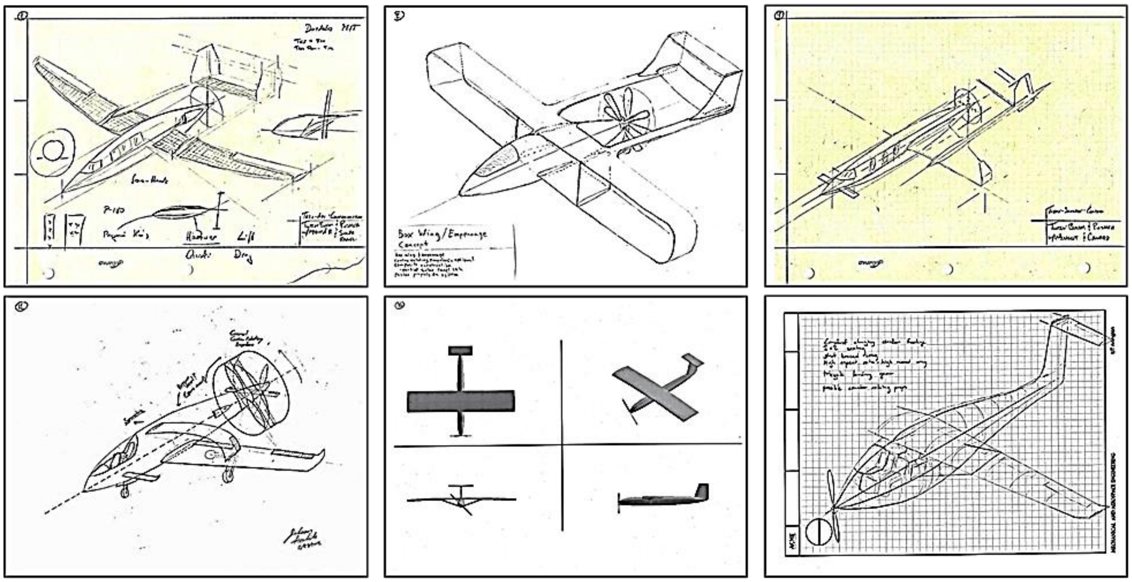


Figure 7 Results of Qualitative Down-Select (looking left to right) Sketch 1, 2, 12, 16, 9, and 18

Initial Analysis

The 1st quantitative down-select is the step in obtaining performance data analytically with a parametric sizing approach. This process was a stepping stone that would lead to the generation of disciplinary sizing modules that would later be integrated into one full analysis sizing code.

The simple flow of information from each discipline is follows an input, analysis, and output (IAO) structure. The initial analysis section of the design process consists of the three main groups, aeronautics, propulsion, and structures. The group interactions start with the initial configuration sketches and the initial design space break down; outlined in previous sections. Each group has initial inputs and outputs that are required in order to determine the range, minimum energy storage at takeoff, velocity at each phase of the mission profile and so on. Then from here, an overall MDA for the initial analysis process was determined so that the flow of information is mapped; as seen in Figure 8.

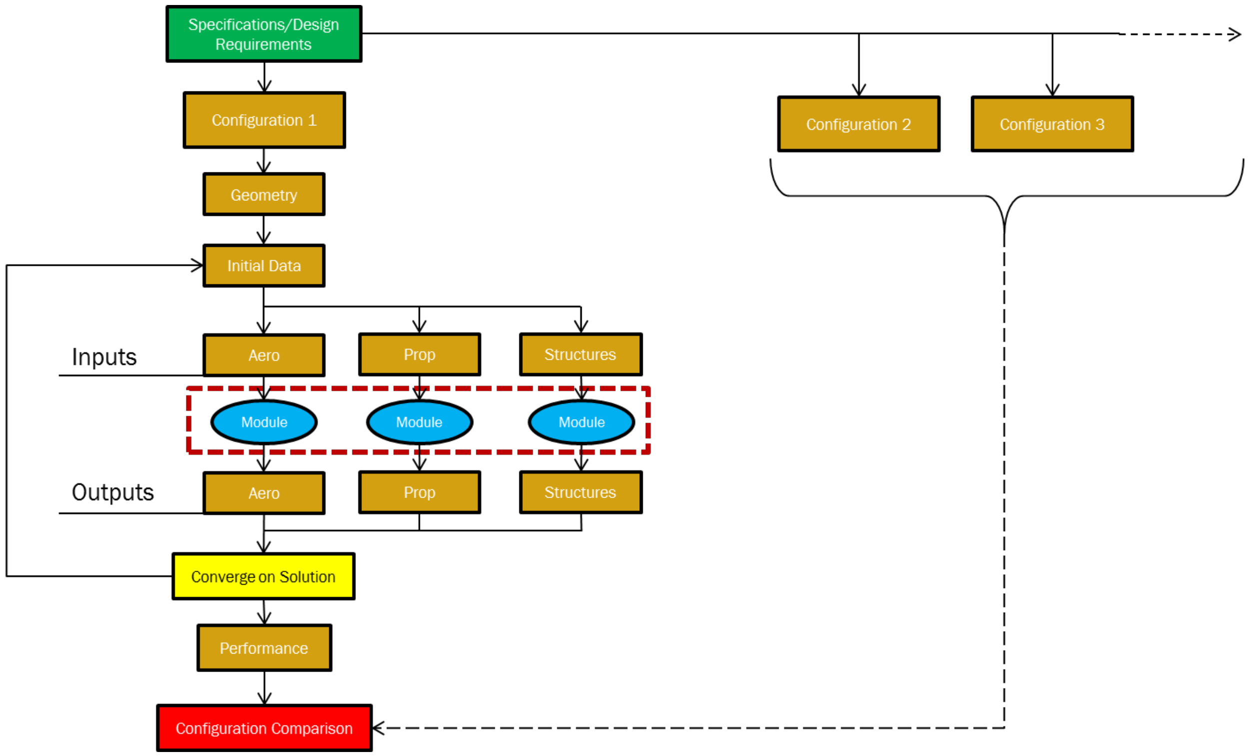


Figure 8 Overall Initial Analysis MDA

The process shown above is transfer of knowledge via hand, meaning that this IAO does not have the characteristic of a fully integrated design process. The data collected will then be used to compare each configuration, with their range, initial battery storage at cruise and so on. The detailed layout of how each of the three main team's interactions is displayed in Figure 9. In order to go through the initial analysis process some assumptions are made. These assumptions are made to simplify the analysis for better run time and are necessary for each sketch to be analyzed equally throughout the process. For the initial analysis the following list are assumptions made to complete the task of quantitative down-select,

<u>Assumptions:</u>

Main:

1. Cruise condition <u>ONLY</u> considered, all parameters found are for cruise segment

Aero:

1. U.S Standard Atmosphere Model
2. Extra Wetted Surface (Ducks, Struts) can be modeled as surfaces with symmetric airfoil sections

Structure:

1. W_{PAX} = 180lbs
2. $W_{payload}$ = 250lbs; AVD

Propulsion:

1. C_{BATT} = 1500 Wh/kg
2. D_{prop}= 7.513ft; AVD Lancair
3. RPM = 2510; AVD Lancair

Other:

1. Pressurized Cabin

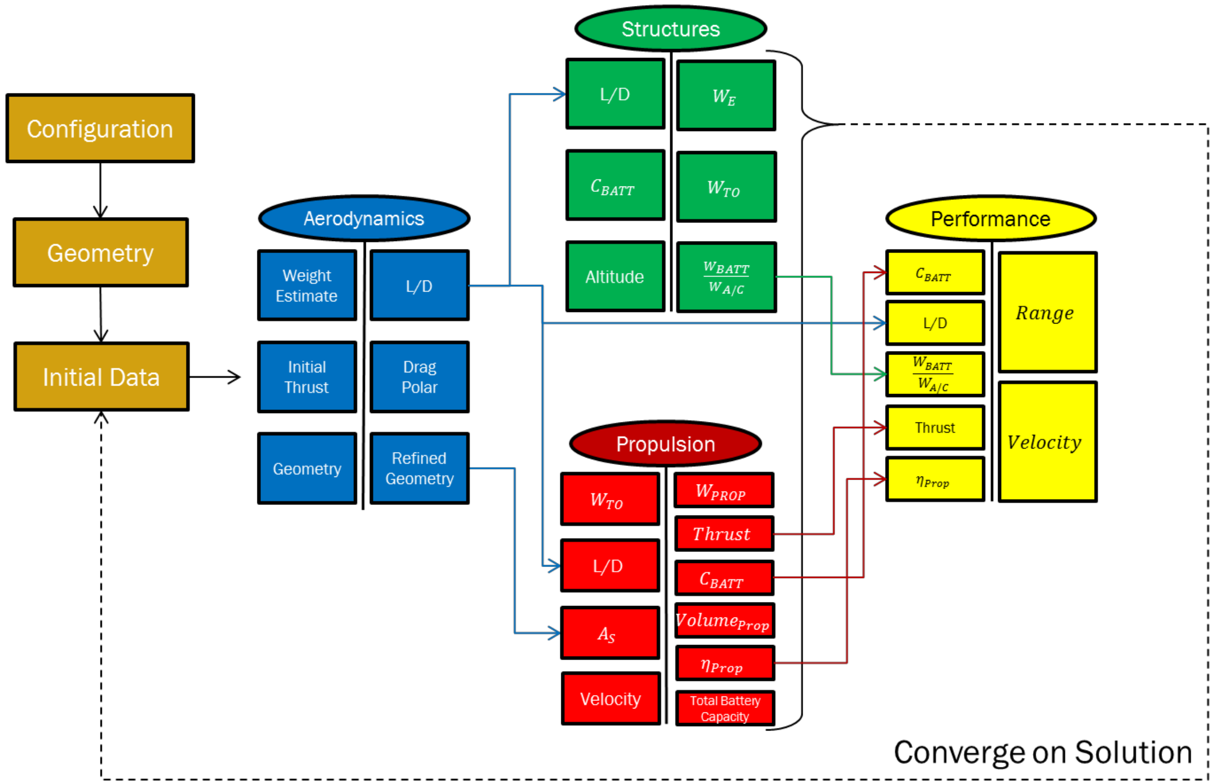


Figure 9 Initial Analysis Team Inputs and Outputs MDA

Once the specifications and assumptions are fixed for the entire team, then the process of initial analysis would only depend on the code developed by the three main groups. The sizing code includes the ability to obtain the most basic parameters needed to understand the aircraft at cruise; this can be seen in Figure 9.

Propulsion Parametric Sizing Code

As discussed earlier in this paper, emphasis is placed on the propulsion department to illustrate the method and work performed by Skybrid Aeronautics. This department serves as an example as at the core of this project, the all-electric propulsion system is a major driving variable. Because of this, the following section of this paper will contain information on the following items:

- Initial Analysis Propulsion Sizing Code - Language (MATLAB)
    - Methods and Logic - analytical, semi-empirical, numerical
    - Design Methodology - Safety
    - Code Validation

The analysis begins with the development of an initial analysis tool. This tool is used to provide quantitative analysis following the IAO process described earlier. The sizing code in essence pulls together the mathematical models of each discipline within the Propulsion Group into one MDA. With each trade selected, or data revised, the sizing code can produce outputs based upon the inputs of the other disciplines. The integration of the Propulsion Department sizing code with the other disciplines forms part of the MDA of Skybrid Aeronautics.

Propulsion Sizing Tool Logic

The main goal of this project is the conceptual design and development of a future all-electric aircraft. To aid in achieving this goal, the sizing code is written to maintain the requirement of minimal energy stored at take-off. The overall logic employed in the propulsion sizing tool is that multiple iterations within the code allows for convergence of a viable solution space. The knowledge can then be shared with the rest of the team allowing for solution space screening and the chosen design visualized. The methods and logic used in the propulsion sizing tool can be seen in Figure 10. At the core of the propulsion sizing tool, the weight, volume, battery capacity, and propulsive efficiencies are calculated. Nested on top of the calculations module is the convergence criterion of matching the power required, an aerodynamics input, to the power available, a propulsion variable. The method of "March along method" is used to test for convergence due to its ability to guarantee convergence at the expense of iteration run time. The weight convergence module works in a similar manner to the power convergence module. The main difference lies on how the data for the percent error is calculated. An initial estimated TOGW is provided from the structures group. Also included is an estimation of the propulsion system weight. Once the power convergence module outputs its results, a new TOGW is calculated by replacing the initial propulsion system weight with the new calculated weight. This module is important in estimating the power required of the Propulsion group and thus the correct size required of the battery. The last layer of the Propulsions Sizing Code is the variable pitch module. This module is positioned on top of the weight convergence module so that for each pitch angle, the power required and weight is converged. Not shown in Figure 10 is the gearbox module. The gearbox is used to both maintain optimum motor efficiency and produces the required RPM and torque at each flight condition.

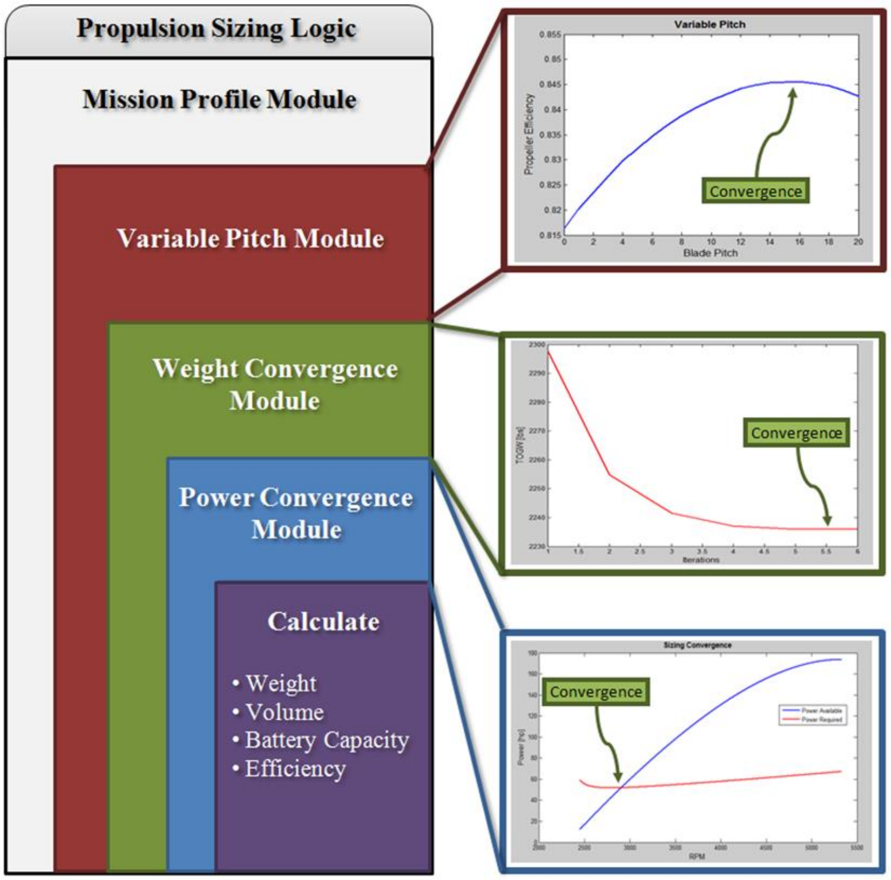


Figure 10 Skybrid Propulsion Sizing Code Logic Structure

Design Methodology with Safety in Mind

In the design and development of the sizing code, the safety and reliability of each simulated component must remain paramount in the mind of the designer. To address this, the physical and technical limitations of the hardware being simulated must be considered. This will insure that the aircraft powertrain remains feasible and conform to conventional standards. The propeller of the powertrain has many aspects that must be considered in its implementation. Both sound pollution and power requirements limit the tip speed of the propeller. The tip speed is simply a function of rotational speed and the radius of the propeller. This constraint governs the sizing of the diameter and maximum revolutions per minute (RPM). As the tip speed approaches Mach 1, exceptionally loud sound is produced including increased drag due to supersonic flow effects7. The location of the propeller with respect to the fuselage must also be considered. Research into propeller "pusher" configurations has revealed that there must be a 20 to 40 inch clearance between the propeller tip and any fuselage structure8. This clearance is to limit the effect of acoustic fatigue on the metal structure. This constraint will have a sizing limit to the propeller diameter for the pusher configuration, for example if it was being nested between two tail booms. With regards to the safety of the electric motor, it is capable of both a peak power output for short duration and a continuous power output at a lesser value. The maximum torque is of the electric motor is a function of the motor power and RPM. These constants will insure the electric motor does not operate outside its safety bounds. The thermal energy produced during the continued operation of the electric motor is also taken into account by including systems weight for equipment used in cooling. The cooling equipment is also utilized to elevate the excess thermal energy from the power controllers and battery compartment. The safe operation of the battery is the responsibility of the battery management system.

Propulsion Sizing Code Validation

The process of validating that the code is working as expected takes on multiple approaches. For example, the general tendencies of the outputs are check against empirical results obtained from the NACA Report in reference 9. In Figure 11, the typical efficiency of a propeller is shown with respect to the output of the code.

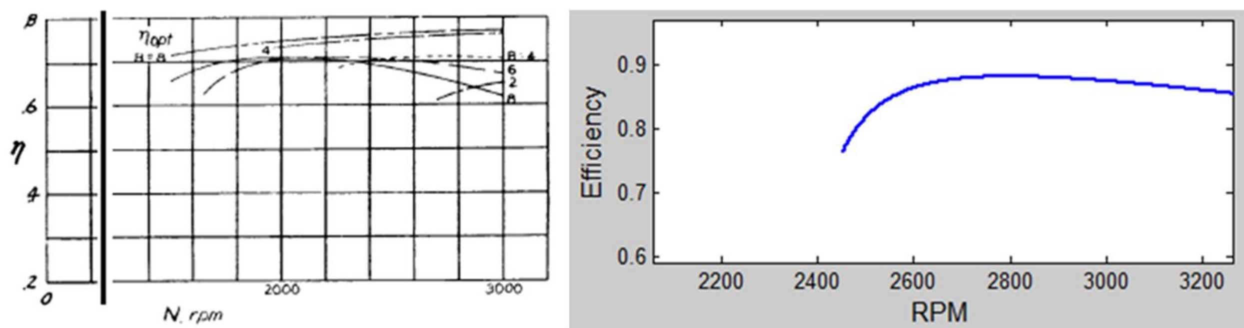


Figure 11 NACA (Left) versus Sizing Code (Right) for Propeller Efficiency versus RPM9

This form of sanity check is one method of assuring that the propeller module is working as expected. The thrust versus RPM is also checked against empirical results and comparison shows the same tendency of nonlinear increase of thrust as RPM increases. The next method to validate the code is to set the inputs to the data provided by the AVD Lab's sizing efforts. These inputs can be found in Table 1. The results of this comparison are shown in Table 3.

Table 3 AVD Sizing comparison with Initial Analysis Propulsions Sizing Code

	AVD Sizing	Skybrid Sizing	Percent Error
Energy (kWh)	824	837.25	1.56%
RPM propeller (rpm)	2310	3383	46.47%
Weight Batteries (lbs)	1212	1230.6	1.56%
Hp Motor cont (Hp)	95	93.907	0.73%
Propeller effiency (cruise)	0.82	0.85805	5.02%

As seen in Table 3, the sizing of the required horsepower, battery weight, and total stored energy is close with low error. The main reason why the propeller RPM comparison shows a large percent error is due to selected propeller. The AVD Lab did not provide enough information regarding the design of their propeller to accurately model with blade element theory. The propeller diameter modeled in the AVD Lab sizing is larger thus requiring lower RPM values to generate the required thrust. The slower RPM has a negative side effect of running the electric motor at less desirable efficiency values. From the research of electric motors, typical performance of electric motors run more efficiently at higher RPM values up to a certain point. The electric motor used in both sizing codes is the UQM PowerPhase 200. Figure 12 shows how both the AVD Lab sizing and the Skybrid sizing both fall outside the optimum efficiency range.

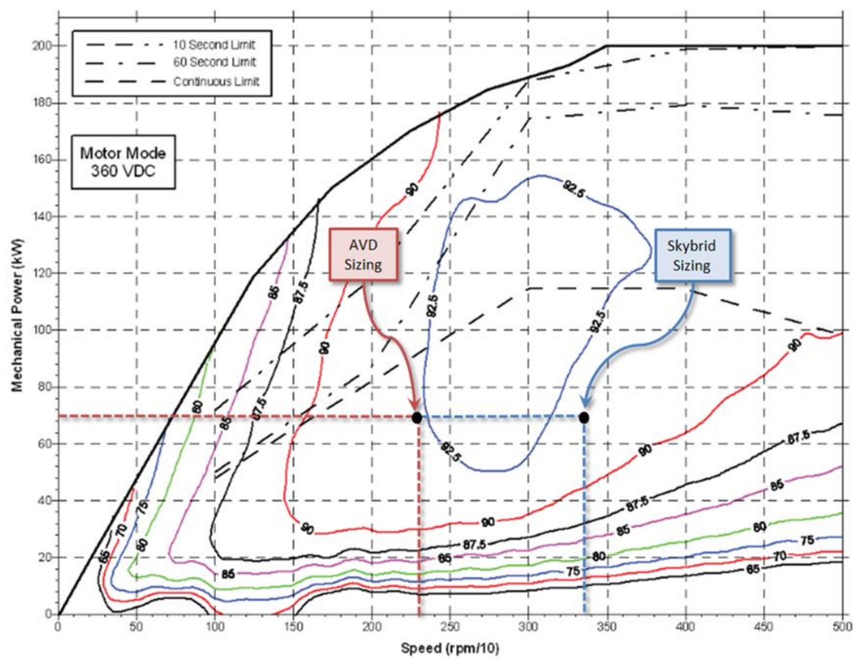


Figure 12 UQM - 200 Electric Motor Power versus RPM[10]

The experimental testing of the motor, performed by the manufacture, clearly show that the optimum operating RPM ranges from around 2375 RPM to about 3600 at maximum continuous operation. Increasing the propeller diameter used in the Skybrid model may yield the desired RPM for this motor. Overall, the initial analysis propulsion sizing code proved to be accurate within acceptable conceptual design limits with respect to empirical and numerical AVD lab results.

Initial Analysis Results

The performance team's outputs are used to compare each sketch and then decide if the sketch can be used to fulfill the mission; those outputs are listed in Table 4 and Table 5.

Table 4 Performance Outputs Sketches 16,18 and 1

	Sketch 16			Sketch 18			Sketch 1		
Altitude (ft)	Range (nm)	V_{cr} (knots)	Endurance (hrs)	Range (nm)	V_{cr} (knots)	Endurance (hrs)	Range (nm)	V_{cr} (knots)	Endurance (hrs)
8000	1782.24	104.72	17.02	1717.11	59.42	28.90	1940.54	66.67	29.11
13000	1771.71	114.27	15.50	1760.10	64.64	27.23	1781.68	72.67	24.52
18000	1746.42	127.10	13.74	1776.13	70.53	25.18	1782.28	79.58	22.40
23000	1698.93	139.76	12.16	1783.12	77.34	23.06	1771.25	87.61	20.22
28000	1610.59	155.26	10.37	1778.86	85.29	20.86	1744.69	96.84	18.02

Table 5 Performance Outputs Sketches 2, 9 and 12

	Sketch 2			Sketch 9			Sketch 12		
Altitude (ft)	Range (nm)	V_{cr} (knots)	Endurance (hrs)	Range (nm)	V_{cr} (knots)	Endurance (hrs)	Range (nm)	V_{cr} (knots)	Endurance (hrs)
8000	1660.57	139.15	11.93	1748.46	101.08	17.30	1779.83	70.97	25.08
13000	1660.58	158.47	10.48	1703.79	111.80	15.24	1763.42	78.07	22.59
18000	1651.24	175.65	9.40	1552.25	124.90	12.43	1734.58	87.03	19.93
23000	1661.83	197.67	8.41	1552.25	139.69	11.11	1665.06	96.02	17.34
28000	1669.56	222.33	7.51	1552.25	157.91	9.83	1493.84	107.65	13.88

As can be seen with the performance outputs for each aircraft the range, velocity and endurance are the deciding metrics. Sketches 1, 12, and 18 do not pass a mission requirement of $V_{cruise} \geq$ 100 knts. Each configuration has the range to pass the mission requirement, except a few have to be above a certain altitude in order to do this, i.e. sketch 16, 2, 9 and 12. Endurance was an output to cover the competition requirements for an aircraft to have the minimum mission time and each aircraft has relatively the same mission time, except sketches 2, 16 and 9 where there times are exceptionally low, about 10 hours less than the others; due to their velocities at cruise.

The results show the sketches 16, 18, 9 and 1 are the best choices to look at to move on. Sketches 12 and 2 will not be used because it became evident that these sketches were too complicated for further analysis; given the lack of experience dealing with advanced conceptual design. It was also determined that sketches of 16 and 18 are similar, one would be a derivative of the other, and would then be combined into one sketch to be moved on the final analysis. A similar notion can be said about sketches 9 and 1 where one has a canard and the other does not. If the two groups of sketches are combined then all that is left are two sketches, sketches 16 and 1. These sketches ultimately become the selected sketches. The winning sketches are both quite different from each other, one is a pusher the other a tractor, both are tail aft configuration but one has a twin boom design and so on. This means methods of differentiating them must be produced for a more complete analysis of the aircraft, which can be seen in the full analysis approach section.

Full Analysis

The initial analysis for this project produced two configurations that are analyzed through full analysis utilizing the entire multidisciplinary teams, in order to optimize and conceptually design the final aircraft. The full analysis is an integrated parametric sizing code that allows a quick determination of all aspects of the electric aircraft. Stability and control is kept separate from the sizing code; explained later in this section. As discussed earlier in this paper this process was achieved by the idea of creating a parametric sizing code that could take all the groups modules and combine them into one code which could consistently converge on a single solution for the aircraft.

Standing on the foundation built up from the literature survey that populated the DB and KB allows the student designers not to just rely on numerical analysis but to incorporate existing knowledge to reinforce design decisions. The goal of the design changes is to optimize the sketches before performing full analysis in the parametric sizing code. This process includes taking the sketches from before and adjusting the fuselage diameters, wing locations and so on; this can be seen in Figure 13.

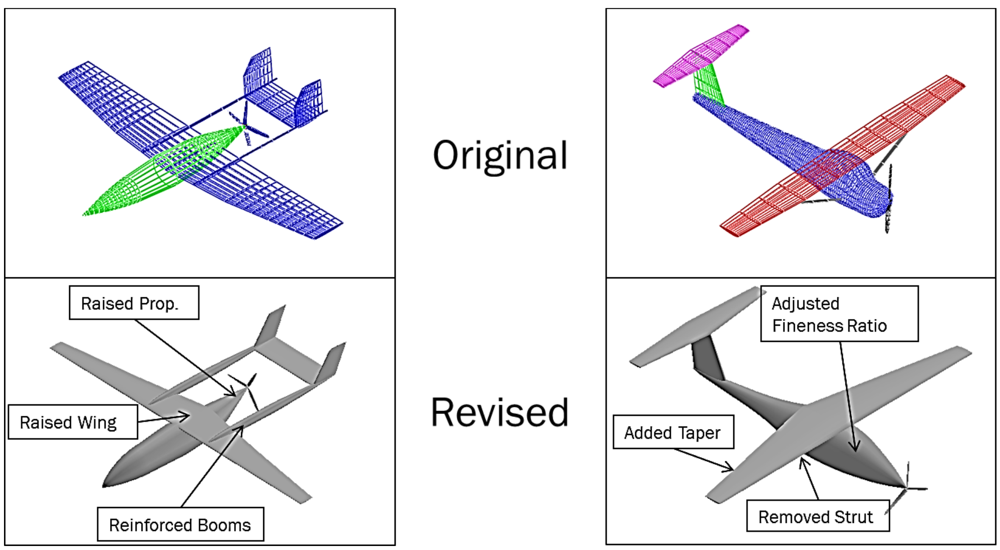


Figure 13 Original and Revised Sketches from 1st Quantitative Down-Select

For example, the following is a brief overview of some of the design changes. Looking at sketch 1 (left side Figure 13) the propeller was moved higher for more clearance from the ground because FAR 23 regulations state there must be nine inches of clearance. The propeller was also moved higher for shorter landing gear and to help create clearance to avoid rocks thrown up from the tires. In doing this, the propulsive weight is behind the neutral point, which could cause some problems later with stability and control. Since the aircraft is a pusher configuration, the fuselage can designed with a reduced fineness ratio due to the twin boom setup to connect the empennage. The fuselage is sized with room for four passengers and enough volume for the propulsion system. In addition, the control surfaces were reduced based on the double vertical tail arrangement. The tip of fuselage is shaped to be more compatible for a pilot with increased visibility. The propeller has three blades instead of four for increased propulsive efficiency.

Looking at sketch 16 the fuselage has been altered to become sleeker, like a Sears-Haack body, and then further area was shaved off in aft section of the fuselage to reduce skin friction. The wing is moved slightly aft and given some taper in the trailing edge for decreased wing weight and better C_{L_α}. The propeller has increased from two blades to three for more thrust. The tail area was increased because it was determined earlier that the horizontal tail would be too small to keep the aircraft longitudinal stable. The strut was remove from the aircraft because of the structures team determining that the wing span was adequate without the strut, so to reduce skin friction on the aircraft the strut was removed. Overall, both sketches are revised and improved, becoming more realistic in design.

Full Analysis Parametric Sizing Code

Initially the tools used to produce numerical results existed in a non-integrated format. The passage of data from one department to another proved to be slow and required full attention of a large group of busy student engineers. The combining of each disciplinary team's tools into one code is essentially the development of the fully integrated parametric sizing code. The following section of this paper contains information on the following items:

- Full Parametric Sizing Code
    - Method and Logic - Propulsion Focused
    - Code Validation

Full Analysis Parametric Sizing Code Logic

The Parametric Sizing Code is written using MATLAB object-oriented programming style. The run time of the code is not the only aspect that is improved by combining the codes. When data is passed from one hand to another there is a chance that error can enter at some point, may it be the units or just incorrect data altogether. Unit errors and pure miscommunication plagues can plague a non-integrated sizing code. This is eliminated by combining the codes together. Another benefit to combining the codes together is the ability to write in numerical convergence logic. Figure 14 shows the graphical user interface (GUI) in MATLAB that the parametric sizing code uses.

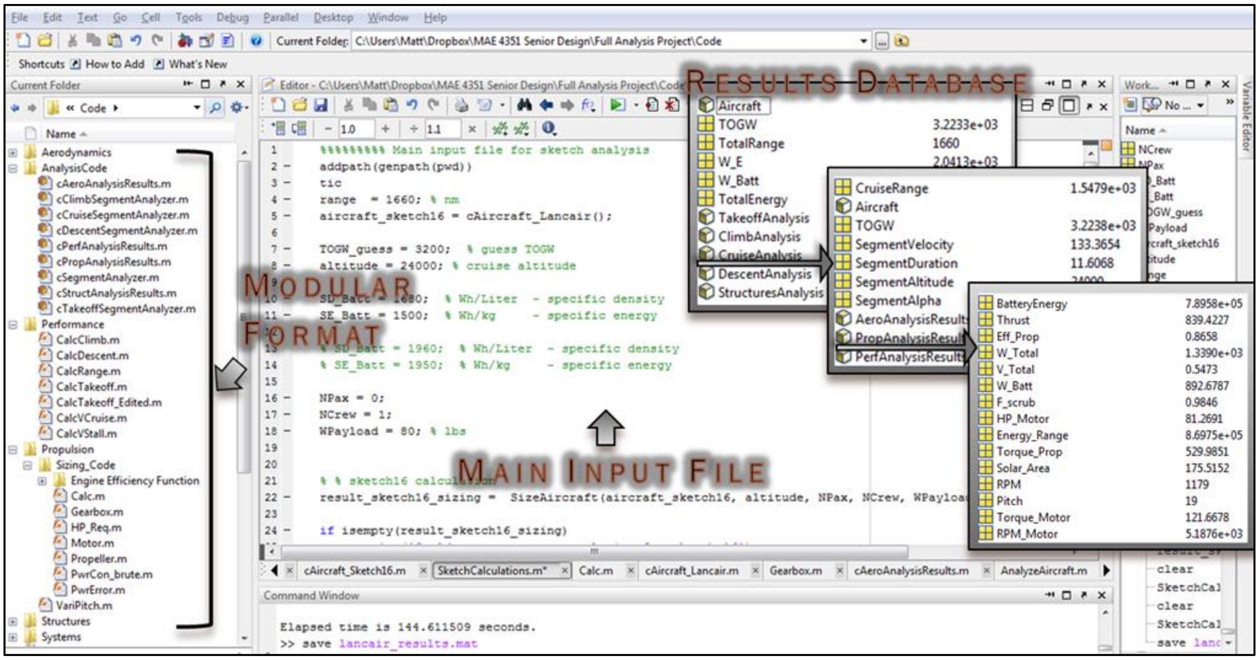


Figure 14 Skybrid Aeronautics Parametric Sizing Code Interface

On the left side of Figure 14, the modular format the code exists in can be seen. This allows the programmer the ability to easily edit and find errors in the code by having each disciplines methods in their respective folder. The right side of Figure 14 shows how the results of an iteration can be easily navigated through via the storage of data into a structure formatted results database. For instance, if the user desired to know the calculated propeller efficiency at cruise, one would simple double click CruiseAnalysis, then PropAnalysisResults, and look at the displayed information for that condition. The Results Database is saved and can be viewed later for comparison and visualization of results. The full Parametric Sizing Code is only briefly discussed as it contains multiple modules from multiple departments. The most unique and driving portion of the parametric sizing code are the propulsion modules. The initial analysis sizing code of the Propulsion department required alteration in order to fit the needs of the full analysis Parametric Sizing Code. This alteration is discussed next.

Parametric Sizing Code with Focus on Propulsion Sizing

The Propulsion Sizing Code is initially written to produce the most accurate results with the data provided. In the nonintegrated version, the existence of a weight convergence module was required. In the integrated format that the parametric sizing code exists, the weight convergence module would be moved to encompass the methods of all disciplines. The structure of the parametric sizing code can be visualized in Figure 15.

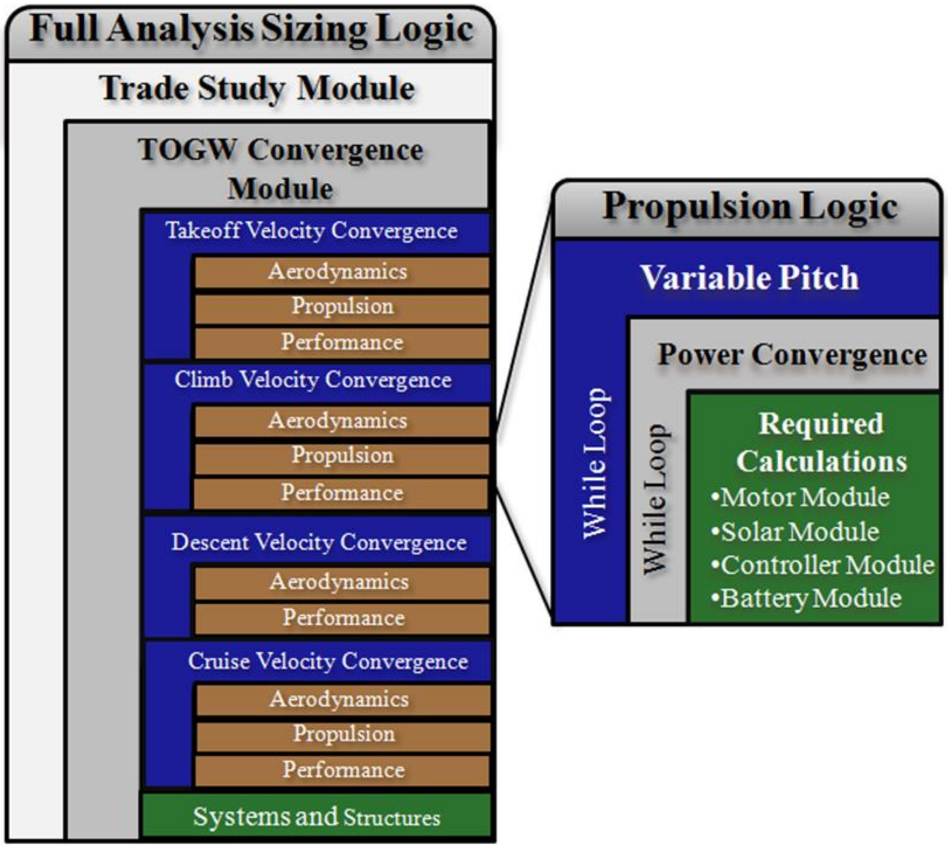


Figure 15 Full Analysis Parametric Sizing Code Logic Structure

As it can be seen in Figure 15 a velocity convergence module exists for each phase of the mission profile. This means that the data is continually passed through the aerodynamics, propulsion, and performance methods until the resulting calculated velocity no longer changes. At the end the systems and structures module, the new empty weight and TOGW estimates are returned to the weight convergence module. Each phase of the mission profile required unique power convergence logic to be written. Most general aviation aircraft take-off at maximum power for a limited time. To estimate the required power of this phase, the motor would be pushed to its maximum peak power rating for duration of take-off. This duration would be limited by the 60 second safety limit of the motor. The climb phase of the mission profile is sized using a relation to achieve minimal energy required for climb. The decent portion of the mission profile did not require any new logic to be written due to powered-off state of the powertrain during this phase. The range covered during decent would be calculated and used to determine the range required to cruise. The logic implemented in the cruise portion of the mission profile remains relatively unchanged from the initial analysis sizing code logic.

Fully Integrated Parametric Sizing Code Validation

The Skybrid Aeronautics Parametric Sizing Code is validated against the results of the AVD Parametric Sizing of the Lancair IV. Additional time is taken to construct an input file to model the Lancair IV. An example the Skybrid modeled aircraft can be seen on the right in Figure 16.

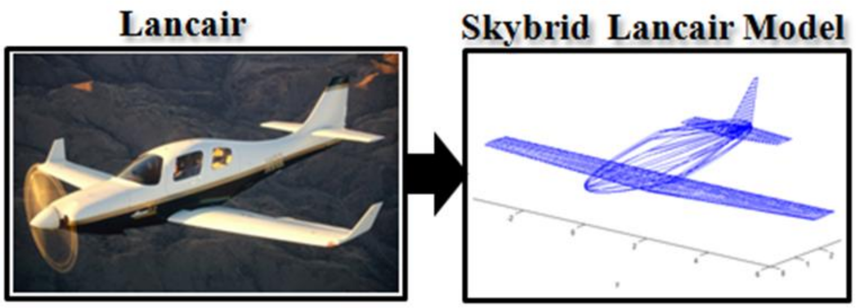


Figure 16 Skybrid Lancair Sizing Model[11]

The data used to model the Lancair mostly came directly from the data provided by the AVD Lab. The results of this effort are seen in Figure 17.

	AVD Sizing	Skybrid Sizing	Percent Error
Energy (kWh)	824	827.17	0.33%
Weight Batteries (lbs)	1212	1216.9	0.43%
Hp Motor cont (Hp)	95	91.5	3.28%
Propulsive efficiency (cruise)	0.82	0.796	2.51%
Cruise Velocity [Kts]	158	155	1.90%
TOGW [lbs]	3305	3439.2	4.07%
L / D Ratio	19.70	19.4129	1.46%
CD_0	0.016	0.0171	6.88%

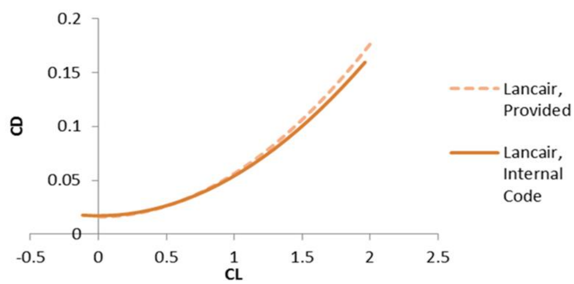
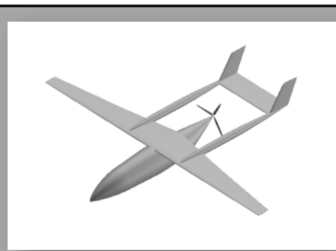


Figure 17 Full Analysis Skybrid Parametric Sizing Code Validation

This analysis shows less than 10% difference between the two parametric sizing codes for all major values. The validation of the Skybrid Aeronautics Parametric Sizing Code against the AVD labs in-house parametric sizing code provides strong evidence to the accuracy of the tool developed to perform the parametric conceptual design of the all-electric aircraft.

Full Analysis Results

After the sketches are put through the parametric sizing code and the stability and control analysis and convergence is reached the results are obtained, seen in Figure 18.



L/D_{cruise}	17.204
TOGW	2520.50 [lbs]
W_{Batt}	785.52 [lbs]
Total Battery Capacity	694797.29 [Wh]
V_{cruise}	171.18 [knts]
Range	1634.39 [nm]

L/D_{cruise}	18.78
TOGW	2428.09 [lbs]
W_{Batt}	705 [lbs]
Total Battery Capacity	617790.84 [Wh]
V_{cruise}	172.38 [knts]
Range	1648.40 [nm]

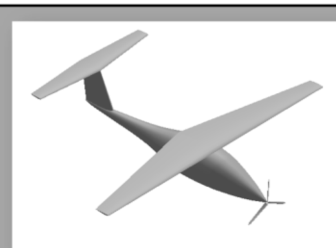


Figure 18 Parametric Sizing Code Results

As seen from Figure 18, sketch 16 has the overall better numbers with battery weight being lower, total battery capacity being much lower (80,000 Wh lower), velocity being higher at cruise and takeoff gross weight being 100 lbs less. Sketch 16 has become the sketch that will move on and become Skybrid Aeronautics final sketch.

To produce a more optimized design sketch 16 was put through another design review, the differences and the results of sketch 16 can be seen in Figure 19 and Table 6.

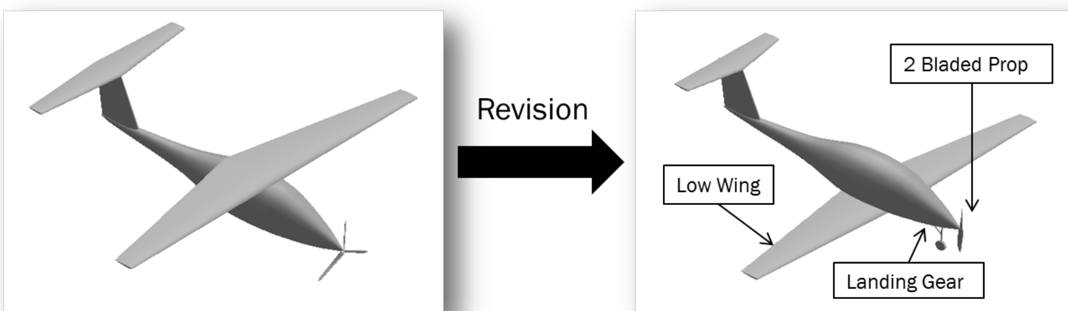


Figure 19 More Refined Sketch 16

As seen in Figure 19 the wing is moved lower for improved roll stability, a change that was made because of the iterative process with stability and control. Next, the propeller was changed from 3 blades to two blades for improved propeller efficiency in flight. Lastly, landing gear was added to the sketch because of the need to know its location for structures and stability and control for a complete design analysis. Now that the sketch is a completed sketch, it can be put back through the parametric sizing code; as seen in Table 6.

Table 6 Refined Sketch 16 Results with Completed Sizing Code

L/D_{cruise}	18.68
TOGW	3224.039 [lbs]
W_{Batt}	934.65 [lbs]
Total Battery Capacity	826703.71 [Wh]
V_{cruise}	133.26 [knts]
Range	1660 [nm]

The results changed dramatically from the full analysis to the new optimized sketch 16, seen from comparing Figure 19 and Table 6. This was due to the validation process revealing minor unit errors involved with the parametric sizing code. The code evolved and improved over time leading to accurate results, seen in Table 6. It should be noted that even with the existence of minor unit errors, this only affected the magnitude of the results, thus the disparity between the two sketches still existed. The refined sketch16 is made to be more aerodynamically efficient and produce better performance data. Looking at Table 6 the cruise velocity went down by 40 knots, the takeoff gross weight increased substantially, the battery weight increased by over 200 lbs and the takeoff battery capacity increased to 200kWh. Having these major changes shows how sensitive the parametric sizing code is when little unit errors are involved. Even after all the major changes took place, the sketch produced still was able to pass all FAR 23 requirements, pass the mission requirements and was liked by all who were involved in the design.

Summary and Conclusions

The result of the senior design project yielded the conceptual design of an all-electric aircraft to meet safely the needs requested. This project provided the authors invaluable experience in the trials of working in a multidisciplinary design environment and the chance to utilize the coursework of their undergraduate career. This project also allowed the authors the ability to enrich their engineering toolbox with respect to programming.

As in all projects, if more time was provided, additional trade studies would be performed in an effort to refine the selected design. The Parametric Sizing Code also has room for improvement. One aspect for the propulsion module that could be added is an automatic gear ratio selection logic. The logic used to estimate the climb portion of the mission profile could also be refined because it exists in an averaged format. One possible solution would be to expand this module to account for climb by segmenting the climb phase into multiple steps. This would yield measurements that are even more accurate. Considering the purpose of the parametric sizing code is to provide rapid sizing estimates to an acceptable level of accuracy in the conceptual design phase, the current level of accuracy is deemed sufficient for the limited time available.

The key difference between a good and a great engineer, is the ability to know when to stop, because there will always be room for improvement.

Acknowledgement

The authors thank the other 19 senior design students of Skybrid Aeronautics including Jackson Greulich, Lisa Vandever, Jacob Carlson, Taylor Cook, Cody Ground, Jared Poempipatana, Christopher Kirkpatrick, Tien Nguyen, John Heiser, Travis Clash, Alexander Tipton, Joshua Smith, Tyler Barmore, Josh Molina, Ezgihan Baydar, Derek Bozarth, Gregory Epps, Robert Dees, and Anup Abhattarai. We would like to specially thank Matthew Crisanti for his work in development of the parametric sizing code. Additionaly, the authors thank the support of professor's Dr. Subbarao, Dr. Chan, Dr. Lawrence, Dr. Maddalena and Dr. Coleman and support from doctoral students Amen Omoragbon, Eric Haney, Lex Gonzalez, and Thomas McCall.

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Online Education for the Student Professional

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Abstract

This proposal outlines the application of the theory of constraints (TOC) to serving the working professionals in the industrial technology (IT) programs at the University of Texas of the Permian Basin (UTPB). Bottlenecks in the process are identified. Changes are then proposed in the delivery of the program to maximize throughput, as it applies to the number of students in the IT programs.

Introduction

This project will apply Goldratt's Theory of Constraints (TOC) to serve the working professionals in the technology courses at UTPB. In education we have to increase enrollment in order to keep up with the increasing cost of education. The constraint in developing online courses is that it takes a lot of work to develop an online course. Finding ways to increase the number of online courses will help serve the working professionals and increase student enrollment and program enrollment.

Overview and Background

In 2004, I was brought in to start up a new Industrial Technology program at UTPB. The curriculum is a combination of manufacturing, petroleum, and business coursework. The program was specifically designed to meet the needs of the manufacturing and petroleum industry in the Permian Basin of West Texas as one out of five jobs in the area is related to manufacturing and exploration related to the petroleum industry. The courses were initially offered at night because we expected working people to be interested in this program.

When we started the Mechanical Engineering program, enrollment in the Industrial Technology program dropped as we were competing for some of the same students. By offering courses online we attracted a new group of working students that were constrained by their jobs from being able to take any day or night courses. Many of these students work on a drilling rig and have to go wherever they are drilling, and do not get back to the office till the drilling job is over.

Project Plan

In Goldratt's Theory of Constraints[1] (TOC), a given group of processes will have a weakest link and the weakest link controls the entire system production rate. In order to maximize the system production, the weakest link must be improved and all other links in the processes regulated to the speed of the weakest link. According to Goldratt[2] the first step in the Thinking Process is to develop a list of at least 10 – 12 undesirable effects (UDE) that currently apply to the problem at hand. It is helpful to write the current state in a diagram format. This diagram shows a logical explanation of the situation (Figure 1 – Current Reality Tree).

In figure 1 the undesirable effects (UDE) of starting the mechanical engineering program was that it reduced the enrollment in the existing industrial technology program. Once the enrollment dropped we had faculty leave, and they were not replaced. Putting courses online helped reverse the trend. However, repeating the same courses too frequently meant that the online students could not take new courses. We had to develop a plan to offer new courses online every semester, so that existing students had new courses that they could enroll in. The constraint was that developing and offering new online courses took time. We developed a five year plan to offer new courses at the rate of one new online course a semester. Offering new online courses meant that we could now repeat courses less frequently and this helped increase enrollment. We tailored the new online courses to meet the needs of the working online students based on their input. Some of our students are telling us that as they are taking our courses they are implementing the lessons learned in their jobs.

Goldratt contends that compromising does not solve the core problem though short-term success may be realized. He suggests using the Evaporating Cloud (EC) (Figure 2 – Evaporative Cloud with Injections) to search for real solutions that will break the conflict that bring about a win-win solution for everyone. The injection in this instance is: Offer online courses in industrial technology to build industrial technology enrollment. This tool will logically show that once the injections are implemented, the desirable effects can be accomplished. When the EC is broken, the Future Reality Tree (FRT) is built using the injections from the EC (Figure 3 – Future Reality Tree). A Future Reality Tree (FRT) was then constructed in an effort to assure that all of the Undesirable Effects (UDE's) would be eliminated using the resolution identified in the Evaporative Cloud (EC). The FRT is essentially the same as the Current Reality Tree (CRT); however the injection(s) identified in the EC are placed into the tree to create a vision of the "future reality."

We were trying to grow both the engineering and technology programs. Both programs were competing for some of the same group of students. Offering evening courses was not enough to grow the technology programs, as the engineering programs also taught evening courses. Many of our working students are on call and have to work odd and long hours when they are on-duty. This makes attending regular classes difficult, if not impossible. The constraint was overcome by offering new online courses that met the needs of these students and their employers. The students were able to enhance their skills in order to be promotable.

The undesirable effect (UDE) of starting new programs is that they sometimes cannibalize students from existing programs. In order to counteract this problem we need to find new methods to differentiate between similar programs. Offering new online courses in the technology programs to meet the needs of working adults allowed us to make this differentiation. The mechanical engineering program is offered mostly during the day with a few night classes.

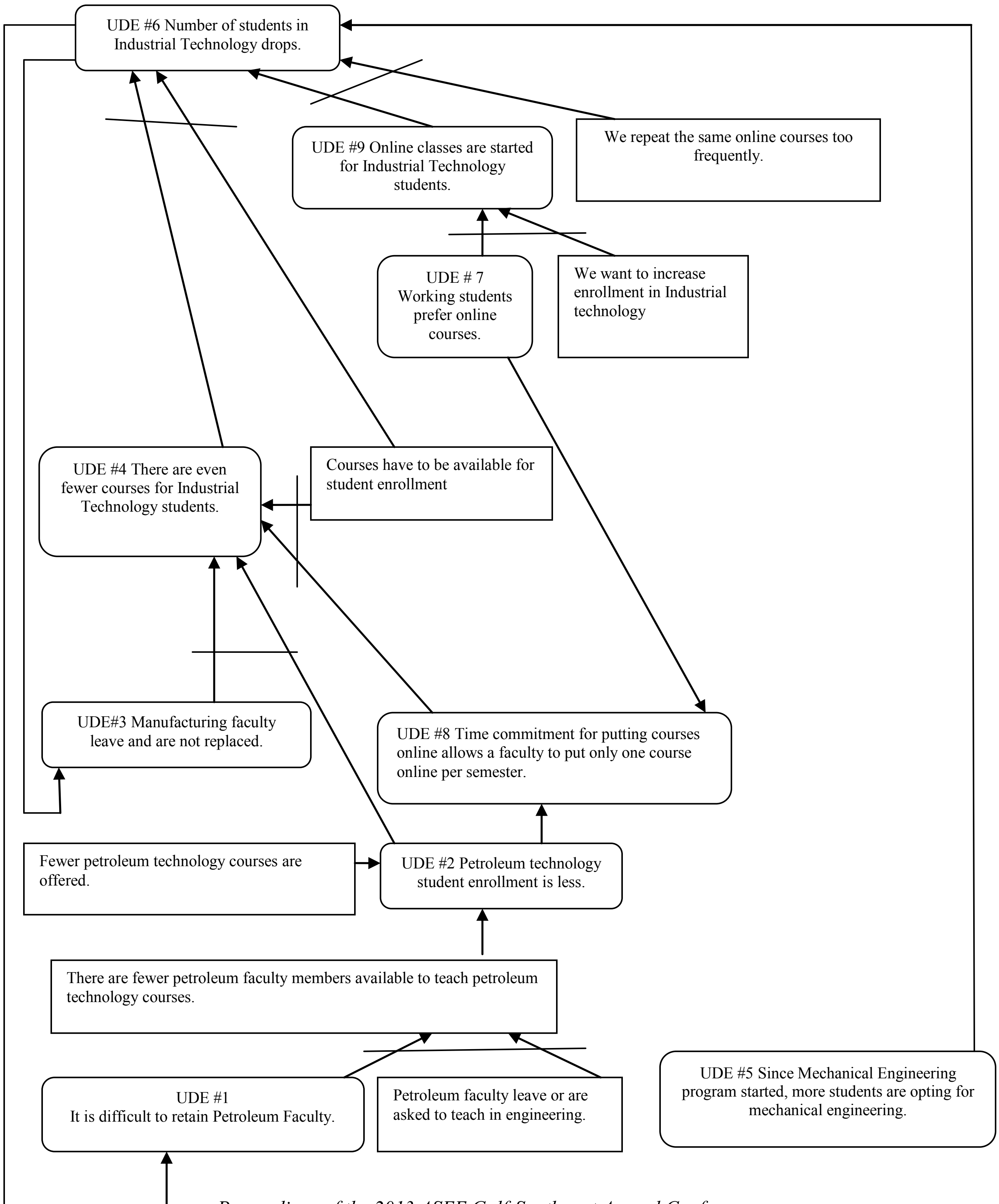


Figure 1 – Current Reality Tree (CRT)

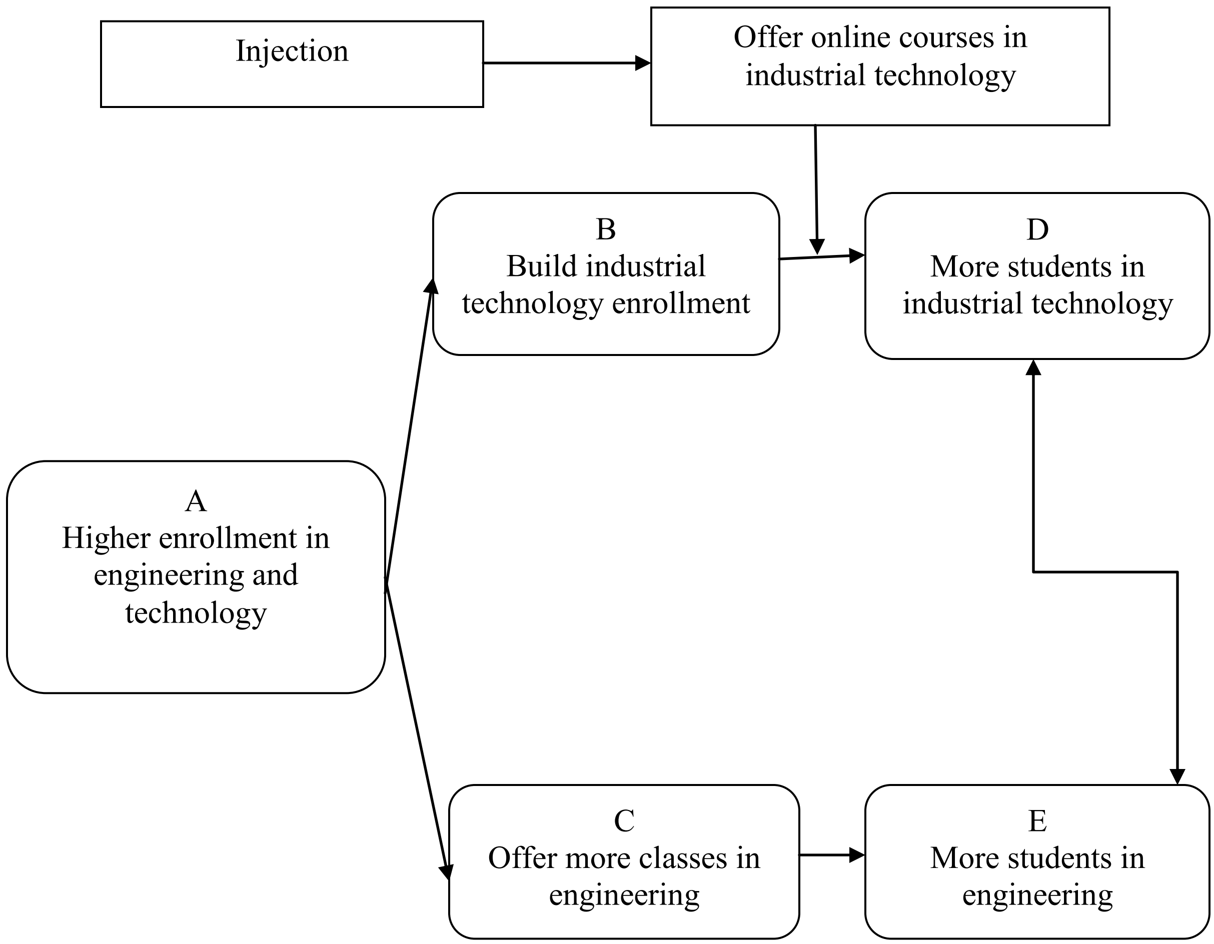
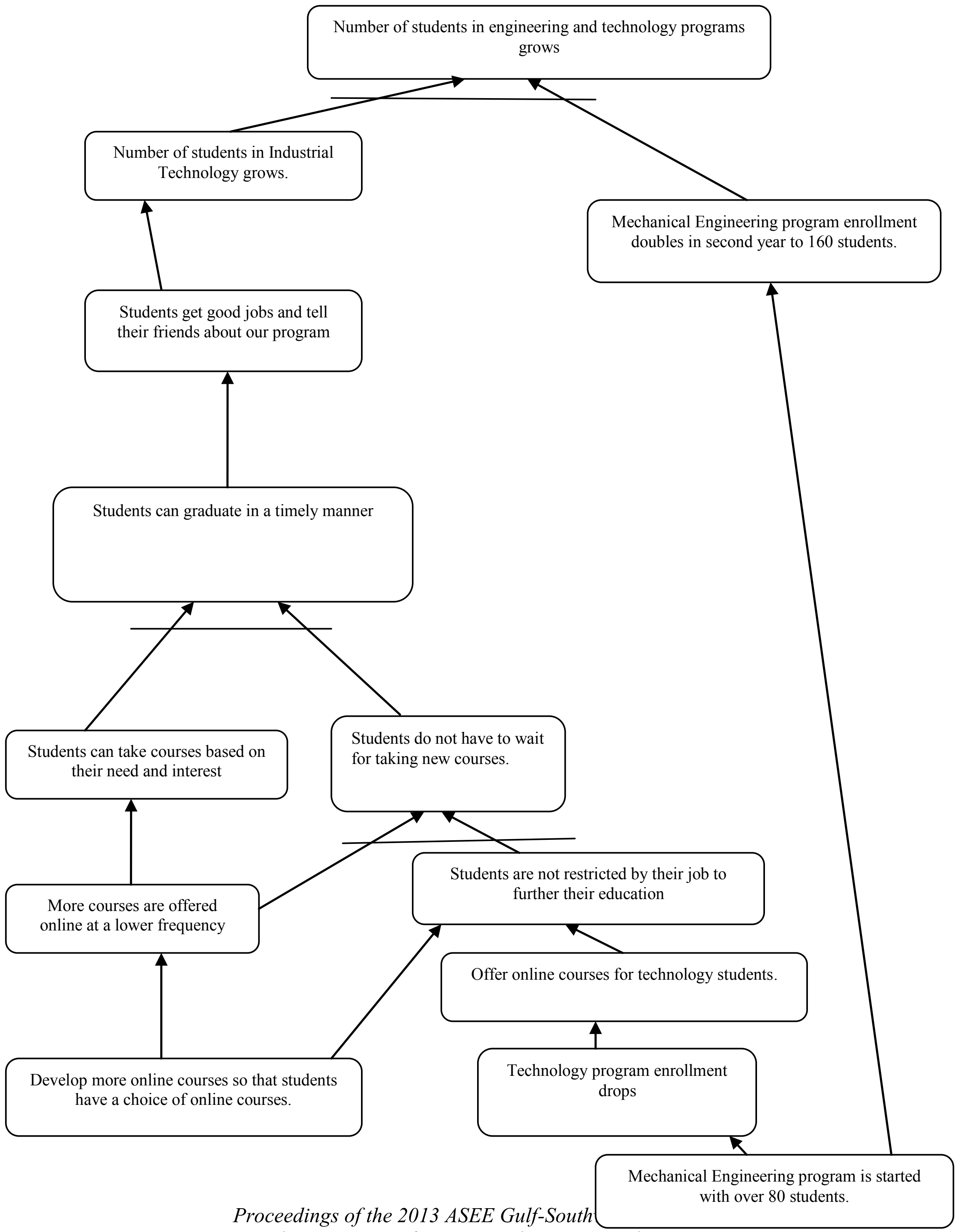


Figure 2 – Evaporative Cloud with Injections

The Industrial Technology program transitioned from an evening program to an online program to better meet the needs of working adults and not compete with the Mechanical Engineering program. Informal survey of students in the Industrial Technology program has told us that because these students have difficult work schedules, online courses have met a need for the professional development and educational enhancement of these extremely busy working adults.

The local oil and gas industry needs educated people to be able to constantly improve their operations in order to compete in a global economy. Offering new courses that met this need helped our program grow. Meeting with employers and working students helped us understand what was needed of our programs to help the local industry. As a result students have been able to get good jobs with leading oil and gas companies.



Number of students in engineering and technology programs grows
Number of students in Industrial Technology grows.
Mechanical Engineering program enrollment doubles in second year to 160 students.
Students get good jobs and tell their friends about our program
Students can graduate in a timely manner
Students can take courses based on their need and interest
Students do not have to wait for taking new courses.
More courses are offered online at a lower frequency
Students are not restricted by their job to further their education
Offer online courses for technology students.
Develop more online courses so that students have a choice of online courses.
Technology program enrollment drops
Mechanical Engineering program is started with over 80 students.

Figure 3 – Future Reality Tree

Project Implementation

A five year online course rotation cycle was developed for the Industrial Technology courses. It is shown in Table 1. One new course is put online in Blackboard each spring and fall semester till we have all the courses online in the fall of 2014. As per the rotation cycle most courses will be taught only once in two years after the cycle is complete. This will allow students to take the course they are interested in during their junior or senior year. Two courses have to be taught once a year because we also serve the management online completion program. The Petroleum Technology courses are also taught every year because the faculty has agreed to develop fewer online courses. As more online courses are available, they can be taught less frequently, and enrollment will be higher.

Course Description		**Yr 1**	**Yr 1**	**Yr 1**	**Yr 2**	**Yr 2**	**Yr 2**	**Yr 3**	**Yr 3**	**Yr 3**	**Yr 4**	**Yr 4**	**Yr 4**	**Yr 5**	**Yr 5**	**Yr 5**
Course no.	**Course title**	**Fa12**	**Sp13**	**Su13**	**Fa13**	**Sp14**	**Su14**	**Fa14**	**Sp15**	**Su15**	**Fa15**	**Sp16**	**Su16**	**Fa16**	**Sp17**	**Su17**
ITEC 3305	Industrial Safety and Health					X			X			X			X	
ITEC 3307/MNGT 3340	Project Management		**X**					X			X			X		
ITEC 3380/MNGT 3380	Managing Technology	X	X			X			X			X			X	
ITEC 4380/MNGT 4380	Total Quality Management		X			X			X			X			X	
ITEC 3390	Technology & Society	X													X	
ITEC 4302	Innovation				X									X		
ITEC 4310	Energy Technology				**X**			X						X		
ITEC 3340	Facilities Design							X			X					
ITEC 4303	Environmental Technology					**X**					X					
ITEC 3310	Manufacturing Technology	X			X		X			X			X			X
ITEC 4340	Construction Technology								X			X				
PTEC 3301/PENG 2301	Petroleum Fundamentals	X			X			X			X			X		
PTEC 3302	Petroleum Fluids and Gas Technology			X			X			X			X			X
PTEC 4302	Pipeline Technology			X			X			X			X			X
PTEC 3304	Drilling Technology					X			X			X			X	

Table 1 – Full program completion rotation cycle

Term	Fall 2011	Spring 2012	Fall 2012	Spring 2013
Total # of Students in Online Classes	91	109	114	127

Table 2 – Enrollment Results

Summary

Regular evening classes had enrollments of 12 to 20 students. Online courses have enrollments of 25 to 40 students. Informal survey of students has indicated that online courses have allowed more students to continue their education. Students with associate degrees need four-year degrees to move into management positions. Online education allows them to keep their job and pursue higher education, so they can move up in their careers. Many of our students have moved into better positions with their current employers after they graduated. Other students with little prospect for advancement in their current jobs have changed jobs in order to move up. . The time commitment associated with online education slows down the process of offering more courses online[3]. Since the program was implemented in fall 2011, my enrollment has grown to over a hundred students per semester. The results are shown in Table 2. This shows that the implementation of Goldratt's Theory was successful in improving enrollment in the online courses and serving the working professionals.

Conclusions

The advantages of online education are learning anytime and anywhere which is especially good for working adults including those that have to travel as part of their job. The use of online education in technical education is growing. E-learning is the new name applied to internet based online education. Online education also helps with scheduling and program costs. Many online students are older working adults balancing studies with demand of family and work

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Information Theoretic thread of Compression, Encryption, and Error Control for the Cloud

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Abstract

This paper is based on the theme, topics and experiences of a senior/first-year-graduate very successful new course taught during the Fall of 2012 to an enthusiastic small group of seniors and graduate students. It was a daring offering: an eclectic course whose main objective was to deal in a single course with the fundamental concepts of the three topics listed, each classically taught in a deep and specialized single topic course. Researchers in these fields have been consistently bemoaning the lack of a cohesive and integrative theory of security beyond the subjects of compression and error correction (already individually well developed) but particularly in cryptology, considered an emerging science, albeit an art [1]. Given the social, economic, scientific and national security implications of the topics it is surprising that more attention is being given to the development of such theoretical basis. While we are still far from currently realizing the goal, we decided to utilize the common thread of Information Theory to highlight a potential road to a unifying an approach applied to information security in areas such as communications engineering, computer science and networking. The results brought out some significant mathematical commonalities in topics like the measures of information, the sequencing for achieving efficiency, security and error control, the transformations that must take place depending on media and data nature to achieve the goals mentioned, evaluations of randomness, a host of modern algebraic, metric and topological spaces issues, protocol security and protection and most significantly, the possibility of system approach that might be a theoretical basis to unify broad aspects of the three topics mentioned. The efforts of writing a paper about this course will be rewarded if it stimulates thought and critical discussion on a central stem treatment on the topics. It may have appropriate specialized branches but a small, more efficient and fundamental set of common concepts explicitly applicable and interconnected throughout the three subjects.

Introduction

Issues associated with the modern aspects of the three topics, and particularly cryptanalysis, developed rapidly and were better appreciated after their use during World War II. Of historical significance was the published work of Shannon on “A theory of secrecy systems” [2], held classified as a memorandum on “A Mathematical Theory of Cryptography” [3], reputedly the first time the phrase “information theory” was used [4]. In particular the cryptographic successes with the breaking of the German encryption by the Enigma machine, the radar, telephone and radio communications developments and subsequent video, audio and network commercial successes, altogether fueled the need for better engineering as the spectrum became crowded and the protection against hacking and costly damage to databases became obvious. While the historical documentation is abundant, there is much which is shielded from the public for proprietary and national security reasons. The publication and selection of standards as done by the NIST in the US and other international organizations through open competitions and disclosures has assisted in the development of specific projects and indirectly provided fundamental experiences. In what follows we develop the subject with the same unifying intent that we introduced in the course.

A Conceptual Map

We offer in Figure 1 the conceptual structure that guided us in our educational journey. Of necessity it starts with the concept of information measures with a probabilistic communications orientation and a structural algorithmic approach, credited mainly to the genius of information theory, Claude Shannon [5] and the visionary of algorithmic complexity Andrei Kolmogorov [6] and to others independently [7].

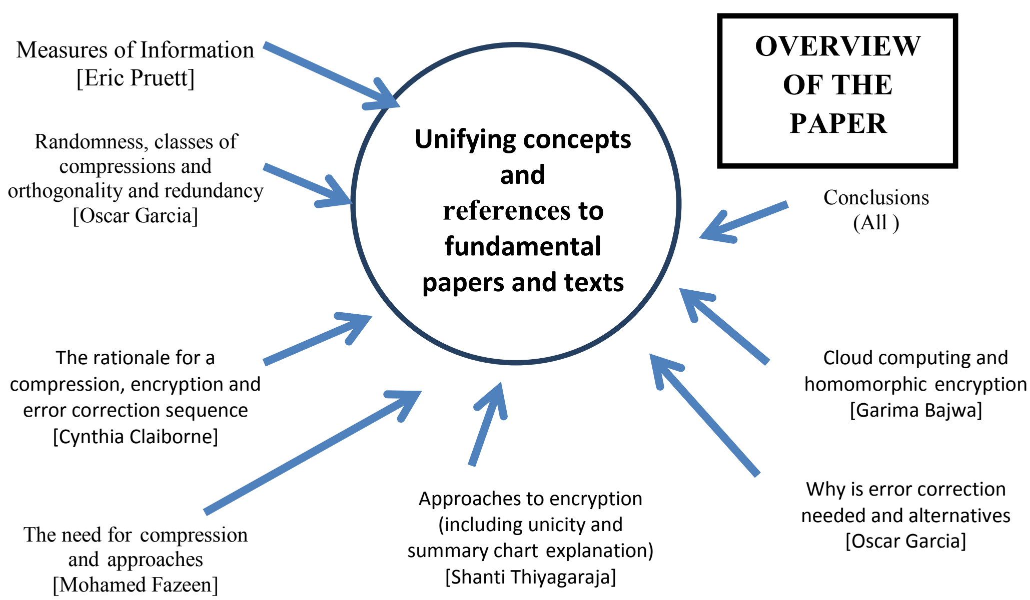


Figure 1. Conceptual map

Measures of Information

In considering the effectiveness of processing information for compression, error correction, and encryption, a predictable measure of information content, or entropy, is an invaluable metric. It would also be convenient if this measure had certain mathematical properties or related well to the number of bits used in transmission or storage. Broadly, these two types of measures were developed chiefly by Shannon and Kolmogorov.

Shannon's measure of entropy [5] was a true generalization of work done earlier by Hartley [7] from a broader probabilistic communications viewpoint where the entropy H(X) of a symbolic string $X=(x_0, x_1, x_2, \ldots, x_n)$ is actually associated with the "*source*" producing the symbols and is evaluated by the now classical sum:

$$H(x) = -\sum_{i=1}^{n} p(x_i) * log_2\left(p(x_i)\right) \quad \textit{bits} \qquad (1)$$

Where $p(x_i)$ is the probability that the symbol x_i occurs.

Shannon's theory is the basis upon which the numerical characterizations and functional relationships of "information" are based [3]. It has the convenience of being easily relatable to situations where we encounter known probabilities, but it is not directly calculable from a particular example in the form of a digital file, for instance, if we do not know the frequency of use of the symbols in the class of files under consideration. It can be shown, however, that this method conforms to convenient mathematical postulates including symmetry, continuity, and various additive definitions. This is convenient, for instance, when needing to predict how, given an entropy value, it changes when adding or diminishing information content.

Kolmogorov proposed an alternative view of information, in terms of complexity of representation, or C(X) for a message X, rather than a probabilistic mathematical theory [4]. This view assigns a value for information content to a message based on the minimum number of bits L(p) of the simplest program necessary to produce that message including necessarily the minimum number of bits required to describe the machine M used to reproduce it. Given a binary string X and a computing machine M, the complexity of X relative to M is given by the **smallest** number of bits $\mathbf{C_M}$ needed to write a program p that exactly reproduces the sequence using the computer M. Let's call L(p) the length of the sequence of binary symbols needed to express the program p that runs in M and produces s as an output. The smallest possible L(p) for a given s over all programs and all machines that outputs s is the *Kolmogorov measure of information in X relative in complexity to M* represented as: $\mathbf{K_M(s) = min(L(p))+C_M}$ where $\mathbf{C_M}$ is the number of bits that it takes to describe the machine M, a quantity that is independent of s. Since a Turing machine may simulate any other machine, it may be used to estimate $\mathbf{C_M}$ except that we cannot be sure of a minimal program. However, the file size in bits of a Lempel-Zif compressed file has been shown to approximate its $\mathbf{K_M(s)}$ [5].

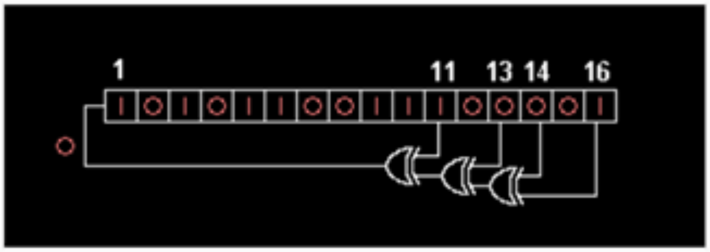
While these two measures approach the problem of measuring information from different perspectives, and are indeed complementary and more suited to different contexts $\mathbf{K_M(s)}$, for symbolic structure or **H(X)** for probabilistic numerical considerations, the information content as measured by these two measures does asymptotatically approach congruity. At the lower end, Shannon's entropy decreases faster than the corresponding Kolmogorov's complexity does for simpler symbolic structures, but this is due to the inherent discrete structural nature of the Kolmogorov measure required to have a simulating mechanism.

The Kolmogorov measure is an indirect and relative measure because it relates the smallest possible size (complexity) of the source program to the length of a given string relative to a computer, not related to the string (although the machine used is not related).. Actually, we can always reproduce a string with a program that copies the string, but then the program may be larger than the string. In cases like that, when we cannot find a shorter program to output the string, we say that the string is random in the Kolmogorov sense which coincides approximately with classical randomness.

Randomness, classes of compressions and orthogonality and redundancy

The best definition of a random variable is that it is unpredictable. However, although the occurring value of the variable may be unpredictable, the frequency of occurrence of a given symbol **might** be estimated or determined from a reliable recording of occurrences or from physical derivation from the type of system producing the symbols that is, their source. The determination of a truly random sequence is difficult and there are a number of criteria that allows us to say how truly random a sequence seems to be. Since most of our electronic sources (except such things as electrical noise, the infinite sequence of decimals of irrational numbers or radioactive emission) have finite states, they repeat their cycle of emissions. We call them pseudo-random generators and classical examples are Linear Feedback Shift Registers (LFSRs). Two well defined types are common. Borrowing figures from Wikipedia we can exemplify.

The first type is the Fibonacci configuration and the second type is the Galois configuration. The feedback configuration may be interpreted in the form of a polynomial P(x) over a finite binary field (or GF(2)) with exclusive OR logic gates. If the polynomial does not have roots which are elements of that field (that is values of 0 or 1 which make the P(x)=0) then it is called irreducible. If that polynomial is implemented in the feedback loop of one of the LFSRs it produces, as the values are shifted to obtain outputs, a sequence of ones and zeros that repeat after 2^N-1 regardless of the non-zero initial N-bit binary values in the LFSR register. Furthermore, the sequence has the appearance of a random one and more so the longer the number of cells of the register is, which delays the repetition of the cycle.



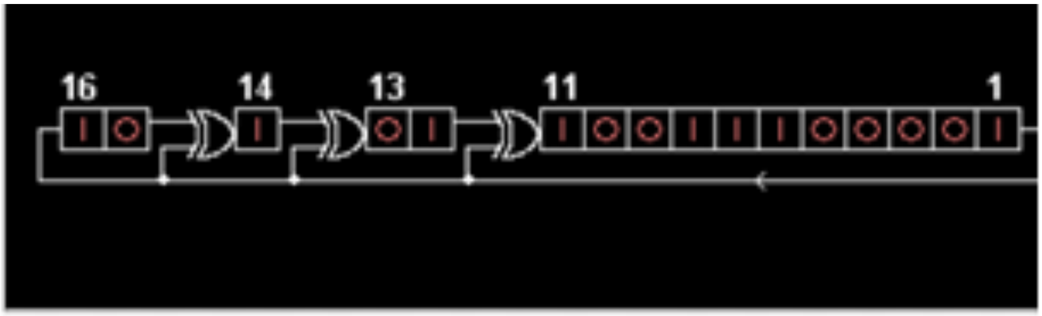
A 16-bit Fibonacci LFSR. The feedback tap numbers in white correspond to a primitive polynomial in the table so the register cycles through the maximum number of 65535 states excluding the all-zeroes state. The state shown, 0xACE1 (hexadecimal) will be followed by 0x5670.

0	1	0	1	0	1	1	0	0	1	1	1	0	0	0	0
1	0	1	0	1	0	1	1	0	0	1	1	1	0	0	0
0	1	0	1	0	1	0	1	1	0	0	1	1	1	0	0
0	0	1	0	1	0	1	0	1	1	0	0	1	1	1	0
0	0	0	1	0	1	0	1	0	1	1	0	0	1	1	1
1	0	0	0	1	0	1	0	1	0	1	1	0	0	1	1

The linear feedback shift register (LFSR) configuration (Galois) is clearly capable of operating at a faster shift rate since the exclusive –OR gates operate in parallel and the signal has a shorter travel delay through them than in the previous (Fibonacci) configuration. The outpust sequences for six shifts are shown in each of the two examples. These are called pseudo-random binary sequence generators, although there is a fuctional (linear) relation between the content of the cells in the register. However, because all the states of the LFSR are different in the sequence and other correlation criteria are met we do not consider them very redundant during a cycle. As a matter of fact, there are three postulates presented by Golomb [11] that are basically necessary for randomness. In the course we dedicate some significant time making sure that the concepts of randomness and redundancy are well understood.

In the course we consider that whenever there is a subsequence of symbols that repeats in a systematic or regular way, we have redundancy which is the opposite of randomness. If we can substitute the repeating sequence by an identifying symbol for it, we reduce the length of the sequence and accomplish compression.

Furthermore we consider not only Golomb's postulates [11] but other randomness tests that are abundant in the literature, as in [12] for example from NIST. The postulates are followed with an example from the references in the literature.



A 16-bit Galois LFSR. The register numbers in white correspond to the same primitive polynomial as the Fibonacci example but are counted in reverse to the shifting direction. This register also cycles through the maximal number of 65535 states excluding the all-zeroes state. The state ACE1 hex shown will be followed by E270 hex.

1	1	1	0	0	0	1	0	0	1	1	1	0	0	0	0
0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0
0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0
0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0
0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0
0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0

Golomb's postulates for randomness are the following:

(G1): The numbers of 0s and 1s in the sequence are as near as possible to n/2(that is, exactly n/2 if n/2 is even, and (n±1)/2 if n is odd).

(G2): The number of runs of given length should halve when the length is in-creased by one (as long as possible), and where possible equally many runs of given length should consist of 0s as of 1s.

(G3): The out-of-phase autocorrelation (ANDing for binary of cyclic shifts) should be constant (independent of the shift).

The consideration of randomness leads naturally to the issues of maximal entropy, the binary symmetric channel, the probability of errors, and the definition of channel capacity (including the economics of spectrum allocation) and the doubling of maximum frequency sampling as a sufficient but not necessary condition, with a simple illustration of the compressed sensing approach to sparse data [13]. The plot illustrating how the entropy changes in a Binary Symmetric Channel $p(x_1) + p(x_2) = 1$ and how it maximizes at the equiprobable point as shown in Figure 2. The same (equiprobable max) is true of the entropy when we include the all probabilities of any number of source symbols that, of course, add to one.

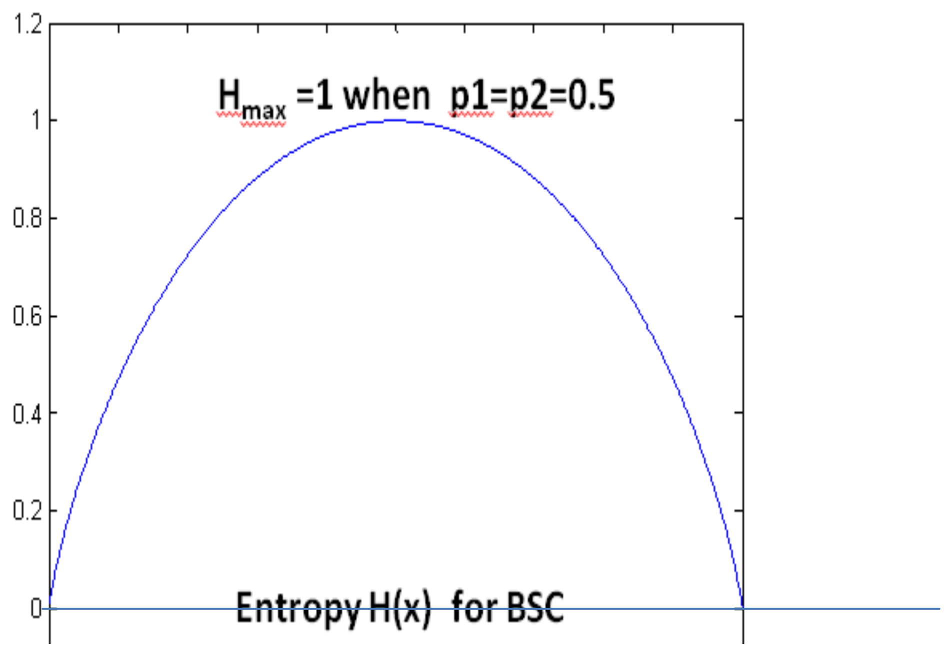


Figure 2. Entropy of the Binary Symmetric channel as $p(x_1)$ goes from 0 to 1.

The point is made that removing redundancy leaves what is left containing more information per bit but the same entropy in the complete message. The issues of what data is suitable for noisy and what for noiseless compression are studied. The psychoacoustic model is described explaining how sound and images can be highly compressed without degrading perceived quality as done in .jpg file format for images. Particular attention is made to the point that the projection of a vector over another provides a measure of the redundancy existing between them and the rationale for transforms using orthogonal functions in compression transformations. More attention is paid to Lempel-Ziv, although the four types of compression approaches are considered as we see when we take up compression.

Following the consideration of compression as it integrates with encryption, the fact that headers in a compressed file often present vulnerability in encryption and that "modes of operation" are used to cover that weakness. The approach of potentially using the modes of operation and the redundancy that they introduce through the functional relation of mixing consecutive blocks to do compression after encryption, contrary to the classical approach that we recommended, is discussed in class. The basis for this is the fundamental work of Slepian as pointed out in [14].

It is pointed out that while the order of the encrypted bits is changed and randomized, the information per bit remains the same (as the block size does) and the average probabilities of these symbols remain the same after encryption in the vector space of the dimensions as the block size. In other words, encryption is lossless. The approaches of one way functions are studied in hashing for identification, integrity and certificate issuing. The following are the themes covered in an introductory manner with examples and procedures well covered in the course textbook [15]:

- Security – BY ENCRYPTION NO ONE CAN LEARN CONTENT OF MESSAGE
- Integrity- BY HASHING NO ONE CAN CHANGE THE MESSAGE WITHOUT YOUR KNOWING
- Non-repudiation- THE AUTHOR CANNOT DENY SENDING THE MESSAGE
- Authentication- THE AUTHOR OF THE MESSAGE IS IDENTIFIABLE AND NOT CHANGEABLE
- Certificates: TRUSTED AUTHORITY PROVIDES ASSURANCE OF THE PROVENANCE OF THE MESSAGE

As explained next, the application of error correction redundancy after encryption is necessary to avoid retransmission when encrypted data is susceptible to noise in the transmission channel, rending it impossible to decrypt reliably if not used. The result is less information per bit when check bits are added but the same amount of total information in the message.

Because there is likely to be more redundancy in the message than that obtained by compressing after implementing the modes of operation for most data, the sequence of compression, encryption and error correction is used. If the data is not sufficiently redundant, compression is possible after encryption.

The rationale for a compression, encryption and error correction sequence when transmitting data to and from "the Cloud"

A modern approach providing computer services as a utility through networking in the WWW, known as "cloud." Those services are classified as using a commercial cloud by accessing its infrastructure, platform, software or any or all of them. In more detail:

IaaS: Cloud Infrastructure as a Service (sometimes called Hardware as a Service). This is where the computing is done in real or more often virtual machines; if the latter they use a hypervisor (Xen, KVM) under a coordinating system. You could have images in a virtual machine image library, raw (block) and file-based storage, firewalls, load balancers, IP addresses, virtual local area nets and software bundles. Cloud providers typically bill IaaS services on a utility computing basis, that is, cost will reflect the amount of resources allocated and consumed.

SaaS: Software as a Service. Seldom including tenancy (such as VMs). SaaS includes the use of applications software most often in areas such as:

- Collaborative work
- Support Service Desk
- Accounting applications (payroll, taxes, etc.)
- CRM (Customer Relationship Management)
- MIS (Management Information Systems)
- ERP (Enterprise Resource Planning)
- Specialized software for particular applications (education, graphics, etc.)

The Cloud SaaS provider is responsible for licensing of the software and amortizes its cost among the users which results in savings to the user. User access security is often resolved using a single sign-on password for a consumer.

PaaS: Platform as a Service. The platform consists of an architecture (say private, public, hybrid) and associated software systems (OS, languages, databases, development tools) in the form of a stack and applications. Stacks are usually characterized by the used OS and the support software. For each of the three major operating systems (Linux, Windows, Mac OS X) the stacks offer different facilities but in general they comprise at least : a) webserver, b) database, c) programming (procedural, functional or scripting) languages; development systems. Examples of stack content:

- Alternatively as web servers (depending of OS)
  Apache ; Internet Information Services
- As DBMSs
  MySQL ; SQL Server or Access ;
- As languages
  Perl, PHP, or Python (scripting languages)

Prior to the transmission of data to or from the cloud, there are three questions that should be asked for every stage in which data will enter:

- Are resources being used efficiently to send/receive and/or store the data?
- Are data secure before, during and after transmission?
- Are the data reliable after transmission?

First, let's consider efficiency – the effectiveness of an operation measured by comparing production with cost. In the context of cloud computing, production would be the transmission of data to or from the cloud. Two costs to analyze would be transmission time and size of storage. To ascertain a reduction in these costs, all data redundancies, in the original data, (plaintext), should be eliminated through compression.

Compression not only contributes to the speed of data transmission through a channel and smaller storage usage because of reduction in size but, it can, also, assist in securing data by increasing the randomness of data, which, inadvertently, increases the entropy. Entropy can be calculated using the below formula where $p(x_i)$ is the probability of the occurrence of a symbol x_i in the data and n is the number of unique occurrences of symbols as in the entropy equation (1).

Data having higher entropy, after compression, than that of the original data, is a very desirable state for which the data to be, prior to encrypting it. [1] "The increased entropy (which equates to increased randomness) makes the compressed data more difficult to decode. This is for what is looked in a good cipher."

One might ask, "Should the security and reliability of data be addressed before the efficiency of transmission?" Because data are secured via encryption, redundancies, which can assist in cypher attacks, should be removed, prior to encrypting the data. This is done through compression, thus, indirectly, aiding in the securing of the encrypted data. Reliability, (dependability), of data comes into question when data are transmitted. Data sent through noisy pathways can commonly have an occasional bit flip [17]: "The general strategy for pin-pointing errors is to send messages with repetition. This repetition allows for some of the data to be corrupted while still retaining the ability to decode the original message." Because ciphertext, (encrypted data), is the information being transmitted it is highly recommended to perform error correction after encryption in a noisy channel according to what type of noise (burst, impulsive, etc.) is present and most likely.

Thus, the rationale for a sequential process composed of

compression => encryption => error-correction

is proposed for transmission of data to and from the cloud: compression saves channel capacity and speeds and makes more efficient the subsequent operations; encryption assures privacy and integrity of the message and error correction diminishes the problems that would be faced in decrypting altered encrypted data through a noisy channel. We will cover these three stages in more detail.

One notable exception to our proposal, already mentioned and worthy of reiterating, is the encryption of data before compression, first presented by Slepian and Wolf who discovered that [14] "compressing one-time pad encrypted data translates to the problem of compressing correlated sources." The work of Slepian and Wolf was expanded further in [14] with the idea of compressing data after encryption, using block ciphers. This is also done without knowledge of the key as in the compressing of the one-time pad. The known difficulty of compressing encrypted, (randomized), data from block ciphers is avoided when block ciphers are used in conjunction with one of the various chaining modes, (modes of operation), such as CBC. This combination [14] introduces simple symbol-wise correlation between successive blocks of data.

The Need for Compression and Approaches

Data compression is a way of reducing the amount of redundant data bytes by eliminating this redundant information in a way that the original data could be reconstructed when needed. Compression can be of two forms, lossless or lossy. In lossless compression, once the data is compressed the original information will preserved and once its uncompressed, the original information could be obtain without any loss of data. Lossless compression is required when we transmit:

- Executable program files ,
- Accounting or scientific data for computation, text files or
- Original multimedia files intended for archiving.

Characteristically, compression takes place, in general by doing as follows:

- Frequent symbols will be encoded by short codes, rare symbols by long codes.
- Sequences that were already part of the former contents will be replaced by addresses.
- Dictionaries will be created that contain previously encoded sequences.
- Repetitions will be indicated by counters.

The lossless approaches to compressions are used in compressing the appropriate data types like text, numerical, financial and tabular data and typically they result a compression ratio of 30% to 60%. In lossy compression, in addition to eliminating redundant information, human imperceptible information will be also eliminated to improve the compression and once the data is uncompressed, the lost information will not be noticed as they are imperceptible. This type of compression is used in compressing data types like images, video and audio [18], [19]. A good lossy compression on images or videos can achieve from 10:1 to 20:1 compression ratio with excellent perceived fidelity.

According to Shannon definition the amount of information in a message x is the entropy called H(x) which is calculated by the defining formula (1) that has been shown above and when x is the equiprobable output emitted by a source, and p(x) is the probability of each emitted message it can be shown to achieve maximum entropy (as seen for the BSC in Figure 2), which is an eventual goal of achieving most efficient compression as it is the maximum information per bit for a certain size message. However, the maximum possible compression is the actual information content of the message. Based on Shannon's theorem the amount of information will not change when a lossless compression was performed, thus the entropy of the total message will remain the same even after the compression. However, in lossy compression the entropy will be decreased due to the loss of information in the compression and whatever information remains is the limit of how efficiently we can encode the lossy message.

Most compression algorithms can be categorized into one of the following four classes:
1. Run-length encoding (RLE),
2. Statistical methods (entropy based) Ex: Huffman encoding Arithmetic encoding etc.,
3. Dictionary-based or LZ (Lempel-Ziv) methods, and
4. Transform methods like Fourier transformation, wavelets, or discrete cosine transformation.

Abraham Lempel and Jacob Ziv are two computer scientists who made an unforgettable contribution to the lossless compression. With their publications of LZ77 and LZ78, two dictionary based compression algorithms, which is published in 1977 and 1978, has brought a new light to the data compression world [21][22]. Presently most of the compression algorithms are root back to the methods known as LZ77 or LZ88 where the second is an enhancement of the first.

In the current world, communication demand is skyrocketing [20]. Amount of communication channel bandwidth available for the demand is not sufficient or costly [20]. The data compression is important fact in communication as it can increase the throughput of a channel while utilizing it. Also since the compression will reduce the amount of redundant information, when the compressed data was encrypted the cypher text is harder to break. All these benefits can be obtained with a cost of compression processing [23]. Optimally is all about balancing the compression cost and compression rate. When dealing with subsequent encryption and error control encoding there is usually compensation in processing work by the reduction of the length of the message that is processed.

From a teacher's perspective, covering these topics can be challenging if the students the lacks a proper background on the subject. It can be pointed out that introducing the information theory concepts like Shannon's information measurements and details about what are redundant data are helpful for the student to understand the data compression, encryption and error correcting algorithms more effectively as the concepts of distance and dimension in a quantized signal vector space are considered.

Approaches to encryption

Information security is provided on computers and over the Internet by a variety of methods. A simple but straightforward security method is to only keep sensitive information isolated on storage media [24]. But the most popular forms of security all rely on encryption, the process of encoding information in such a way that only the person (or computer) with the key can decode it.

Encryption [24] procedures can be categorized as symmetric or asymmetric. Symmetric encryption is where two parties share a secret key that is used to encrypt a packet of information before it is sent over the network to each other. Symmetric-key encryption is essentially the same as a secret code that each of the two parties must know in order to decode the information. The code provides the key to decoding the message. Symmetric algorithms can be divided into two main classes: stream algorithms and block algorithms. Stream algorithms operate directly on a continuous stream of buffered flowing bits whereas block algorithms operate by transforming fixed-length groups of bits, a block and waiting until the block is formed again. The first major symmetric encryption algorithm developed as a standard for computers in the United States was the Data Encryption Standard (DES) [26]. Other examples of symmetric algorithms are Advanced Encryption Standard (AES), International Data Encryption Algorithm (IDEA), Blowfish and CAST.

Asymmetric encryption, also known as public key encryption uses a combination of a private key and a public key. The private key is possessed only by the user or computer that generates the key pair. The public key can be distributed to any person who wishes to send encrypted data to the private key holder. It is impossible to compute the private key if the public key is known. Hence it is safe to publish the public key. The key pair is based on prime numbers of long length. One very popular public-key encryption program is Pretty Good Privacy (PGP). To implement public key encryption with certainty of the identity of the key requester on a large scale, it requires digital certificates. PGP utilizes a certifying group called a "Community of Trust."

A digital certificate is a unique piece code that allows a record of user's credentials by an independent source known as certificate authority. The Certificate Authority verifies the entity's credentials and certifies that they are who they say they are.

The major asymmetric encryption algorithms are known as Diffie-Hellman [27], RSA, ElGamal, Elliptic Curve Cryptography (ECC) and Digital Signature Algorithm (DSA).

The key in public-key encryption is based on a hash value. This is a value that is computed from a base input number using a hashing algorithm [16]. A hashing algorithm takes a variable length data message and creates a fixed size message digest. It's a one way function such that a little modification made to the data will change the hash value. Birthday attacks [16] are one of the useful concepts that paved the way for a better understanding the limits in cryptographic systems. It is often used to find collisions of hash functions. If the output length of the hash function is n bits, the attack finds a collision with better than 50% probability trying out no more than $2^{n/2}$ hash function evaluations. To avoid this attack, the output length of the hash function used for a signature scheme can be chosen large enough so that the birthday attack becomes computationally infeasible. Another important concept is unicity distance defined by Shannon [2]. Unicity distance is the minimal length of an original cipher text needed to break the cipher by reducing the number of possible spurious keys to zero in a brute force attack.

Why is Error-correction Needed and Alternatives

Whenever information is transmitted through real channels it may be changed by natural or intentional (jamming) causes. If the information contains redundancies it may be possible to overcome the errors that have occurred regardless of cause. This is only possible with certainty if the error that has taken place affected fewer bits than the largest integer less or equal to half (floor) than the Hamming distance between the damaged and the original block.
The issue of errors in the transmission becomes particularly critical if the information is encrypted. The process of decryption depends strictly in having no duplicates of the encrypted message that would provide more than one decrypted result given the previous or associated symbols. Should an error occur the decrypting process would either not produce a meaningful result or it might, although unlikely, provide a wrong result. Should the code have been broken signs that a decryptable but unexpected plaintext is obtained would point to the code breach.

It is therefore desirable to apply the techniques of error correcting codes to encrypted information, lest errors render the message undecryptable.

It is possible to combine the error correction approach with the encryption approach. However, error correction is carried out at the physical layer of the network while security by encryption is done at the upper layers. The approach that has been proposed and implemented [28]. It has been called "cryptocoding" as combining encryption and error correction

Error correction will continue to be an indispensable part of securing a recoverable decryption in noisy channel communications.

Cloud Computing and Homomorphic Encryption

Cloud computing is a model for enabling convenient, on demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [29]. Vivek Kundra (first chief information officer of the United States) explains this technology in a simple analogy as "There was a time when every household, town, farm or village had its own water well. Today, shared public utilities give us access to clean water by simply turning on the tap; cloud computing works in a similar fashion. Just like water from the tap in your kitchen, cloud computing services can be turned on or off quickly as needed. Like at the water company, there is a team of dedicated professionals making sure the service provided is safe, secure and available on a 24/7 basis. When the tap isn't on, not only are you saving water, but you aren't paying for resources you don't currently need" [30].

Thus, cloud computing is empowering people with internet access to run, and manage data and applications more efficiently from anywhere. This technology is gaining popularity making every sphere of society dependent on it in some manner. Security is required for any technology's existence, so as researchers and academicians we certainly have a responsibility to lay the fundamentals and challenges of cloud computing and security in school via an organized course. The following are the key topics and principles covered:

A. **Cloud Computing as a utility (Services)** includes Infrastructure as a Service, Platform as a Service, and Software as a Service.
B. **Types of clouds (Deployment)** include Public Cloud, Private Cloud, Community Cloud and Hybrid Cloud.

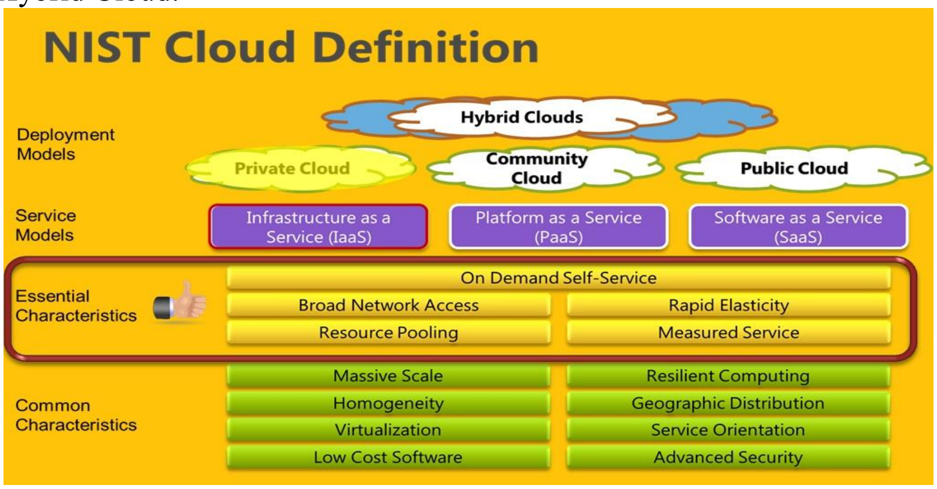


Figure 3: Framework of cloud computing as given by NIST [31]

Challenges: Major challenges with their percentages faced by organizations that prevent cloud computing to be adopted are listed in the Figure 4. Its main challenge as quoted by Cisco CEO John Chambers, describes cloud computing as security nightmare which cannot be handled in traditional ways. One of the most promising solutions for this is Homomorphic encryption as discussed in next section.

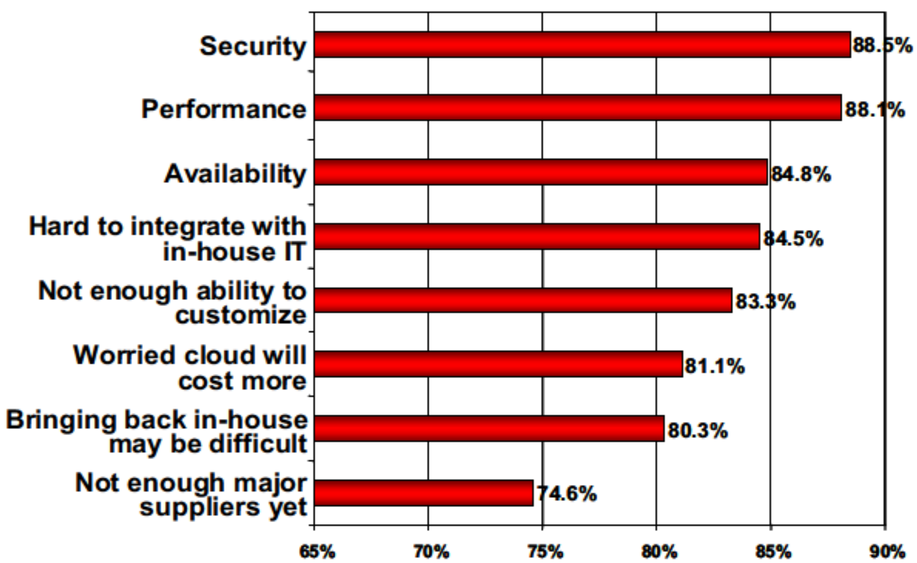


Figure 4: Adoption challenges faced by cloud computing [32]

Homomorphic encryption: There are conceptual and practical advantages in looking at the continuum flow of information to and from the Clouds being compressed for efficient transmission to being encrypted for privacy to then being augmented for error correction to its destination and then proceed in reverse order to retrieval. But, if the cloud provider has to decrypt the data first to perform the computation and then send the encrypted result to the user, raises the issue of issue of privacy and confidentiality which existed at the sender side prior to communication. To overcome this, the idea of homomorphism encryption allows transformation of ciphertext *C(m)* of message m, to ciphertext *C(f(m))* of a computation/function of message m, without disclosing the message [33]. A simple example over integers is shown in Figure 5.

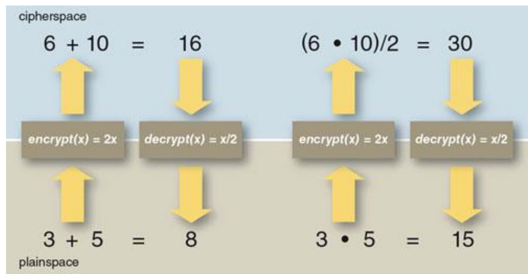


Figure 5: Example illustrating Homomorphic encryption [34]

Full Homorphism: *Groups G, H* $f: G \rightarrow H$ such that for any elements $g_1, g_2 \in G$,

$$f(g_1 * g_2) = f(g_1) *' f(g_2)$$

where * denotes the group operation in G and *' denotes an operation in H. If there is more than one operation as in algebraic fields, the homorphism must hold for all operators. Examples include Craig Gentry's lattice-based homomorphic encryption and Van Dijk et al, fully homomorphic encryption over the integers.

Partial Homomorphism include Benolah, Goldwasser-Micali, Paillier cryptosystems etc.

Students' Response to the Course

We have been traditionally studying Compression, Encryption (Security) and Error Control as three different threads of Information Theory. Although the relation between them is established, but it has never been organized in a way to discuss their interdependence and impact on the information generation and delivery to the end node (in the era of revolutionary dynamic Internet). The relationship between the three threads was well discussed while covering each topic of the lecture. Series of comprehensive homeworks on topics like L-Z compression, AES encryption, Compressed sensing etc. gave us more insight into the details of each one. Practical aspects of the course were covered through implementation of projects ranging from Elliptic Curve encryption to simple RLE encoding schemes. Apart from the home-works and projects, discussion on the new research ideas and relevant papers were a part of the routine class group discussion.

While this content could have been distributed in a more traditional pedagogical approach of separate focused courses, the unique format of this course lead to furthering the student's ability to not only recognize other applications of the concepts covered, but to develop the valuable ability of connecting concepts and theories across disciplines. A traditional approach may have yielded more competence in applying the current techniques of compression, encryption, and error correction. The students might have been more skilled at algorithmic development for the implementation of a specific encryption scheme, for instance. But that deep knowledge would gradually become less useful, as the implementation specifics and schemes evolved over their careers. Instead this course provided the students, something that would become gradually more useful over their careers – to expose them to how basic concepts are interweaved among technological solutions of seemingly different types. Not only has this lead to a firmer grasp of the fundamental tenets of information theory, but to the ability to apply these concepts to new problems. Instead of studying solutions, this course has studied how concepts are applied to problems. Engineers of this century will not be assigned solutions to learn about, but problems to solve. Exposing this subject matter in this way has lead the students to not only apply the content from this course in this way, but to imagine other applications of cross-disciplinary techniques that might be possible with other knowledge areas of the broad field of engineering. The importance of applying existing ideas to new problems cannot be understated, as it has been the bud of new discovery many times, and history is sure to repeat itself if we train ourselves to think in this manner.

The course was taught very well and the more challenging concepts were covered such way that it was a delight to research with the intent of gaining a better understanding of the purpose and application of these concepts. The topic lineup was well laid out and presented to the class in a timely manner. One suggestion would be is to give students a choice of doing individual or group projects at the beginning of the term.

Conclusions

In the present and near future, the overwhelming influence of network communications in all aspects of our society is going to require efficiency, security and reliability to a degree never before required. Those are characteristics are demanding the development of a more robust science of information transformations that provide above all security, integrity and authentication of the information being communicated. The challenges as outlined are significant and will require the collaboration of many engineers, corporate entities and academia to meet them.

The approach presented in this course consists of sequential transformations founded on principles of entropy, complexity, randomness, cryptology and error control with common algebraic, algorithmic and probabilistic communication theory and computer science basis:

1. Information, randomness and its determination, entropic and complexity metrics, and their importance in determining the limits of compression and the use of redundancy, confusion, diffusion in our endeavor.
2. The representation of information in audio, graphic, video or data formats in blocks and streams and its practical requirements for efficiency, security and error control
3. Extraction of redundancy by compression and its lossless and lossy technologies. Lempel-Ziv and probabilistic compression. Commonality of the approaches, refinements and evolution of sampling and perceptive optimization advances.
4. Authenticity, security, integrity, non-repudiation, and the protocols that may be used to guarantee them. Evolution of approaches and standards through cryptography hash one-way, discrete logarithms and factorization basis. Classical and elliptical curves responding to faster computation and potential quantum computing expectations.
5. Rationale for compressing before encrypting and the needs to avoid errors in communication channels the may inhibit the decryption. Considerations of possible exceptions to this order of operation under certain applications such as in the distributed sensor networks (with Slepian-Wolf correlations).
6. The changes in information content by the reduction of redundancy, permutations, selective mapping in higher dimensions and the efficient implementation of their inversion at the user with the potential of full homomorphic encryption throughout processing in a less vulnerable cloud use.
7. Processing and services at the cloud, risks and virtualization isolation assistance. Software, storage, processing
8. The overall objective is a world with an efficient, secure and connected flow of information, in providing goods and services to better satisfy societal needs.

This course and the approach taken have been extremely intellectually rewarding to the teacher and his students alike.

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Conceptual Architecture Planning for Manned Geo Satellite Servicing

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Abstract

In an effort to quantify the feasibility of candidate space architectures for manned geostationary (GEO) satellite servicing (MGS), NASA and DARPA have teamed up with the Aerospace Vehicle Design (AVD) Laboratory at the University of Texas Arlington (UTA) in order to provide a conceptual assessment of architecture/concept of operations/technology combinations. The primary challenge has been the exploration of past, present, and future in-space investments in the context of mission performance, mission complexity, and industrial capability. Consequently, this study necessitated the use of a simulation capability to assess and visualize the physical design drivers and sensitivities of the operational and technical domain.
The overall goal of the study has been the development of a system with the capability to transfer payload to and from GEO. To this end the following concepts of operations (ConOp) have been studied: direct insertion/reentry (ConOp 1), and launch to low earth orbit (LEO), at Kennedy Space Center (KSC) inclination angle, with an orbital transfer to/from GEO (ConOp 2). The technology elements traded varied between hardware for in-space maneuvers, aero-assisted maneuvers, and reentry vehicles.

This report introduces the AVD Laboratory's product development and technology forecasting methodology as applied to the problem introduced above. Because the focus of this activity has been on the exploration of the available solution space, a unique screening process has been employed to assess the implication of (a) the mission, (b) hardware/technology selection, and (c) the operational scenarios on key research objectives to be defined.
The study concludes that a Capsule + Descent Propulsion Module (DPM) system sized for the MGS mission is feasible for a direct insertion/reentry concept of operation. Vehicles sized for orbital transfer from LEO-KSC to GEO-0, and back to LEO-KSC (ConOp 2) show a total mass savings when utilizing Aero-assisted Orbital Transfer Vehicle (AOTV) DPM options compared to the pure propulsive baseline case. Overall, the selection between AOTV concepts and a

reusable/expendable Ascent Propulsion Module (APM) must come from considerations of their maintenance/durability and total cost of operation with an associated flight rate.

Nomenclature

OTV = orbital transfer vehicle

AOTV = aero-assisted orbital transfer vehicle

CTV = crew transfer vehicle

TPS = thermal protection system

UNW = unit weight

β = ballistic coefficient

C_D = drag coefficient

L/D = lift-to-drag ratio

GEO = geostationary earth orbit

LEO = low earth orbit

KSC = Kennedy Space Center inclination orbit

APM = ascent propulsion module

DPM = descent propulsion module

SBCM = space-based crew module

Introduction

The current study, manned GEO servicing (MGS), has been conducted as part of a joint research activity between NASA and DARPA in order to assess technology development and investment by both agencies. The goals of the MGS study are technology, concept, and architecture assessment/forecasting for manned servicing missions within the next 5 to 10 years.

The MGS research project is decomposed into five constituents; Team 1 - Hardware to GEO, Team 2 - Crew to and from GEO, Team 3 - Human Presence, Team 4 - Human/Robotics Synergy, and Core Team - Project Definition and Synthesis. As a member of Team 2, the Aerospace Vehicle Design Laboratory (AVD Lab) is responsible for the assessment of technology/vehicle requirements to transfer crew to and from GEO. This article summarizes the

AVD Lab systems-level solution space screening process and solution space screening for the variety of crew transfer and return vehicle concepts and technology for the two primary MGS concept of operations considered; (1) direct insertion and return from GEO, and (2) orbital transfer to and from GEO.

AVD Sizing Process

The AVD sizing process is a 'best-practice' methodology based on parametric sizing processes developed from a comprehensive review of commercial transport aircraft, hypersonic cruisers, expendable and reusable launch vehicles from 1936 to the present [1]. This process has been applied to transonic commercial transports, supersonic business jets, hypersonic cruisers, launch vehicles, re-entry vehicles and in-space elements. The generic process is shown in Figure 1 with highlighted modifications for in-space elements required for the current MGS study.

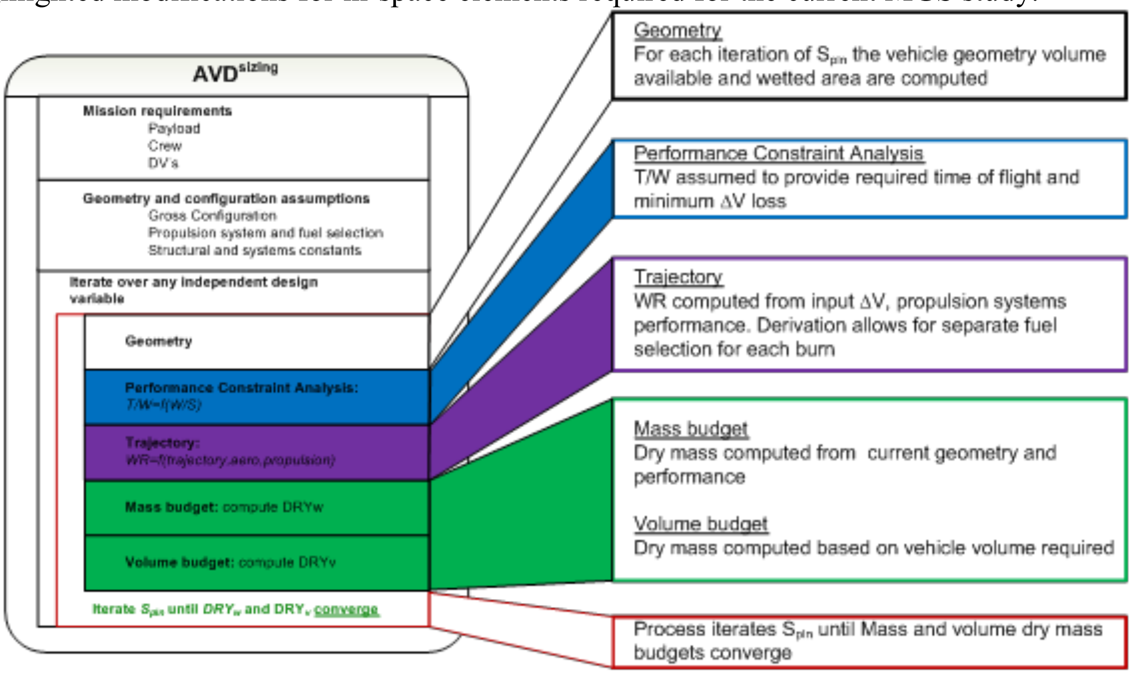


Figure 1. AVD parametric sizing process applied to in-space element sizing.

The sizing process is implemented in modular FORTRAN 77/90 source code consisting of 194+ subroutines linked with a dedicated database management system (DBS). Within the execution of one convergence cycle, a text file database is produced of all relevant vehicle parameters. If a module requires information which is not passed directly to the subroutine, it can access and rewrite the current vehicle database. This straight forward DBS system allows for easy integration of multi-platform and multi-language disciplinary methods.

The final piece of this process is the Aerospace Sizing Disciplinary Methods Library. This library consists of 70+ documented and implemented methods for geometry, aerodynamics, propulsion, mass and balance, performance, etc. This library serves as quick reference for each method's assumptions, application, and Input-Analysis-Output (I-A-O). This library is not a static document. The Methods Library is used to document experience with disciplinary methods, including accuracy, runtime, and additional applicability discovered. The result is a living document to communicate design and disciplinary experience that allows for correct usage of disciplinary analysis. Together, the generic convergence logic, modular implementation, and dedicated methods library allow for timely parametric sizing to address early design stage solution space screening and decision making.

Concept of Operations Descriptions

Team 2 explored two primary ConOps for MGS crew transportation to and from GEO. The minimum mass and complexity ConOp 1 consists of a crew capsule directly launched and returned from GEO is considered. The second is a reusable transfer system ConOp 2 utilizes a refuelable AOTV which transfers crew from LEO to GEO.

It is a focus of the current study to place all launch activities in the context of a production or near-production vehicle, notably the Delta IV class of rockets. This choice of launch vehicle constrains the diameter of all payloads launched to 5 m [13] and, along with the upper-stage propulsion module selected, defines the maximum payload insertion mass.

ConOp 1 - Direct Return Capsule Results

This ConOp is intended to be the minimum mass, minimum complexity mission. The upper stage of the launcher inserts the crew capsule + expendable descent module to GEO. After completion of the servicing mission, the descent module then transfers the crew to a direct reentry return. As such, this ConOp requires three in-space elements: (1) an expendable upper stage for insertion into GEO, (2) a crew capsule, and (3) an expendable de-orbit propulsion module (DPM). The study of ConOp 1 includes two primary components: (1) parametric capsule definition based on historical review, and (2) generic capsule and DPM sizing to the specific MGS mission.

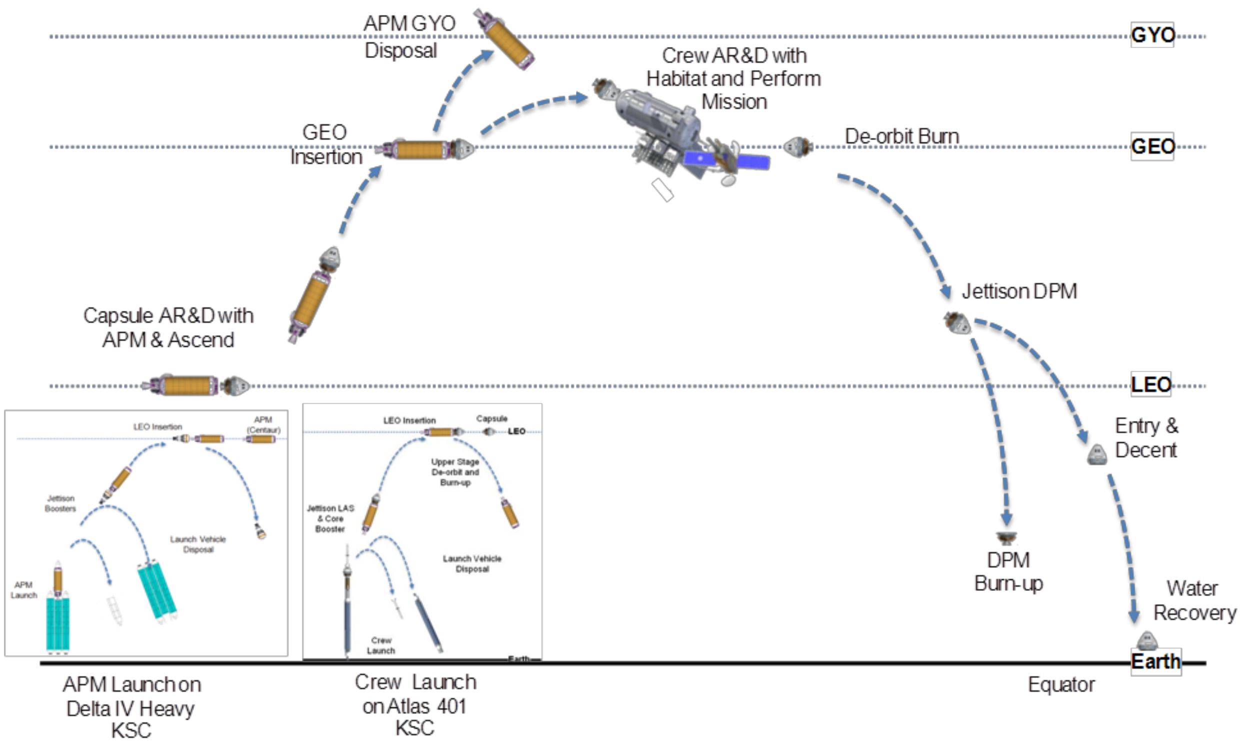


Figure 2. Direct insertion and return concept of operation. [3]

ConOp 1 Trade-Study Ground Rules

- Hypergolic fuels are utilized for commonality with other MGS elements. Early trade-studies demonstrate that methane does not provide a significant benefit for this ConOp.
- A volume of 2 m^3 per crew member with 4 days worth of provisions are provided (2 days up, 2 days down). The capsule volume is sized for a 2 consecutive day mission, rather than a 4 consecutive day mission.
- ILIDS docking mechanism assumed (211 kg).
- Attempt to keep CTV dry mass or inert mass under maximum Delta IV Heavy launch mass to LEO-KSC.
- Attempt to comply with Delta IV Heavy 5 m diameter faring.
- Attempt to keep peak heating and integrated heating loads under reusable TPS limits.

ConOp 2 - Aero-Assisted Orbital Transfer Vehicle LEO-KSC / GEO-0 / LEO-KSC

ConOp 2 explores the elements required for roundtrip transfer of crew from LEO (at KSC inclination) to GEO and back. It is assumed that an additional, standalone crew vehicle launches the crew from ground to LEO-KSC. This study is broken into two operational tracks: (1) an

expendable Ascent Propulsion Module (APM) and (2) a reusable APM. Figure 3 represents an operational concept diagram for ConOp 2. It should be noted that a pure propulsive variant of ConOp 2 is included as the baseline for comparison with aerobraking concepts.
Expendable Ascent Propulsion Module

For this ConOp 2 branch, the expendable APM is launched, docked with the crew vehicle, and then transfers and inserts the crew vehicle to GEO before being discarded. The crew vehicle's integral DPM transfers the crew back to GTO, an aerobrake maneuver is accomplished with the AOTV structure, and a small LEO insertion burn is performed to return the crew to LEO (except in the pure propulsive case where propellant is utilized in place of the aeromanuever to complete LEO insertion). A commercial crew return vehicle is then required to dock with the AOTV for crew return to Earth.

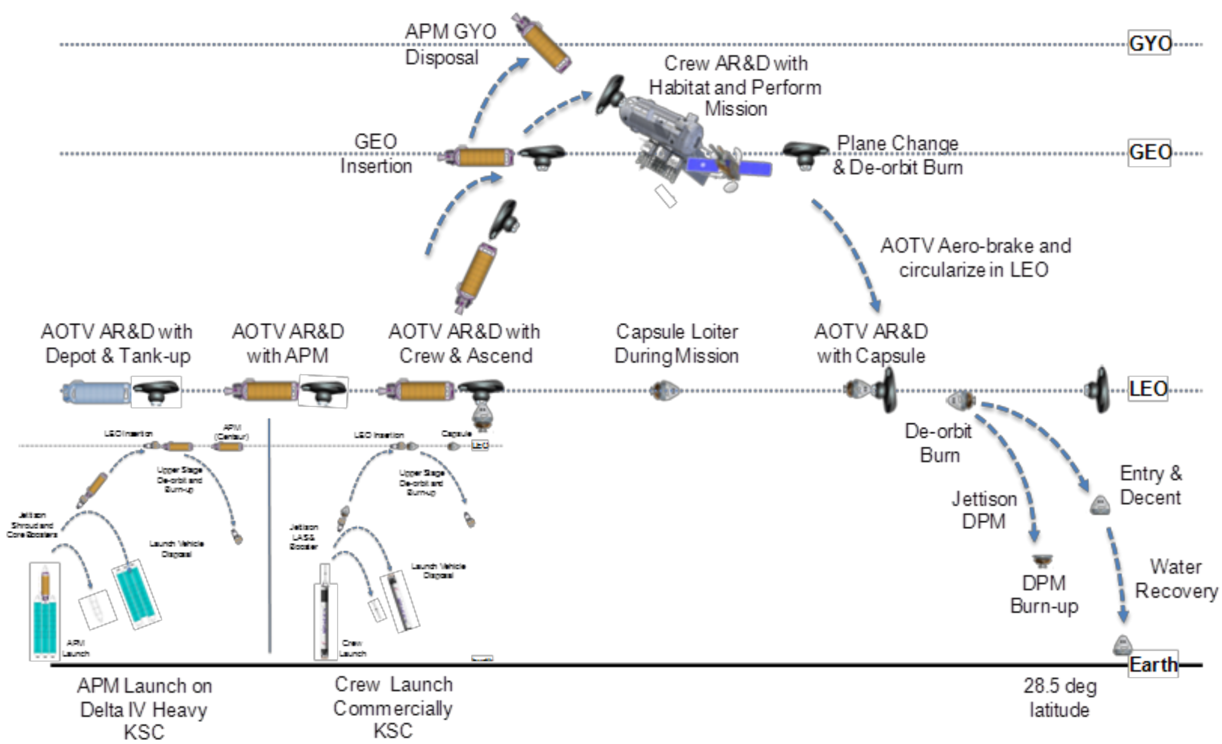


Figure 3. LEO insertion, orbital transfer to/from GEO, LEO return concept of operation. [3]

Reusable Ascent Propulsion Module

Hydrogen is utilized for the APM to reduce the fuel mass required to reach GTO. The DPM uses hydrogen for the GEO insertion burn (stored in drop tanks) and then uses methane for the de-orbit, plane change, and LEO circularization burns, requiring a dual-fuel LH2/CH4 Engine. The

APM will separate from the payload and DPM at GEO, autonomously perform an atmospheric pass to reduce orbital altitude, and re-circularize at LEO to be used for future missions.

<u>ConOp 2 Trade-Study Ground Rules</u>

- A volume of 2 m^3 per crew member with 4 days' worth of provisions is provided (2 days up, 2 days down). Early studies show that greater crew volume results in an excessive mass penalty. Thus, the capsule volume is sized for a 2 consecutive day mission, rather than the 4 consecutive day mission.
- ILIDS docking mechanism assumed (211 kg).
- Attempt to keep CTV dry or inert mass under maximum Delta IV Heavy launch mass to LEO-KSC.
- Attempt to comply with Delta IV Heavy 5 m diameter faring.
- Attempt to keep peak heating and integrated heating loads under reusable TPS limits.

Vehicle Concept Description

In order to apply the sizing process described in Section II to the specific mission and vehicle combinations in Section III, an analytic description of the geometry and weight of each vehicle element is needed. A literature review of established space vehicle projects pertaining to the vehicle elements required for MGS establishes a database and knowledge-base that is the basis for all vehicle and architecture sizing activities presented.

Capsule

The capsule utilized for the minimum-complexity ConOp 1 demands parametric geometry and mass descriptions. Figure 4 shows the capsule geometry parameterization consisting of a spherical cap connected to a conical frustram, Equations 1-6 derive the geometric relations of the needed parameters to the overall diameter of the capsule, and Table 1 shows the non-dimensional values assumed based on reference vehicles [4]. The TPS configuration of a capsule involves a high-temperature ablative material located on the windward spherical cap, whereas the leeward conical frustram features a low-temperature ceramic tile TPS, both of which are high-maturity technologies. It is shown from both theory and practice that the mass of TPS per surface area remains relatively constant for capsules [4], therefore areal weights are assumed constant for current TPS technologies as well as for structural support. All areal weight values assumed are shown in Table 2.

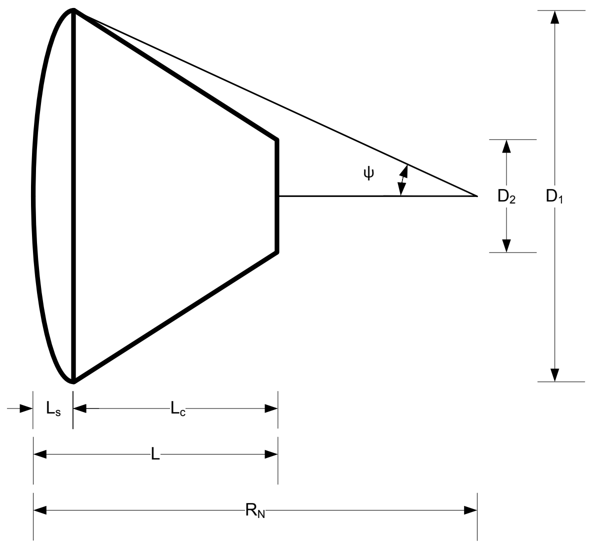


Figure 4. Geometry parameterization of generic re-entry capsule.

1) $\psi = \arcsin\left(\frac{\frac{1}{2}}{R_N/D_1}\right)$

2) $L_s/D_1 = R_N/D_1 - \frac{\frac{1}{2}}{\tan(\psi)}$

3) $S_{\text{spherical cap}}/D_1^2 = 2\pi\, R_N/D_1\; L_s/D_1$

4) $L_C/D_1 = L/D_1 - L_s/D_1$

5) $S_{\text{conical frustram}}/D_1^2 = \pi\left(\frac{1+D_2/D_1}{2}\right)\sqrt{\left(\frac{1-2\,D_2/D_1+\left(D_2/D_1\right)^2}{2}\right)+\left(L_c/D_1\right)^2}$

6) $UNW_{avg} = \frac{UNW_{ablator}S_{\text{sperical cap}}+UNW_{\text{Sidewall}}S_{\text{conical frustram}}}{S_{\text{sperical cap}}+S_{\text{conical frustram}}}$

Table 1. Capsule geometry relations

Geometry	Value
R_N/D_1	1.20
L/D_1	.65
D_2/D_1	.30
Ψ	24.70°

Table 2. Capsule areal weights

Component	UNW, kg/m^2
Ablator TPS	6.59
Tile TPS	8.98
Average TPS	8.04
Structure [5]	24.40

All-Propulsive OTV

As a baseline configuration for ConOp 2, an all-propulsive OTV is established in order to assess the delta- improvement in propellant mass of an aerobraking OTV. The mass of the all-propulsive OTV is dominated by the propellant mass as a direct result of the ΔV budget allotted for the mission.

Aerobraking OTV's

Aerobraking vehicles are subject to a demanding aero-thermal environment, and to ensure both the physical and logistical feasibility of vehicle and architecture designs, constraints are implemented into both the computational sizing process and the off-line analysis. The aero-thermal constraints considered for the MGS study are: (1) wake impingement heating, and (2) stagnation point nose heating.

Wake Impingement Heating

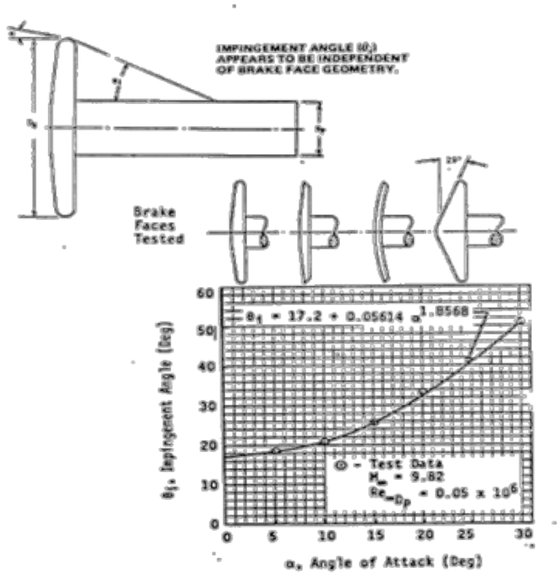


Figure 5. Wake impingement angle versus angle of attack for open aerobrake vehicles [8]

Afterbody heating is a major consideration in the TPS layout development of OTV concepts. Past studies have shown that in open aerobrake structures (deployable and raked cone aerobrake vehicles), the angle between the edge of the forebody structure and the area of increased heating is a known function of angle of attack (Fig. 12). By implementing this impingement angle as an active constraint on the vehicle layout, the aerobrake geometry can be sized such that the payload and systems located behind the main aerobrake structure do not require a high-temperature, high-density TPS.

Stagnation Point Nose Heating

Stagnation point heating at the nose of a re-entry vehicle governs the TPS material required, which in turn affects the reusability and weight of the vehicle system. As a first order approximation, an empirical relation between ballistic coefficient, hypersonic *L/D*, nose radius, and stagnation point heat transfer rate has been developed for aerobraking vehicles [7]. This relationship has been utilized to identify areas of unreasonable heating environments within the vehicle trade space. In the context of equation 7, maximum heating rate is known as a function of TPS material selected, while the ballistic coefficient and hypersonic *L/D* are determined from the geometry/mission definition of the vehicle. Equation 7 then yields the minimum feasible nose radius for a given combination of vehicle configuration and technology.

$$\dot{q}_{MAX}\sqrt{R_N} = 7.3(\beta)^{.467}\left(\frac{L}{D}\right)^{-.242} \qquad \left[\frac{W\sqrt{m}}{cm}\right]$$

Off-line, Team 2 hypersonic aerothermodynamic analysts at NASA Johnson performed computational mission-specific trajectory and heating simulations. This information was incorporated into the sizing knowledge-base and led to more accurate TPS material requirements and overall vehicle mass estimates.

AOTV Concepts

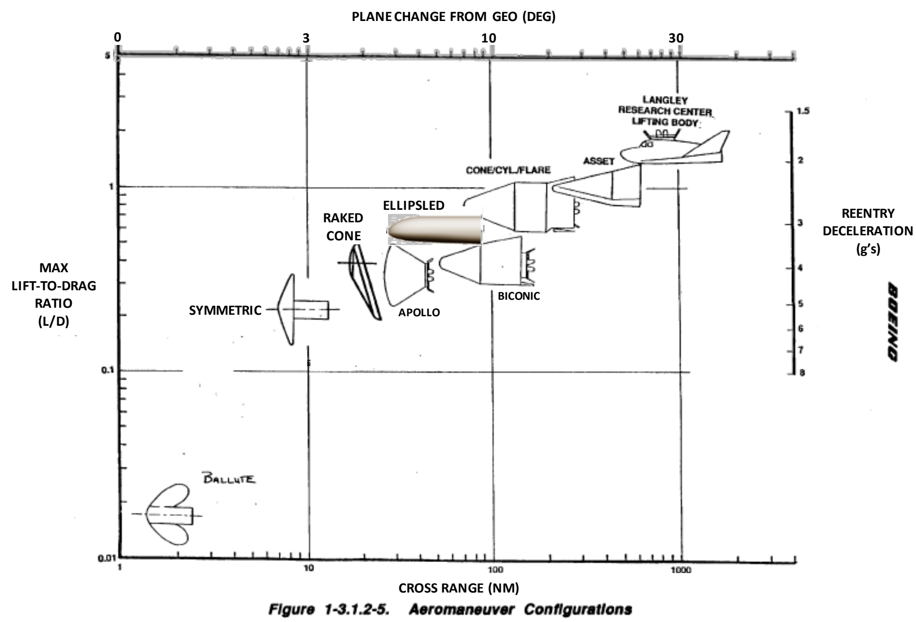


Figure 6. Relative performance of aerobraking and re-entry vehicle concepts (modified from [6])

Aerobraking performance is governed by the ballistic coefficient [β], defined as the mass of the vehicle divided by the product of the drag coefficient and the reference area, and the hypersonic *L/D*. As β decreases, the greater deceleration the vehicle will encounter when passing through the atmosphere and as *L/D* increases, control authority improves, as does the ability to perform a propellant-free plane change maneuver during the atmospheric pass as shown in Figure 5. The current project involves three distinct aerobraking OTV concepts that allow for a range of performance to be quantified into a trade space by overall vehicle size and weight. The concepts, from low to high performance: (1) deployable symmetric aerobrake, (2) raked cone aerobrake, and (3) COBRA ellipsled aerobrake.

Deployable Symmetric Aerobrake

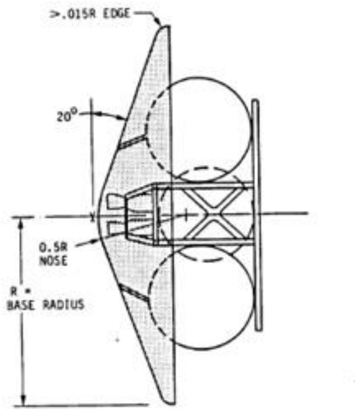


Figure 7. Symmetric aerobrake geometry [6]

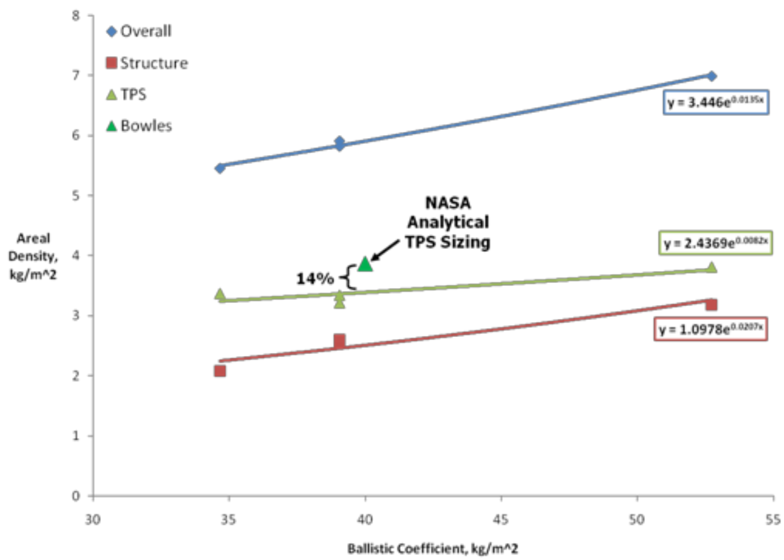


Figure 8. Parametric mass breakdown of deployable aerobrake [8, 9]

The first vehicle concept is the axis-symmetric conical aerobrake, which has the lowest aerodynamic performance (hypersonic *L/D* of approximately .12). The classical geometric shape has been well-studied theoretically, in hypersonic wind tunnels, and in production research spacecraft [7] (i.e., the Stardust and Hayabusa re-entry capsules). The axis-symmetric geometry shown in Figure 6, utilizes an operational scheme for in-space deployment of a portion of the aerobraking structure [8,9]. This concept has a flexible, TPS-supported, deployable outer substructure that is opened like an umbrella prior to the aeromanuever. By confining the rigid structure and TPS to only the centermost section of the aerobrake, this deployable structural configuration lessens the launch vehicle diameter constraints as well as reducing heating environments by increasing the allowable planform area of the aerobrake. Figure 7 shows a parametric assessment of structure and TPS areal masses derived from a data-base of deployable symmetric aerobrake concepts.

Raked Cone Aerobrake

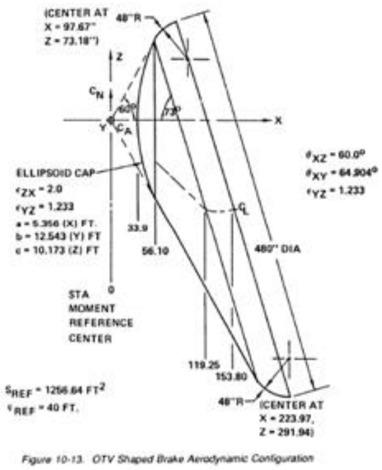


Figure 9. Raked cone aerobrake geometry [10]

As an alternative to the deployable aerobrake structure, a vehicle concept based on an existing-capability rigid structural layout was also considered. Through work for the Aeroassist Flight Experiment [8], NASA developed an asymmetric aerobrake concept (referred to as 'raked cone') with the intent of increasing hypersonic *L/D* to roughly .3. This increase in aero-performance comes at the price of higher ballistic coefficients, and therefore more extreme heating environments. A mass database of rigid aerobrake configurations [6, 8, 9, 10] develops a functional variation of structure and TPS masses with ballistic coefficient (Fig. 9), and is implemented within the sizing logic for mass estimation of raked cones.

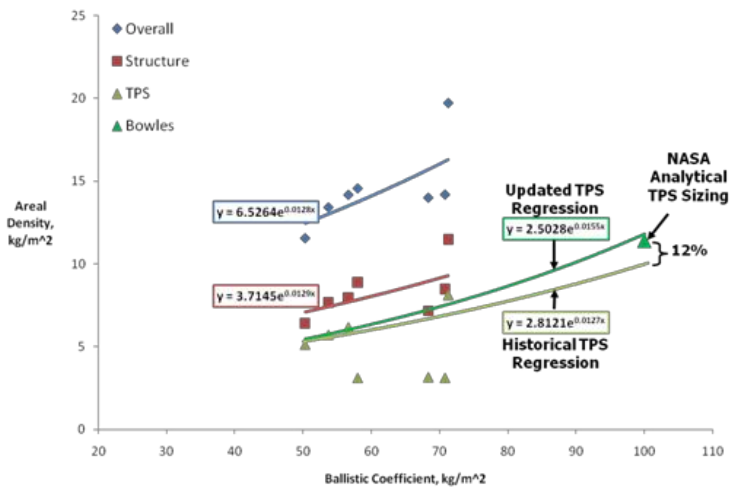


Figure 10. Parametric mass breakdown of raked cone aerobrake [6, 8, 9, 10]

COBRA Ellipsled Aerobrake

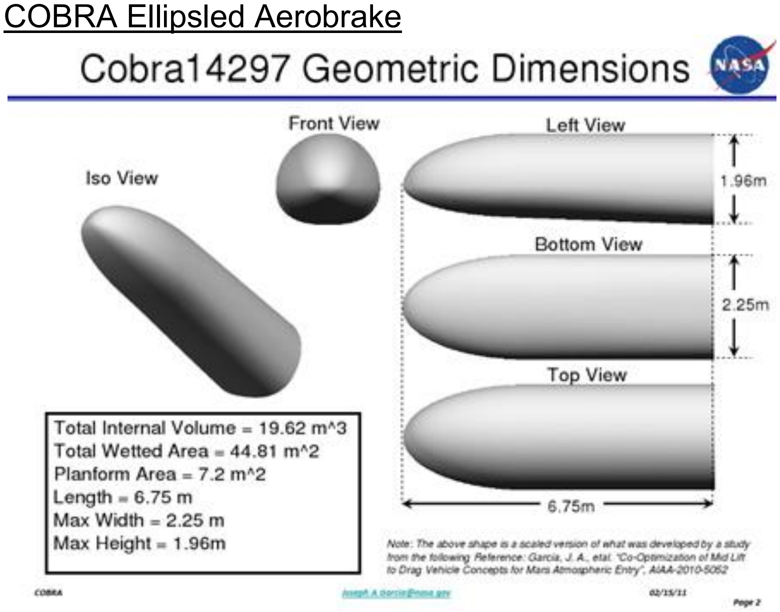


Figure 11. Ellipsled geometry [11]

The highest performance (hypersonic *L/D* of .5) aerobrake considered is the COBRA Ellipsled. This vehicle configuration is an enclosed aeroshell and therefore does not have a wake impingement constraint for protecting the payload. Because of this, the ellipsled aerobrake shows the potential to have the smallest cross-sectional diameter, allowing for easier launch packaging. However, this vehicle concept has increased TPS and structure areal mass densities, resulting in higher ballistic coefficients. The geometry required for an MGS payload results in smaller relative nose radii, producing extreme heating environments that exceed reusable TPS levels. The configuration may hold merit for design payloads with a volume requirement exceeding that of MGS; increase in vehicle size, relaxes the aeroheating constraint. The aeroshell definition and subsequent performance and mass estimates are based on the COBRA Ellipsled series of vehicle publications [11, 12].

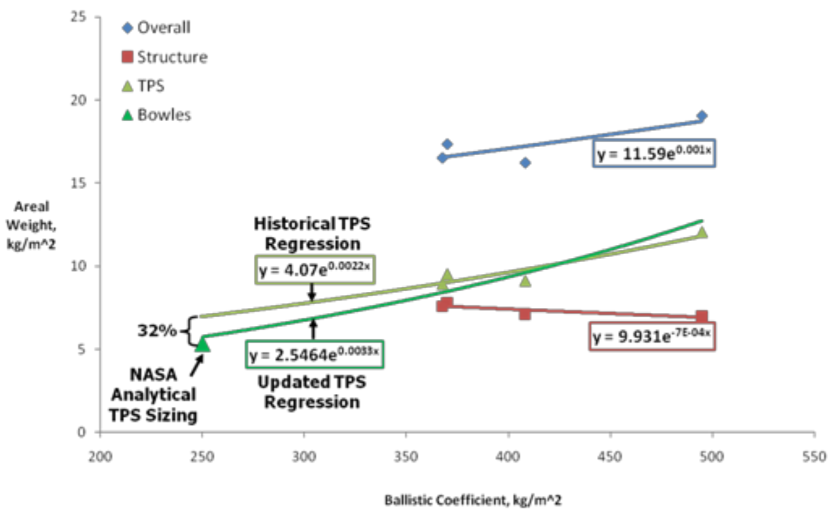


Figure 12. Parametric mass breakdown of ellipsled aerobrake [11]

Solution Space Visualization

Conop 1 – Direct Insertion/Reentry

The parametric generic capsule is utilized to explore the effect of number of crew and volume per crew on the size of an MGS Capsule. Figure 13 compares two-, three-, and four-crew capsules with varying crew volume. Passive gross mass constraints corresponding to Delta IV-Heavy maximum launch mass, Delta-IV Heavy with ACES upper stage, and dual launch Delta IV heavy with a delta cryogenic second stage (DCSS) ascent propulsion module for transfer from LEO-GEO are plotted in the trade space.

The selected MGS design point allows for three crew members with 2 m^3 allocated per crew member. The three-crew configuration was selected as the minimum required to perform the MGS mission (Team 3), and 2 m^3 per crew was determined acceptable for a two day trip going and two day trip back from GEO. As a result, this design point allows for two launch options: (1) dual launch of an existing Delta-IV Heavy, and (2) a single launch with a proposed Delta-IV Heavy with ACES. Table 3 summarizes the mass breakdown for this design point.

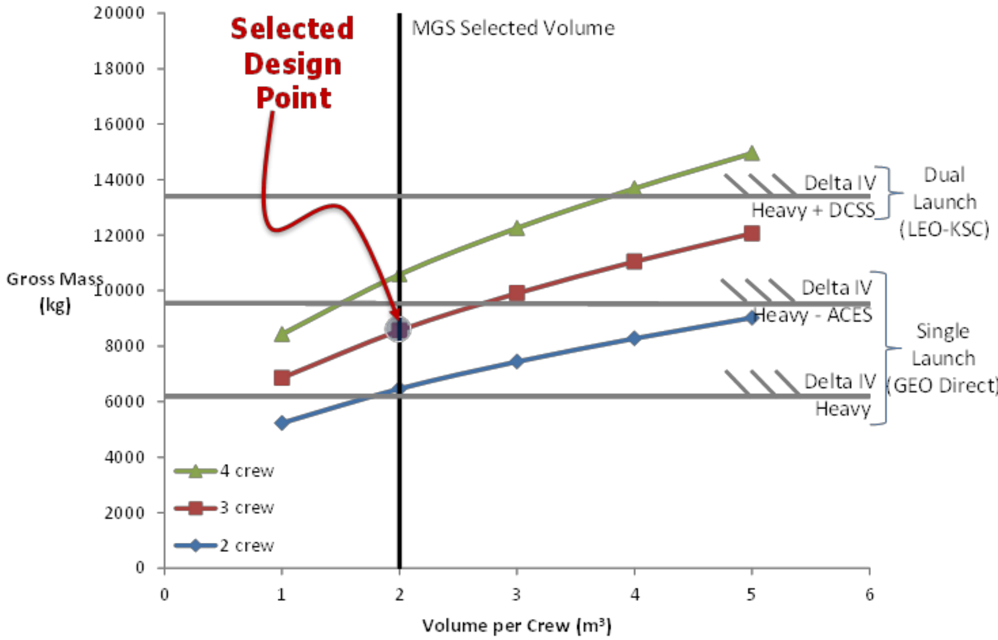
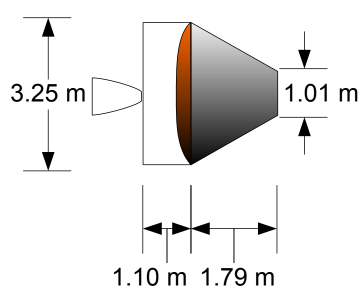


Figure 13. Effect of number of crew and volume per crew on capsule service module gross mass

Table 3. Design Mass Summary for Generic Capsule

Function	CM, kg	SM, kg	Total, kg	Geometry
Structure	570	237	807	
TPS	188	-	188	
Main Propulsion	0	385	385	
Systems	1827	474	2300	
Other	155	0	155	
Growth	556	219	775	
Dry Mass	3295	1315	4610	
Non Cargo	420	0	420	
Cargo	45	0	45	
Inert Mass	3760	1315	5075	
Non-Propellant	70	0	70	
Propellant	0	3384	3384	
Gross Mass	3830	4698	8528	



Summary of Results and Recommendations

The direct entry capsule represents the simplest ConOp explored for this study,

1. Crew volume and number of crew are primary drivers in the scale of the capsule.
2. MGS generic capsule shows feasibility with current Delta IV-Heavy launch vehicle

Conop 2 – Expendable Ascent Propulsion Module

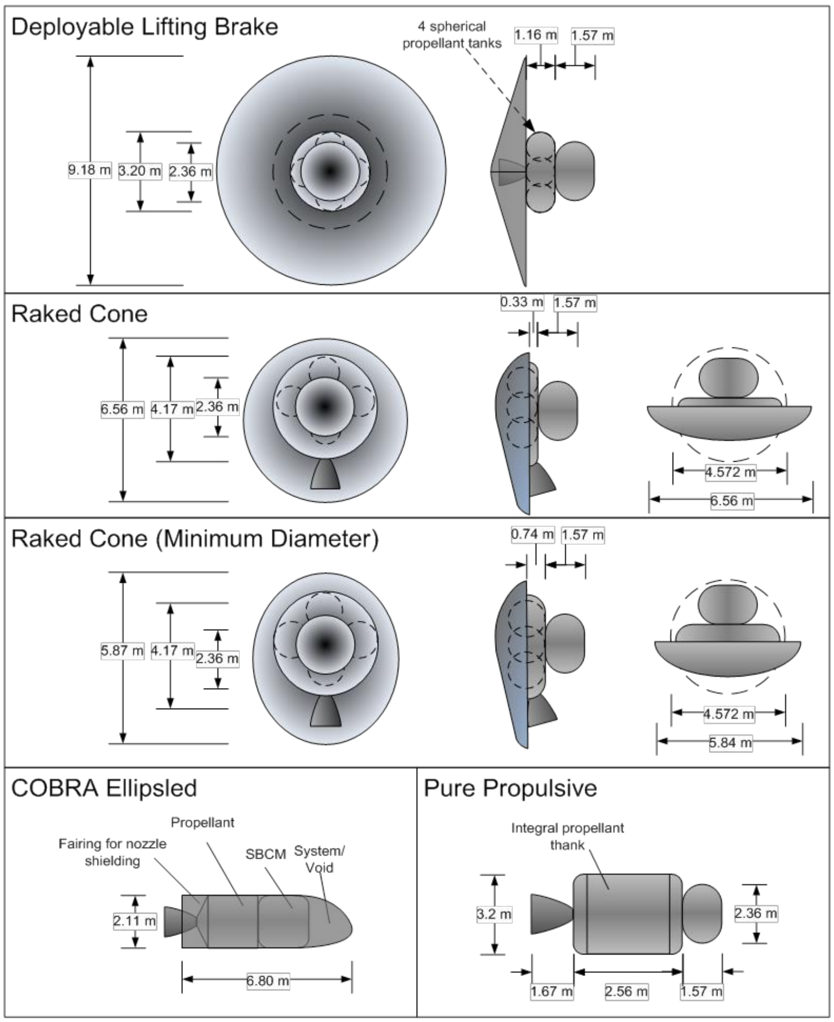


Figure 14. Geometric summary of OTV concepts – Expendable APM

For the Expendable APM branch of ConOp 2, five orbital transfer vehicle configurations are traded: (1) Deployable Aerobrake, (2) Raked Cone Aerobrake, (3) Minimum Diameter Raked Cone Aerobrake, (4) Ellipsled Aerobrake, and (5) Pure Propulsive Orbital Transfer Vehicle

(POTV). The Minimum Diameter Raked Cone is an extrapolation of lifting break regressions towards a high ballistic coefficient Raked Cone (~125 kg/m2). This has been done to determine if it is geometrically possible to fit a Raked Cone into the 5 m diameter Delta IV Heavy fairing and what (if any) TPS technology can handle these heat loads. All five concepts are summarized in Table 4 and Figure 14.

Table 4. Design Mass Summary for OTV Vehicles – Expendable APM

CTV	Deployable, kg	Raked Cone, kg	Raked Cone (min diameter), kg	Ellipsled, kg	POTV, kg
Dry Mass	3296	3880	4268	4367	3475
Propellant	3560	4100	4462	4553	12402
Reentry Mass	4101	4724	5140	5192	-
Gross Mass	7391	8515	9265	9454	16412
			Excessive Peak Heating No Convergence with TPS Analysis		

Comparison of Concepts

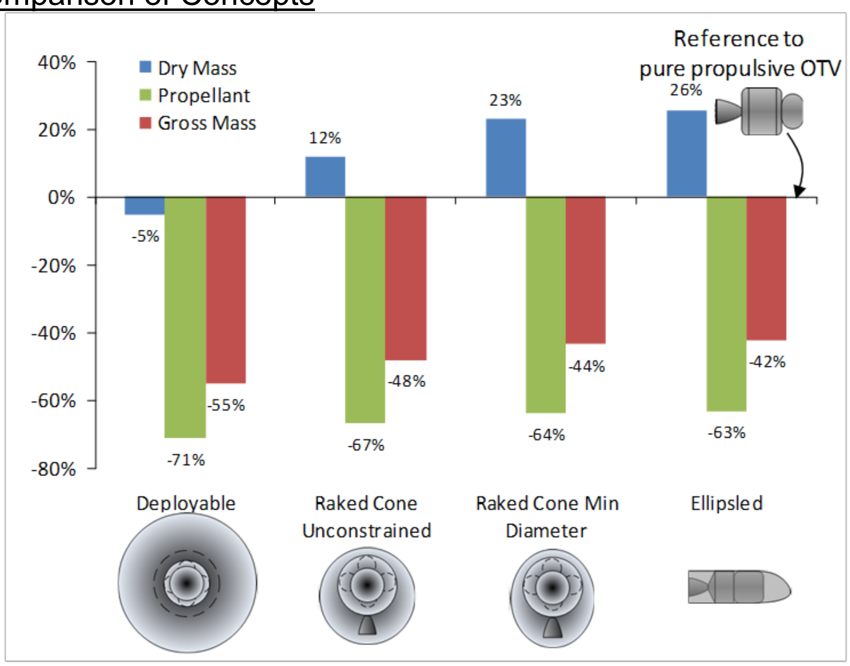


Figure 15. Comparison of AOTV mass savings relative to POTV – Expendable APM

In general, all converged AOTV concepts show promise for significant mass savings over the pure propulsive OTV. Figure 15 compares all four AOTV concepts to the pure propulsive OTV. The Deployable aerobrake shows the greatest propellant and dry mass savings with the Raked Cone showing similar propellant mass savings. Although the Raked Cone (Minimum Diameter) and Ellipsled also show mass savings, later aero-thermal analysis demonstrates that these solutions are not viable for reusable TPS due to peak heating loads. In addition, the Minimum Diameter Raked Cone still could not meet the 4.57 m constraint from Delta IV Heavy 5 m faring. Therefore, the unconstrained Raked Cone is suggested for further study, requiring some assembly in-space, or modification to the Delta-IV Heavy 5 meter fairing.

All things considered, AOTVs (Deployable or Raked Cone) show promise for this ConOp. Further study is required to select between the lighter but possibly less-durable Deployable AOTV, and the rigid, in-space assembled Raked Cone AOTV.

Conop 2 – Reusable Ascent Propulsion Module

Element mass estimation for ConOp 2 requires that DPM concepts be sized first, and then APM concepts can be sized based on the required up-mass of the entire system. Because several concepts for both the DPM and APM are considered, a matrix of possible architecture solutions is obtained.

Descent Propulsion Module

For this trade of ConOp 2, three OTV configurations are explored as possible descent propulsion module options in Table 5 and Figure 16: (1) Deployable, (2) Raked Cone, and (3) Pure Propulsive. The Minimum Diameter Raked Cone and COBRA Ellipsled have been excluded based on the results from the Expendable APM study, which concludes that these vehicles are impractical due to aero-thermal and small body radii considerations.

Table 5. Design Mass Summary for DPM OTVs – Reusable APM

CTV	Deployable, kg	Raked Cone, kg	POTV, kg
Dry Mass	4846	5713	5009
Propellant	9345	10871	23263
Reentry Mass	5381	6267	-
Gross Mass	14725	17120	28807

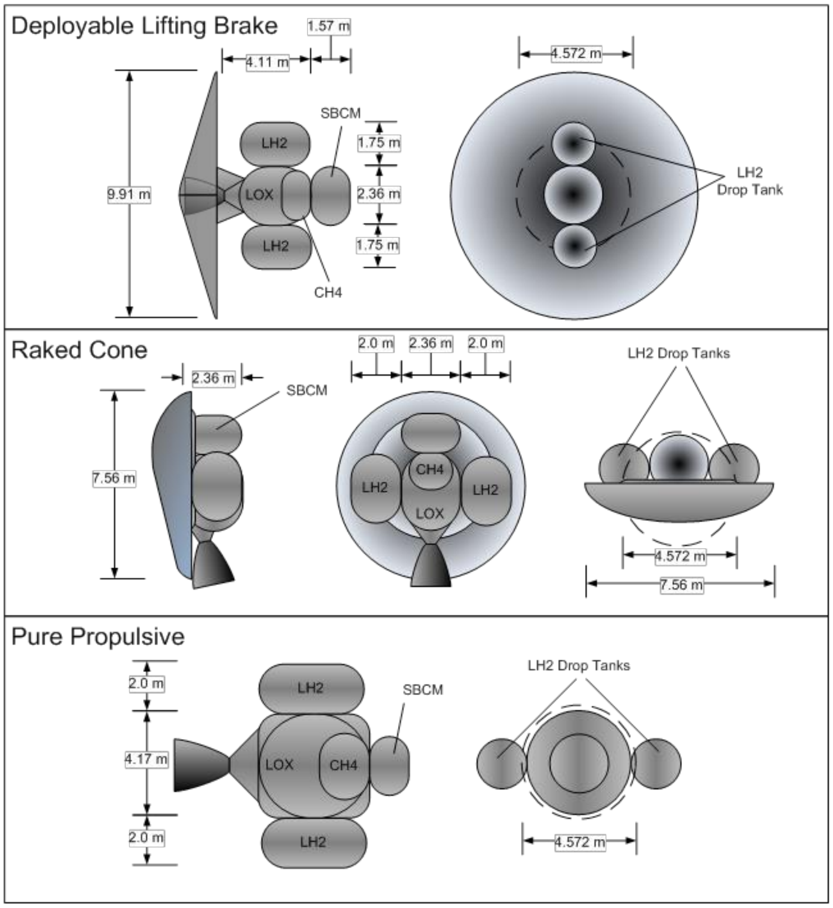


Figure 16. Geometry summary of OTV DPM concepts – Reusable APM

Comparison of DPM Concepts

As with the Expendable APM trade, the larger GEO insertion DPM benefits greatly from the AOTV concept in terms of propellant mass (Figure 17). The rigid Raked Cone structure results in an increased dry mass relative to the Pure Propulsive AOTV; however, the reduction in propellant mass more than compensates. Overall, the AOTV concepts show significant gross mass reduction which will allow for decreased propellant and dry mass of the reusable APM.

Ascent Propulsion Module

For this trade, four APM OTV configurations are explored: (1) Deployable, (2) Raked Cone, (3) Ellipsled, and (4) Pure Propulsive. The Ellipsled AOTV is reintroduced in this study because the increased propellant volume of LH2 and staging of payload (DPM) prior to aeropass reduces the ballistic coefficient and increases the body radii relative to the crew DPM from the Expendable

APM trade. Each APM is sized for each DPM possibility discussed in the previous section, leaving 12 total system configurations sized (4 APM x 3 DPM) (Table 6 and Figure 18).

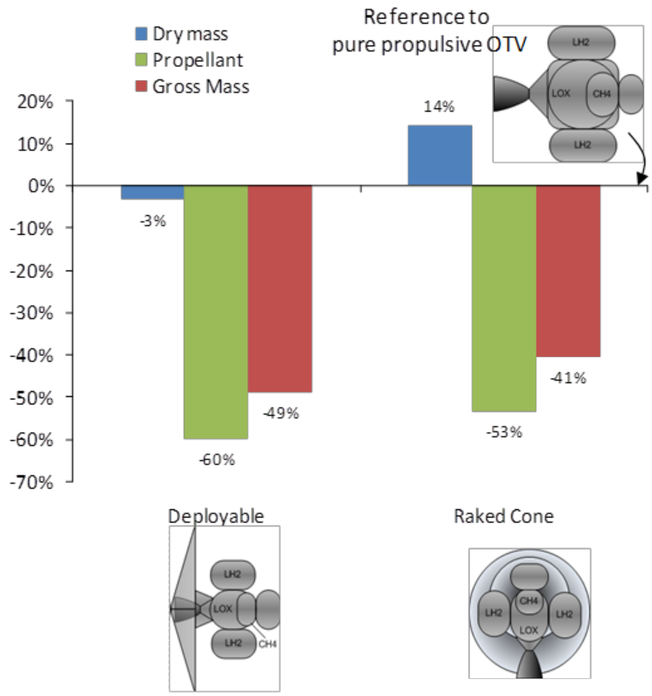


Figure 17. Comparison of AOTV DPM mass savings relative to POTV – Reusable APM

Table 6. Design Mass Summary for APM+DPM OTVs – Reusable APM

Function	Deployable Lifting Break APM			Raked Cone APM		
	Deployable DPM, kg	Raked Cone DPM, kg	Propulsive DPM, kg	Deployable DPM, kg	Raked Cone DPM, kg	Propulsive DPM, kg
Dry Weight	5084	5697	8528	5206	5571	8337
Propellant	15376	17704	28931	15477	17818	29101
Reentry Mass	5526	6201	9332	5656	6348	9550
Gross Mass	35185	40522	66266	35408	40510	66245

Function	Ellipsled APM			Propulsive APM		
	Deployable DPM, kg	Raked Cone DPM, kg	Propulsive DPM, kg	Deployable DPM, kg	Raked Cone DPM, kg	Propulsive DPM, kg
Dry Mass	7949	8674	11847	3996	4400	6233
Propellant	17698	20117	31623	19943	22670	35685
Reentry Mass	8513	9306	12795	-	-	-
Gross Mass	40372	45913	72277	38664	44191	70725

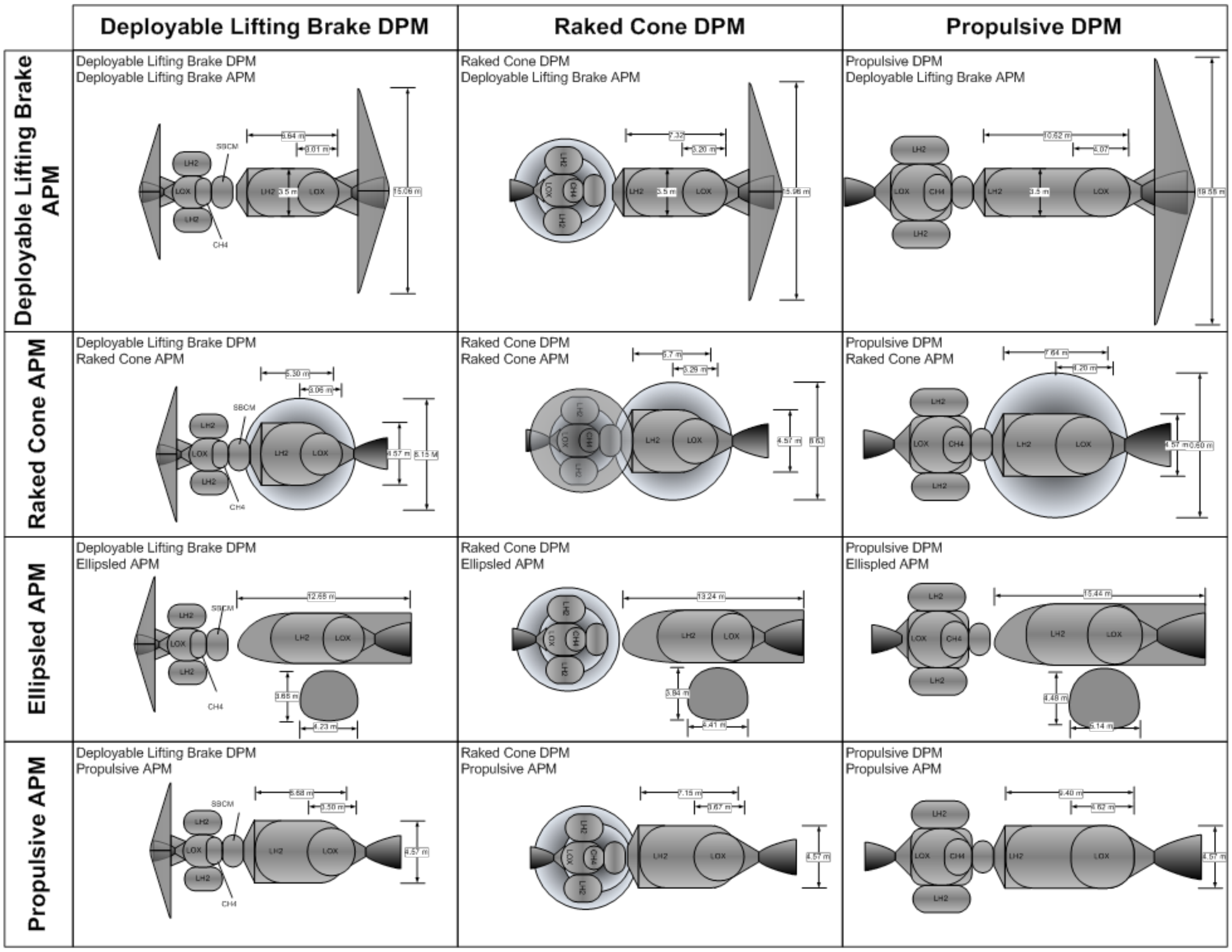


Figure 18. Geometry summary of OTV DPM+APM concepts – Reusable APM

When comparing the dry, propellant, and gross masses of the total APM+DPM system, it is clear that the primary driver for the AOTV DPM is the reduced total propellant mass, with the secondary driver being the APM concept (Figure 19). The selection of a Deployable or Raked Cone DPM results in roughly a 50 to 60% propellant reduction relative to the all propulsive systems, with the selection of the APM only having a 10 to 20% effect on the total propellant mass over its corresponding all propulsive concept.

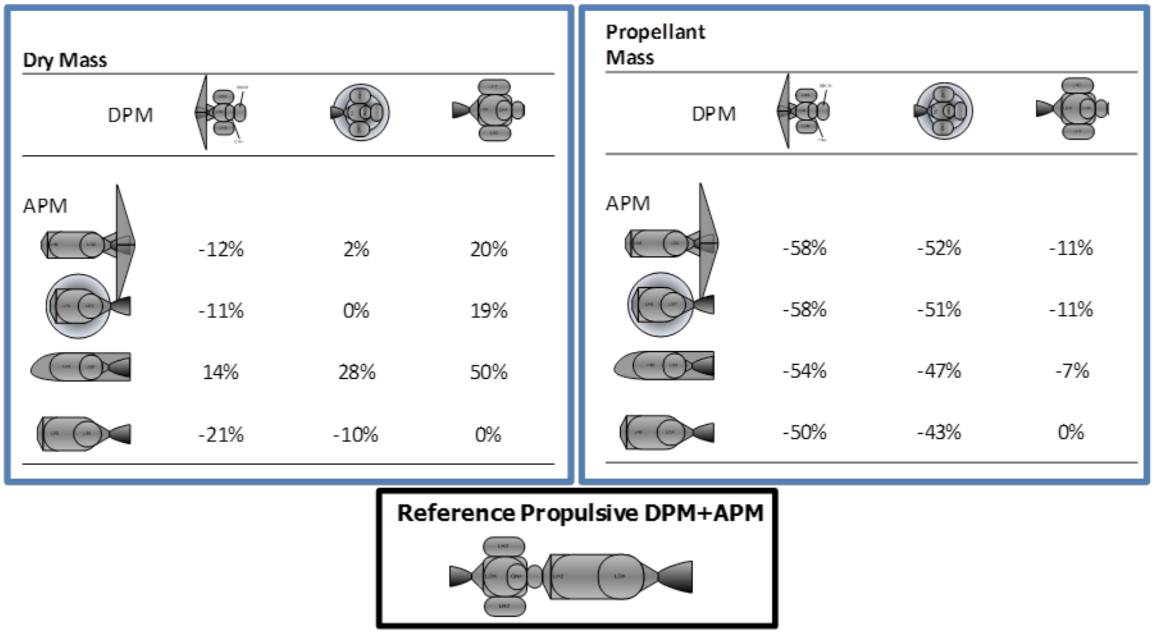


Figure 19. Comparison of 12 DPM+APM concepts relative to propulsive DPM+APM

The Reusable APM and DPM variation from ConOp 2 shows that the Deployable or Raked Cone DPM concepts will provide similar propellant mass, while the Raked Cone dry mass is 10% heavier due to the rigid structure and higher ballistic coefficient. The APM can certainly benefit from an AOTV concept, however, the selection between AOTV concepts must come from metrics other than mass alone. From this standpoint, all AOTV APM and DPM concepts could provide an operational benefit with a sufficiently high flight rate and low maintenance costs. Such cost comparison is beyond the scope of this study, but is required for realistic comparison between reusable and expendable crew transfer architectures.

Summary of Results and Recommendations for ConOp 2

Expendable APM Trade:

1. Deployable and Raked Cone aerobrake concepts show promise for reducing propellant mass in the crew return vehicle for return from GEO-0 to LEO-KSC.
2. Minimum Diameter Raked Cone and Ellipsled concepts present a reusable TPS material problem due to their high ballistic coefficient and small radii.

Reusable APM Trade:

1. APM concepts sized for LEO - GTO transfer with Deployable DPM.
2. The staging of the DPM results in a significant reduction in mass at LEO circularization. Thus, the pure propulsive OTV APM is not as severely penalized as the POTV DPM, which must return the SBCM. As such, use of an AOTV shows less mass-reduction

potential in APMs than in DPMs.

3. The Ellipsled has a greater TPS wetted area relative to the Deployable and Raked Cone concepts. This attribute along with the increased volume required to store the LH2 propellant results in a significant increase in dry mass over the propulsive OTV. As a consequence, propellant savings over the baseline is reduced to only 7 % for the Ellipsled.

Summary and Conclusions

The results from the ConOp 1 study show that a Capsule+DPM designed for MGS is technologically feasible and of a size comparable with past and proposed capsules. Current launch capability allows for an MGS architecture under this concept of operations.

ConOp 2 has two branches: (1) Expendable APM and (2) Reusable APM. In both branches the AOTV DPM shows significant propellant mass savings. Overall, the selection between AOTV concepts and reusable/expendable APM must come from consideration of their maintenance/durability and cost of operation with an associated flight rate. Based on mass alone, the expendable system will always demonstrate lower propellant mass per mission. Reusability is appealing only if the flight rate such that the propellant and maintenance costs of the reusable system under-bid the launching of an expendable APM each mission.

For both ConOp 1 and 2, if the flight rate to GEO is low, an expendable launcher and DPM with a direct reentry capsule will show the lowest mass and complexity per mission. This conclusion holds unless the flight rate is high enough to benefit from a more complex reusable architecture.

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Integrated Engineering Database: A 21st Century Decision Aid

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Abstract

The exponentially increasing amount of information accumulated from past and current engineering projects has created an environment where retaining and utilizing existing knowledge is paramount. The modern engineer is tasked with leveraging the intellectual and financial efforts of legacy projects in order to ensure on-time, on-budget completion of modern day engineering tasks. A system that encompasses this information from relevant past and current projects and is integrated into the design process allows for transparent, best practice decision-making. The prototype data-base (DB) system presented focuses on current efforts in hypersonic vehicle research & development. The Hypersonic DB is presented as an example case study for modern aerospace data collection, categorization, and comparison. Focus has been on repurposing data to provide insight into financial and technical trends in hypersonic research to support objective managerial program decision-making. The end-product is a dynamic aerospace data-base that is capable of rapidly providing information and deliverables tailored to the user's required level of detail and provides a generic framework that is adaptable to many 21st century engineering applications.

Introduction

Dedicated data-base (DB) systems built to aid decision making has become the status quo in many industries. The availability of large pools of data and the ability to quickly turn this data into knowledge has increased productivity by providing a numerical basis for seemingly complex, non-numerical problems. Any reluctance to rely on past data points to make future decisions brings about the peril of having to perpetually reinvent the wheel in an economic and political environment where cost / time overruns are increasingly not accepted. Unfortunately, this has been the case in the Aerospace Engineering field and one does not have to look very far to see examples of failed projects that could / should have been avoided if better supported at the early product design life cycle. Therefore, it is the authors' goal to augment the status quo in decision-making by creating a prototype support system and illustrate the power of such a tool.

Research Contract

The authors outline a DB system to tackle the lack of consistent decision-making support with respect to US and international hypersonic vehicle research. The focus has been to:

> "*…identify current international government and commercial sponsored programs that are investing in research and development of technologies for hypersonics air-breathing engines, atmospheric re-entry, and spaceplane concepts. Identify and describe the key technologies each projects is attempting to mature, their current schedule or roadmap, and the mission that the technologies would support.*"

The current DB user is focused on top-level managerial and policy-making decisions, therefore the content displayed is broad but shallow, and does not explore the deeper technical workings of project. The goal of this project is to not only produce a support capability for the current user, but to engage in a generic DB process that can be individually tailored to personnel on the three main levels of product development: technical specialist, product integrator, and program management. By including information necessary to all three levels, the DB is not constraining itself or alienating any potential user from a better decision-making process.

Data-Base System in Product Development Lifecycle

A data-base alone is a useful tool, but as a subsystem to larger early product design methodology, it has an even larger potential benefit. A best-practice approach for the product design lifecycle is adopted utilizing three separate but connected tools: data-base (DB), knowledge-base (KB), and parametric process (PP). DB stores and categorizes raw data; similar data for different products is compared. KB stores lessons learned and draws embedded trends from DB. PP provides parametric systems level analysis and quantifies performance.

All three tools are able to function independently, but a data-base without a parametric process can be seen as shallow, and a parametric process without a data-base can be seen as unfounded. The current prototype DB is a first step in creating fully-functioning product-forecasting system. It is the ultimate goal to have all three tools seamlessly connected in a product development environment that has the capability to assess the performance of a novel product in physics-based platform using proven, justifiable methods and considering the most complete supporting information available.

Status Quo in Aerospace Data-Base Systems

Although a huge amount of documentation has been produced about past aerospace engineering efforts, formalized collections in the form of a DB tend to be focused on production flight vehicles of only a select subset of vehicles. Current DB offerings fail to adequately cover research efforts that were never meant to or failed to produce an operational flight vehicle. This is counterintuitive to the notion that it is necessary for modern engineers to learn from unsuccessful past programs that had significant investments of monetary and human capital invested. A program failure because of a lack of historical knowledge in one's own field is an unacceptable outcome. Figure 1 shows the capabilities and short-comings of the current DB capabilities in aerospace, as well as the portions where the current Hypersonic DB effort seeks to expand the status quo. The authors intend to increase capability by widening the data-pool available by including company internal documents, professional educational courses, interviews and personal documents from retired engineers.

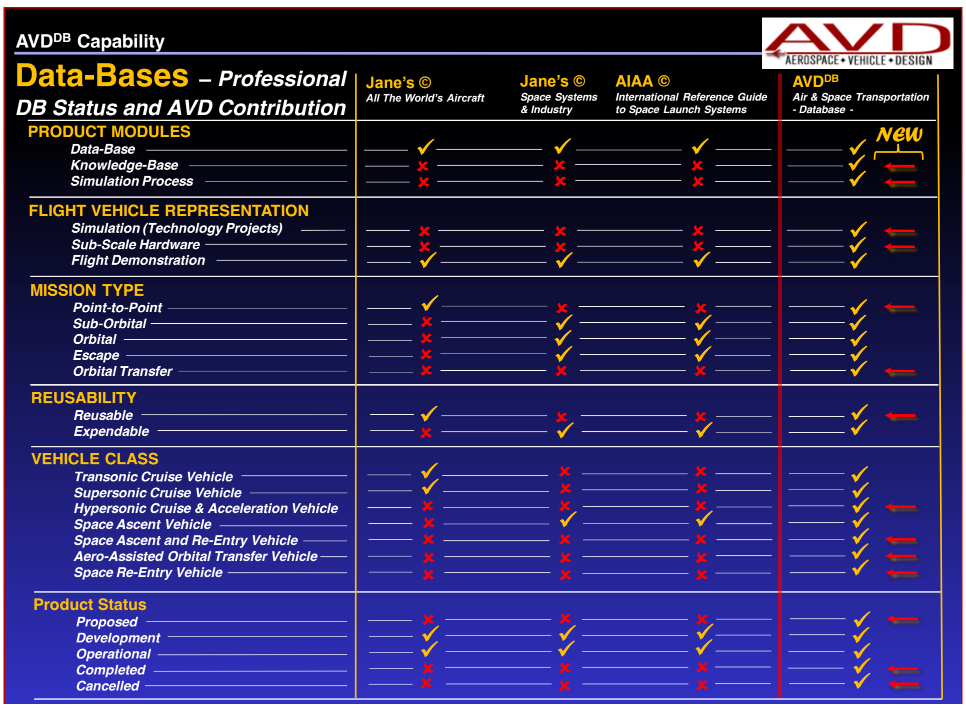

Figure 1. Aerospace Data-Base Capability Assessment

In addition to only covering a portion of past engineering efforts, traditional DB systems are often built as stand-alone data sources that solely focus on data collection. Information can usually be searched and queried, but the user is required to extract data ad-hoc if any form of knowledge buildup or analysis is required. This disintegrated environment leads to an inefficient forecasting system when considering a full DB-KB-PP approach. With the traditional paradigm, information is first taken from its native sources and logged in a standardized format by the database developer. Then the user must access the DB and find the vehicle data based on their own knowledge or intuition of which projects are relevant. The user must then form their own data management system in order to compare information, and is required to re-purpose the data into a suitable input format for analysis. A system that actively connects a data-rich DB to a parametric analysis process with a built-in knowledge management tool has the potential to drastically increase engineering development efficiency and is the long-term goal for the authors' DB system presented.

Data-Base Structure

A truly next-generation aerospace DB has the following traits:

- Database must be unified to guarantee data consistency and quality
- Past and present data must be represented for completeness
- Technology projects and demonstrators should be included
- Historical product evolution should be tracked to understand cause/effect relations
- DB should produce automated decision-making aides that are user-tailored for quick and easy display

Software Implementation

Microsoft Access © is chosen as the software package for AVD^{DB} because of its availability, ease of use, and its ability to produce graphical output from numerical data input. At its core, Access stores data within tables where each column variable is referred to as a Field and each row contains information about a single entry. Data in separate tables can be linked by one or more fields, creating the opportunity for data of different levels or types of information about the same entry to be stored separately. Entries can be searched within a Query by matching criteria from one or more fields (from one or more tables). Data from one entry can then be displayed in a Form that utilizes the (Visual Basic) VBA programming language to output data fields. Forms can be used either as a data entry device or for non-editable deliverables.

For AVD^{DB}, the Access table structure is split into two main levels: general project information and technology-specific information. Technology-specific information is then dissected into air-breathing propulsion, spaceplane concepts, and re-entry research and technologies tables to mirror the goals stated in the contract specification. Data in each table is linked together by a Project ID which uniquely identifies each research project. Data from all tables is then used to output information for each project in a graphically formatted deliverable Form.

Content

The heart of any data-base is the quantity and quality of data it contains. A fine-tuned DB software is of no use if the data-base is sparse or filled with incorrect data-points. Therefore, the most important step in creating a next generation data-base is to organize a system to identify useful data, collect it from its native source, and systematically translate it to a DB. Data can then be categorized and compared to entries with similar traits to show information specific to a user's needs. While the data-base effort has the most steps and is the focus of this paper, the complete, integrated environment of static data with actionable knowledge along with physics-based analytical assessment is the end-goal **Error! Reference source not found.**,**Error! Reference source not found.**. **Error! Reference source not found.** shows the overall methodology envisioned for total systems forecasting and the associated tools required.

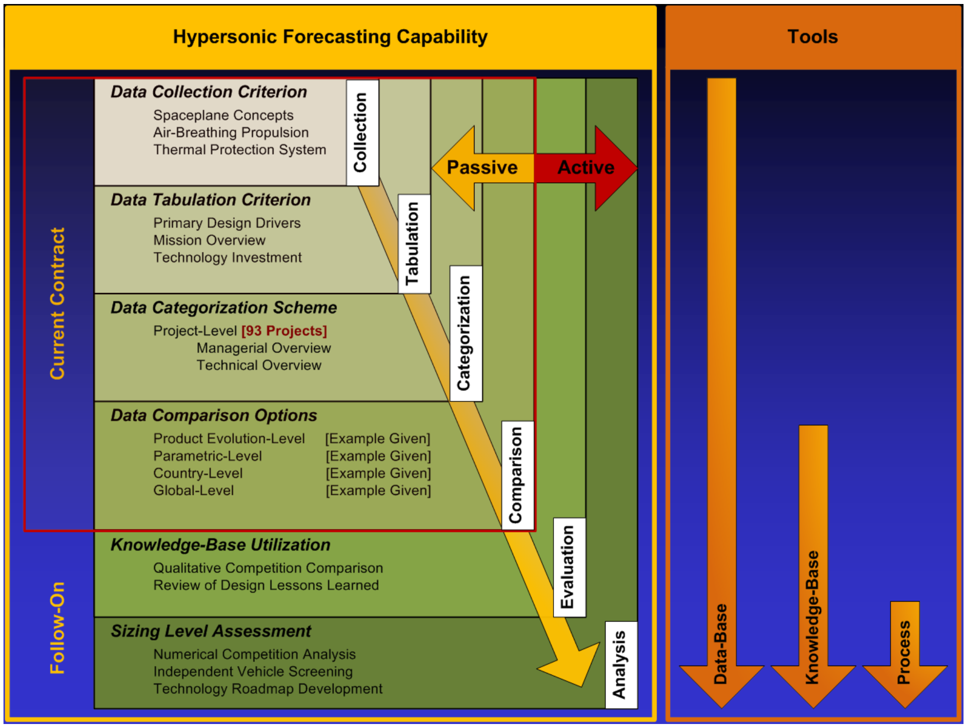

Figure 2. Total System Forecasting Capability

Data Collection

Dedicated data collection spanning approximately one month encompassed:

- Public Domain – Aviation Week, Flight International, Report Servers, Astronautix, etc.
- Proprietary Domain – Company Reports, Internal Report Servers, etc.
- Expert Domain – Interviews, Email Correspondence, Past Lessons Learned, etc.
- Data Domain – Existing AVD Database

Because AVD^{DB} is created as an adaptable tool, new data and updates to old data are easily implemented within the system. Data-base management is required throughout the research project to ensure the best possible DB quality. Over 1700 references are screened in the Data Collection phase of the Hypersonic DB, and references 3-18 illustrate a snapshot of some of the most data-rich sources (Table 1).

Table 1. Hypersonic Data-Base Selected Reference List

Title	Project(s)	Reference
Army Eyes Advanced Hypersonic Weapon	AHW	Grossman 3
Hypersonics in the USA: New Partnerships in the 21st Century	AHW, CSM, HTV-2, X-37B, X-51	Rutledge 4
Japan's Activities	BOV, CAMUI, Experimental Vehicle, Hayabusa, HYTEX, Pollux, RBCC Technology	Maita 5
NASA Invests in Private Sector Space Flight with SpaceX, Rocketplane-Kistler	Dragon	Anon. 6
2011 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports	CSM, Dragon, Dream Chase, Lynx, RocketPlane XP, Silver Dart, SpaceShipTwo, Super-MOD, X-51A, Xaero	Anon. 7
Current and Near-Term RLV/Hypersonic Vehicle Programs	Expert, FTB-X, Hercules, HTV-3X, HyFly, HyShot, IXV, LEA, Pheonix, SOCRATES, X-37, X-43	Erbland 8
USA Applied Hypersonics	Facet, HiFIRE, HTV-3X, HyCause, HyFly, HyShot, Hy-V, X-43, X-51A	Jackson 9
Hypersonic International Flight Research and Experimentation (HIFiRE) - Fundamental Sciences and Technology Development Strategy	HiFIRE	Dolvin 10
Australia National Report, 2011	HiFIRE, Scramspace	Boyce 11
France National Report	ATLLAS, LAPCAT, LEA, Expert	Falempin 12
Lockheed Martin Receives $218 Million for Long Range Anti-Ship Missile (LRASM) Demonstrations	LRASM-B	Vanbebber 13
Shenlong Space Plane Advances China's Military Space Potential	Shenlong	Fisher 14
Skylon User's Manual	Skylon	Hempsell 15
USAF Space Plane Program In Works - Unmanned X-37B To Be Service's Space Test Vehicle	X-37B	Anon. 16
Air-Breathing Hypersonics Research At Boeing Phantom Works	X-43	Orton 17

Hypersonic technologies and aerospace plane	FTB-X, HiFIRE, HTV-2, HyFly, LEA, Pollux, Shefex, X-37B, X-51A	Mehta 18

Data Tabulation

Tabulation is the data-entry process of taking raw data found from the Data Collection phase and implementing it into a structured DB. The most undefined, but important, step in the entire DB process is identifying the primary design driving variables that describe a project. This is often an iterative procedure involving the DB developer and the DB user. It is imperative that type, breadth, and depth of information required by the end user be specified clearly. The DB developer is responsible for including all desired fields, as well as including fields that intuitively add complexity and depth to the DB. This phase is dependent on the DB developer being well-versed in the technical field; a DB made with little or no knowledge of the subject will require much more micro-management by the user in these early phases of development.

Data Categorization

Data Categorization arranges fields with similarities about a single entry to output an overview allowing a user to gain some level of insight. Categorization within AVD^{DB} is implemented as a Dashboard; a "visual display of the most information needed to achieve one or more objectives which fits entirely on a single computer screen so it can be monitored at a glance." 20 Dashboards have become commonplace in business, manufacturing, and finance, and is used in this situation because of the user's desire to quickly assess a projects key players, purpose, and current progress towards its stated goals.

The Data Categorization phase is also heavily dependent on the user's objectives for the DB; technically-specific data will be of little use to a technologist with a different specialty, and a manager will have little use for complex technical data. The Dashboard(s) within AVD^{DB} are formatted by user specification to include both managerial and basic technical information, but just enough to grasp the complexity of the project. This allows different levels of conclusion to be drawn from the same Dashboard, depending on the user's background and decision-making purpose.

Data Comparison

Data Comparison makes the broadest use of the DB. Specific fields are established that identify an entry's merit, and a subset of entries are compared against each other. This establishes context for a project's established performance goals, and provides a consistent metric comparison between competitive projects. The Query that establishes a Data Comparison can be as wide or narrow as desired by the user, and it is seen in the variety of deliverables produced that different conclusions can be made by simply comparing different subgroups of the same data pool.

Data-Base Decision-Making Tools

The main deliverable for the Air & Space Transportation DB is a project-level dashboard displaying key managerial and technical metrics. Additional example deliverables are produced with varying levels of data categorization and comparison to illustrate the potential alternatives outputs available to the customer from the same DB. Figure 3 shows five levels of example deliverables:

1. Product Evolution-Level – project in context of larger development program
2. Project-Level – selected information about a single project
3. Parametric-Level – technical comparison of project to similar entries
4. Country-Level – overview of single nation's investments
5. World-Level – summary of all entries in DB

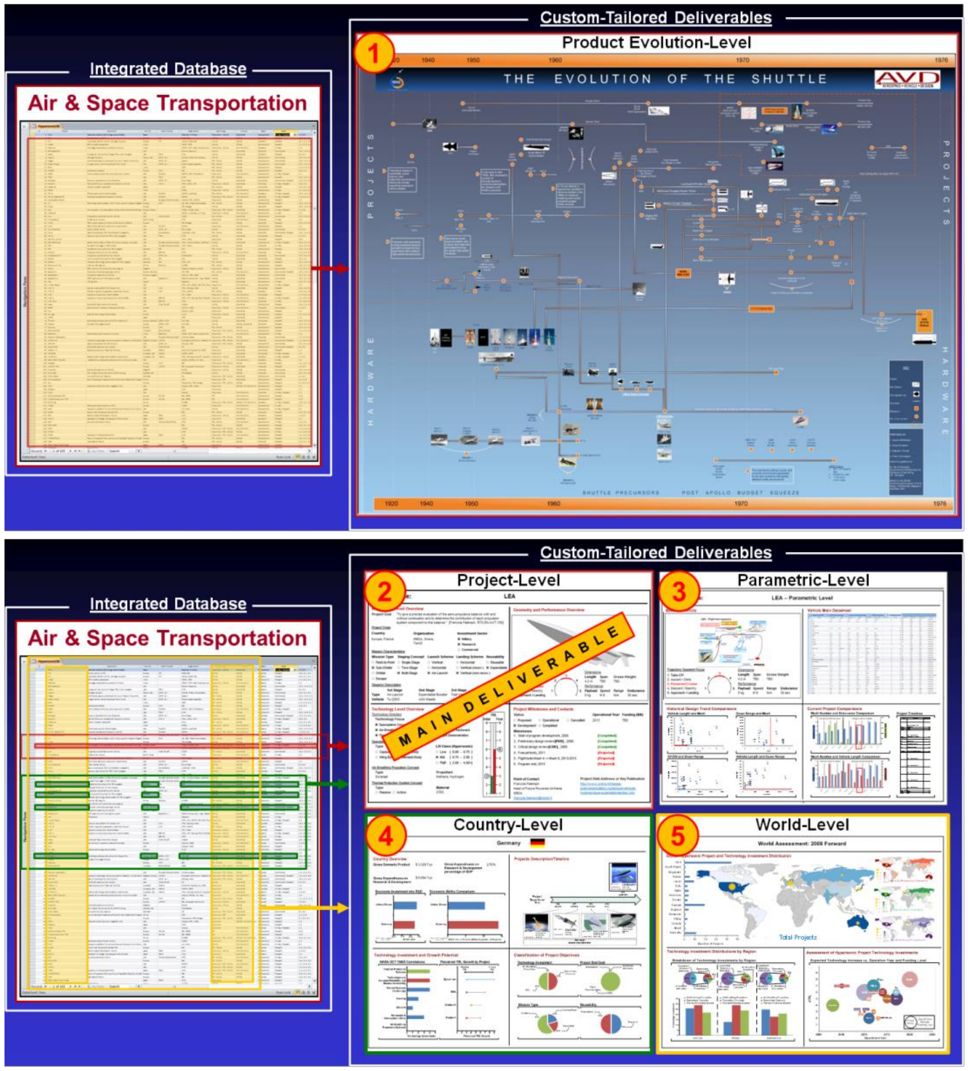

Figure 3. AVD[DB] Deliverables Structure

Product Evolution-Level

An evolution of the research efforts and flight vehicles that contributed technology and/or momentum to the development of the Space Shuttle is produced in Figure 4. Emphasis for this deliverable is top-level program understanding; little to no technical information is displayed.

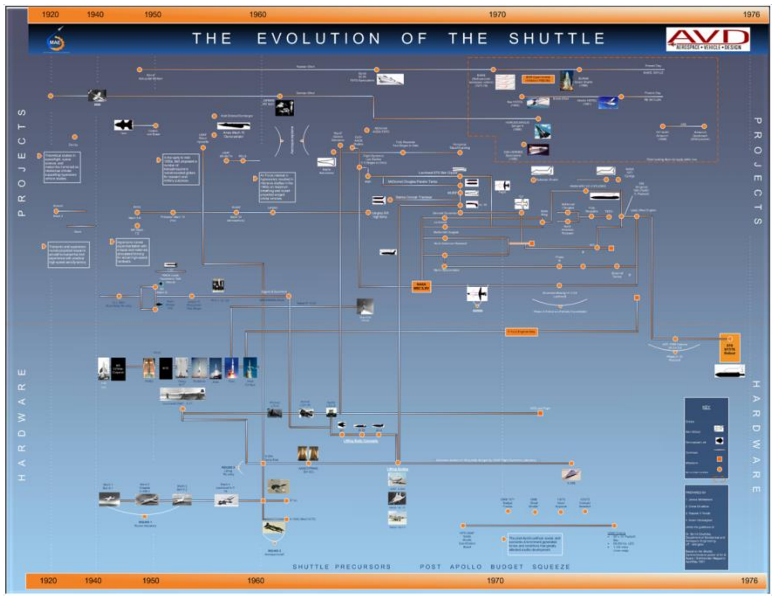

Figure 4. Product Evolution Example – Evolution of the Space Shuttle

Project-Level

This deliverable contains the information selected as relevant to the main user in a graphically formatted dashboard that allows for a consistent at-the-glance impression of a hypersonic technology project (Figure 5). The four segments categorize information relevant for different user objectives and are independently viewed. Checkboxes are used to illustrate that logical descriptive metrics are defined.

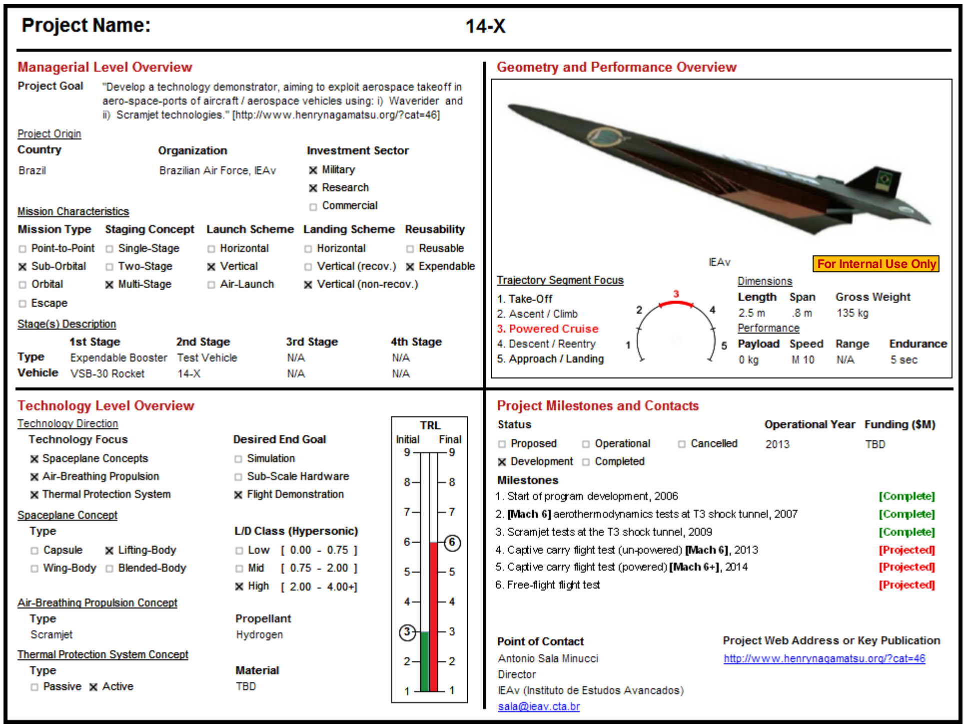

Figure 5. Project Example – 14-X Scramjet Demonstrator

Display fields are linked to corresponding data in the DB to automatically produce a project-level deliverable for every entry (Figure 6). Because the DB user has focused the research effort on project-level deliverables, only this deliverable is created in such an automated fashion.

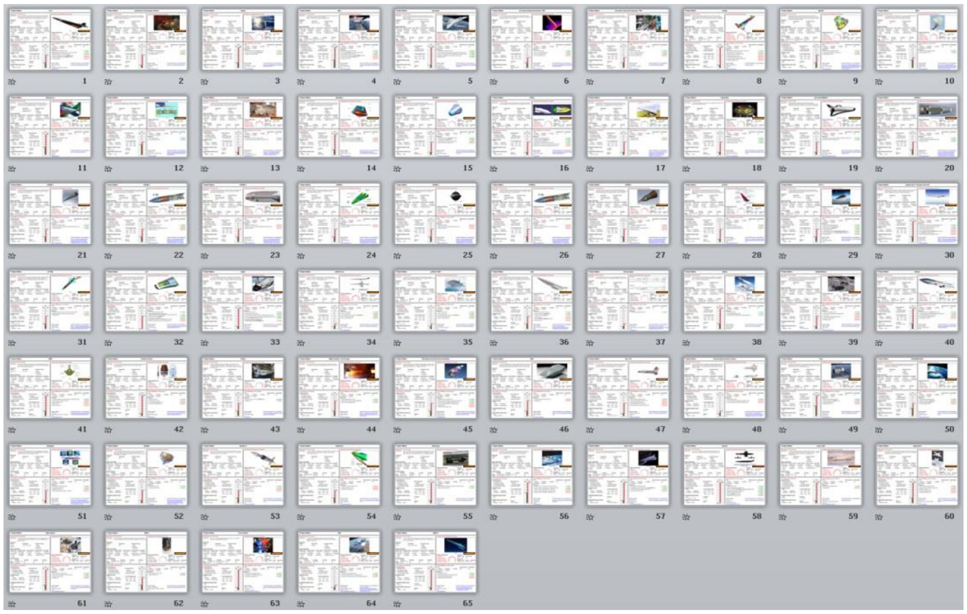
Figure 6. Project-Level Deliverables – International Hypersonic Research

Managerial

The upper left quadrant (**Error! Reference source not found.**) of the project-level dashboard contains a general description of the project goal, project origin, mission characteristics, and the vehicle stage descriptions. The mission is defined by a series of categories that define the energy required, staging, launch & landing scheme, and reusability. The organizations listed are the funding organizations and do not seek to portray all of the subcontracting partners that contribute to a project. Division is also made to distinguish whether the funding organizations are of a military, commercial, or research background.

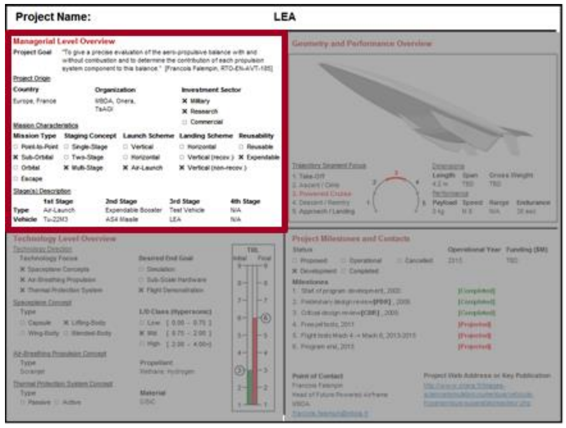

Figure 7. Project-Level Deliverable – Managerial

Geometry & Performance

The upper right quadrant (**Error! Reference source not found.**) shows a graphical depiction of the project, along with numerical performance indicators. The mission segment arc defines to which flight segments the project is contributing novel hypersonic vehicle research. General performance indicators include size, weight, payload, speed, range, and endurance. Vehicles for which these metrics do not apply are noted (i.e. a wind-tunnel tested scramjet engine does not have an applicable range).

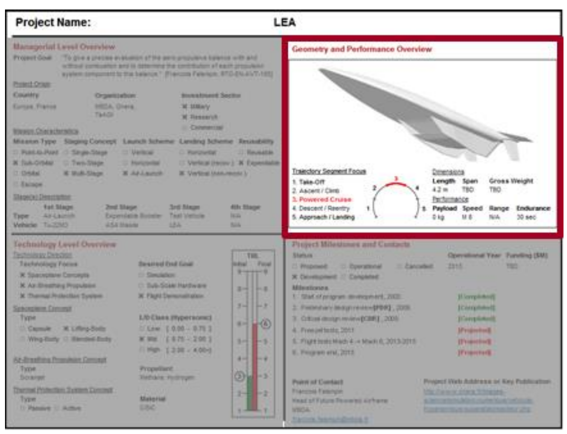

Figure 8. Project-Level Deliverable – Geometry & Performance

Technology

The lower left quadrant (**Error! Reference source not found.**) is a user-defined description of the hypersonic technology benefits of the project. Contributions are described by the three driving hypersonic technologies defined by the user (spaceplane concepts, air-breathing propulsion, and thermal protection systems). Each technology is designated top-level to quickly provide the user with a grasp of the scope and complexity of the project. Attempt is made to numerically convert project technology development efforts (from project start to projected finish) with the Technology Readiness Level scale adopted by NASA and other research organizations. The TRL scale goes from 1 (unproven theoretical concept) to 9 (reliable, flight-tested operational hardware). See reference 19 for a more detailed definition of the complete TRL scale.

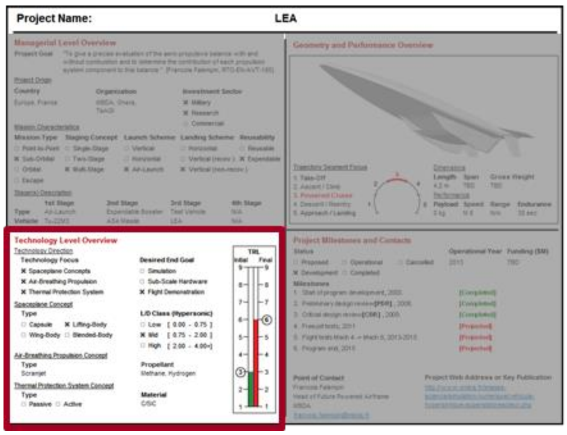

Figure 9. Project-Level Deliverable – Technology

Project Milestones & Contacts

The lower right quadrant (**Error! Reference source not found.**) contains program management information including the project status, funding level, operational year (goal), milestones, points of contact, and reference for further information. Milestones may include projected goals with tentative dates set forth in project roadmaps or press interviews. Key project successes, failures, and changes in funding commitments are also noted here.

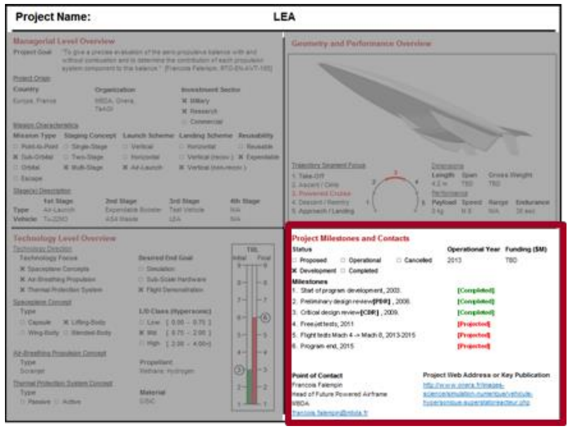

Figure 10. Project-Level Deliverable – Project Milestones & Contacts

Parametric-Level

An example deliverables is created to display more detailed technical specifics about a project in direct comparison to technical indicators from similar past and current projects (**Error! Reference source not found.**). Goal of a parametric-level assessment dashboard is to objectively match project characteristics with known successful projects to determine feasibility and technical complexity. A parametric-level deliverable is not produced for all entries and is shown as an illustration of repurposing DB information for a technology-focused user.

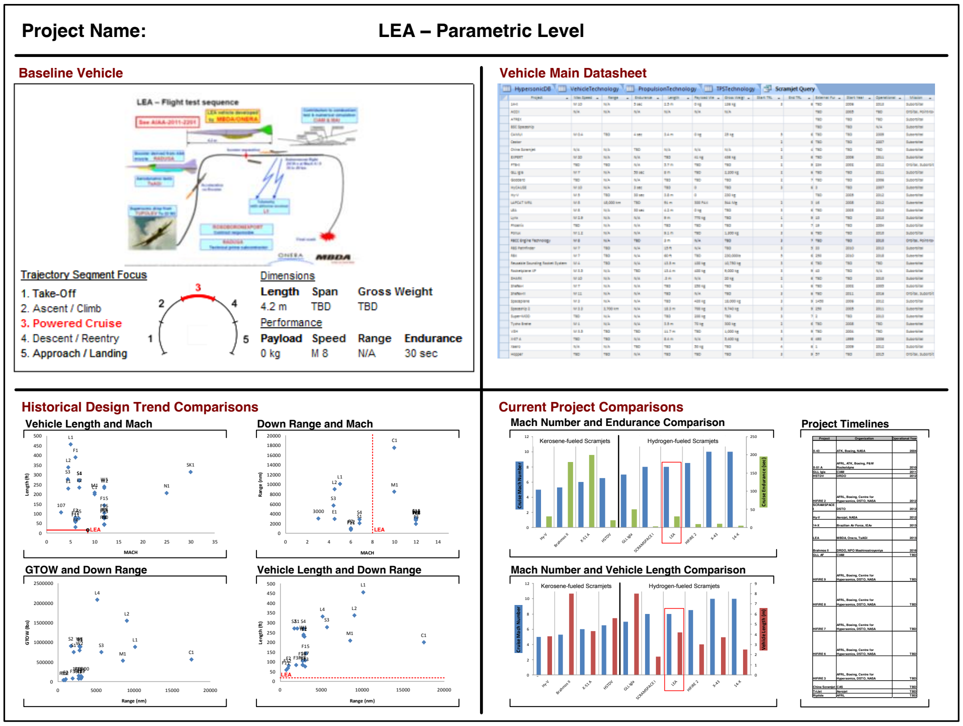

Figure 11. Parametric Example – LEA Scramjet Demonstrator

Country-Level

Summary of a nation's hypersonic research efforts is directly applicable to the current user for policy-making and program planning purposes. Figure 12 shows an example country-level deliverable for Germany. The country's financial expenditures into hypersonic research and development are compared with a common metric (USA) and the technology focuses are categorized to show the national hypersonic program momentum.

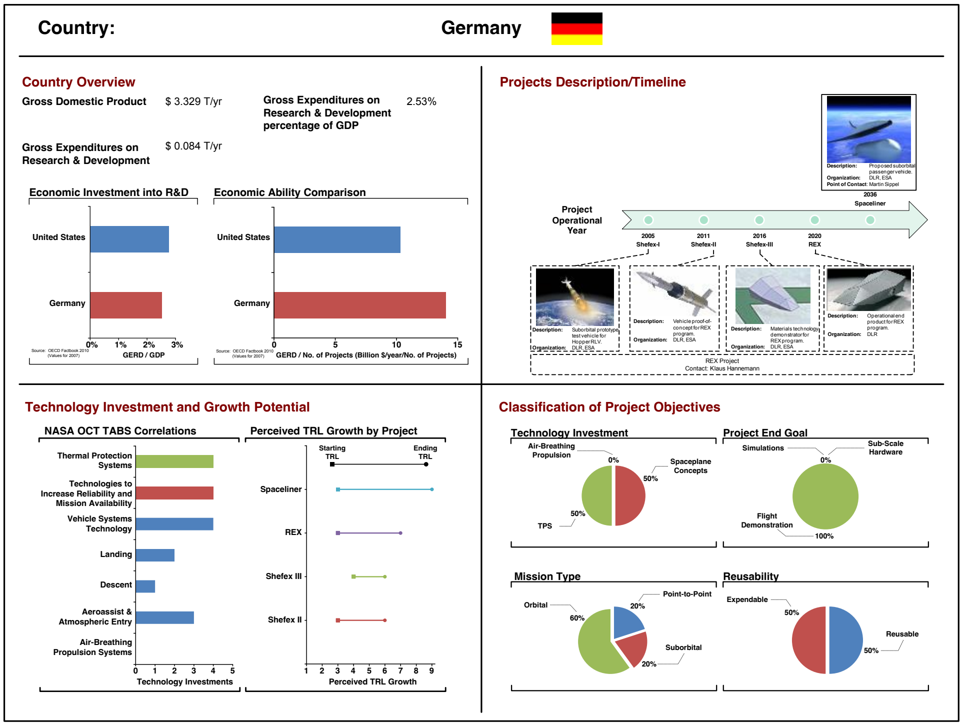

Figure 12. Country Example – Germany

Figure 13 shows another example of a country-level deliverable (USA). Created is a timeline graphic showing all recently finished/cancelled and current hypersonic research projects with ties to the United States. Location of the project along the vertical axis corresponds to the funding organization. Timeline, delta TRL, and technology focus displays are presented separately with emphasis on the start, finish, and intermediate milestones of each project. Blue shaded regions connect projects of the same organizational program. Graphical summary of all US hypersonic technology research is shown at bottom of the figure.

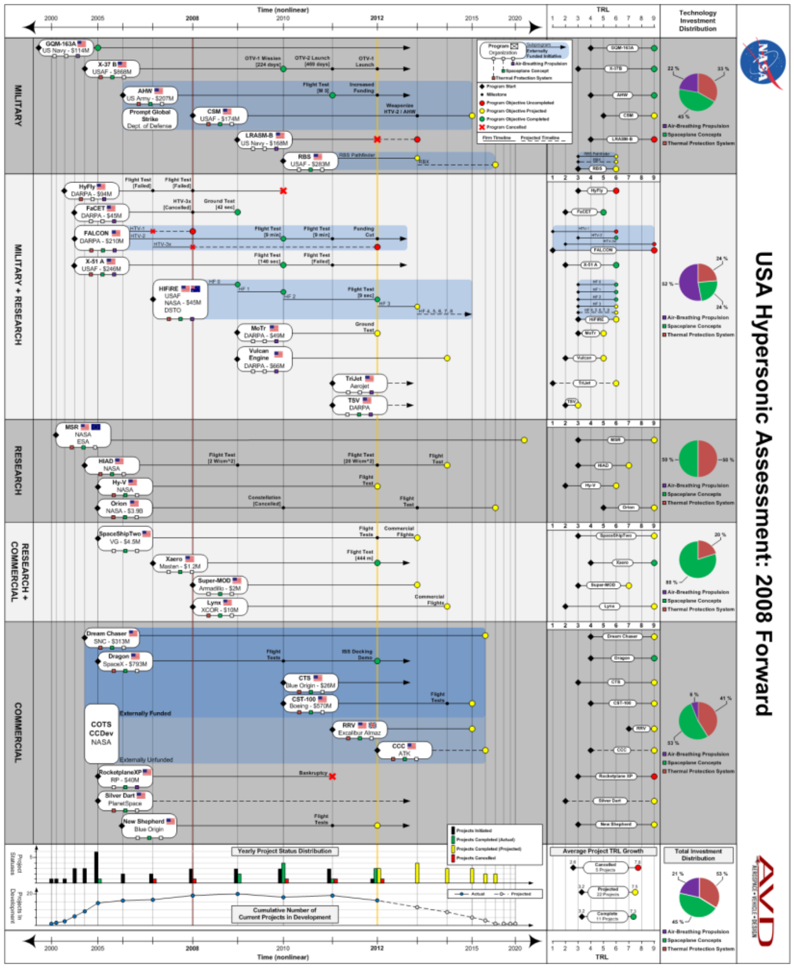

Figure 13. Country Example – USA

Worldwide-Level

The broadest scope of categorization possible is used as the basis for the global deliverable in Figure 14. Geographic distribution of total investments and technology-specific investments is shown at the top. Itemized technology breakdowns by continent and a scatterplot of perceived technology difficulty versus operational year are shown below. Goal of the world-level assessment deliverable is to determine what countries are actively engaged in hypersonic technology research and the technology areas in which they are focused.

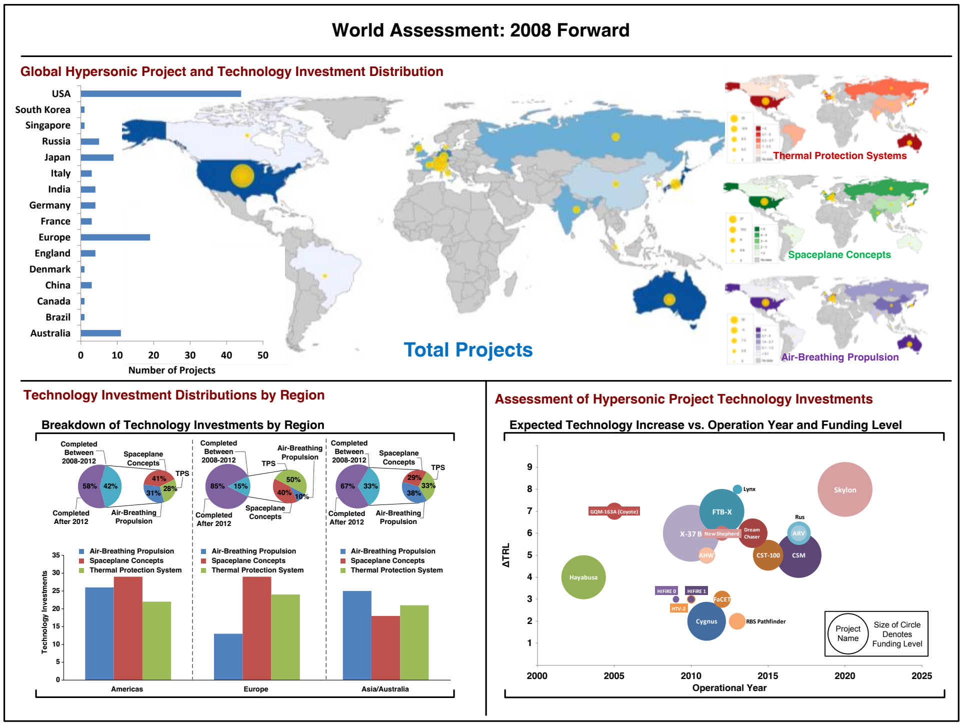

Figure 14. Global Example – Earth

Conclusions

Presented is a methodology for creating a next generation data-base system as the basis for a larger engineering forecasting capability. The Hypersonic Data-Base is presented as a prototype case study for modern aerospace data collection, categorization, and comparison. Focus has been on repurposing data to provide insight into financial and technical trends in hypersonic research to support managerial program decision-making. The end-product is a dynamic aerospace data-base that is capable of rapidly providing objective information and deliverables tailored to the user's required level of detail and provides a generic framework that is adaptable to many 21st century engineering applications.

Acknowledgments

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Leveraging History in the Context of Project Engineer Education: *Project Mercury*

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Abstract

The first manned U.S. space program, *Project Mercury*, is leveraged as a data-rich aerospace systems engineering design case study. The extensive amount of contract design reports, technical memorandums, and project overviews documented by NASA and the prime contractor, McDonnell Aircraft Corporation, allow for a comprehensive data-base (DB) and knowledge-base (KB) buildup. Emphasis is placed on identifying, retaining and integrating available *Project Mercury* knowledge to the aerospace community into a physics-based parametric sizing (PS) process. The primary goal is to reverse-engineer the principal *Project Mercury* vehicles, as well as to reverse-engineer top-level design and program architecture decisions leading to the successful system design.

In order to provide a consistent, objective assessment, the total vehicle system performance is quantified with an existing, validated PS process and is gauged numerically based on technical, operational, and political requirements set forth by the US government and NASA. The process of reverse engineering the design decisions made in the history-making *Project Mercury* lays the framework for modern engineers to leverage past knowledge to better understand the potential solutions of today's aerospace challenges.

Introduction

The modern engineer is in a very unique position. There is an enormous amount of knowledge available from past engineering efforts readily available. One hundred plus years of aerospace knowledge build-up and millions of engineers' careers can be found in books, internal company documents, technical memorandums, design reports, press briefings and others. The concern for the modern engineer is the overabundance of information, and the lack of time and emphasis by most engineering environments to utilize historic documents, thus lessons learned. It is the intention of the Aerospace Vehicle Design (AVD) Laboratory at the University of Texas at Arlington to demonstrate with an example best-practice design re-engineering case study, how today's engineers can leverage a historic project like *Project Mercury* to gain insight and increase systems-level design proficiency.

Project Mercury Introduction

Project Mercury was a minimum complexity space system intended to put one man in space orbit for a limited amount of time. The system comprised of a (1) rocket launcher, and (2) re-entry capsule, both of which heavily leveraged on existing technical and industrial capability available at the time of design. Mercury was in direct competition at the time of actual engineering to the Soviet Vostok system, which is assessed here in parallel as a reference and for competition analysis purposes.

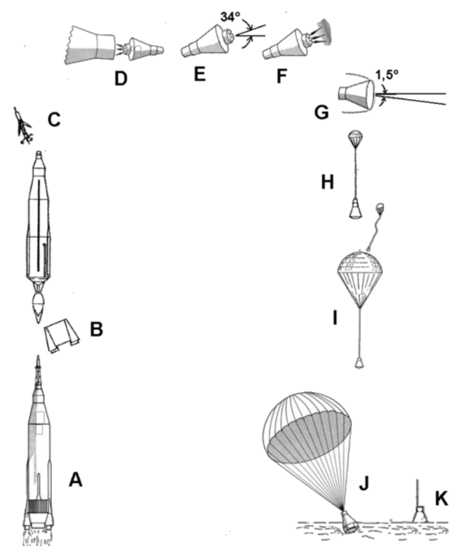

Figure 1. Reference Mission for Project Mercury [1]

The following is a direct excerpt from the *Congressional Panel for Manned Space Flight* in October of 1958, directly before the official start of *Project Mercury*. Sections have been selected here that effectively locked the mission and the overall configuration design.

I. OBJECTIVES

The objectives of the project are to achieve at the earliest practicable date orbital flight and successful recovery of a manned satellite, and to investigate the capabilities of man in this environment.

II. MISSION

To accomplish these objectives, the most reliable available boost system will be used. A nearly circular orbit will be established at an altitude sufficiently high to permit a 24-hour satellite lifetime; however, the number of orbital cycles is arbitrary. Descent from orbit will be initiated by the application of retro-thrust. Parachutes will be deployed after the vehicle has been slowed down by aerodynamic drag, and recovery on land or water will be possible.

III. CONFIGURATION

A. Vehicle

The vehicle will be a ballistic capsule with high aerodynamic drag. It should be statically stable over the Mach number range corresponding to flight within the atmosphere. Structurally, the capsule will be designed to withstand any combination of acceleration, heat loads, and aerodynamic forces that might occur during boost and reentry of successful or aborted missions.

…

D. Retrograde System

The retro-rocket system will supply sufficient impulse to permit atmospheric entry in less than 1⁄2 revolution after application of retro-thrust. The magnitude and direction of the retro-thrust will be predetermined on the basis of allowable declarations and heating within the atmosphere, and miss distance.

…

Research Project Introduction

The goals of the present research project are to (a) utilize *Project Mercury* as a case study to integrate the DB-KB-PP forecasting modules, (b) calibrate the AVD Laboratory parametric sizing process for a total space architecture, (c) gain experience with a multi-disciplinary design team, and (d) retrieve systems engineering knowledge from a highly successful national space program. The semester-long research project has the ultimate goal of reverse engineering the primary Mercury flight vehicle system by adopting the identical design-constraining mission, requirements, limitations, and vehicle elements.

Research Project Structure

In order to correctly implement any engineering forecasting activity, it has been established that an industry best-practice approach requires a Data-Base (DB), Knowledge-Base (KB), and Parametric Process (PP). Figure 2 illustrates the logic flow of information between the three tools; the primary tasks of each module are indicated in order to successfully support forecasting the total system performance.

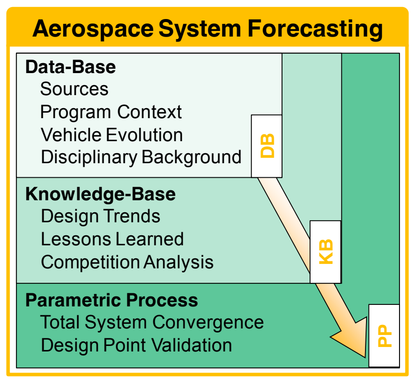

Figure 2. Design Process Hierarchy

Data-Base (DB)

A Data-Base is defined as a collection of data or information organized for rapid search and retrieval, especially by a computer. While the use of a DB is not groundbreaking in many fields, the development of a structured DB covering varied levels of information in support of an engineering design effort is seen as a novel contribution. A condensed literature survey is performed at the beginning of research project and each member is assigned a minimum amount of general project documents to associate each source with the data it contains (topic, scope, depth). Research team members are encouraged to continue a systematic update of any new references or indexes within current references they encounter in their individual research tasks throughout their research period. In this manner, the DB is a dynamic tool that will be leveraged in all further research efforts.

Knowledge-Base (KB)

A Knowledge-Base is a somewhat more loosely defined term. In practice, a KB is a collection of condensed information from a previous research that provides some level of insight into a specific field. This knowledge can either come from data included in the DB or from separate research that has commonality with the current project. Discipline-specific technical methods, rules of thumb, and design trends are examples of information found in the KB.

Parametric-Process (PP)

A Parametric Process is a multidisciplinary model that logically connects numerical methods describing all relevant technical aspects of the elements needed to describe the total system in question. Given a set of system performance requirements and an initial guess for its characteristics, a PP must stably converge through numerical iteration. Final output is the size, weight, and performance of a vehicle system that satisfies the given information considering the mission requirements. A framework parametric process is in place from previous work at the AVD Laboratory and is leveraged for sizing activities.

Research Team Structure

The research team for the re-engineering task of *Project Mercury* is segmented into four teams; the first three roughly representing the flight segments (Ascent, Reentry, Landing), whilst the fourth team engages in a concurrent effort using the Space Planner design text. The Chief Engineer is responsible for integrating the analytical work of all teams into the sizing synthesis environment.

Ascent Team

The ascent team is mainly focused on the rocket booster required to send a manned capsule into a low earth orbit (LEO). The actual development cycle saw use of two smaller, single-stage rockets for testing and suborbital flight tests (Little Joe and Redstone) and a production, two-stage launcher for orbital flights (Atlas). The ascent team characterizes the performance and development of these three launch vehicles.

Reentry Team

The reentry team is tasked with characterizing the Mercury capsule. This includes mission requirements, technology development/utilization, and vehicle performance. The development process of the Mercury capsule is also detailed to understand how the testing environment surrounding the design process shaped the final capsule product.

Landing Team

The landing team deals with the final segment of the capsule return to earth. The parachute and landing system performance is determined after the capsule's size and weight is fully determined. Therefore, this demanding flight segment for the capsule requires its own research team.

Space Planners Guide Team

This activity seeks to understand and utilize the *USAF Space Planners Guide* [2] document which allows an engineer to perform a focused, empirically-based synthesis of a space vehicle system. The *USAF Space Planners Guide* regressions include *Project Mercury* and will therefore provide a trustworthy sanity check of the design results otherwise generated.

Data-Base and Knowledge-Base

To initiate the research project, the design team undertakes an effort to harvest knowledge from historic documents (source database) and convert that information into a useable format for use in the parametric sizing process (vehicle main data-sheet). The source database is an organized collection of all reference materials used during the re-engineering study. Standard bibliography information is logged and specific sections of documents where useful information can be found are indexed for further use. The main data-sheet (MDS) is a collection of all pertinent engineering information about a vehicle. All values presented in the MDS are cross-linked with the reference that supports it to provide full transparency.

Source Database

Because of the amount of data available about *Project Mercury*, it is desired to have a systematic and organized method for storing and extracting information. Implementation of the DB is a searchable Microsoft Access database that allows users from different backgrounds, focuses, and research levels to contribute data in a consistent manner. All available sources have a generic bibliography, followed by a more detailed catalog of the discipline-specific information contained. It is the goal of the indexing process to re-create the feeling of going through a physical text and labeling sticky notes on the most important sections.

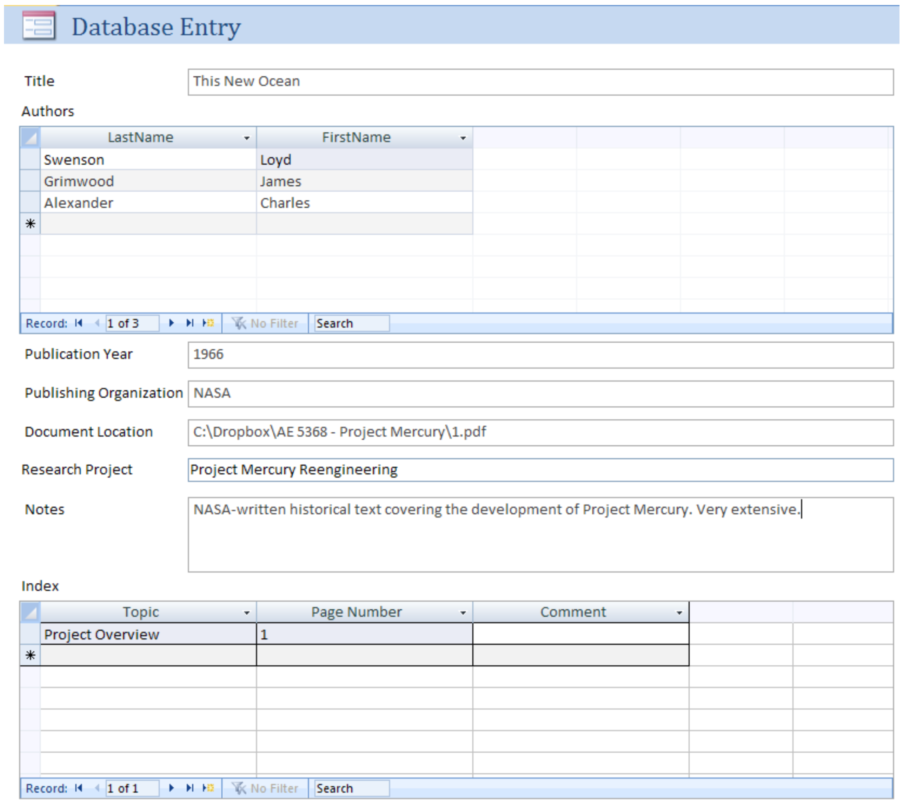

Figure 3. Access Source Information Form

Main Data Sheet

The vehicle main data sheet (MDS) mirrors a traditional aerospace vehicle data-base aimed at keeping track of technical values for a vehicle. The current system allows for different categories of vehicles to have their own set of pertinent variables, but at the same time reside within the same generic database. For this research project, *hypersonic vehicles* and *launch vehicles* are separated due to their inherent differences and the need for different technical values based on the type of vehicle.

Hypersonic Vehicle MDS

The hypersonic vehicle datasheet contains all information needed to describe the Mercury and Vostok capsules. The data fields describe a generic hypersonic vehicle; therefore, some fields are not relevant. Data is decomposed into general project-level information and more detailed discipline-specific data that is for the parametric sizing process.

Launch Vehicle MDS

The launch vehicle datasheet contains information about the launch vehicle pertinent to the *Project Mercury* re-engineering effort. Because Mercury was tested in an incremental fashion, data about the Redstone, Atlas (and its variants), alternative US launch systems available at the time, and the Soviet Vostok rocket are all included. The field categories are based on the *International Reference Guide to Space Launch Systems* [3] and the parameters needed for later parametric sizing methods.

Knowledge-Base

The current KB consists of a prototype disciplinary methods library. Because the KB is implemented within the same data-base file as the *Source Database* and *Main Data Sheets*, references describing the method are linked to the DB, and method-specific variables are logged for PP sizing. Continuity between the DB-KB-PP environments is seen as key to producing a novel case-study effort.

Parametric Sizing

Previous AVD research is leveraged to perform parametric sizing for the Mercury re-engineering task. A modular, multi-disciplinary analysis methodology is put in place to determine the size, weight, and performance of a vehicle system for a known mission. In summary, the computer program takes in the mission, technologies assumed, and performance required as input and calculates a converged vehicle design or vehicle design trade space. The sizing code (AVD^{SIZING}) has previously been used, validated, and verified for vehicles with broad missions, technology assumptions, and vehicle concepts. The basis for hypersonic vehicle sizing is taken from previous work initiated by Coleman [4] based on the text by Czysz [5].

Programming Structure

The most current version of AVD^{SIZING} is implemented using the MATLAB/Octave programming code. Each disciplinary method is found within its own function file to ensure modularity. Methods within one discipline may change based on driving parameters (i.e. aerodynamic methods change with Mach number). The connection between different disciplines is handled within a separate convergence function which can be adapted for novel architectures. All information that is vehicle specific and held constant throughout the design simulation is held within a unique vehicle input file.

Methods

At the heart of the sizing process are the disciplinary methods that are responsible for analysis. At the beginning of an iteration, the vehicle size and/or weight is estimated for use as a starting point. The analysis methods, see Table 1, are compiled in a systematic progression to produce an updated estimate for the vehicle size, weight, and performance that is the starting point for the successive iteration.

Table 1. Parametric Sizing Disciplines

Discipline	**Input**	**Output**
Convergence	Input file	Converged vehicle
Geometry	Vehicle size	Geometric description
Aerodynamics	Flight condition, geometry	Aerodynamic coefficients
Propulsion	Flight condition	Propulsion performance
Trajectory	Geometry, weight, aerodynamics, propulsion	Trajectory profile
Heating	Trajectory, geometry	Heating environment
Weight & Volume	Geometry, propulsion, trajectory, heating	Weight & volume breakdown

Convergence

Convergence, in the context of AVD^{SIZING}, is the practice of iterating a design-driving variable until the vehicle size and weight are held within error bounds for two successive iterations. The number and type of variables used for convergence is dependent on the complexity of the vehicle system. The process of convergence is constant for all vehicle elements, but the steps, analysis, and convergence criteria may change.

Capsule

The capsule is converged using the planform area and the wing loading (gross weight divided by planform area) as the input variables, with wing loading and capsule weight being the converging variables. The wing loading convergence requires the vehicle to be at a stable convergence, and the capsule weight convergence requires a feasible design under the analysis methods assumed. At the end of each convergence cycle, the current value for capsule gross weight updates the stored wing loading value. The difference between the old and new values must be driven to zero. The capsule operating weight empty (OWE) is determined in two different methods: (1) using the capsule volume from Geometry, and (2) using a systems buildup methodology.

Table 2. Capsule Convergence Criteria

Convergence Variable	Converging Variable
Planform Area	OWE from Weight Buildup – OWE from Volume Buildup
Wing Loading	Wing Loading (Previous Iteration) – Wing Loading (Current)

Launch Vehicle

Launch vehicles are sized with a known payload (capsule + retro-rocket + escape tower + adapter) and total stack height. The convergence variable used is the ratio of takeoff gross weight to total stack height of the launch vehicle (stack loading). The vehicle is simulated until the capsule is run through trajectory and the maximum altitude is reached. The total stack height is input as a design variable to identify the solution space for alternative launch options given a known capsule payload.

Table 3. Launch Vehicle Convergence Criteria

Convergence Variable	Converging Variable
Stack Loading	Stack Loading (Previous Iteration) – Stack Loading (Current)

Geometry

Capsule

The Mercury capsule geometry is described as a spherically-capped conical frustrum with a small cylinder extending from the top. This basic geometric shape is assumed to remain constant for all vehicle designs considered. The top adapter diameter is a fixed dimension; the ratio of total capsule diameter to nose radius is constant; the geometry of the capsule can be described by knowing only the planform area (an input variable).

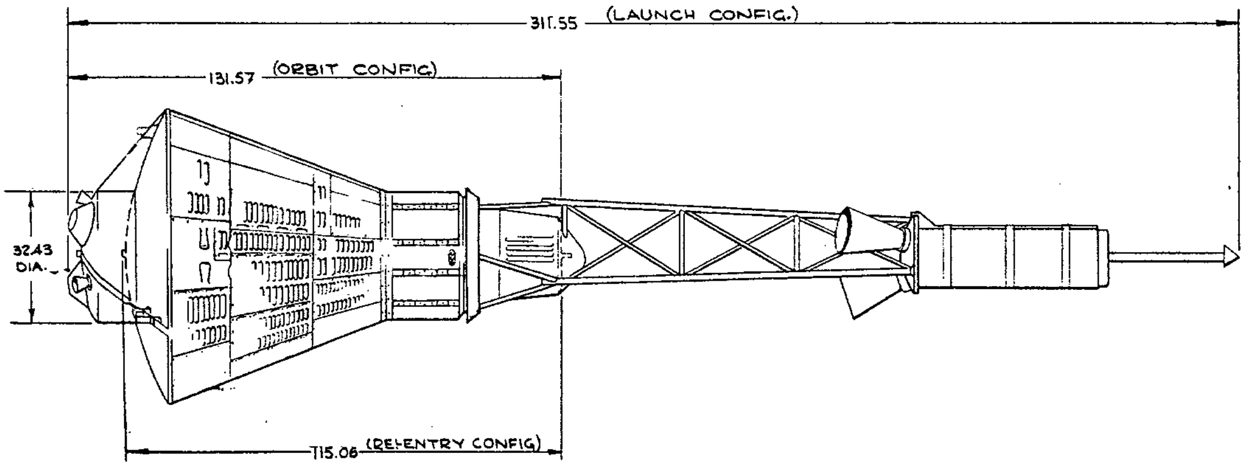

Figure 4. Mercury Capsule [6]

The Vostok capsule (descent module in Figure 5. Vostok Capsule) sheds its asymmetric service module after the retro-rocket is fired, becoming a sphere during the reentry portion of the mission. Like Mercury, the planform area is sufficient to describe the Vostok geometry.

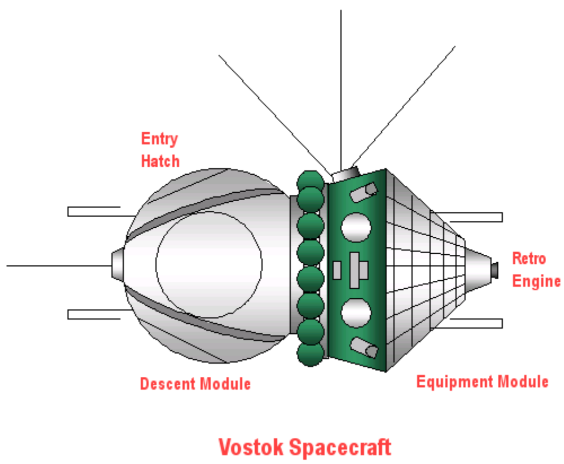

Figure 5. Vostok Capsule [7]

Launch Vehicles

All launch vehicles are considered to be fixed-diameter cylinders for sizing purposes. The maximum diameter is determined by the launch facilities available to the specific vehicle, and the height is solved for as a convergence variable.

Aerodynamics

Capsule

Both the Mercury and Vostok capsule configurations were studied in great detail during the design phase of *Project Mercury*; therefore extensive wind tunnel data is available throughout the relevant Mach number range. In order to reduce the complexity and run time of the sizing program, the aerodynamics are implemented as an empirical method directly from the experimental results. Using actual vehicle aerodynamic data reduces the generic quality of the method, but this approach is simple to implement and allows for modularity between vehicles with similarly explored aerodynamic characteristics.

Launch Vehicles

Like the capsule, launch vehicle aerodynamics are described empirically. Mercury-Redstone reported values are used to create a lookup function for drag coefficient as a function of Mach.

Propulsion

Capsule

The in-orbit ΔV's for insertion and de-orbit are modeled as instantaneous changes in velocity that are accompanied by losses in mass (fuel burn and/or propulsion element jettison). Because of this assumption, a propulsion disciplinary method is not needed for the capsules, only technology-related values for retro-rocket performance in the input file.

Launch Vehicle

Disciplinary analysis for launch vehicle propulsion uses an estimation method for liquid rocket performance (Pratt & Whitney Method). The user input for this method includes the thrust and specific impulse of the rocket in vacuum, as well as the rocket chamber pressure, and nozzle area ratio. Output is the thrust and specific impulse as a function of altitude. It is assumed that alternative launch vehicle concepts considered for *Project Mercury* would have made use of available rocket engines and would not have developed an engine from scratch.

Trajectory

The trajectory for the entire flight envelope is reduced to a 2-D, time-integrated series of equations. Because of the mission profile (no change of orbital plane) and the ballistic re-entry (no lift), the assumption is made that the trajectory can be adequately described by the altitude, range, velocity, flight path angle, and time. Integration is carried out numerically with a Runge-Kutta differential equation solution technique. The integration requires drag coefficient from aerodynamics, thrust from propulsion, weight from weight & volume, an atmospheric model, and a gravity model.

Capsule

The capsule trajectory is initialized from a design orbit and a specified retro-burn. This inserts the capsule into a re-entry trajectory. Both Mercury and Vostok missions have ballistic re-entry trajectories with a fixed zero degrees angle of attack. For sizing purposes, only the re-entry portion through the upper atmosphere is critical. Parachute deployment and landing is modeled as step changes in aerodynamic methods (calculation of drag coefficient), but is done only for completeness and parachute sizing. The landing flight phase does not produce any design-driving parameters for the capsule.

Launch Vehicle

During each convergence iteration, the payload weight of the launcher (capsule + retro-engines + escape tower + adapter) is considered a fixed value. The launcher accelerates upwards until all the fuel is expended, the payload is separated from the launcher, and the payload is integrated within trajectory until reaching a maximum altitude. In the case of the Redstone mission, the capsule is further integrated until parachute opening altitude because of the driving mission constraints (weightlessness time and maximum re-entry acceleration).

Heating

Heating analysis is only performed for the capsule during the reentry phase of the mission. All other combinations of vehicle elements and mission phase are non-critical. Values for the heating rate are obtained by utilizing a semi-empirical engineering relation for stagnation-point heat transfer rate on a sphere developed by Fay and Riddell [8]. The inputs required are the geometry (nose radius) and the trajectory (velocity, density). Both the Mercury and Vostok capsules have spherical heat shields, therefore the method is directly applicable with the definition of the nose radius solved for in the respective geometry modules.

Weight and Volume

Capsule

Capsule weight is determined by using a weight and volume budget methodology from Hypersonic Convergence [5]. The methodology is generic in its formulation, but because the re-entry capsule does not requires weight and volume allocations for propulsion elements, the following variables are the driving weights/volumes, see Table 4. Capsule Weight Method Variables of Merit

Table 4. Capsule Weight Method Variables of Merit

Variable	**Description**
WSTR	Structure Weight
WOPER	Operational Weight
WSYS	Systems Weight
WMARGIN	Empty Weight Margin
OEW_W	Empty Weight from Weight Budget
V_SYS	Systems Volume
V_PAY	Payload Volume
V_CREW	Crew Volume
V_VOID	Void Volume
OEW_V	Empty Weight from Volume Budget

Each component of weight and volume is calculated using a combination of non-dimensional correlation factors and fixed values (i.e. *Void Volume* is specified in the input file as a fixed percentage of total vehicle volume, *Crew Volume* is input as a fixed, dimensioned design variable). This allows the weights and volumes to be divided between subsystems that are independent of the vehicle size and those that are dependent of the vehicle size.

Launch Vehicle

The disciplinary weight method for launch vehicles uses a component buildup process. Empirical relations for each component are implemented and calibrated separately to match the line by line and total weight values of the launch vehicle.

Table 5. Launch Vehicle Weight Method Variables of Merit

Variable	Description
WB	Body Weight
WVF	Vertical Fin Weight
WENG	Engine Weight
WTNK	Tank Weight
WADPTR	Adapter Weight
WSYS	Systems Weight
WBLLST	Ballast Weight
TOGW	Takeoff Gross Weight

Results

Space Planners Guide

The Space Planners Guide [2] was created by the United States Air Force in 1965 to provide a *"… first approximation for evaluating conceptual space missions …"* and to *"… reduce complex analyses to a straightforward step-by-step procedure. …"* It uses a series of inter-related empirical curves (nomographs) to give a first order estimate of the size, weight, and performance of space system elements. Figure 6 shows an example how one of the nomographs is used in practice. This specific graph gives an initial estimate of re-entry weight for a manned capsule which is then used as an input to more detailed systems-level weight estimation.

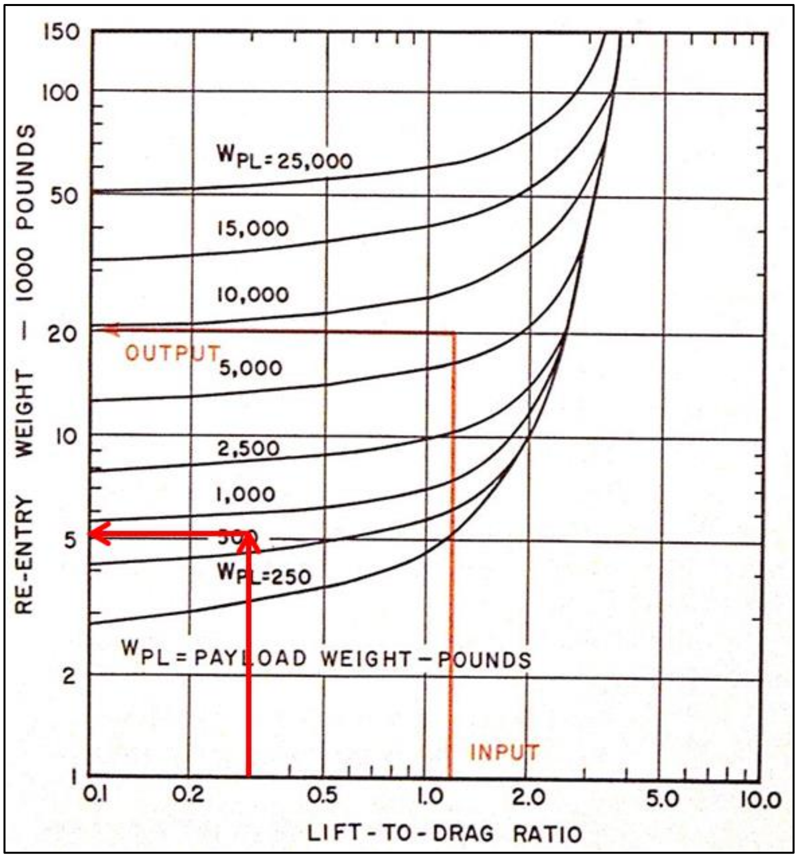

Figure 6. Nomograph to Determine Initial Reentry Weight Estimate [2]

The Space Planners Guide (SPG) is capable of performing systems definition for both re-entry vehicles and for launch vehicles. Therefore, Mercury, Atlas, and Redstone have all been assessed with the SPG. The results in Table 6 show an acceptable error bound in determining the size, weight, and performance of all vehicles except for Atlas, which can be attributed to the non-standard staging of the Atlas first stage boosters. Overall, the SPG provides a very sufficient early design analysis if considering a vehicle and mission within its intended range of applicability.

Table 6. Space Planners Guide Results & Comparison

		SPG	Actual	Units	%Error
Mercury Capsule	Orbital Weight	1,207.0	1,237.2	kg	2%
	Takeoff Weight	1,978.1	1,938.7	kg	2%
Atlas Launch Vehicle	Orbital Velocity	7,650.5	7,858.0	m/s	3%
	Gross Weight	155850.7	116,074.3	kg	34%
	Height	27.4	25.0	m	10%
	Diameter	3.7	3.0	m	20%
	Thrust	1,986,887.1	1,587,192.2	N	25%
Redstone Launch Vehicle	Maximum Velocity	2,295.1	2,324.4	m/s	1%
	Gross Weight	27,693.6	28,394.9	kg	2%
	Height	18.3	19.8	m	8%
	Diameter	1.5	1.8	m	14%
	Thrust	353,055.3	356,996.5	N	1%

Parametric Sizing Design Point Validation

In order to continue with any design trade studies, the parametric sizing process must be calibrated. A design reference mission is used as the input, and method-specific variables are calculated or iterated until the simulated vehicle matches the actual vehicle. The result is an individual point design (the vehicle is not put in context of other solution possibilities). Because the overall goal of the reverse engineering case-study is correctness not accuracy, any error within 10% is considered tolerable. Correct sensitivity to input variables is the key to insightful design trade conclusions, and is verified as well.

Mercury Capsule

The capsule sizing has been decoupled from trajectory and heating due to time and complexity limitations. Because of the narrow design envelope considered for this research, the geometry and weight is considered only a function of their own disciplinary design inputs, while the mission only has an effect on the performance (i.e. a capsule will be roughly the same size and require the same technology for a 100 km orbital mission as a 150 km orbital mission, but the reentry performance will vary between the two missions).

The Mercury-Atlas 7 mission is used as the input for the Mercury capsule design point, because the orbital Atlas missions are much closer to the design-limiting cases than the Mercury-

Redstone demonstration missions. The Redstone missions were tests of operational capability and logistics and do not push the design towards the design-constraining flight conditions that define the capsule requirements. The top-level geometry, weights, and volume results for a MA-7 mission-sized capsule are shown in Table 7 and the design point geometry is shown overlaid with the actual Mercury mold line in Figure 7.

Table 7. Parametric Sizing Design Point Capsule Results & Comparison

	Sizing	**Actual**	**Units**	**%Error**
Orbital Weight	1,241.6	1,237.2	kg	0.4%
Structure Weight	422.2	409.8	kg	3.0%
Systems Weight	432.5	445.0	kg	2.8%
Propulsion Weight	225.0	222.0	kg	1.4%
Total Volume	3.4	3.2	m^3	6.2%
Systems Volume	0.9	1.0	m^3	10.0%
Planform Area	3.1	2.8	m^2	10.7%
Wetted Area	14.2	13.8	m^2	2.9%
Capsule Diameter	2.0	1.9	m	5.3%

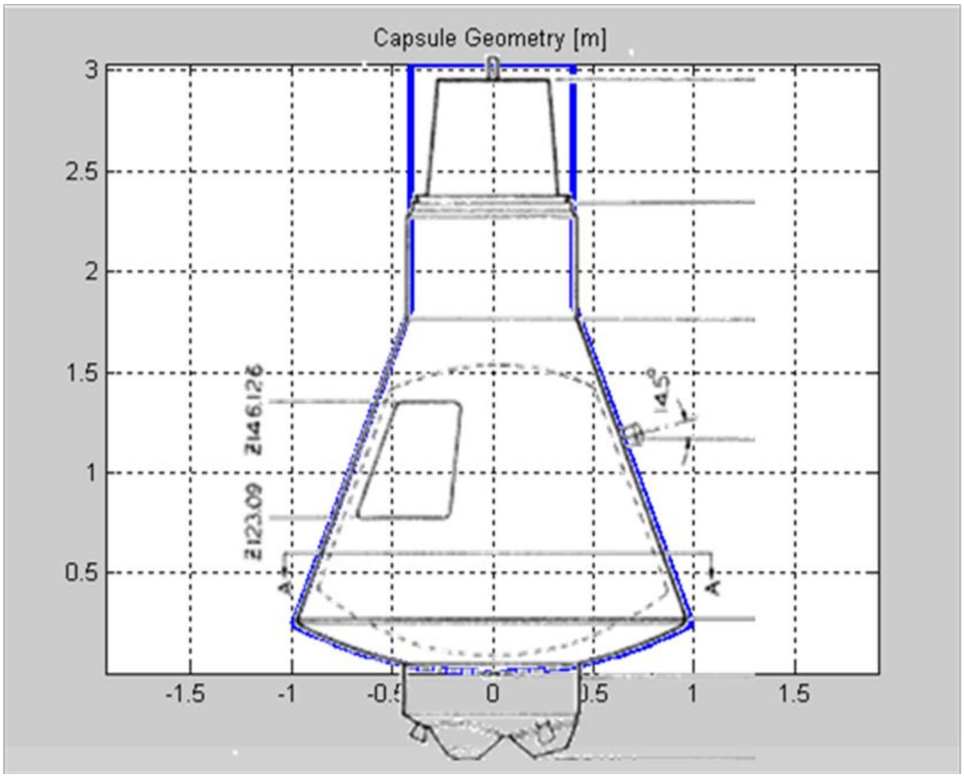

Figure 7. Design Point Capsule Geometry [6]

Redstone Launch Vehicle

The Mercury-Redstone 3 mission is chosen to calibrate the launch vehicle sizing process because of its simple single-stage configuration, and straight-forward performance objectives. Table 8 shows the results of the sizing results and illustrates a very correct and accurate design point.

Table 8. Parametric Design Point Launch Vehicle Results & Comparison

	Parametric Sizing	Mercury Redstone	Units	% Error
Booster Height	17.3	17.5	m	-0.8%
Booster Diameter	1.8	1.8	m	0.0%
Wetted Area	96.9	97.7	m^2	-0.8%
Tank Volume	26.8	27.0	m^3	-0.5%
Tank Height	10.8	10.9	m	-0.6%
Fuel Fraction	0.8	0.8		-0.1%
Operating Empty Weight	3,868.1	3,875.5	kg	-0.2%
Operating Weight Empty	5,523.4	5,530.7	kg	-0.1%
Fuel Weight	24,310.7	24,436.4	kg	-0.5%
Takeoff Gross Weight	29,834.1	29,967.0	kg	-0.4%

Design Trades

With a calibrated, converging model for a LEO capsule – expendable booster space architecture, design-driving input variables can be identified and then varied to create a design trade space that consists of converged vehicles offering alternative design choices. The goal is to identify the interrelationship between design variables and the overall vehicle size, weight, and performance. Physical and technological constraints are added to the design space to illustrate which grouping of vehicle options are feasible and which vehicle options violate the Mercury program constraints, and are therefore unfeasible designs for the given mission and technology.

Constraints

Size, weight, and performance requirements are pulled from various sources that must be considered in the early design phase. For ease of implementation, all constraints have been added passively in post-processing. This means a vehicle can be a plausible, converged design but because it violates a constraint, it is not feasible for the given combination of technology and mission. In this way, the engineer can see the entire range of vehicle possibilities and at the same time see the smaller range of acceptable possibilities.

Capsule

Table 9. Capsule Constraints

Constraint Variable	Value	Reason
Longitudinal Acceleration	11 g	Maximum tolerable amount for astronaut
Maximum Heating Rate	300 W/cm^2	Approximate max. for ablative TPS of era
Capsule Diameter	1.78 m	Atlas max. payload diameter
	2.56 m	Vostok max. payload diameter
Orbital Weight	1,400 kg	Atlas max. orbital mass [LEO]
	4,400 kg	Vostok max. orbital mass [LEO]

Launch Vehicle

Table 10. Launch Vehicle Constraints

Constraint Variable	Value	Reason
Longitudinal Acceleration	11 g	Maximum tolerable amount for astronaut
Weightless Time (Redstone Mission)	5 min	Operational goal for test mission

Capsule Trades

Volume per Crew Trade

In order to justify the designer's choice for the overall size of the Mercury capsule, a design-driving input needs to be varied while keeping the design mission constant. The volume allotted for the crew member is chosen as the key variable to keep volumetric efficiency (and as a product the aerodynamic performance) roughly constant, while allowing the capsule to grow or contract based on the input, see Figure 8. In this way a family of possible Mercury capsules can be identified that fit within the launch capabilities and re-entry performance requirements.

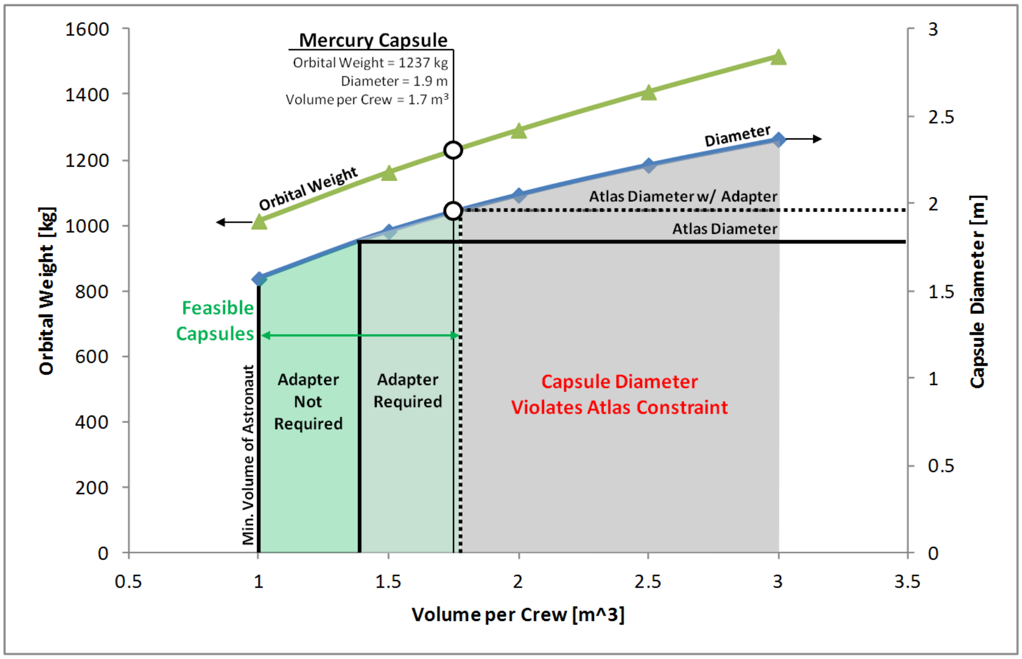

Figure 8. Mercury Capsule Volume per Crew Trade

The starting value of 1 m^3 is a rough estimate of the minimum volume an astronaut-sized human requires. As volume increases, the size and weight increases as expected. When the Atlas booster constraints are overlaid on the capsule results, it can be seen that the Mercury Capsule design point roughly corresponds to the widest vehicle that could fit as payload on the Atlas launcher. An adapter is required for the design point capsule with an increase in diameter of 10% over the standard payload section of Atlas. Increasing the potential adapter size past 10% would further decrease aerodynamic performance during the ascent phase, necessitating development of a more complex payload adapter system. Further, the Atlas maximum payload constraint of 1,400 kg (not shown) will only allow the capsule diameter to grow to 2.2 m; this will limit the design space even if a larger adapter can be adequately designed.

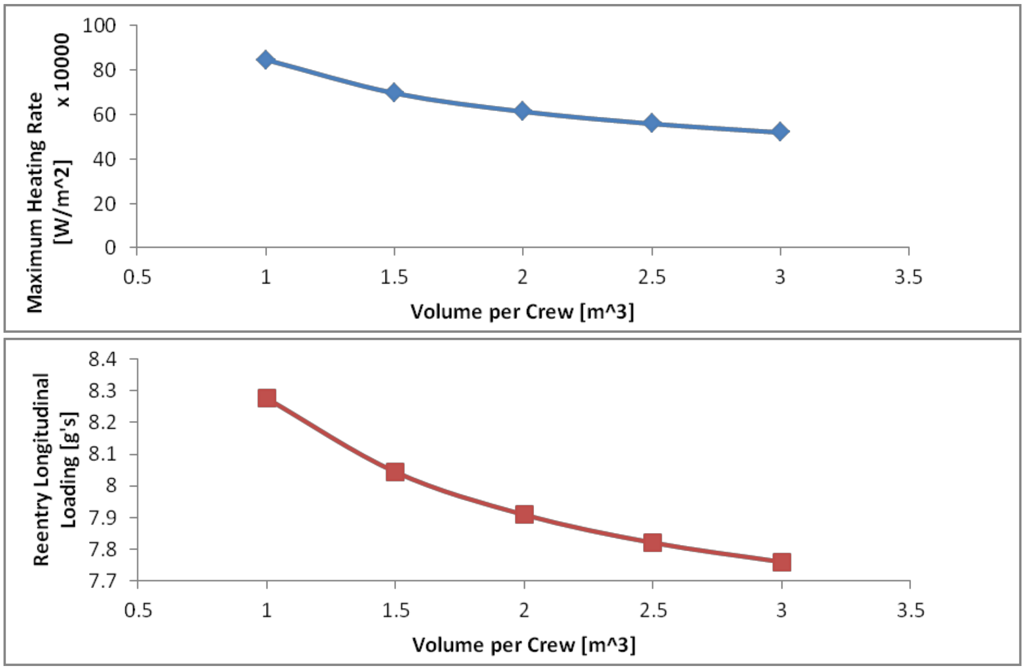

Figure 9. Mercury Capsule Volume per Crew Trade – Performance

Figure 9 shows the trend of heating rate and longitudinal acceleration as part of the same volume per crew trade. The maximum heating constraint of approximately 300 W/cm2 and the maximum loading constraint of 11 g's both appear off the top of each graph. This illustrates that the mission alone has a first order effect on heating and load, while the vehicle configuration choice has only a secondary effect. Still, the trend suggests that the largest possible capsule be selected to minimize undue stress on the thermal protection system and the astronaut.

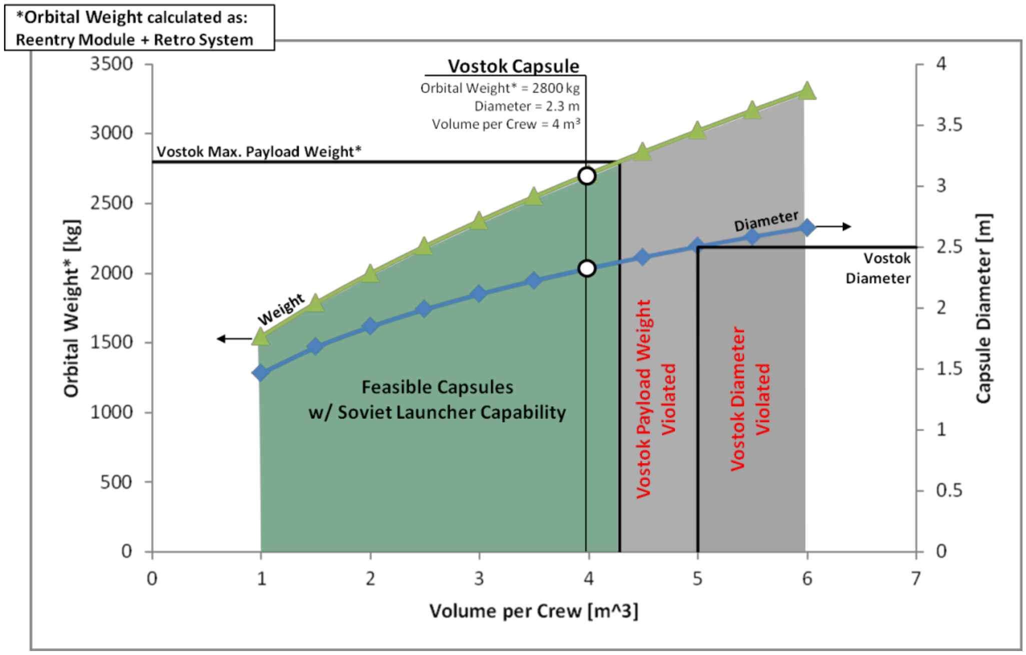

Figure 10. Vostok Capsule Volume per Crew Trade

The Vostok capsule was similarly evaluated in Figure 10. In order to compare systems of the same operational capability, the retro-rocket installed on the service module is modelled as a part of the manned capsule. The reported orbital weight is therefore not the actual orbital weight of Vostok, but the weight of a re-entry module modelled after the Vostok capsule and a retro-rocket propulsion system. It is seen that because of the much larger and more powerful Vostok launcher, a wider portion of the solution space is usable.

The Vostok spherical design has an operational advantage since it is able to re-enter at any attitude. The decrease in complexity is countered by the decrease in re-entry performance, see Figure 11. The trend with increasing vehicle size is the same as Mercury, although the magnitudes are increased. A Mercury-based capsule of the same diameter as a Vostok-based capsule has a larger nose radius (reduced heating) and weighs less (reduced max. acceleration).

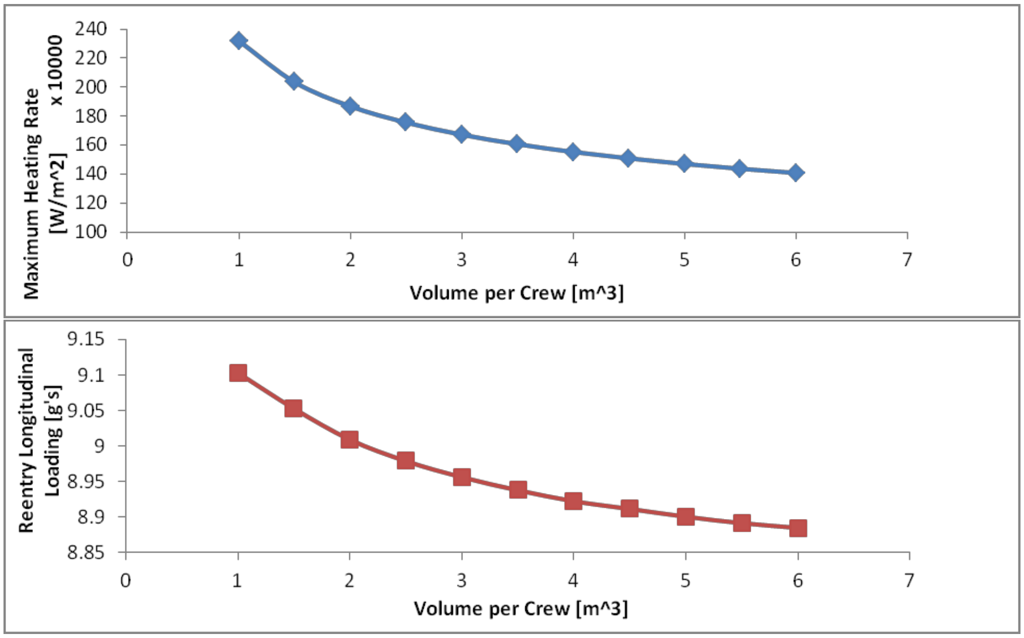

Figure 11. Vostok Capsule Volume per Crew Trade – Performance

By overlaying the results of a spherical geometry with the Mercury capsule geometry design space, novel conclusions can be made, see Figure 12. The design space shows that with the Atlas launch capability available at the time of *Project Mercury*, a purely spherical capsule is not a feasible solution. The sphere is able to fit within the Atlas payload diameter, but the stouter design increases weight past the maximum payload constraint of the existing booster.

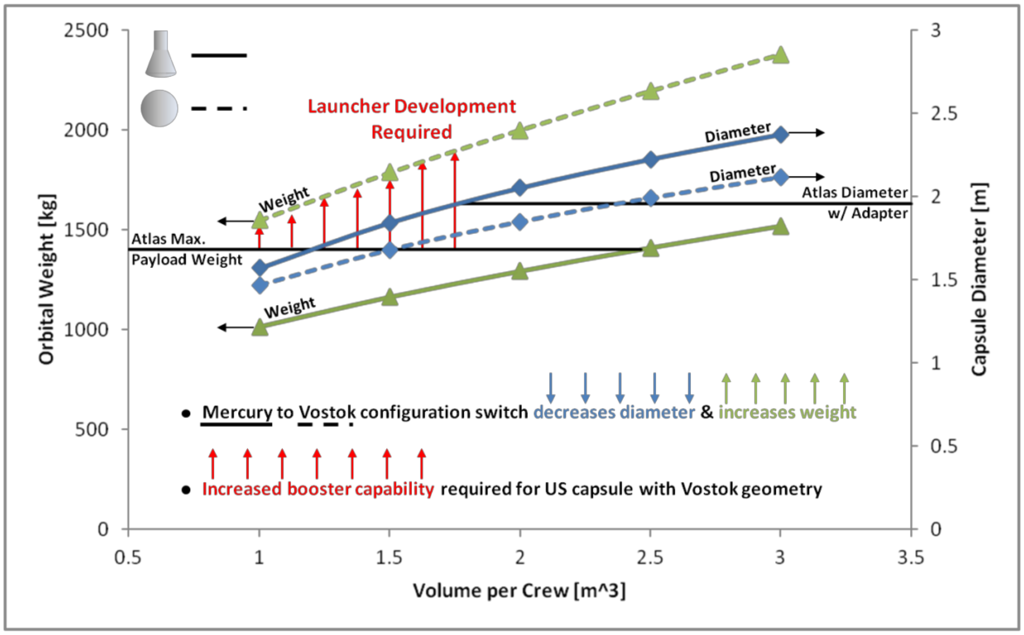

Figure 12. Spherical Geometry Trade

This analysis numerically illustrates that the USA was launcher-constrained in their design possibilities at the time of *Project Mercury*. Because the USSR had invested more heavily into a larger rocket booster system (for nuclear warheads), a more robust spherical capsule was possible. The US manned capsule had to be a smaller vehicle, but at the same time required to have a sufficiently large spherical forward section to handle the re-entry heating environment. This led to the Mercury spherically-capped conical frustrum configuration that maintains a wide spherical heat shield and reduces weight by decreasing useable volume within the capsule.

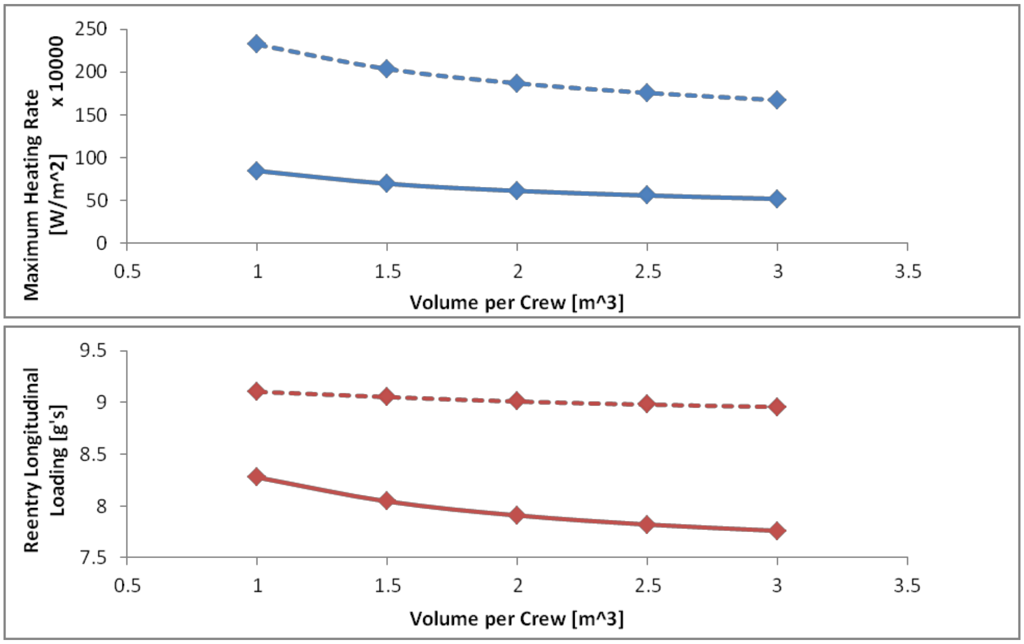

Figure 13. Spherical Geometry Trade – Performance

Launch Vehicle Trades

Booster Height Trade (Redstone)

This section details the build-up of the solution space for the Mercury Redstone Booster. Figure 14 shows the design space for vehicles containing Mercury Redstone level technology levels for aerodynamics, propulsion, and weights. Each point on the figure represents a converged vehicle concept. The design space is visualized through varying the height of the booster and payload mass (mass of re-entry capsule). Height is selected as the independent variable by assuming that the rocket engine selection locks diameter and propulsion performance and therefore total stack height, which is the primary driver for mission performance. The results show that an increase in either booster height or design payload results in an increase in lift-off mass.

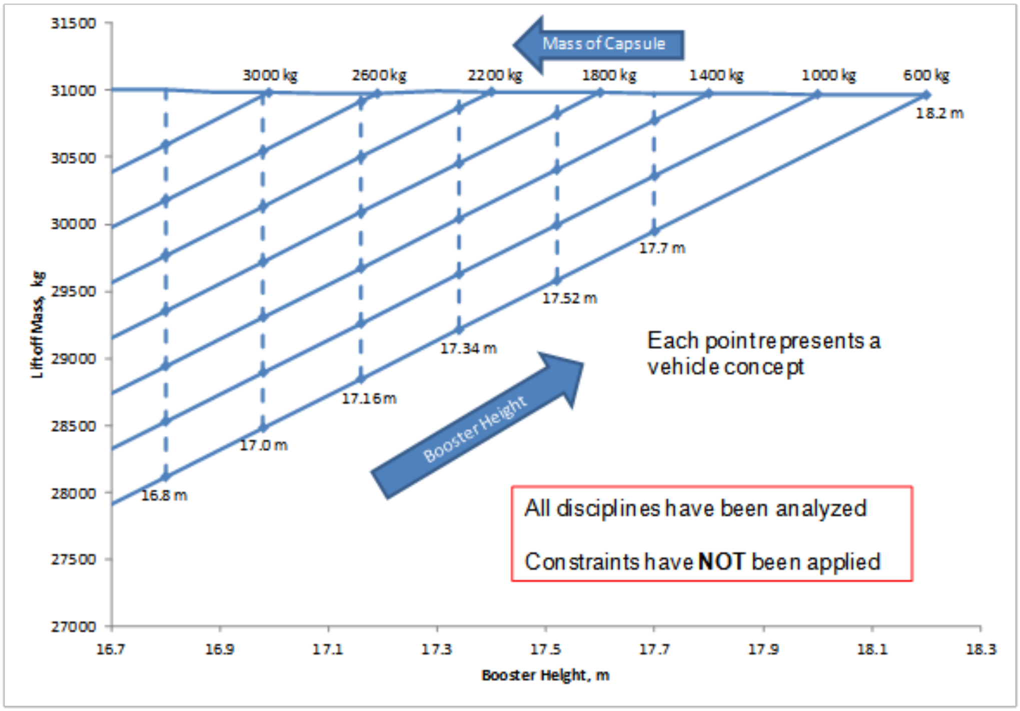

Figure 14. Booster Height Trade – No Constraints

In order to choose a specific vehicle concept or region of applicable vehicle concepts, mission constraints must be applied. The Mercury Redstone mission consisted of three mission constraints:

- Maximum **11-g** deceleration on re-entry
- Minimum **5 Minutes** of Weightless
- Minimum **185.2 km** apogee altitude

The constraints cut through the design space, effectively shrinking the number of vehicle concepts that could feasibly satisfy the mission. It should be noted that the deceleration constraint and the apogee altitude/weightlessness constraint have opposing trends. This means that the parts of the design space that satisfy these constraints are opposing. Anything above the deceleration constraint is feasible, while anything below the apogee altitude/weightlessness constraints is feasible. The result of superimposing all constraints is the highlighting of the feasible solution space for the Mercury Redstone mission, see Figure 16.

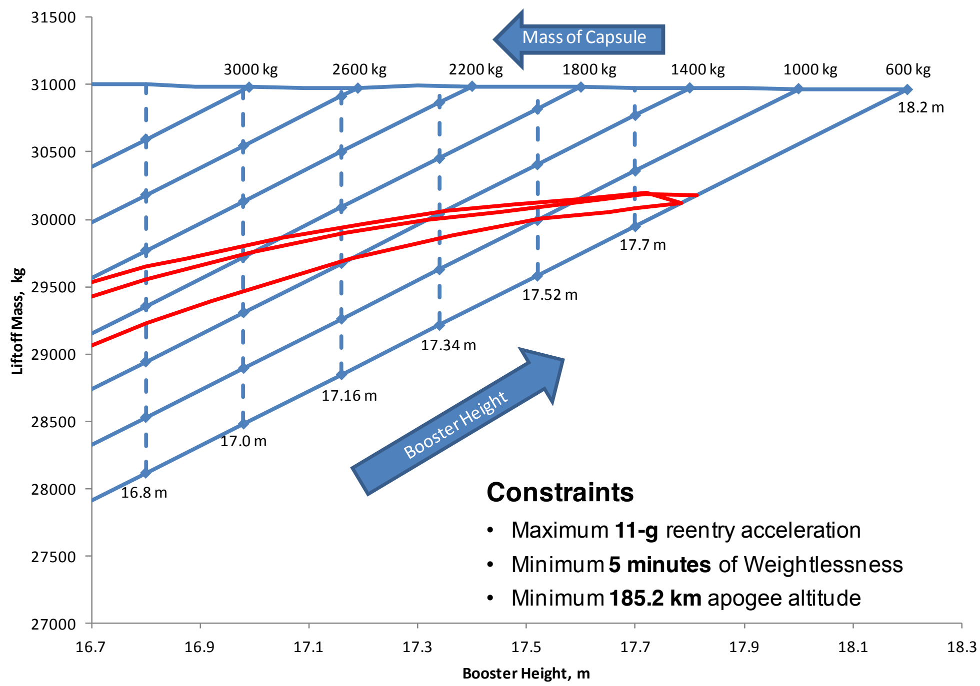

Figure 15. Booster Height Trade – Constraints Overlaid

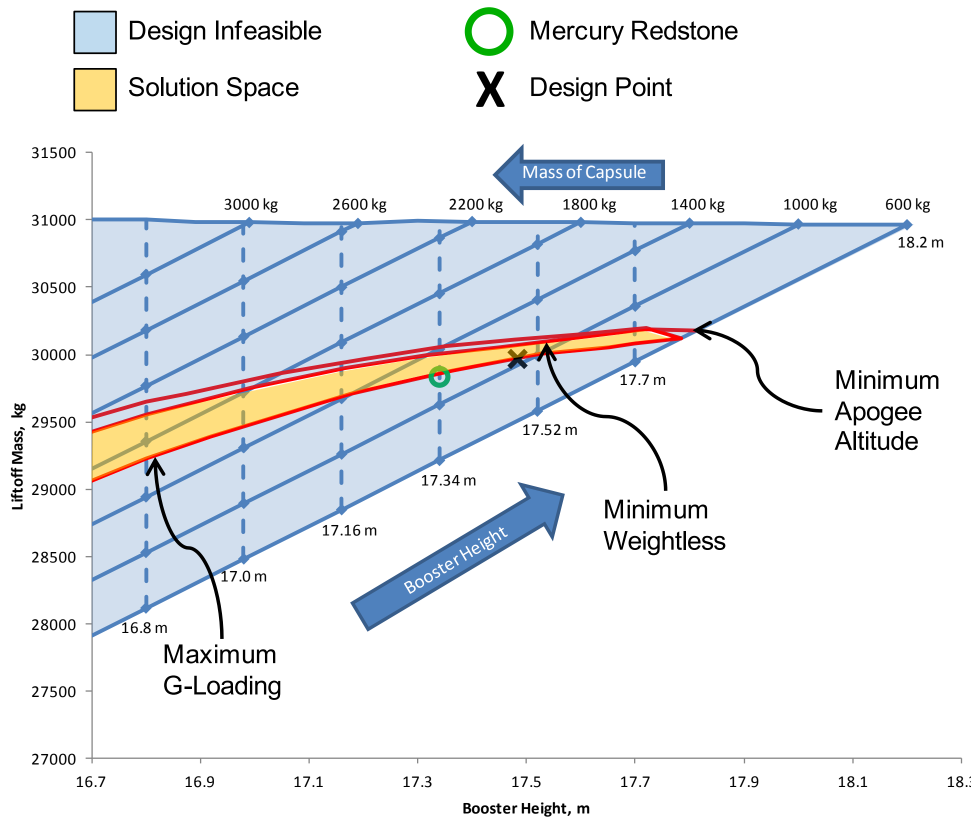

Figure 16. Booster Height Trade – Mercury Redstone Solution Space

Because of the competing nature of the performance constraints, the solution space indicates that the Mercury-Redstone combination has a very small window of feasibility. Since thrust is an independent parameter (locked value), any increase in payload from the design point requires a decrease in launch vehicle size to ensure constant performance. The design point for a Mercury-Redstone launch vehicle lies directly on the maximum g-loading constraint; capsule weight growth results in a mission that does not reach the minimum apogee altitude and/or is not weightless for 5 minutes, while weight reduction from the design point results in a mission that exceeds the safe re-entry loading limits.

Study Conclusions and Follow-On Research

Conclusions

- Capsule and launcher vehicle systems are independently implemented and validated.
- *USAF Space Planners Guide* provides efficient first-order space vehicle sizing guidance.

- Mercury capsule design point is justifiable the largest possible capsule that fits within Atlas launcher constraints.
- Vostok-like spherical geometry not feasible at the time of Project Mercury due to limitations in launcher payload weight capability.
- Redstone launch vehicle is justifiable the smallest feasible booster for fixed Mercury capsule and fixed performance constraints.

Follow-on Research

- Implement analytic models for aerodynamics and heating.
- Adapt structure weight to be dependent on maximum dynamic pressure.
- Adapt thermal protection system weight to be dependent on heating rate / heat load.
- Connect vehicle elements for total system convergence.
- Quantify performance in abort / emergency scenarios.

Project Mercury has been brought to life as a modern case-study example of disciplinary integration and systems level design solution space creation. Historic engineering efforts can be leveraged to gain insight into still-relevant problems and to help today's engineer understand the top-level decision-making of past projects that have pushed the boundaries of multi-disciplinary engineering.

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The Impact of Peer Interaction Exercises in a Signals and Systems Course

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Abstract

This paper investigates the impact that peer interaction exercises have on student learning in the context of a Signals and Systems course. This junior-level course in the electrical engineering curriculum provides foundational material for several senior-level classes. The extent of the peer interaction activities varied from conceptual problems that required a few minutes of interaction between neighboring students to small group exercises requiring an extended amount of class time to complete. For the more challenging problems, such as those involving sampling theory, a scaffolding approach was utilized to direct the students to the solution. This involved the use of worksheets containing an outline of the key steps in the solution of the problem. Assessment of student learning gains was obtained through analysis of exam scores and results from a concept inventory test. Analysis of the assessment data does indicate a modest improvement in test scores compared to material not covered through peer interaction exercises. Student self-assessment surveys indicated the students generally perceived the value of the in-class peer interaction activities.

Introduction

Several studies have indicated the benefits of utilizing in-class peer interaction exercises to improve student learning and motivation. For example, the use of peer interaction activities centered around conceptual questions in an undergraduate genetics class was found to produce gains in conceptual understanding.[1] A similar study in computer architecture classes indicated the learning benefits associated with the active engagement of the students discussing problems with their peers.[2] This paper investigates the potential learning benefits from implementing active learning exercises centered around peer discussion groups in a Signals and Systems course. This junior-level course provides much of the foundational material in the electrical engineering curriculum for other courses such as Communications and Controls Theory.

The assessment instrument known as the Signals and Systems Concept Inventory (SSCI)[3] allows instructors to determine the conceptual understanding of the foundational material in a Signals and Systems course. The SSCI is a 25 question multiple choice test that can assist in uncovering common student misconceptions in the course and thus, can be used to improve the curriculum.

The SSCI was utilized in this study as a source of peer interaction questions as well as an assessment instrument to gauge student conceptual understanding of the course material. The use of in-class exercises to reinforce key concepts in a Signals and Systems course have been investigated by others.[4,5] Both studies report the positive impact of actively engaging the students in the classroom. The analysis of problems solved in-class was also used to better understand how students apply their mathematical background to understand key concepts in signals and systems with the ultimate goal of providing a framework for curriculum and assessment design.[6]

A study was undertaken in Spring 2012 at our institution to determine the impact of various types of peer interaction exercises on student learning in a Signals and Systems course. This is a junior-level course in the electrical engineering curriculum, which provides foundational material for several senior-level classes. This paper is outlined as follows. First, a general background of the Signals and Systems class is described followed by a description of the different types of peer interaction exercises utilized in this study. Second, the methods of assessment and an analysis of these results are given. The paper concludes with a summary and discussion of plans to further improve the use of peer interaction in-class exercises.

Implementation

The Signals and Systems course covers the analysis of linear time invariant (LTI) systems involving continuous-time and discrete-time signals. Several types of transforms, such as the Fourier transform, Laplace transform, and z-transform are used in this analysis. The students are also introduced to sampling theory as the bridge between the continuous-time and discrete-time domains. As such, the course draws upon a fair amount of mathematical theory that the students learn in their first two years of college. As a result, the students find many of the topics in this course, such as convolution and sampling theory, rather abstract and difficult to comprehend. Due to the importance of this course in laying a foundation for other senior-level classes and the challenging nature of the material, it is worthwhile to investigate the potential learning benefits associated with peer interaction exercises.

The extent and type of peer interaction activity varied depending on the conceptual difficulty of the topic. Table I lists the seven exercises administered in this course.

Table I. Peer Interaction Exercises Implemented

Exercise	Type
1. Continuous-Time Convolution	Concept
2. Signal Transformation	Concept
3. Sampling Theorem	Worksheet
4. Discrete Fourier Transform	Worksheet
5. Discrete Time Convolution	Graphical
6. Discrete Linear Time Invariant System	Worksheet
7. Pole-zero Frequency Response	Graphical

Three types of peer interaction exercises were implemented, which we have categorized as concept, graphical, and worksheet exercises. The concept exercise presented the student with a conceptual problem and a multiple choice set of answers to choose from. The students were given a few minutes to discuss the question with a neighbor before selecting an answer. The problem was subsequently explained by the instructor. Conceptual problems in basic signal transformations and the characteristics of a linear time-invariant (LTI) system are representative problems of this type. Figure 1 illustrates the concept question that tests the student's understanding of continuous-time convolution. This example was taken from the SSCI.[3]

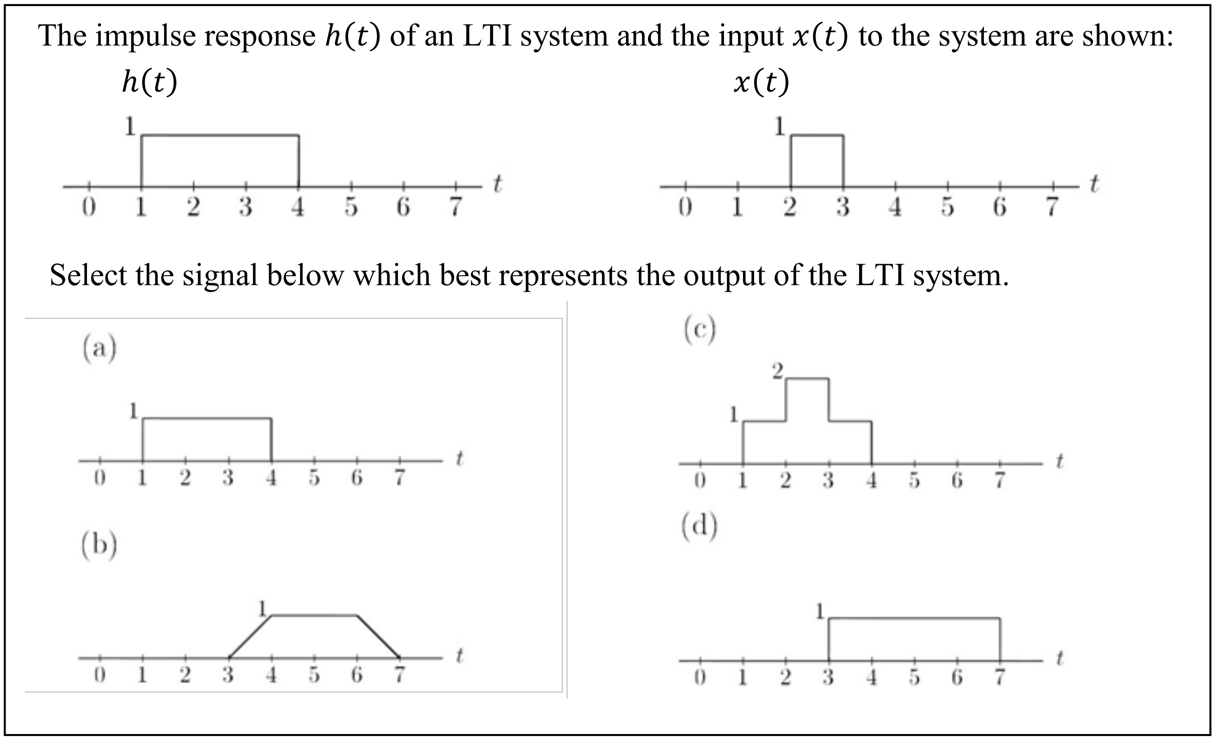

Figure 1. A conceptual question involving continuous-time convolution.

An intermediate type of problem involved the students working in small groups to produce a graphical solution to a given question, such as plotting the frequency response to a plot-zero plot, as shown in Figure 2.

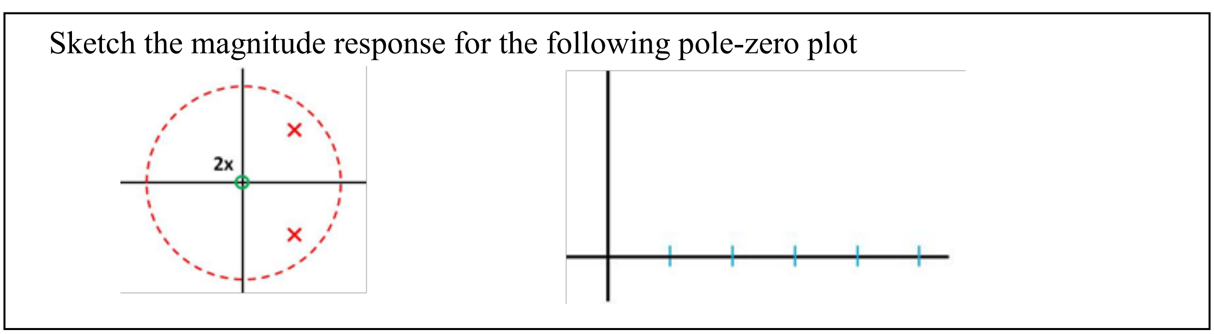

Figure 2. A graphical question involving a pole-zero plot.

For more challenging problems, such as those involving sampling theory, a scaffolding approach was utilized to direct the students to the solution. This involved the use of worksheets containing an outline of the key steps in the problem solution. The instructor worked with student groups in class to provide additional guidance where necessary. An excerpt from a Discrete Fourier Transform (DFT) worksheet is illustrated in Figure 3.

Given a signal $x(t) = \frac{2}{t^2+1}$, determine suitable values for T and T_0.

1. Find the Fourier Transform $X(\omega)$.

   Review the Duality Property from your textbook (p. 700).

   If $x(t) \quad \leftrightarrow \quad X(\omega)$ then

   $X(t) \quad \leftrightarrow$

   Find a suitable entry from Table 7.1 (p. 702)

   If $X_1(t) = \frac{2}{t^2+1}$ then

   Then $X(\omega) =$

2. Find the effective bandwidth B for $X(\omega)$. Use the criteria that $|X(\omega)|$ is equal to 1% of its peak value at $\omega = 2\pi B$.

   Observe: the peak value of $X(\omega)$ occurs at $\omega =$

   Solve for $\omega = 2\pi B$:

   Then: $B =$

   $T \leq \frac{1}{2B} =$

Figure 3. An excerpt of a worksheet exercise involving the Discrete Fourier Transform.

The first part of the worksheet guides the student to review some key points about the Fourier transform from their textbook, while the second part outlines the steps needed to solve the problem. The scaffolding approach is evident as suitable hints are given throughout the worksheet, with key equations given, and blanks requiring the student to complete an answer.

Assessment and Discussion

A variety of assessment methods were utilized. First, student self-assessment surveys were distributed at various points in the semester to gauge student reaction and attitudes to this teaching method. Second, student performance on the final exam was analyzed for evidence of learning gains. Third, a concept inventory test was administered to the students at the end of the semester to determine the impact on their conceptual understanding.

First, we present results for the first two peer interaction exercises involving the multiple choice concept questions. In these exercises, the students were asked to study the problems on their own and select an answer. Then they were directed to discuss the problem with a peer, and select an answer again. Table II summarizes the responses which are grouped into four categories, based upon whether the initial answer and second answer after peer interaction were correct or not.

Table II. Student Responses to the Concept Exercises

Question	Both Correct	Incorrect-Correct	Correct-Incorrect	Both Incorrect
1.	2	2	2	14
2 (a)	17	1	1	0
2 (b)	17	2	0	0
2 (c)	16	3	0	0

The first question covered continuous-time convolution, as illustrated in Figure 1. This was given in the third week of the semester before the topic was reviewed in class. Continuous-time convolution was covered in the previous semester. Most students favored answer (a) or (d) in Figure 1. The students apparently did not remember that convolution involves integrating the product of two signals, so the correct answer in this case must be (b). Also it appears that peer interaction did not help much since only two students changed their answer to the correct one after interacting. Questions 2 (a) to (c), covering signal transformations, was given a week later. This topic was covered at the beginning of the semester. It is evident from the results that the students understood this topic much better as it is conceptually easier than convolution and was reviewed in class prior to giving this assignment. It is interesting to look at the student attitudes towards peer interaction exercises at various points in the semester. After both concept questions, the students were surveyed, with their responses summarized in Table III.

Table III. Student Attitudes towards Peer Interaction Exercises
(*Scale*: 1= Strongly Disagree, 2= Disagree, 3 = Neutral, 4= Agree, 5 = Strongly Agree)

Statement: I was able to get a better grasp of this material by either explaining it to one of my peers or listening to an explanation from one of my peers	Rating	Sample Size
1. Continuous-time convolution problem.	3.50	20
2. Signal transformations.	4.20	19
3. Sampling Theory	3.95	21
4. Pole-zero Frequency Response	4.35	20
5. End of semester (Week 17)	4.33	21

The benefits of peer interaction were perceived as being more useful for the second set of problems even though most of them had the correct answer before discussing it with a peer. One student wrote a comment that the peer interaction helped clear up some confusion while another wrote that there was not much peer interaction since both concurred on the correct answer. For the pole-zero plot exercise, the instructor observed that the students were most engaged in this exercise. Select students were asked to present and explain their results in front of the class to the four graphical problems that were assigned. The survey of student attitudes given in the table above seem to concur with this observation as it is rated the highest. By the end of the semester, they had an overall positive attitude to the use the exercises.

In addition, the student attitudes in general towards the peer interaction exercises was sampled once before the second test (Week 13) and again at the end of the semester (Week 17). Overall, they viewed the exercises as a beneficial use of class time, as summarized in the table below.

Table IV. Student Attitudes towards Peer Interaction Exercises
(*Scale*: 1= Strongly Disagree, 2= Disagree, 3 = Neutral, 4= Agree, 5 = Strongly Agree)

Statement	Rating Week 13	Rating Week 17
1. Overall, I find interacting with my peers during an in-class exercise to be a beneficial use of class time.	4.10	4.43
2. We should have more peer-interaction exercises in this class	3.95	4.14
Sample Size	21	21

The final exam consisted of seven questions with four of the questions (3 to 6) covered by the peer interaction exercises. A summary of the student performance is given in Table V.

Table V. Analysis of Final Exam Scores

Question	Score %	Vs. Avg
1. Exponential Fourier Series	68.2	
2. Frequency Shifting Property	66.9	
3. Frequency Spectrum and Signal Reconstruction	87.6	+11.7
4. Discrete Fourier Transform	79.5	+3.7
5. Discrete Linear Time Invariant System	65.7	-10.1
6. Frequency Domain Analysis – Pole/Zero Plots	78.1	+2.3
7. Implementing a Discrete System Transfer Function	79.5	

The overall average of the final exam was 75.6%. The last column shows how the four questions compared with the overall exam average. Modest improvements from 2.3% to 11.7% are observed for three of the questions. The discrete LTI system question was below average. This is a more challenging problem that was covered by a worksheet exercise. It is conjectured that without the benefit of scaffolding on the exam, the students were not able to do as well on this problem on the final exam.

A concept inventory test was given at the end of the semester to assess the conceptual understanding of the students. Twelve questions were selected from the standard SSCI, with seven of them (highlighted in blue) covered by the peer interaction exercises. The results are summarized in Table VI.

Table VI. Results of the Concept Inventory Test

Question	Number Correct	Percent Correct
1. Exponential Fourier Series	18	90%
2. Signal Transform $\rho(t-2)$	18	90%
3. Signal Transform $\rho(2-t)$	8	40%
4. Plot $r(t)-r(t-2)$	19	95%
5. Time Delay in Linear Time Invariant System	19	95%
6. Frequency Spectrum Plot Given $x(t)$	9	45%
7. Fourier Transform	9	45%
8. Convolution (continuous-time)	4	20%
9. Pole-zero plot for BIBO stability	19	95%
10. Convolution (frequency)	2	10%
11. Frequency response from Pole-zero plot	11	55%
12. Convolution (discrete)	1	5%

From these results, it is difficult to make any definitive conclusions on the impact of the peer interaction exercises on the conceptual understanding of the students. Some of the answers indicate a solid conceptual understanding while others, most noteworthy those involving convolution, appear to be still not well understood by the students. The notion of convolution is typically the most difficult concept for students to grasp in this course. The students, can generally work with the equations to solve a problem in convolution numerically, but the underlying concepts usually seem to elude them. The challenge of understanding convolution in our courses concurs with experience of other instructors.[5,7] Going forward, greater attention needs to be paid to teaching this concept although a significant amount of class time is already devoted to this topic, with several Matlab assignments given to illustrate this concept.

Finally, we present results from the end of semester survey that asked the students to rate the learning benefits associated with various teaching methods used in the Signals and Systems course. Table VII summarizes these results.

Table VII. Student Attitudes towards Teaching Methods
(1) Least Helpful (2) Not very helpful (3) Neutral (4) Somewhat helpful (5) Most helpful

Statement	Rating
1. Listening to a lecture/taking notes	4.1
2. Reading the textbook	3.3
3. In-class activity – working on a problem individually	3.4
4. In-class activity – peer interaction	4.1
5. Professor working out example in class	4.6
6. Doing the homework	4.3
7. Doing the Matlab assignments	2.9

The high value placed on professor-led activities (categories 1 and 5) are not surprising since these are components of a traditional lecture that the students would be most comfortable with. The in-class peer interaction activities, though, also scored highly in the student self-assessment.

Summary and Future Work

This paper has investigated the potential learning benefits that can be obtained from peer interaction activities in a Signals and Systems course. Various forms of peer learning activities were attempted. From an analysis of the tests and exams, there is some evidence for the positive impact of peer discussion on student learning. For example, on the final exam, on three of the four questions that were covered by peer discussion, the students scored above the exam average (ranging from 2 to 11% gains). Similarly, on the concept inventory test, some topics showed the majority of students had grasped the concept, while others indicated there was room for improvement. Of note is the student understanding of convolution, which is traditionally a difficult concept for students to grasp. The results do correlate with the student self-assessment of their conceptual understanding of the material. The assessment of student attitudes were positive overall as they felt on average that the peer interaction in class was beneficial in their understanding and was a good use of class time.

Future implementations will attempt to expand the use of peer interaction exercises in this course. The multiple choice concept questions only take a few minutes of class time and thus can be used more regularly. Concept inventory tests could be administered at several points during the semester to monitor student conceptual understanding and implement appropriate interventions to improve understanding where necessary.

Acknowledgement

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Outreach to K-12 Students with Bio-Nano Concepts

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Abstract

We report a unique, engaging and interesting scenario to make K-12 students familiar with concepts of nanoscale. The approach incorporates an anchored instructional scheme supported by highly motivating and attention-grabbing hands-on activities followed by a visit to Nanotechnology Research and Education Center (NanoFab). The tutorial content is carefully designed to integrate basic and application-oriented knowledge to teach students with dissimilar knowledge-base and diverse backgrounds. The learning objectives are achieved by taking examples from daily life and demonstrating the underlying principles with simple but highly convincing hands-on activities. Practical demonstration of in-class learned concepts motivate the students to explore the new territory of bio-nanotechnology. Their excitement, thought processes and quest for exploring this field deeper is evident from the burst of questions and exchange of knowledge from their side. A tour of the NanoFab and Nano-Bio Lab is a very exciting addition to their learning environment and has helped better assimilation of the learnt concepts. The reported schemed has been repeatedly (3-4 times every year) implemented to educate K-12 students with bio-nano concepts. The exceptional outcome observed in result to the applied technique has established its efficacy over the past couple of years. The approach provides an appealing method to facilitate K-12 students with information, self-learning motivation and research aptitude development. The approach may cultivate next generation of engineers

dedicated to working in life science applications. Many collaborative efforts at academic and research levels are well-established already and these students can fuel our efforts to revive US higher education and high-tech research superiority in the world.

Introduction

Innovation and technological development requires skilled, trained and devoted citizenry. Modern electronic gadgets and other technological advancements trigger the natural curiosity and quest to explore these gadgets nurtures insights of students from very early parts of their lives. But, over the past few decades, students with engineering as their major have declined even in technically advanced countries like the United States.[1] Therefore, the youngsters should be encouraged and facilitated with tutorials, seminars and educational programs to augment their interest and knowledge in advanced technologies in order to expand a capable work force for next generation.

Nanotechnology has rapidly emerged among other fields of science and engineering. Growth and development of this field over the last few years has convinced researchers and scientists that it can sustainably knock over the prevailing technological models.[2] It has been speculated in many reports from last decade that nanotechnology would be a $1 trillion industry by 2015 and would accommodate more than a million employees in the United States. Evolution of this technology has been forecasted to incorporate approximately two million personnel all over the world engaged with this field by that same time.[3-6] Integration of biology and nanotechnology promises a great impact in life sciences. Collaboration of scientists and engineers can stimulate innovative ideas at the interface of the two streams (Biology and Nanotechnology). They can together possibly resolve various health issues by interrogating a certain disease at molecular level and offering an innovative, rational and realistic solution to the matter. Such a gigantic implication of bio-nanotechnology demands for a carefully designed academic program that merges basic and application-oriented knowledge from biology and nanotechnology to introduce bio-nano concepts to young students. Knowledge of this evolving technology at early stages of life would frame mature and skilled technological workforce that can revolutionize the characterization of diseased cells to predict their behavior and contribute towards early disease diagnostics, rapid drug discovery and localized drug delivery for better interventional therapies.

The growing field of bio-nanotechnology requires more individuals to dedicate their time and effort in making new discoveries about life at nanoscale. These individuals must be sought out and introduced to these concepts at a young age when their minds are capable of freely exploring and brainstorming new and creative ideas. K-12 students are at a perfect age to be taught the basic principles of nanotechnology so that they may gain an interest and pursue a career in this rapidly growing field. Teaching K-12 students is an important concern because their knowledge and interests will transform the future of nanotechnology. These students need the motivation to instigate a thought-provoking interest in bio-nanotechnology. This instituted curiosity will help them to bring in more innovations and reach greater achievements in the field. With students learning more about nanotechnology at a younger age, a much vibrant future in this field will be guaranteed. Also, it will induce a research aptitude in our youngsters and can result in cultivating our next generation with larger number of researchers in the field. Having trained and dedicated scientists/engineers would maintain the lead of the United States in key areas of nanotechnology innovation.

Educating K-12 students about new technologies and concepts has always been a challenge. Many efforts have been made to equip the K-12 students with nanotechnology that include various educational programs, teacher development plans and distant education services.[7-10] We report an appealing, straightforward and productive strategy to outreach K-12 students with bio-nano concepts. The students are approached with fundamental concepts supported by practical demonstration of the core impression through engaging activities, design problems of common interests and finally visit of the labs. This learning scheme has proved to be extremely helpful for the students to absorb the new concepts in a very exciting and inspiring environment.

Design and Description

The reported scheme incorporated three key elements to ensure a factual and effective assimilation of bio-nano concepts by K-12 students as shown by Figure 1. The first element involved a vigilantly designed integrative instructional material that combined basic and application-oriented knowledge from biology and nanotechnology. The second part incorporated various hands-on activities that were intended to demonstrate the learnt concept in a more convincing manner. Third and the most important component included a tour of the NanoFab for better internalization of the in-class learnt concepts.

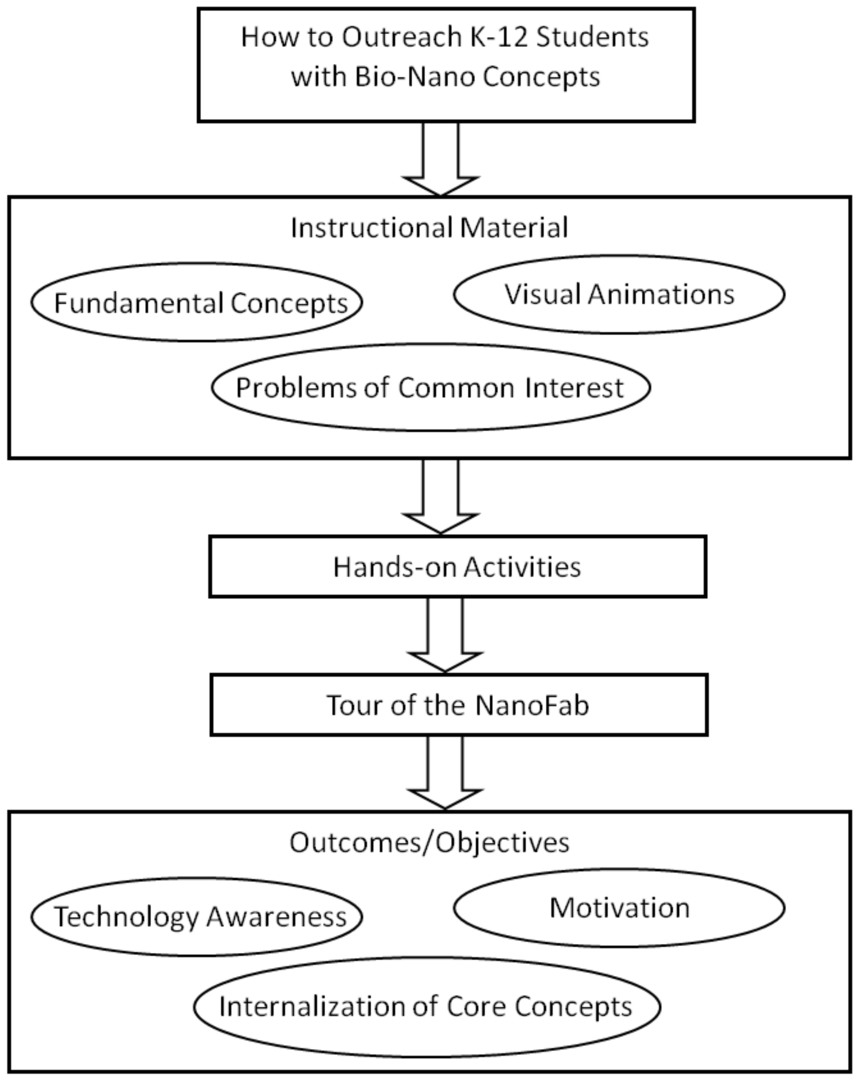

Figure 1. The design and intended outcomes of the learning scheme.

Developing Instructional Materials

The tutorial session contents were carefully designed with an aim to address K-12 students with varying backgrounds and different grasps of fundamental knowledge. The program course was offered to all students from elementary to high school grades. Therefore, students with a clearly indicated disparity of fundamental knowledge made up the class. This incongruity was sorted out by educating some very basic concepts and determining the students comfort level on these fundamental concepts. The students were triggered off to think of smallest things in their routine life. It helped to develop an interactive network in the class at the very beginning of the session. Verbal examples and visual paradigms from their daily life were deployed to take the students down the scale. The students were familiarized with different size scales by introducing interesting and exciting images of relatively larger objects step by step. Similarly, they were taken down the scale with the aid of fascinating images for smaller and smaller objects so that they could visualize nanoscale on comparative basis.

After establishing the nanoscale concept, the students were made acquainted with the significance and power of manipulating things at nanoscale. Nanoscale material properties (color, hardness, absorption band, biological behavior, etc.), its significance in daily routine life and potential impact in future was brought out in a very interesting fashion. The visual and electronic materials like videos and animations were employed for better internalization of the concepts and making it more attention-grabbing for the students. Several impressions and notions were demonstrated by certain hands-on activities which were carefully designed and embedded in the course contents to implement the just-in-time learning. The students' understanding of the concepts was also monitored after regular intervals by initiating a relevant problem-based activity. The tutorial material was developed in such a way that conclusion of every major concept was followed by hands-on activity or a problem-based activity. Integration of theoretical concepts, animations, practical activities, short questions and daily life examples into one course made it a very successful format to approach K-12 students with bio-nano concepts.

Hands-on Activities

Bio-nanotechnology broadly encircles nano-scale devices and biological entities. Awareness of K-12 students with the concepts of nanofabrication and behavior of biological molecules at nanoscale were the core objectives of the class. Oftentimes, comprehension of bio-nano concepts could be difficult for K-12 students. Therefore, the theoretical concepts were extended to practical hands-on experience for better understanding and absorption of the core concept. The students were facilitated with certain hands-on activities in order to grasp a particular concept. The activities were carefully devised with the clear intention to attain explicit objectives. Practical demonstration of theoretical concepts made the students more convinced in their understanding and motivated them to learn more about bio-nanotechnology.

Hydrophilic and Hydrophobic Surfaces

The activity intended to comprehend hydrophilic and hydrophobic surface incorporated colorful crayons, glass slide and a bowl of water. The students were provided an opportunity to make any pattern or writing on glass slides with crayons, followed by dipping the glass slides in water. The hydrophobic nature of crayon didn't allow the water to spread on its surface while hydrophilic glass surface permitted water to flow on its surface smoothly. This practical exercise directed the students to a quick, simple and comprehensible understanding of hydrophilic and hydrophobic natures of the surface.

Self-Assembly

Molecular self-assembly is present throughout the nature and technology. A wide range of complex biological structures owe their formation to self-assembling processes.[11] Therefore, knowledge of self-assembly is incredibly vital in bio-nanotechnology. The hands-on activity designed to demonstrate this concept involved a bunch of 3-4 cm long cut pieces of plastic drinking straws and a bowl of water. The students put a few of these straw pieces into water bowl and observed the movement of these hydrophobic tubes. Without external intervention, the hydrophobic straw tubes showed a tendency towards getting close to each other and form bundles. This autonomous patterning of the tubes stemming from their hydrophobic nature assisted the students to understand the concept of self-assembly in a very inspiring and pleasing manner.

Tour of the NanoFab

The NanoFab consists of a 10,000 sq. ft. cleanroom. The cleanroom has a large range of state-of-the-art instruments and equipment for fabrication and characterization, maintained by dedicated staff. The ever-increasing list of NanoFab equipment includes AFM, electron microscopes, focused ion beam and e-beam writers, nanoimprinter, mask aligners and standard silicon fabrication apparatus. The floor-to-ceiling glass panels make it easy to see all the activities going on inside. The students were taken on a walking tour of the Nanotechnology Research and Education Center (NanoFab). This activity worked as a catalyst for young students' motivation. They excitedly observed the researchers working in their white bunny suites in the cleanroom. Their excitement was evident from the continuous stream of questions from their side. This part of the learning scheme not only provided the students with an opportunity to experience the working of different nanotechnology equipment, better understanding of various bio-nano concepts but also induced a research aptitude in them. They were tremendously energized to pursue their career as research scientists after visiting the lab. This activity proved to be a crucial element for promoting interest and knowledge of advanced technologies in these youngsters who could be our next generation workforce for engineering and life sciences.

Conclusion

A simple yet very effective scheme has been developed to reach out to K-12 students with bio-nano concepts. The instructional system design and contents were intended to accommodate students from different age groups with assorted knowledge-base. An integrative tutorial content was designed to guide students' natural curiosity. The objective to familiarize the young students with bio-nano concepts was successfully achieved through visual-aided lessons, persuasive animations, supportive hands-on activities and thought-provoking problems. The practical display of in-class learnt concepts and visit of the lab electrified the K-12 students and provided them a more interesting and exciting environment to assimilate the core concepts. Focused learning of the new technology concepts increased the confidence in K-12 students. They showed more interest and pledge for scientific knowledge and it may result into a step forward towards technological development of our society.

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U.S. ENGINEERING EDUCATION: A GLOBAL PRESPECTIVE

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Abstract

Over the last several years a number of reports have raised concern about the growing challenge to U.S. science and technology (S&T) leadership – and long-term economic competitiveness – from both rapidly developing Asian nations and European countries with a renewed competitive focus. Such reports have collectively argued that the United States faces intensifying foreign competition in science and technology, and that the country is falling behind in key building blocks of the S&T base, specifically its research and development infrastructure, science and engineering (S&E) workforce, and math and science education.

On the other side, there is a growing trend in the demand for U.S. based and/or modeled engineering education. U.S. institutions of higher education in partnership with local entities have established branches in the Arab Countries and also American Universities (AU) such AU of Kuwait, Dubai, Sharjah, …etc are mushrooming all over the region. All the engineering programs at those institutions are either ABET accredited or actively seeking ABET accreditation. In addition, the engineering programs at the local non-U.S. affiliated Intuitions are also acquiring or seeking ABET accreditation. In this paper, the desire and quest for an ABET accredited engineering education is analyzed. There is clear evidence that U.S. modeled engineering education is a self promoting engineering educational system. The culture of assessment and continuous improvement is becoming dominant.

Introduction

American higher education is often seen from abroad as the best quality available in the world, and as such a model to be emulated. The U.S. system of quality assurance – accreditation – is perceived to be a major reason for this quality, and higher education institutions in developing countries often seek some form of U.S. accreditation as a way to have their own quality recognized. In many cases, these institutions, which are frequently pioneers in quality assurance in their region, need to be assisted in a developmental mode until they are prepared to pass the scrutiny of U.S. accreditation standards. Table 1 display a list of US Licensed Overseas Institutions.

Table 1. U.S. Licensed Overseas Institutions

NAME	LOCATION	US LINCENSING STATE
American College Dublin	Ireland	Delaware
American College of Thessaloniki	Greece	Massachusetts
American Graduate School of Business	Switzerland	Georgia
American InterContinental University	London, UK	Georgia
American University in Bulgaria	Bulgaria	N/A (USAID)
American University in Dubai	Dubai (UAE)	Georgia
American University in Kosovo	Kosovo	N/A (USAID)
American University of Armenia	Armenia	California
American University of Beirut	Lebanon	New York
American University of Cairo	Egypt	Delaware
American University of Central Asia	Kyrgyzstan	N/A (USAID)
American University of Paris	France	Delaware
American University of Rome	Italy	Washington, DC
American University of Rome	Italy	Delaware
American University of Sharjah	Sharjah (UAE)	Delaware
Bogazici University	Turkey	Massachusetts
Central European University	Hungary	New York
Franklin College Switzerland	Switzerland	Delaware
John Cabot University	Italy	Delaware
Lebanese American University	Lebanon	New York
The American College of Greece	Greece	Massachusetts
Webster University Geneva	Switzerland	Missouri

Many well-established U.S. specialized/professional accreditation agencies have in recent years been offering international accreditation evaluations, and status, as appropriate: engineering, business, and soon teacher education. In each case, the move to offering full accreditation abroad has reflected an evolutionary process on the part of the accrediting agency, often starting with a Memoranda of Understanding (MOU), then some sort of "substantial equivalency", then full accreditation. There are many issues involved in evaluating foreign institutions utilizing U.S. standards. This paper draws upon the experience of the author in quality assurance and accreditation in the U.S. and abroad to explore such issues by examining engineering accreditation.

ABET Accreditation

Engineering programs in the United States are accredited by ABET, formerly the Accreditation Board for Engineering and Technology. After some eight decades of development and activity, ABET has earned a reputation as one of the best, if not the best, accreditation systems for engineering and related area academic programs. "ABET is a non-profit and non-governmental accrediting agency for academic programs in the disciplines of applied science, computing, engineering, and engineering technology. ABET is a recognized accreditor in the United States by the Council for Higher Education Accreditation[1]." Essentially all engineering and engineering technology programs in the United States are currently accredited by ABET. Any engineering program not accredited by ABET would have a very difficult time attracting students and having its graduates recognized as employable.

ABET was established in 1932 under its former title, Engineers Council for Professional Development. ECPD was founded by seven engineering societies – six technical societies plus the national organization for licensure of engineers. ECPD evaluated its first engineering degree programs in 1936, and began evaluating engineering technology programs ten years later. ECPD was renamed the Accreditation Board for Engineering and Technology in 1980 to better reflect its emphasis on accreditation[2].

"ABET accreditation provides assurance that a college or university program meets the quality standards established by the profession for which the program prepares its students. ABET accredits postsecondary programs housed in degree-granting institutions which have been recognized by national or regional institutional accreditation agencies or national education authorities worldwide[1]".

ABET undertakes specialized accreditation for programs at various levels in four areas:

-- Applied Science Programs
-- Computing Programs
-- Engineering Programs
-- Engineering Technology Programs

ABET began international activities in 1979 when its predecessor, ECPD, signed its first mutual recognition agreement with its Canadian counterpart, the Canadian Engineering Accreditation Board. It then entered into a series of Memorandum of Understanding agreements with engineering organization in various developing countries, aimed at assisting the development of quality assurance mechanisms in those countries based on the ABET model.

As engineering education institutions in developing countries evolved sufficiently to be considered for the type of accreditation evaluations that U.S. schools underwent in the U.S., ABET developed and operated for several years a "substantial equivalency" program. Under this program the non-U.S. programs were evaluated to determine whether they were comparable in program content and educational experience to U.S. accredited programs and prepared their graduates to begin professional engineering practice at the entry level. These "substantial equivalency" evaluations were conducted by approved ABET evaluators from the U.S. following similar policies and procedures used for U.S. accreditation – but no formal accreditation action was taken at the end of the evaluation. By 2006 there were more than 140 substantially equivalent programs at 27 institutions in 14 countries[2]. In 2006 ABET began phasing out substantial equivalency evaluations and instead proceeded with full international accreditation evaluations, using the regular ABET standards. In the fall of 2007 the first international accreditation visits were conducted.

"To date, ABET has accredited over 3,100 applied sciences, computing, engineering, and engineering technology programs at more than 660 colleges and universities in 23 countries worldwide[1]". Table 2 displays the distribution of the 261 ABET Accredited Engineering Programs by the Engineering Accreditation Commission (EAC). The total number of overseas programs represents about 12 % of the total accredited engineering programs by the ABET EAC which totals 2242 worldwide.

Table 2. Overseas ABET Accredited Engineering Programs

Country	EAC
Kazakhstan	1
Spain	1
Jordan	3
Indonesia	4
Oman	4
Chile	5
Bahrain	7
Qatar	7
Kuwait	8
India	9
Philippines	9
Lebanon	10
Egypt	12
Peru	15
Colombia	16
United Arab Emirates	25
Mexico	30
Saudi Arabia	44
Turkey	51
TOTAL	261

The type of approach ABET has adopted has been successful in encouraging engineering institutions in developing countries to move toward a recognizable world standard for engineering education. The pattern of starting with MOUs, moving to "substantial equivalency", then full accreditation has proven to be effective for ABET[3].

Engineering Manpower Shortfall

In the past the United States has compensated for its shortfall in engineers to a considerable degree by attracting talented students from around the world. But post 9-11 constraints on immigration policies and an increasingly cynical view of American foreign policy have cut deeply into the flow of international students into U.S. universities and industry[4]. This situation is compounded by U.S, inability to address the relatively low participation of women and underrepresented ethnic minorities in science and engineering. Today nearly two-thirds of today's engineering students who are U.S. citizens are white males, at a time when the largest growth in U.S. workforce over the next decade will come from women and underrepresented minorities.

As presidential science advisor John Marburger[5] concluded: "The future strength of the U.S. science and engineering workforce is imperiled by two long-term trends: First the global competition for science and engineering talent is intensifying, such that the U.S. may not be able to rely on the international science and engineering labor market for its unmet skill needs. Second, the number of native-born science and engineering graduates entering the workforce is likely to decline unless the nation intervenes to improve success in educating S&E students from all demographic groups, especially those that have been underrepresented in science and engineering careers".

Of course, some would argue that the marketplace itself should determine the number of engineering graduates, and that the erosion of student interest in these fields may reflect the realities of both future job opportunities and future need. It is also the case that recent studies of salary and employment data fail to find indication of a shortage of engineers in the United States[6]. Most companies indicate that they are able to fill 80% of engineering jobs within four months. Furthermore, many companies actually limit the head count of U.S. graduates in preference to off shoring any growth in domestic engineering capacity, motivated both by lower costs and greater flexibility[7].

However, as Charles Vest [9] argues, no one can look at today's labor market for engineers and predict what students will experience in 30 years. "A generation ago computers and communication technology were esoteric fields with relatively small job demand. Yet today virtually every industry is at heart about information technology and communications in one way or another, which will only intensify as the United States completes its shift from a manufacturing to a knowledge services economy. Virtually every industry is already dependent upon sophisticated logistics, global supply chains, and an integrated global economy. The success of US economy–not to mention US democracy–will require more people with technical knowledge and skills, not less." As Vest[8] puts the question before us: "The world is changing remarkably fast, and leadership in science and engineering will drive it. Where will this leadership come from? China? India? The United States? The choice is ours to make".

Given the recent trends in business, it is perfectly understandable why engineering enrollments have declined in this country over the past two decades. Students are very market sensitive. As Norm Augustine[4] suggests, “All the signals are wrong to attract kids into engineering these days”. Imagine the impact on student perspectives of engineering careers when they read a recent headline in a leading Detroit newspaper[9]: “GM Fires 500 Engineers”, which quoted a company spokesman’s rationalization: “It is all about aligning the workforce with our business needs”. Students are very sensitive to such actions, and although many have the aptitude and interests to major in engineering, they view it as a dead-end profession, subject to this commodity treatment and associated with too many risks, in contrast to broader professions such as law, medicine, and business. The same ambiguity characterizes public perception, with images of large rooms of rows upon rows of engineers working on narrow elements of large systems such as airplanes or automobile platforms until the next round of layoffs. Particularly during these days of economic stress, these images are more prevalent than those of master engineers creating the highly innovative products and systems that address critical human needs while adding economic value. Ironically, even as the need for engineers and engineering services continues to intensify in this country, the global marketplace is drawing many engineering activities offshore. While initially this was for more routine engineering services, primarily driven by the wage differential between the U.S. and off-shore providers (particularly in India, China, and Eastern Europe), today we find the off-shoring of engineering services is rising rapidly up the value chain to include sophisticated functions such as product design, research, and development.

Politicians usually rationalize the current phenomenon of off-shoring, the increasing tendency for companies to export knowledge-intensive service jobs like engineering and information services to developing nations like India, China, and Eastern Europe, by suggesting that it is the low wage rates that shift jobs overseas (typically 20 cents on the dollar in India, for example). But increasingly companies are going off shore because they sometimes find higher quality engineering services in high-tech areas like computer software development. They also seek to use off shoring to penetrate new markets. Why? Many of the nations benefiting from the global sourcing of engineering benefit from cultures with strong pre-college education in science and mathematics, a stronger interest of college students in majors in science, mathematics, and engineering, which are seen as the route to leadership roles in business or government, and large populations from which to draw top talent. Furthermore many of these nations are making massive investments in higher education, particularly in technology-intensive areas like engineering and computer science, to create a more highly skilled workforce at a time when our nation and states have been throttling back such investments. Yet despite the advantages of off shoring engineering services–cost savings, 24/7 development cycles, access to new markets–there are also concerns of a bandwagon psychology in which companies, driven by the short-term focus of investors, are moving too many activities off shore, losing their domestic core competence in key technological areas. To be sure today’s globally integrated companies no longer embrace the linear, vertical process for value creation characteristic of 20th century industry–from R&D to product design to manufacturing to sales to distribution. Today’s global supply chain depends on a horizontal process, in which each activity is allocated to wherever it can be performed at highest quality and acceptable costs, and then integrated back together again to produce products, services, and values. A company can now procure the best product or service or capacity or competency from anywhere in the world because of the new knowledge infrastructure. Such global sourcing changes quite dramatically the incentives for sustaining domestic capacity in many areas including engineering.

U.S. Universities Outposts Abroad[10]

The American system of higher education, long the envy of the world, is becoming an important export as more universities take their programs overseas. In a kind of educational gold rush, American universities are competing to set up outposts in countries with limited higher education opportunities. American universities — not to mention Australian and British ones, which also offer instruction in English, the lingua franca of academia — are starting, or expanding, hundreds of programs and partnerships in booming markets like China, India and Singapore.
And many are now considering full-fledged foreign branch campuses, particularly in the oil-rich Middle East. Already, students in the Persian Gulf state of Qatar can attend an American university without the expense, culture shock or post-9/11 visa problems of traveling to America. At Education City in Doha, Qatar's capital, they can study medicine at Weill Medical College of Cornell University, international affairs at Georgetown, computer science and business at Carnegie Mellon, fine arts at Virginia Commonwealth, engineering at Texas A&M, and soon, journalism at Northwestern.

In Dubai, another emirate, Michigan State University and Rochester Institute of Technology recently started to offer classes. According to Howard Rollins, US universities are heading now toward becoming global universities. Georgia Tech a primer engineering university, is offering degree programs in France, Singapore, Italy, South Africa and China, and has plans for India. More and more universities are competing internationally for resources, faculty and the best students. Since the terrorist attacks of Sept. 11, 2001, internationalization has moved high on the agenda at most universities, to prepare students for a globalized world, and to help faculty members stay up-to-date in their disciplines.

Overseas programs can help American universities raise their profile, build international relationships, attract top research talent who, in turn, may attract grants and produce patents, and gain access to a new pool of tuition-paying students, just as the number of college-age Americans is about to decline. Even public universities, whose primary mission is to educate in-state students, are trying to establish a global brand in an era of limited state financing.

Partly, it is about prestige. American universities have long worried about their ratings in U.S. News and World Report. These days, they are also mindful of the international rankings published in Britain, by the Times Higher Education Supplement, and in China, by Shanghai Jiao

Tong University. The demand from overseas is huge. Traditionally, top universities built their international presence through study-abroad sites, research partnerships, faculty exchanges and joint degree programs offered with foreign universities. Yale has dozens of research collaborations with Chinese universities. Overseas branches, with the same requirements and degrees as the home campuses, are a newer — and riskier — phenomenon.

Regardless, after a decade of rapid growth, American universities have slowed the pace of opening branch campuses abroad, and much of the activity has moved from the Middle East to the Far East, according to a survey by the Observatory on Borderless Higher Education, a private British research group. The survey, based on data from the second half of 2011, found 200 degree-granting international branch campuses, with 37 more expected to open over the next two years. The group found 162 branches in a 2009 survey, and 82 in 2006.

While universities with overseas branches insist that the education equals what is offered in the United States, much of the faculty is hired locally, on a short-term basis. And certainly overseas branches raise fundamental questions:

Will the programs reflect American values and culture, or the host country's?
Will American taxpayers end up footing part of the bill for overseas students?
What happens if relations between the United States and the host country deteriorate?
Will foreign branches that spread American know-how hurt American competitiveness?

Even though, a lot of these educators are trying to present themselves as benevolent and altruistic, when in reality, their programs are aimed at making money. Whereas, others claim that higher education is the most important diplomatic asset the U.S. has. Some really believe these programs can actually reduce friction between countries and cultures.

The bottom line is that most overseas campuses offer only a narrow slice of American higher education, most often programs in business, science, engineering and computers. Schools of technology have the most cachet. So although the New York Institute of Technology may not be one of America's leading universities, it is a leading globalizer, with programs in Bahrain, Jordan, Abu Dhabi, Canada, Brazil and China. Some lawmakers are wondering how that rush overseas will affect the United States. In July, the House Science and Technology subcommittee on research and science education held a hearing on university globalization.

Another important note is that the engineering degrees offered by all of these branches are not ABET accredited by the mere fact that the main campus is accredited. As a matter of fact, ABET would only accredit these programs as standalone programs. Thus, these engineering programs offered by the branches have certainly lost their luster and are being marginalized.

Engineering Globalization

Globalization is a term that is used interchangeably with internationalization, but both terms describe different concepts that are important to explain in regard to the context of this paper on Global Engineering Education. However and interestingly enough, one point in common between the two definitions is that both phenomena produce change, and change sometimes can be confused with the concept of modernity or progress, which has a totally different philosophical stand. Globalization expresses the growing changing environment in the economic sphere and the geographical growing interdependence, whereas according to Marginson and Van Der Wende[11], "internationalization is a more modest process which translates into the conventional regulation between states". In higher education, Marginson et al.[11] explain that "internationalization has a long history as a relatively safe method of broadening one's intellectual horizons through reflective comparison". Globalization, on the other hand, is a term originally used to describe contemporary economic phenomena that are related to the expansion of a global free market. There are opponents and proponents of the theory of globalization. Many suggest that globalization has negative effects on the people around the world, but others think that its new developments are positive. Opponents are concerned with the social and ecological devastations provoked by this type of globalization, whereas proponents argue that globalization will bring prosperity and international collaboration[12]. Analysts argue also about the "novelty" of the phenomenon of globalization, observing that economical competition and expansion of economical spheres have existed since the sixteenth century in Europe with the creation of empires and later on with colonization in the late 19th century[12]. Fernand Braudel[13] explained that a world economy is not a global economy and what is experienced today "has nothing in common with previous human experience[14]". Giddens[15] argue that globalization is an ideological myth created by "free-marketeers" to deregulate the social state and that the biggest change is in the increasing use of "electronic money that only exist as a digit in computers" that can destabilize solid country's economies. Carnoy[16] suggests that the emergence of a global economy has been possible since the mid-1980s with "the technological infrastructure provided by telecommunication information systems, microelectronics machinery, and computer-based transportation, which allows economical activities to function on a planetary scale on real-time". Thomas Friedman[17]explains that from an historical point of view globalization's driving mechanisms can be divided into three eras. The first one (1492 to 1800), that he calls globalization 1.0, was essentially the result of countries competing with each other and international economic opportunities. The second globalization 2.0 era (1800 to 2000) was driven by multinational companies interests and the last one, globalization 3.0 (2000 to present), is "the new found power for individuals to collaborate and compete globally". Friedman describes our world as a shrinking place where global competition and collaboration is now at an individual level and this phenomenon leads to a flattening process with people all over the globe. According to Tony Brown[18] who has a critical view of globalization, the process of change called globalization is threefold: the first one describes "the transfers of money around the world, the production and exchange of services and the declining role of the nation state"; the second one refers to globalization as being "an objective entity seemingly with its own conscious purpose" as if it were some kind of "independent active agent". The third conception is related to globalization as a discourse in which the concept is viewed as an inevitable natural process, independent of human influence[19]. Most analysts like Schaeffer[12] and policy makers "use globalization to describe the growth and spread of investment, trade and production, the introduction of new technology, and the spread of democracy around the world".

The word internationalization in regard to higher education, like the word globalization in the sphere of economics, lacks a firm agreement on its meaning. However, there is an historical antecedent with the Medieval European universities where wandering scholars traveled and studied at different universities across Europe. Presently in Europe, there is an effort through different European programs such as SOCRATES and ERASMUS (exchanges and scholarly programs) to harmonize the structure of programs of studies and the mobility of students which reminds us of their prestigious predecessors[20]. In the United States, however, the field of international education is "fragmented and compartmentalized" with no unifying theory to consolidate the field[21].

In summary, global engineering offers the seductive image of engineers figuring out how to optimize work through collaboration and mobility. Its biggest challenge to engineers, however, is more fundamental and difficult: to better understand what they know and value qua engineers and why.

Changes in Engineering Education

Engineering education in the U.S. has changed dramatically during recent years. Not only has the number of graduates in traditional engineering disciplines such as mechanical, civil, electrical, chemical, and aeronautical engineering declined, but in most of the premier American universities engineering curricula now concentrate on and encourage largely the study of engineering science. As a result, there are declining offerings in engineering subjects dealing with infrastructure, the environment, and related issues, and greater concentration on high technology subjects, largely supporting increasingly complex scientific developments. While the latter is important, it should not be at the expense of more traditional engineering.
Rapidly developing economies such as China and India, as well as other industrial countries in Europe and Asia, continue to encourage and advance the teaching of engineering. Both China and India, respectively, graduate six and eight times as many traditional engineers as does the U.S. Other industrial countries at minimum maintain their output, while the US suffers an increasingly serious decline in the number of engineering graduates and a lack of well-educated engineers.

While until quite recently U.S. engineering firms dominated in global infrastructure projects and the development of new design and engineering solutions, they are now becoming minor participants and are quite often not even invited to propose and bid for important projects. Earlier last century the US has built structures such as the Empire State Building in fewer than 18 months, a feat which could not possibly be repeated today. U.S. engineering used to be the global gold standard in infrastructure engineering and construction, while now the premier examples of major engineering projects are primarily developed abroad. US increasingly lags not only in engineering research, development, and design, but also in methods of survey, construction materials handling, materials fabrication, site development, and more, again particularly in infrastructure engineering.

The results have caused U.S. roads, rail networks, electric power, ports, airports, and other essential infrastructure to not only remain in ill-maintained states, but also to be quite often badly designed and constructed. There are many examples which parallel the shameful so-called Big Dig project in Boston, and there are now few major U.S. engineering projects that measure up to world standards, something that not only adversely affects our economy, but also our standing in the world. For example, much of the Katrina and similar disasters could have been prevented by more competent engineering. For too long, we have somehow failed to give the proper respect, recognition, and resources to engineering education, and now suffer the consequences which may affect not only our reputation but ultimately our economy and standard of living.

Engineering is the most essential of human disciplines. From early on it was the way humankind lifted themselves up from other creatures. It provides the wherewithal for all human physical advances and is as much – if not more – of an intellectual challenge as the sciences and other subjects that advance human standards. History has many examples where the decline of civilizations paralleled the lack of importance given to engineering. The Greeks, Romans, Chinese, and others built their civilizations largely on the foundations of engineering competence and advances. Their power, status, and standards of living rapidly declined as soon as they failed to maintain their superior engineering competence and developments. The hope is that U.S. will learn from history, and not repeat it.

Engineering education should teach the effective application and use of scientific principles to the solution of real-world problems and the development of materials, tools, facilities, appliances, shelters, foods, and services to meet human needs and advance human living conditions, opportunities, and standards. It should probably be broadened to include engineering and project management, in addition to wider, more comprehensive courses in the application of science and technology to the solution to real-world problems – so as to assure that graduates hit the ground running, particularly after completing graduate studies. MIT has for long been the world leader in the application of engineering education, and should follow its success by furthering its study in this direction.

Summary and Conclusions

In this paper, U.S. modeled engineering education was explored within its global ramifications. There is no doubt that the demand for the U.S. branding is very high and desirable.

Unfortunately, the real U.S. engineering educational experience can only be fully attained at U.S. based institutions. The spirit and culture is more important than the model.

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Factors Influencing Student Graduation Rates

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Abstract

In recent years pressure has been placed on the public universities to increase their four and six year graduation rates. As faculty, we are aware of some factors that slow down student progress towards graduation. A large number of students enrolled in universities in urban locations are non-traditional students. Some entering freshmen are not prepared for college courses and are required to complete remedial courses. In a structured degree program such as engineering, students are required to satisfy prerequisites in order to proceed through the curriculum. Lack of course offerings, especially offering all required courses every semester, can delay progress towards graduation for some students. This paper surveys a cohort of senior engineering mechanical engineering students to determine the causes for delays in graduation. In responding to survey questionnaire, students provide such information as whether they attend school full time or part-time, how many years to graduation, whether they attend summer school, the courses that students have difficulty passing, and other questions related to length of study for the degree. Feedback from students is essential as public universities are looking for ways to improve graduation rates.

Introduction

In the recent years there has been a major discussion on the time it takes for students enrolled in public institutions of higher education to receive a four year undergraduate degree. The numbers for four-year and six-year graduation rates are typically very low for most public institutions that do not have selective admission policies. The numbers are as low as 10% graduation rates in four year and lower than 30% in six years. Pressures from public and state authorities are rising for the public university to increase their four and six year graduation rates. Many states are providing some incentives for students who graduate in four years and penalizing those students who accumulate a large number of semester credit hours (SCH) before they receive their four year degree. For example, Texas Education Code, § 54.0065 "The Tuition Rebate Program" offers students who have enrolled for the first time in an institution of higher education in the

Fall 1997 semester or later, up to $1,000 in tuition rebates, if they have attempted no more than three hours in excess of the minimum number of semester credit hours required to complete their degree.[1] For example, if the degree requires a minimum of 120 semester credit hours, student must graduate with no more than 123 attempted hours in order to qualify for a rebate. There is an additional requirement for those students who enrolled in college for the first time in the Fall 2005 semester or later. For these students, the degree must be completed within four calendar years for a four-year degree. For some degree programs such as engineering that typically require more than four years to complete, the student must graduate within five calendar years.

State of Texas legislatures have established credit hour limitation for funding students enrolled in undergraduate programs in public institutions of higher educations. In these cases state of Texas do not provide funds for students who have exceeded the established undergraduate credit limitation. Section 54.068 of the Texas Education Code was amended during the 76th legislative session to allow institutions of higher education to charge resident students a higher tuition rates for attempting more than 45 SCH above the minimum SCH required for a degree program. The law applies only to new undergraduate resident students who started college in a public institution in Fall 1999 or later. The 79th legislative session reduced the SCH to 30 semester credit hours for all new undergraduate resident students who started college in a public institution for the first time in Fall 2006 or thereafter (§ 54.014 of the Texas Education Code[2]). The total attempted hours contains all those taken by students at any public institution including all those repeated, duplicated, withdrawn after the Census date in which the student received a grade of "W." Starting in Fall 2006, UTSA has been charging an additional fee of $121 per SCH for students who have exceeded the 30 or 45 hour credit limits.

Depending on the type of calculation methods used, graduation rates can be strongly influenced by students who initially seek an engineering degree but later change their mind and pursue another degree. The factors that influence a student's decision to leave engineering are linked to both academic and non-academic factors[3]. Academic factors include teaching, advising and curriculum. Non-academic factors are related to cohorts and a sense of community. Students who believe they belong in engineering are more likely to be retained in engineering.

The impact of freshmen-level courses on student retention have been studied[4,5]. The freshman level classes do have an impact on 4-year retention. This finding is consistent with the understanding that curriculum and instruction have strong impacts on retention. Students who build connections between theoretical academic aspects of the curriculum and professional engineering practice, are more likely to be retained in engineering. Likewise, those who build connections with other students develop a sense of belonging and are less likely to change majors.

The American Society for Engineering Education (ASEE) promotes practices and strategies for retaining students in engineering[5]. Based on best-practices submitted by College Deans from many universities, a common theme found is that creating a "community" is important for student retention. There are a number of ways to create such a community and no single solution is sufficient. The best recommendation is for the university to have a holistic approach employing multiple strategies such as: tutoring, mentoring, learning centers, first-year students, at-risk students, academic advising, and career awareness.

Much has been done to understand and improve the retention of students[6-10]. Universities use problem solving recitations, and the integration of math/science/engineering into more exciting engineering courses with more active design project for students. Much of these efforts have limited success and can often be overwhelmed by changes in the student body attending the university, changes in faculty teaching key engineering courses, and changes in seemingly insignificant aspects such as classroom scheduling. In many cases, modest changes impact the rate of progress through particular classes and the overall program.

In this work, it is proposed to study the students who have succeeded to their senior-year and final semester of a mechanical engineering program of study. These students have succeeded and are soon to graduate. Much of their academic experience is fresh and they offer unique perspectives on how to improve the system. One can interview these students, ask them to complete a survey directed at retention issues, and one can review their academic path to better understand how they were able to progress to their current level. Through the examination of students' academic record and surveys, we have attempted to determine the possible root causes of student graduation delay. We have analyzed the academic record of 60 mechanical engineering students who are completing their capstone design project in the Spring 2013 and conducted surveys in two upper-division courses to determine areas that have contributed in delaying student graduation.

Analysis of Student Academic Record

The mechanical engineering program at UTSA requires 128 SCH of course work in order for a student to receive a Bachelor of Science in Mechanical Engineering (BSME) degree. The degree requirement includes 42 SCH of the University Core Curriculum. Courses in general chemistry, engineering physics, and calculus are parts of both the University Core Curriculum and mechanical engineering degree requirements. In examining the academic records of 60 students who are completing their senior design project in spring 2013 we made several observations as are summarized below. Including courses taken in spring semester 2013, these students have between 6 to 21 SCH remaining in their degree program. Almost all of these students will complete their degrees either in May 2013 or August 2013. The examination of student transcripts reveals that these senior students have attempted as low as 129 and as high as 239 SCH by the time they graduate. On the average these students have attempted 166 SCH for completing their degrees. There are several factors contributing to excess number of credit hours required for the degree. One student has already completed a degree in communication. Several others are either double major (seeking a second degree in either mathematics or business) or taking additional courses for a minor. Several students started in a different major and then changed major into mechanical engineering. A large number of students have transferred from community and four year colleges to UTSA. Twenty eight (28) students have more than 30 SCH of transferred courses and more than 40 students have at least 15 SCH of transferred courses. In some cases, not all transferred courses applied to the degree program.

Table 1. Recommended program of study for 2010-14 BSME degree

Semester I			**Semester II**		
CHE 1103	General Chemistry	3	MAT 1224	Calculus II	4
MAT 1214	Calculus I	4	ME 1402	M.E Practice & Graphics	2
ME 1302	Mechanical Engineering Practice	3	PHY 1903	Engineering Physics I	3
WRC1013	Freshman Composition I	3	PHY 1911	Engineering Physics Lab	1
COR 1203	Freshman Seminar/Soc.Behav Sci	3	WRC 1023	Freshman Composition II	
			CORE	U.S. History & Diversity	
Semester Total		15	Semester Total		16
Semester III			**Semester IV**		
EGR 2103	Statics	3	EGR 2513	Dynamics	3
EGR 2323	Applied Engineering Analysis I	3	EGR 3323	Applied Engineering Analysis II	3
ME 2173	Numerical Methods	3	ME 3244	Materials Engineering & Lab	4
PHY 1923	Engineering Physics II	3	ME 3293	Thermodynamics I	3
PHY 1931	Engineering Physics II Lab			Math/Science Elective	3
CORE	U.S. History & Diversity				
Semester Total		16	Semester Total		16
Semester V			**Semester VI**		
EE 2213	Electric Circuits & Electronics	3	ME 3113	Measurements & Instrumentation	3
ME 3543	Dynamic System & Control	3	ME 3263	Manufacturing Engineering	3
ME 3663	Fluid Mechanics	3	ME 3823	Machine Element Design	3
ME 3813	Mechanics of Solids	3	ME 4313	Heat Transfer	3
ME 4292	Thermodynamics II	3	CORE	Political Science	3
CORE	Literature	3	CORE	Visual & Performing Arts	3
Semester Total		18	Semester Total		18
Semester VII			**Semester VIII**		
ME 4543	Mechatronics	3	ME 4813	Design II	3
ME 4733	Mechanical Engineering Lab	3		Technical Elective	3
ME 4812	Senior Design I	2		Technical Elective	3
	Technical Elective	3		Economics 2003, 2013, or 2023	3
	Political Science (Texas)	3		World Society & Issues	3
Semester Total		14	Semester Total		15

The examination of transcripts revealed that many students had to take introductory courses in chemistry, mathematics, and physics, before they were allowed to take CHE 1103-general Chemistry, MAT 1214-Calculus-I, or PHY 1903-Engineering Physics. Of the 60 students, 46 students had to take 3 SCH to 19 SCH of additional introductory courses in chemistry, mathematics, and physics during their freshman year.

Unsuccessful attempts of required courses also delays student graduation. Figure 1 shows those courses that a number of students have difficulty passing. The transcript analysis reveals that out of 60 students, 24 students had to repeat EGR 2323-Engineering Analysis-I, 18 students repeated ME 3293, and 17 students repeated ME 3543-Dynamics System and Control at least once. Figure 1 shows that some students had difficulties with such freshman level courses as MAT 1224-Calculus II, CHE 1103, PHY 1903-Engineering Physics-I, PHY 1923-Engineering Physics-II. Few students repeated some of the courses shown in Fig. 1 more than once. One student repeated MAT 1214-Calculus-I five times.

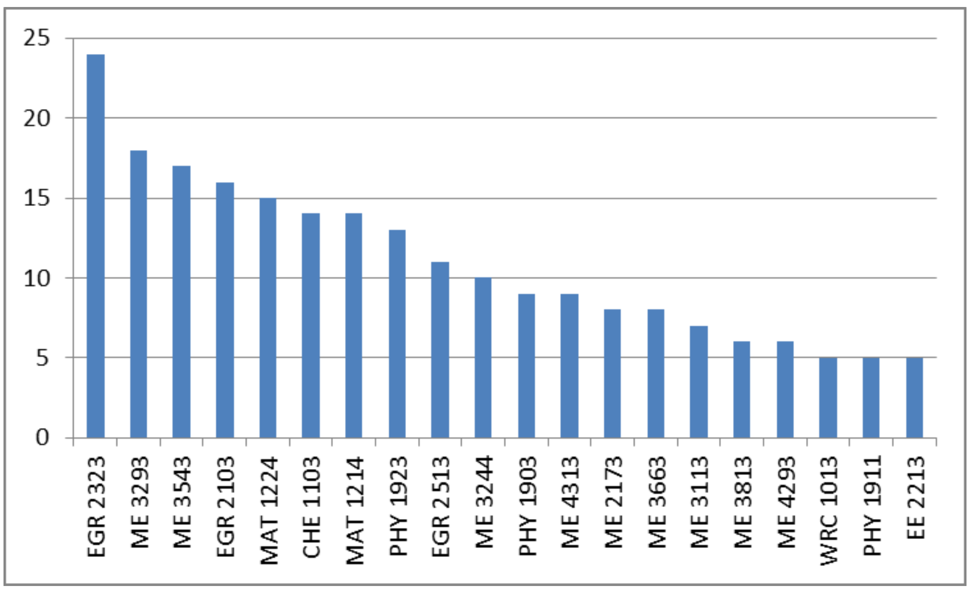

Fig. 1. Number of students repeating courses required for the BS degree in mechanical engineering

Survey

A survey was conducted to assess the perception of students on graduation rate issues. It is relatively well-known that faculty have ideas about retention. These ideas are reflected in the curriculum and in the assignment of instructors to particular classes. There is less information about the beliefs of students concerning their progress toward graduation, especially their thoughts on impediments to them earning an engineering degree in 4-years.

A survey on graduation rate was given to senior-level engineering students. Fourteen questions provide the main part of the survey. Given the following statement:

The following have slowed down your progress towards graduation

		Disagree				Agree
a)	Financial difficulties	1	2	3	4	5
b)	Failing/withdrawing from courses	1	2	3	4	5
c)	Starting in pre-Calculus math courses	1	2	3	4	5
d)	Changing majors	1	2	3	4	5
e)	Difficulties taking prerequisite classes	1	2	3	4	5
f)	Difficulties transferring courses to UTSA	1	2	3	4	5
g)	Poor study habits	1	2	3	4	5
h)	Poor time management skills	1	2	3	4	5
i)	Immature attitude toward college	1	2	3	4	5
j)	Lack of seats in classes	1	2	3	4	5
k)	Lack of summer classes	1	2	3	4	5
l)	Lack of on-campus study space	1	2	3	4	5
m)	Lack of on-campus jobs	1	2	3	4	5
n)	Personal or family issues outside of school	1	2	3	4	5

In total, 49 students responded to the survey. Results are shown in Fig. 2. The numeric value of 1 to 5 was recorded for each student for each response. The numerical results were first normalized for each student. The student's average response for the fourteen questions (a-n) was calculated and thensubtracted from each of the student's responses. If the resulting number was below zero, it was set to zero. The non-zero results are for those above the average for the individual student. The sum of these was computed and then each non-zero result was multiplied by a weighting factor so that the sum was equal to 5.0 for each student. Once each student's response has been normalized, the average class response was calculated for each question. This was done by summing the normalized response across all students. The relative score indicates the group consensus for which is most important.

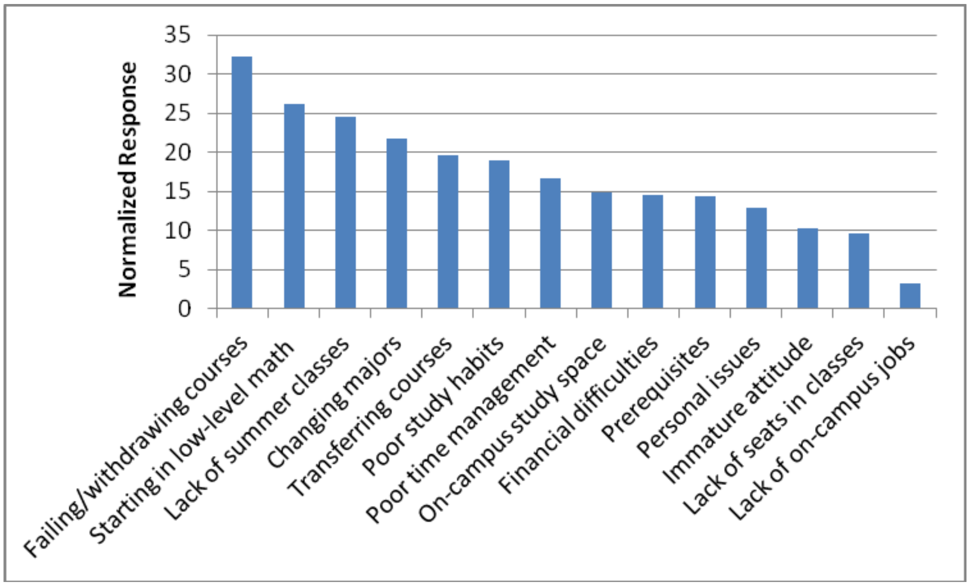

Fig. 2. Normalized results from senior-level student survey to "identify things that have slowed down your progress towards graduation." From left to right, responses showing strongest positive response.

Most of the results are self explanatory by the description used in Fig. 2. The most significant result is understandable: if a student fails or withdraws from a class this often delays their graduation by a semester. Senior-level students know this by either first-hand experience or by seeing the effect on fellow students. There is little forgiveness for failing a class.

The second highest response is associated with students not being "Calculus ready" when they start college. In the recommended four-year degree program (Table 2), it is essential that students take and pass Calculus I their first semester. If not, this delays taking Calculus II and Calculus-based Physics. These are important prerequisites in the engineering program. This was explored further in the same survey. Students were asked to list the "first math course you took in college" with the choices being: below College Algebra, College Algebra, Pre-Calculus, Calculus I, Calculus II or Above Calculus II. The results are shown in Fig. 3.

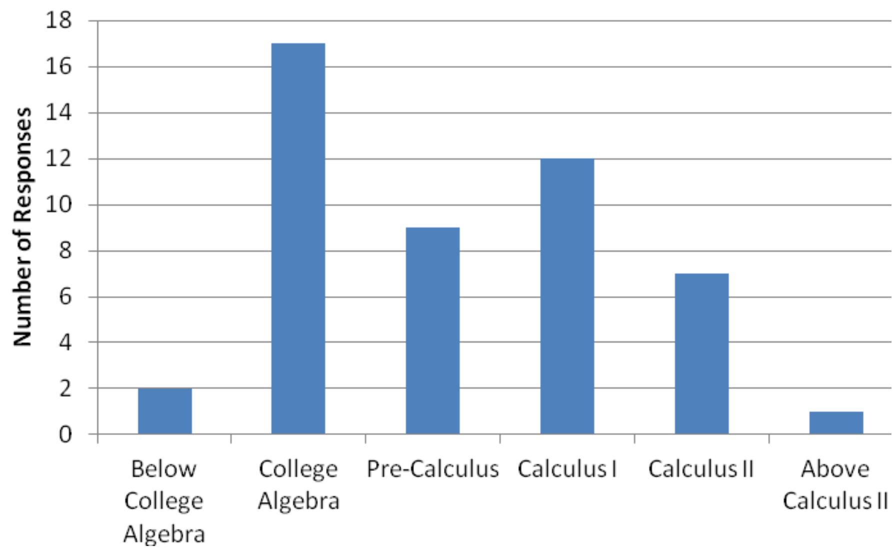

Fig. 3. Response to "The first math course you took in college was".

Figure 3 show that nearly 60% of the senior-level engineering students were not calculus-ready when they started taking college classes. The same is expected to be true for many other engineering programs at other universities. If a student starts in College Algebra, then they must take pre-calculus before Calculus, hence they are one-year behind and already working toward a 5-year engineering program. Students can take summer classes to catch-up, but many freshmen don't recognize the importance of math classes. The authors of this paper have taught introduction to engineering classes for freshmen. In the first week, students were told to enroll into a math class. The importance of math was emphasized during the first few lectures, because it is relatively straightforward for a student to add a math class early in the semester. After the census date, the instructor asked the advising office to run a report on the 200+ students in the introduction to engineering class. It was found that 15% of the class was not enrolled in any math class. Regardless of the advice from faculty, freshmen often have the misconception that math is optional or it can be delayed with little consequence. The results from the survey presented in this paper support the idea that senior-level students understand the importance of math, and it is one of the major reasons they are not going to graduate in 4 years. As freshmen, they may not have understood. But as seniors, they see where their progress was delayed.

The third highest response was about the lack of summer classes. Summer is often a time when students catch-up or get-ahead. It is critical for those who have failed or withdrawn from a class, or those who need to take remedial Mathematics, Chemistry, or English classes. It is a little surprising that this response was so high since the Department of Mechanical Engineering has been offering numerous summer classes for well over 10+ years.

The next highest response concerns changing majors. It is understandable that students who never change majors are the most streamlined in taking classes, while those who change may find that courses taken don't count toward the new major. There is another surprise in that one doesn't think about students changing into the mechanical engineering major. One often thinks of those changing away from engineering. An additional survey question was

You started college as (circle one): mechanical engineering major
other engineering major
non-engineering major

Results are shown in Fig. 4. About 50% of the students claim to have started college as either "other engineering" or "non engineering" majors. This is a surprisingly high number.

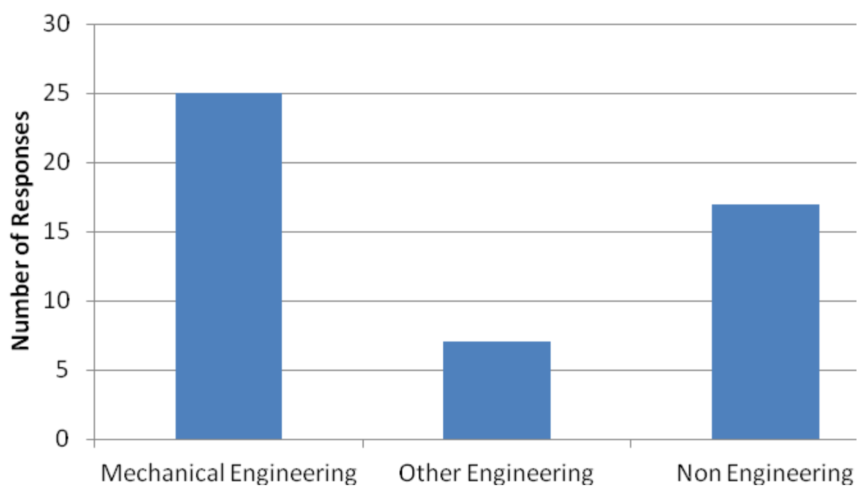

Fig. 4. As what major students started college.

The next most significant issue identified by students was transferring courses to the University. This is similar to changing majors. Anytime one changes institutions, there is the possibility that some courses aren't accepted or they don't contribute to the degree program. This could be for "Core" academic courses or required engineering courses. An additional question on the survey determined the number of transfer students. An additional survey question was

You started college at (circle one): UTSA
another 4-year University/College
Community College

Results are shown in Fig. 5. About 55% of the students claim to have started college either "at another 4-year University/College" or "2-year Community College". Again, this is a surprisingly high number and contradicts many of the ideas held by somefaculty. The perception is that retention is an issue at the freshmen level. Retention initiatives often focus on the development of cohorts in freshmen classes. It is just as important that transfer students be integrated into the new university. Likewise, some faculty have the mentality of building hurdles for transfer students, instead of bridges to allow a smooth transition between institutions. UTSA has active 2+2 transfer agreements with local junior colleges. These agreements can be either strong or weak, based on the standardization of the first two years curriculum. Some faculty purpose to make unique prerequisite courses so they can't be offered at a junior college and hence can't be transferred. This then make the 2+2 program more of a 2+3 program, hence a 5 year program. Over the years, one can see changes to courses as shifting bace and forth between being more or less accommodating to transfer students.

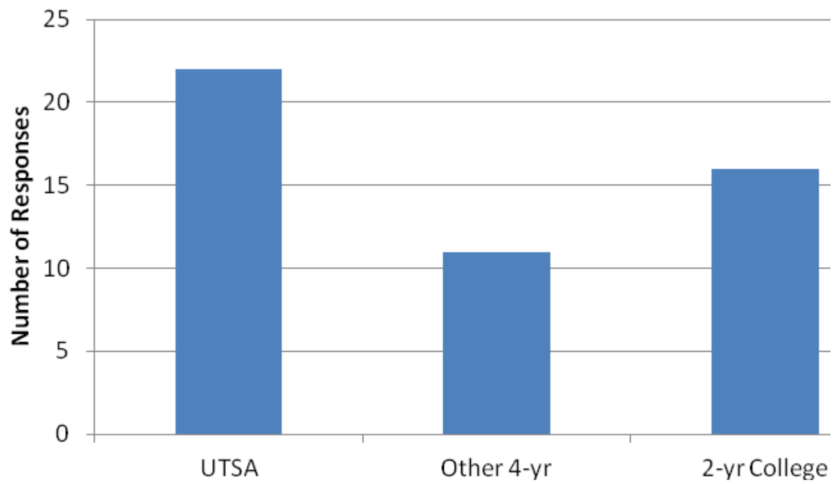

Fig. 5. Where students started college.

There are other issues students identify in the survey on graduation rate. The next two are concerned about poor study habits and time management. Learning these are essential to becoming a successful student. Many courses cover these topics, but they must be embraced by the student. Once students realize the importance of strong study habits and good time management, they will work hard to be better in these area.

Another question explored how many years it will take to complete an undergraduate degree in mechanical engineering, and the responses are shown in Fig. 6. Only 13% of the students will finish in 4 years. The most frequently given response is 5 years. There are some students who are working full-time and will take 6 or more years to finish. It appears that the pressure is on to accommodate a wide spectrum of students so that higher education is more accessible, yet some students can only attend part-time, hence they will never be able to finish in four years. This appears to be a contradiction in directives and it is feared that institutions with the greatest accessibility will be penalized for having more non-traditional students who take longer to complete a degree.

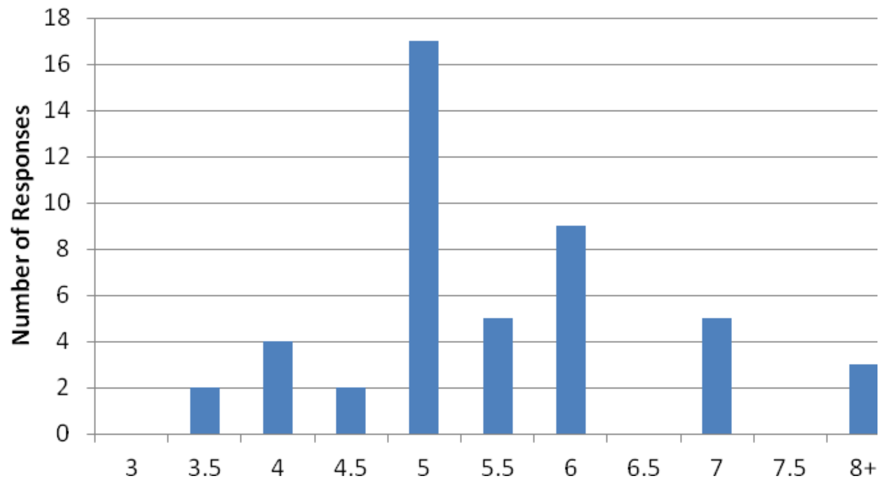

Fig. 6. Number of years to complete an undergraduate mechanical engineering degree.

In the recommended 4-year program of study, students are expected to take 16 and 17 semester credit hours in many semesters. The minimum is 15 SCH. In reality, many student take fewer classes per semester. Fig. 7 shows that only 20% of the respondants completed 16 or more SCH last semester. At that rate, it will be difficult to complete a degree in 4-years. It will be a challenge to have students take 16+ SCH per semester required to finish a 128 SCH in 4 years. An alternative would be to reduce the number of hours to 120 SCH to earn a BSME, but it is doubtful if it could be implemented.

Summary

Senior-level engineering students were surveyed to identify issues important to their prompt completion of a BSME program. There is increased emphasis on institutional accountability and the need for universities to track and improve graduation rates. The survey highlights some key areas. After having identified the key reasons for students to have slow progress toward graduation, a university is better prepared to address the most meaningful issues and improve their graduation rates.

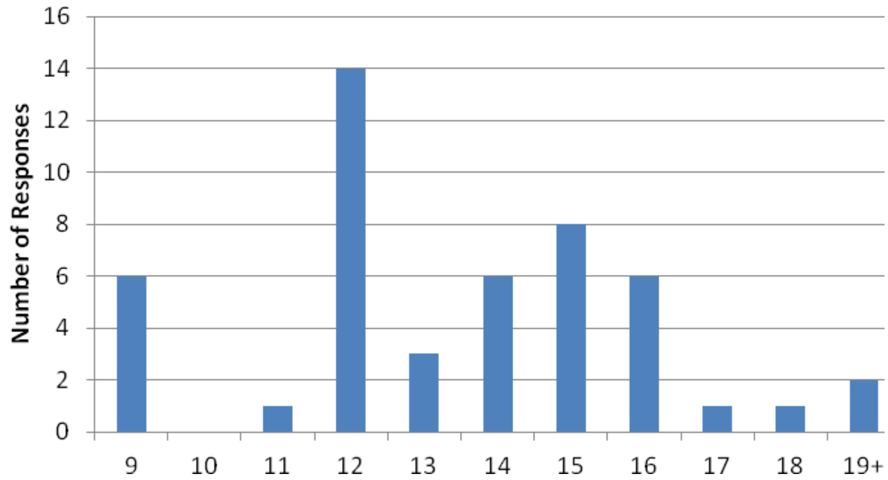

Fig. 7. Number of SCH completed last semester.

Student feedback is overwhelming that failing or withdrawing for a course is the most important issue. If this is true, then a university should focus on things like (1) instructor effectiveness, (2) early detection of at-risk students, and (3) intervention strategies for at-risk students. Students often give valuable feedback to identify unreasonable impediments to their progress through the program. It is less common for engineering programs to have active detection mechanisms in place and follow-up action which are designed to prevent a student from failing a class. Universities have mentoring and tutoring program, but this survey highlights that it is important for a university to seek to do more in this area.

There is little a university can do to fix the problem of unprepared high school graduates. This has been a persistent problem and is expected to continue to be so. If students are not ready for Calculus, but start in College Algebra, then the program becomes a de-facto 5-year program because the student has 1-year to remediate math deficiencies.

Universities should consider treating the summer as equivalent to spring/fall long semesters. It is apparent students seek more opportunities to learn during the summer.

The first two years of an engineering program should be as generic as possible. It does little good to develop a unique course or sequence of courses that are inconsistent with the majority of other 4-year institutions or community colleges. More emphasis should be on building curriculum bridges to ease the transfer of courses between institutions.

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Establishment of a Nuclear Engineering Minor Program

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Abstract

In Fall 2009, the College of Engineering at UT Arlington began to offer a minor in nuclear engineering for its students. The rationale for the establishment of the program is explained, as well as the nature of the program and the status of the program after three full years.

Introduction

The impact of the Fukushima nuclear accident on the future of nuclear industry has not been experienced uniformly worldwide. Different countries have had differing reactions to the accident, and generally speaking the impact can be categorized in four ways. Some European countries like Germany, Italy and Switzerland had the reactionary decision to scale down or stop their nuclear energy programs, but no one knows whether these countries will rethink their nuclear energy policy when faced with economic realities and carbon emission restrictions. At the same time, some countries like China and India are continuing their nuclear program with determination. China has 16 existing nuclear power plants and is planning to add 197 new plants of which 26 are already under construction [1]. India has 20 nuclear power plants and aims to add 64 reactors that will supply 25% of their electricity demand by 2050 [1,2]. A third category consists of countries that plan to jump start their nuclear programs; countries like Saudi Arabia have high ambitions to build 16 nuclear reactors over the next 20 years [3]. Finally the United States with 104 operating nuclear power plants produces 30% of the worldwide electric generation by nuclear energy. Although this is the largest in the world, there have been no new reactors built in USA and the future growth looks sluggish with 4-6 new nuclear power plants planned by 2020.

One can conclude that, in spite of the Fukushima disaster, a number of countries are proceeding to develop their domestic nuclear energy programs. However, these countries are facing a severe shortage of qualified, available personnel. The problem is compounded by the fact that many experienced nuclear workers and professionals are approaching their retirement age;-soon there will be a shortage of nuclear engineers able to fill the available positions. This workforce scarcity is already existing within the USA and worldwide.

Hence, in response to the existing and anticipated future national and regional need for nuclear engineers, UT Arlington's College of Engineering began to offer a minor in Nuclear Engineering (NE) in fall of 2009. The decision to begin this offering was strongly influenced by the following observations:

- UT Arlington is in a close proximity to the Comanche Peak Nuclear Power Plant and the Region IV Office of the US Nuclear Regulatory Commission (NRC). In addition there are a number of companies in the area which provide services and consultation to these entities.
- Comanche Peak has indicated the intent to build two more new nuclear power plants in the state of Texas.
- The national and regional need for engineers with training in nuclear engineering is currently not being met by any university in the Dallas / Fort Worth area.
- Several faculty members at UT Arlington hold PhD degrees in nuclear and related engineering fields.
- Several members of the College's Advisory Board are involved in power generation industry and have voiced unequivocal support for this program.
- The faculty and administration of the College of Engineering have been very supportive, providing both moral and financial support to initiate the minor.

The nuclear industry, particularly nuclear power generating companies, hires engineers from all disciplines. The majority of these hires come from mechanical or electrical engineering. These engineers are involved with design, construction, operations, maintenance, quality assurance, information technology and radiation protection / monitoring. The NE minor is available to UT Arlington students pursuing a major in either engineering or physics. Our minor in NE is intended to provide additional breadth to our existing engineering curriculum. Students planning to seek an advanced degree in engineering can also benefit from a minor in nuclear engineering. Over the last three years we also have had students that pursue the nuclear minor simply because of their personal interest.

Requirements for Minor in Nuclear Engineering

In general, at a higher education institution, courses towards minor degrees are considered to be additional courses in a specific area of study. In the College of Engineering at UT Arlington, there are six different engineering minors which are adjunct to the major engineering degrees. The undergraduate minor in Nuclear Engineering (NE) program was developed mainly for mechanical & aerospace (MAE) and electrical engineering (EE) students, but it is open to all undergraduate engineering majors and science students who meet the math and physics requirements.

The NE minor requires core courses in nuclear engineering and elective courses in thermal sciences, material science and electrical courses in electromechanical energy conversion and control. These optional courses already exist in the course catalog within the College of Engineering.

The minor program requires at least six 3000 and 4000 level courses, including three core courses (Introduction to Nuclear Engineering, Nuclear Reactor Theory/Analysis and Nuclear Reactor Thermal Hydraulics) and three 3000 and 4000 level elective courses, chosen from a set of 8 courses currently available. The following three core courses were developed for the Nuclear Engineering minor:

NE 3301. Introduction to Nuclear Engineering (3 credit hours, 3 lecture + 2 hours lab)
Catalog Course Description
Catalog description: Fundamentals of radiation, radiation decay, binding energy, types of interactions, shielding, and radioisotopes, fission cross section, fission in a reactor, controlling fission chains, basic reactor model, reactor theory, reactor generations I, II, III, IV, review heat transfer terms, reactor coolant, LOCA, reactor accidents, safety, emergency planning zone, nuclear fuel and fuel cycle, waste storage, decontamination and decommissioning, fusion power, regulating nuclear reactors, nuclear power economics and environment;
Prerequisite: Math 3319 (differential equations / linear algebra) or MAE 3360, Phys 1444 (general technical physics II)

Course Learning Goals/ Objectives
The course objectives for NE 3301 Introduction to Nuclear Engineering are to provide the following:

- Introduction to the fundamental principles of nuclear engineering. These topics include atomic and nuclear physics, fission and fusion, isotopes and radioactivity, nuclear reactions, chart of nuclides, radiations; detection and interaction with matter.
- Introduction to criticality and reactor kinetics, reactor licensing, safety, economic and environment impact.
- In addition to light water reactors, introduction to the CANDU, Gas Cooled Reactors, Liquid Metal Fast Breeder and fusion reactors design.
- Discussion of lessons learned from the Three Mile Island and Chenobyl accidents.
- Discussion of Generation II (current) and Generation III, IV (future nuclear) nuclear power plants.
- Discussion of fuel loading, coolant, loss of coolant, severe accidents, reprocessing, spent fuel management and storage.
- Use of radiation detection instruments, detection limits, and uncertainty analysis of measurements.
- Visit to a nuclear power plant
- Interaction with invited guest speakers from the nuclear industry

NE 4302. Nuclear Reactor Theory/Analysis (3 credit hours, lecture)
Catalog Course Description
The neutronics behavior of fission reactors, primarily from a theoretical, one-speed perspective. Criticality, fission product poisoning, reactivity control, reactor stability and introductory concepts in fuel management, followed by slowing down and one-speed diffusion theory. Multi-group diffusion theory, finite-difference and nodal methods, core heterogeneous effects, pin power reconstruction, thermal neutron spectra, fine group whole spectrum calculations and coarse group constant generation.
Prerequisite: Introduction to Nuclear Engineering

Course Learning Goals/ Objectives

The course objectives for NE 4302 Nuclear Reactor Theory/Analysis are to provide the following:

♦ Introduction to the fundamental principles governing nuclear fission chain reactions in a manner that renders the transition to practical nuclear reactor design methods.

♦ Demonstration of the close relationship between the nuclear analysis of the reactor core and those nonnuclear aspects of the core analysis, such as nuclear materials and thermal-hydraulics.

♦ Introduction to a number of more practical problems in the nuclear reactor design for various types of power reactors.

NE 4303. Nuclear Reactor Thermalhydraulics (3 credit hours, lecture)
Catalog Course Description

This course will introduce the students to the processes of energy (heat) generation in nuclear reactor, the transport of that energy by the reactor coolant to the power cycle, and the limitations imposed by the transport mechanism on the design of nuclear reactor cores. Fundamental calculations associated with these processes will be explained, examples set and their results will be discussed. An effort would be made to familiarize the students with a thermal hydraulic software code**.**

Prerequisite: NE 3301 (Introduction to Nuclear Engineering), MAE 3314 (Heat Transfer) or MAE 3309 (Thermal Engineering)

Course Learning Goals/ Objectives

The course objectives for NE 4303 Nuclear Reactor Thermalhydraulics are to provide the following:

♦ An understanding of the heat transfer and fluid flow mechanisms in reactor systems. These topics include conduction, convection and radiation and how heat is generated in the fuel rod and transferred to the coolant. Heat generated in the reactor shield and other structural material due to gamma-ray interaction is also discussed.

♦ An appreciation of the limits on safe power removal from reactor cores. The topics include thermal safety limits like critical heat flux, departure from nucleate boiling and hot channel and hot-spot factors.

♦ The ability to perform basic calculations of thermal hydraulic quantities in core channels. This involves both computer based and traditional calculations for fuel rod, sub-channel and reactor core analysis.

All courses for the minor require a grade of C or higher. Figure 1 shows the coursework requirement and sequence for the minor in NE at UT Arlington.

MAE students are required to take three technical electives as their curriculum requirement and they can take the three NE core courses to satisfy the requirements for the NE minor degree. EE students could use NE 3301 for their engineering elective but two additional courses are required beyond their EE curriculum requirement. Physics majors and other engineering disciplines will likely have to take more than two additional courses to complete their degree plans.

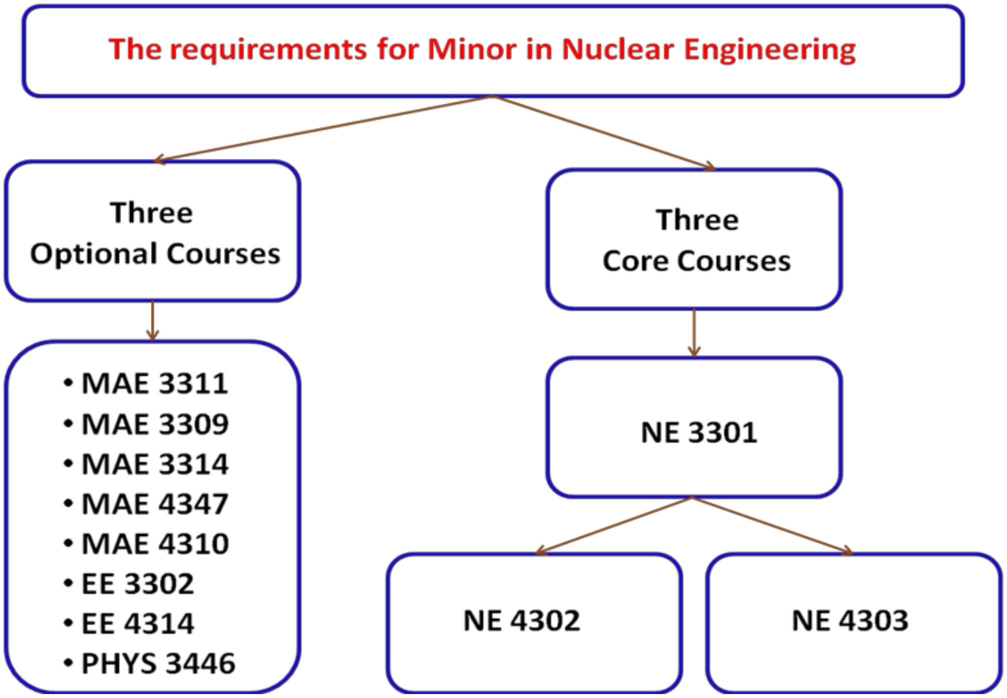

Fig 1. Coursework Requirement and Sequence for Minor in NE at UT Arlington

Since Fall 2009, there has been a strong interest in the NE minor among students. Following approval of the NE minor by the university in the Spring 2009, the first course in the minor, Introduction to Nuclear Engineering, was first offered in Fall 2009. The course capacity was initially capped at 20, raised to 30 and was actually taught with 39 students. Figure 2 shows the statistics for the Enrollment in NE 3301 course. High enrollment in the first year shows the need for the program and excitement of the students. The enrollment for last three years shows a steady increase.

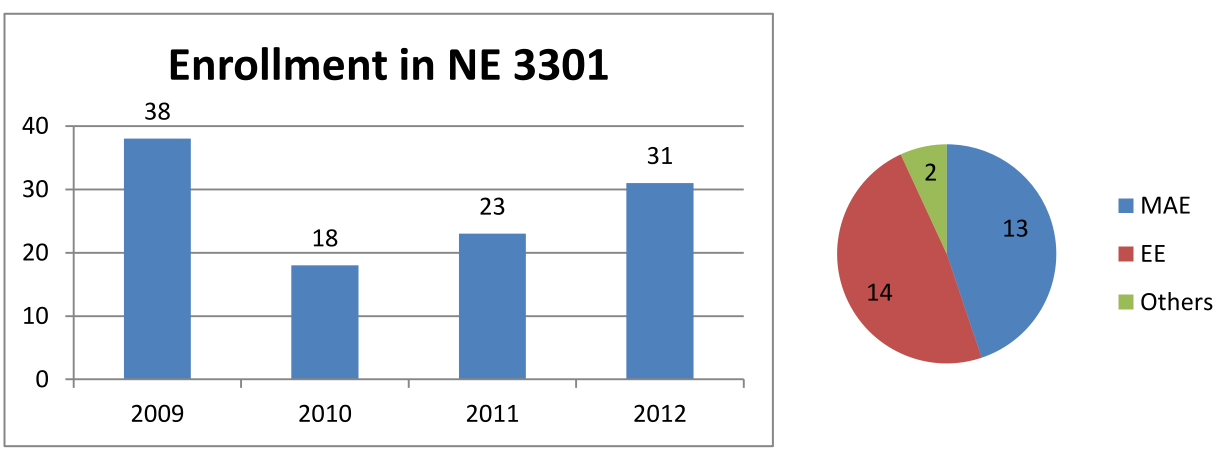

Fig 2. Enrollment in the first core course, NE 3301, during 2009–2012 and the enrollment by major (showing the average number of majors each year, over four years)

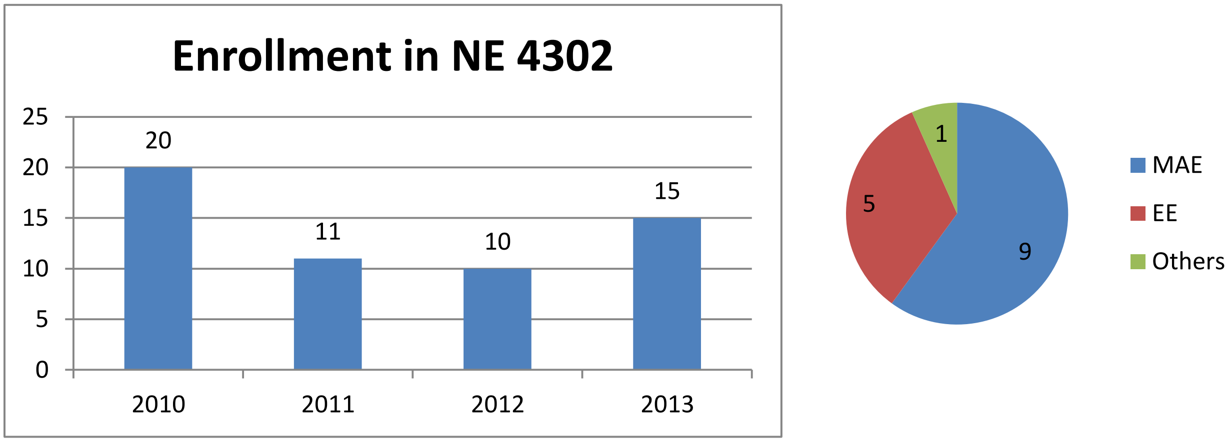

Fig 3. Enrollment in the second core course, NE 4302, during 2009–2012 and the enrollment by major (showing the average number of majors each year, over four years)

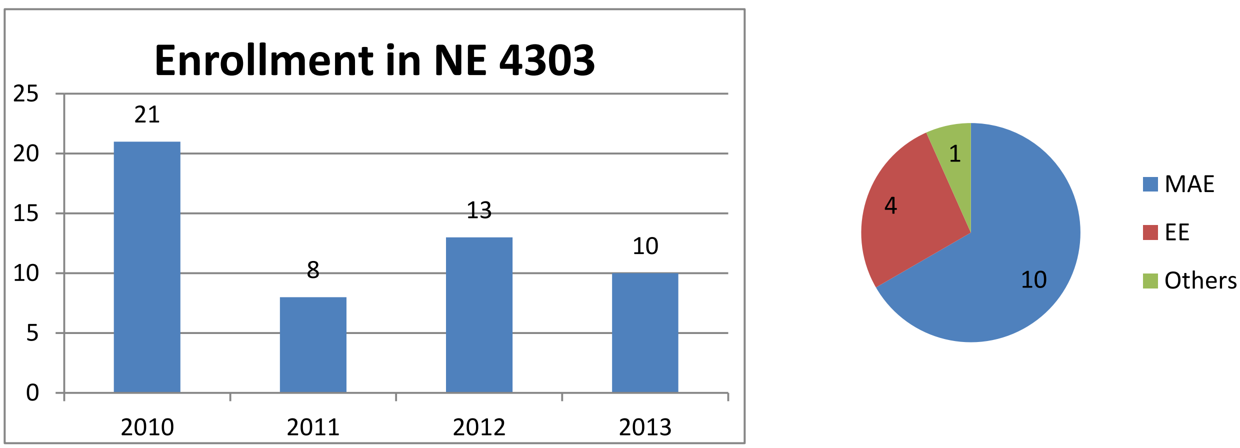

Fig 3. Enrollment in the third core course, NE 4303, during 2009–2012 and the enrollment by major (showing the average number of majors each year, over three years)

The enrollments for NE 4302 and NE 4303 are shown in Figs 3 and 4. As shown, only about 50% of the students continue to complete the program and earn the minor in NE. This drop is for several reasons: EE students can only use one of NE course for the EE degree, some students choose to graduate by the end of fall semester (rather than stay to complete the 2 additional core courses), and some are interested in only learning the fundamentals of nuclear engineering.

Impact of NE Minor at COE at UT Arlington

UT Arlington is a comprehensive research, teaching and public service institution whose mission is the advancement of knowledge and the pursuit of excellence. It is striving to attain national research university status. As such, the offering of additional engineering curriculum options such as NE is completely in line with the university's mission. Since its initiation in fall 2009, the UT Arlington NE minor has begun contributing to the nation's NE education infrastructure. Indications are that interest will continue to be at a high level among our students in this minor, as shown in student surveys, class enrollments, large attendance at seminars where attendance was voluntary, and perceived interest among pre-college students.

In addition, the establishment of the NE minor has improved the educational infrastructure of the College of Engineering by the establishment of the Radiation Measurement Application Laboratory though a grant from the Department of Energy and an educational grant from the Nuclear Regulatory Commission (NRC) for web-based learning. Furthermore it has facilitated the establishment of collaboration with NRC Region IV in Arlington, Comanche Peak Nuclear Power Plant in Granbury, nuclear industries, national laboratories and other universities with stronger nuclear engineering programs.

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Instructional Courseware Developed for Thermodynamics Course

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Abstract

This paper presents concise computer courseware for solving three types of fundamental thermodynamic problems: determine gas status after specified processes; evaluate pure substance's thermodynamic properties at a given state; analyze basic thermodynamic cycles, including power cycle, refrigeration cycle, and heat pump cycle. Common programming language C# is selected to develop the courseware and interfaces. The application of the developed courseware in teaching thermodynamic courses can efficiently help students to improve their problem-solving skills and make them better understand basic thermodynamic laws. The presented teaching approach can be expansively applied in thermodynamics education.

Keywords: thermodynamics, courseware, C#, education.

Introduction

A major objective of a thermodynamic course is to develop students' capability in solving engineering problems that involve thermodynamic principles. However, it is a common phenomenon that most students have trouble in solving thermodynamic problems: some of them cannot properly build an image of the problem and do not know how to start; some of them are not familiar with fundamental thermodynamic principles and generally used problem-solving techniques therefore they struggle everywhere when solve the problem; even worse, without thinking carefully ahead, some students hastily start the problem in the middle by selecting some seemingly appropriate equation, substituting in numbers, and quickly calculating a result. Such common pitfalls associated with problem solving can result in difficulties as problems become more complicated.

In order to efficiently guide the students in solving such thermodynamic problems and improve their problem-solving capability, an instructional computer program is a useful tool. Development and application of instructional programs have been widely employed in engineering education. Canakci [1] developed a program called Pile-D using Microsoft Excel for the teaching of pile foundation design to geotechnical engineering students. Kahn-Jetter and Sasser [2] presented software that used spreadsheets to analyze advanced machine design problems involving optimization concepts. Sieres and Fernandez-Seara [3] designed a courseware for simulating vapor compression refrigeration systems that are self designed by the user. Rivas et al [4] used Microsoft spreadsheet Excel to develop a program that can define, analyze and optimize models of systems and processes of medium complexity.

Based on the above literature, this study develops courseware using C#, which can help and guide students in solving three types of thermodynamic problems: determine gas status after specified processes; evaluate thermodynamic properties at a given state; and analyze power, refrigeration and heat pump cycles. Friendly user interfaces are designed for a user to input given data and information and for providing useful hints for the step-by-step approach. Mathematical models and algorithms of these problems have been implemented in the C# programs.

Determine Gas Status

Determining gas status during a series of processes is a fundamental type of thermodynamic problem. Given an initial status and a series of quasi-equilibrium processes, such problems may require you to solve the gas status after each process and evaluate the work during each process. Typical quasi-equilibrium processes and their governing equations are (assume the process is from state 1 to 2):

Isothermal process:

$$T_1 = T_2,\ W = \int_1^2 p dV = p_1 V_1 \ln\frac{V_2}{V_1} \ \text{or}\ W = mRT\ln\frac{V_2}{V_1}\ \text{(ideal gas)} \tag{1}$$

Isobaric process:

$$P_1 = P_2,\ W = P(V_2 - V_1) \tag{2}$$

Isometric process:

$$V_1 = V_2,\ W = 0 \tag{3}$$

Polytropic process:

$$PV^n = \text{constant},\ W = \frac{p_2 V_2 - p_1 V_1}{1-n}\ \text{or}\ W = \frac{mR(T_2 - T_1)}{1-n}\ \text{(ideal gas)} \tag{4}$$

In the above equations, P denotes pressure, V denotes volume (small letter v means specific volume v = V/m), T denotes temperature, W denotes work, m denotes mass of the gas, and R is the gas constant. In many books, an isothermal process is also considered as a special polytropic process with n = 1.

The basic approach of solving such problems is to correctly identify the number and type of individual processes, and number of states of the process series; next to locate all the given conditions at the proper state or process; and finally to calculate the gas properties at unknown states using eq. (1) to (4). Based on this approach, the courseware program is developed, in which the listed mathematical models have been implemented.

Example 1

Air in a closed system undergoes three processes in series: process 1 to 2 is a polytropic compression with $n = 1.3$ from $P_1 = 180kPa$, $v_1 = 0.05m^3/kg$ to $v_2 = 0.03m^3/kg$; process 2 to 3 is an isometric process and $P_3 = P_1$.

Question: determine the unknown P and v at each state and evaluate the work per mass (kJ/kg) for each of the processes; sketch the processes on the P-v diagram.

This problem can be easily solved using the presented courseware as shown from Figs. 1 to 3.

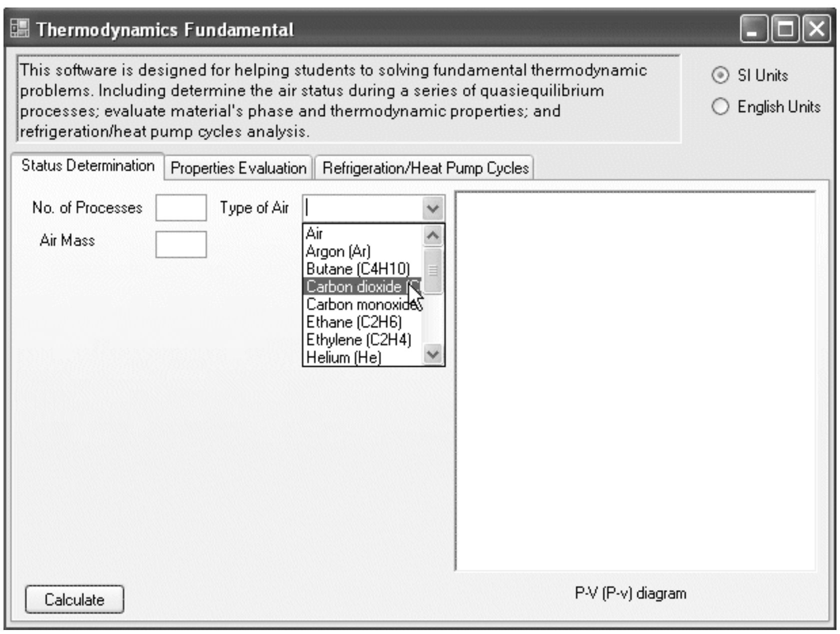

Figure 1. Main interface for determining gas status

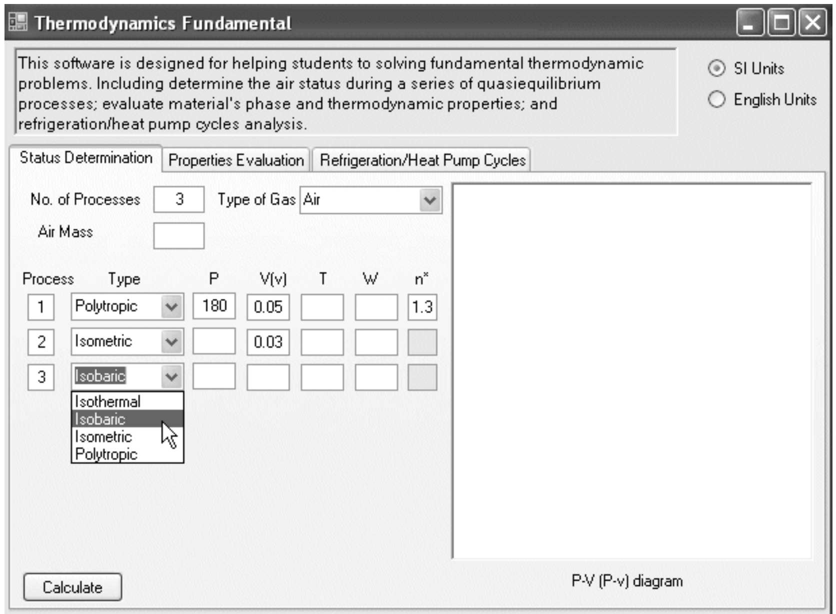

Figure 2. Input given conditions to solve problem 1

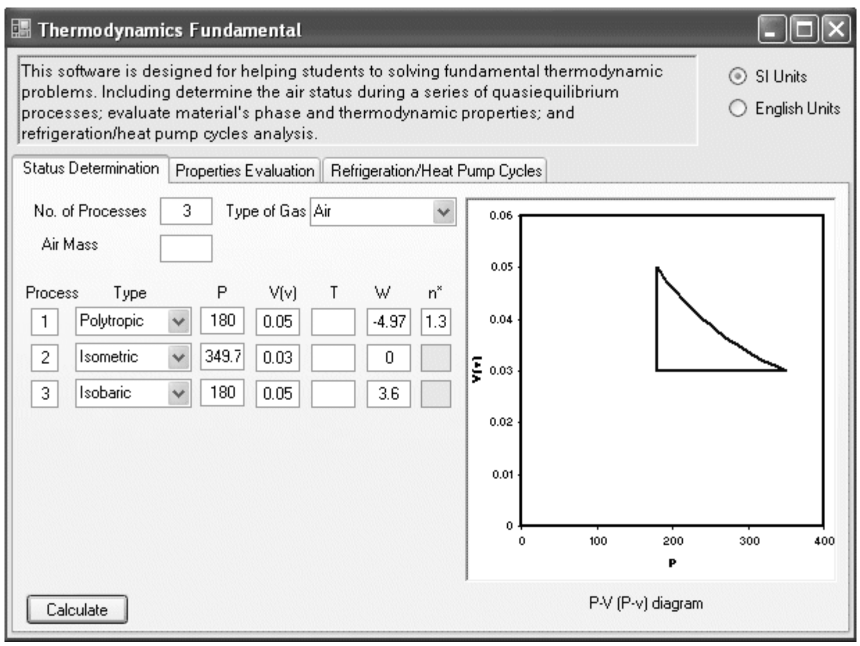

Figure 3. Calculate and display solutions of problem 1

Evaluate Substance's Properties

Evaluating thermodynamic properties of pure substances based on given conditions is an important skill in solving thermodynamic problems. Engineers usually have such problems when analyzing thermodynamic cycles and systems. Besides P, V(v), T, other important thermodynamic properties include internal energy (u), enthalpy (h), and entropy (s). The same substance may have different properties at different states: liquid, liquid-vapor mixture, and vapor state. In order to correctly identify the properties, students have to first determine the state of that pure substance at given conditions. In teaching practices, it is found that most students were confused about how to properly determine the substance's state. A systematic approach has to be created to guide the students in solving such problems.

The best way to evaluate the thermodynamic properties of a substance at a certain state is using property tables, which can be found in any thermodynamic text book. For any substance, three types of property tables are prepared in the books: saturation (liquid-vapor) temperature table – lists of properties for liquid state or liquid-vapor mixture with respect to different temperatures; saturation (liquid-vapor) pressure table – lists of properties for liquid state or liquid-vapor mixture with respect to different pressures; superheated (vapor) table – lists of properties for vapor state with respect to different temperatures. In practice, students usually have difficulties in properly locating the state of the substance on the right property table. In this section, we introduce how to use the correct property tables to determine a substance's state based on given information and retrieve any property p, where p_g denotes the property of saturated vapor and p_f denotes the property of saturated liquid. The algorithm is:

Case 1: if the substance's P and T are given

From the property table to find the saturation temperature T_{sat} at the given P, if $T > T_{sat}$, the substance is in vapor state so go to the superheated table to retrieve properties at temperature T; if $T < T_{sat}$, it is in liquid state so go to the saturation table and evaluate the property using $p \approx p_f$; if $T = T_{sat}$, it is in saturated state and more information is needed to calculate the quality x (see case 2) and fully determine the unknown properties.

Case 2: if P or T is given and another property r is given

Find r_f and r_g based on the given P or T from the saturation pressure or temperature table. If $r > r_g$, the substance is in the vapor state so go to the superheated table to retrieve other properties; if $r \approx r_f$, it is in liquid state so evaluate the unknown properties using $p \approx p_f$; if $r_f < r < r_g$, the substance is a liquid-vapor mixture and we have to determine the quality x using

$$x = (r - r_f)/(r_g - r_f) \text{ or } (r_{fg}) \qquad (5)$$

Other properties then can be calculated as

$$p = (1 - x)p_f + xp_g \qquad (6)$$

Here the r and p can be any properties that are listed in the property tables. In case the given P or T do not locate exactly on the grid of values provided by property tables, the property has to be evaluated using linear interpolation between two adjacent table entries [4, 5]. This approach has been embedded into the proposed courseware.

Example 2

Given: 1) water at T = 200°C and v = 0.1m^3/kg, find its phase and u; 2) water at P = 300kPa and T = 100°C, find its phase and v.

By using the courseware, question 1) was solved from Figs. 4 to 8 and question 2) can be solved as shown in Figs. 9 and 10.

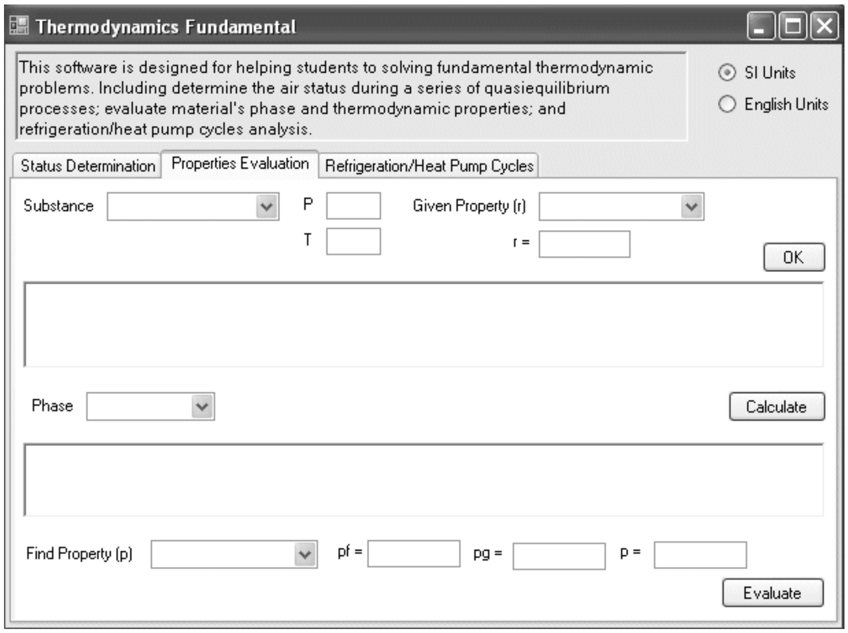

Figure 4. Main interface for evaluating substance's properties

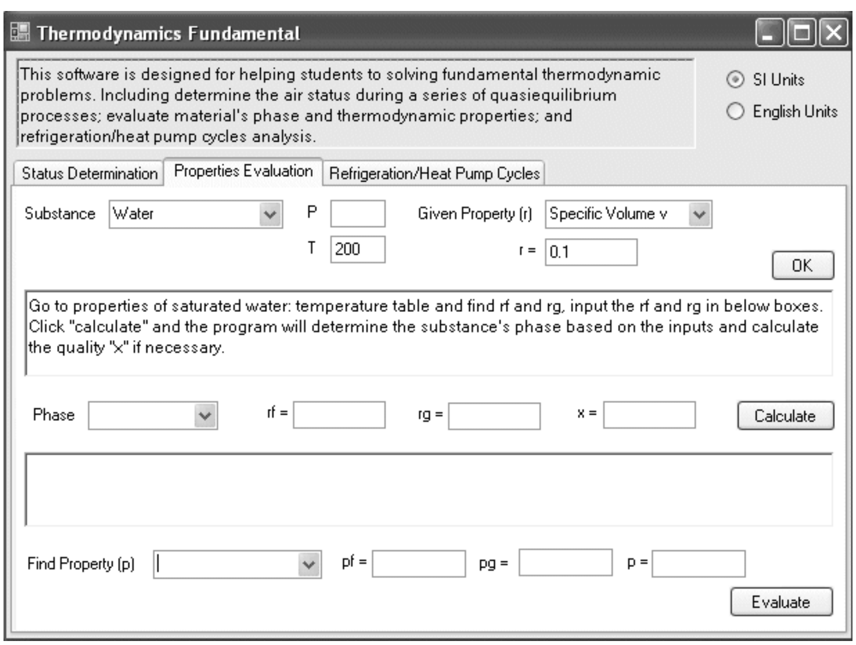

Figure 5. Solve 1) using the interface, step 1

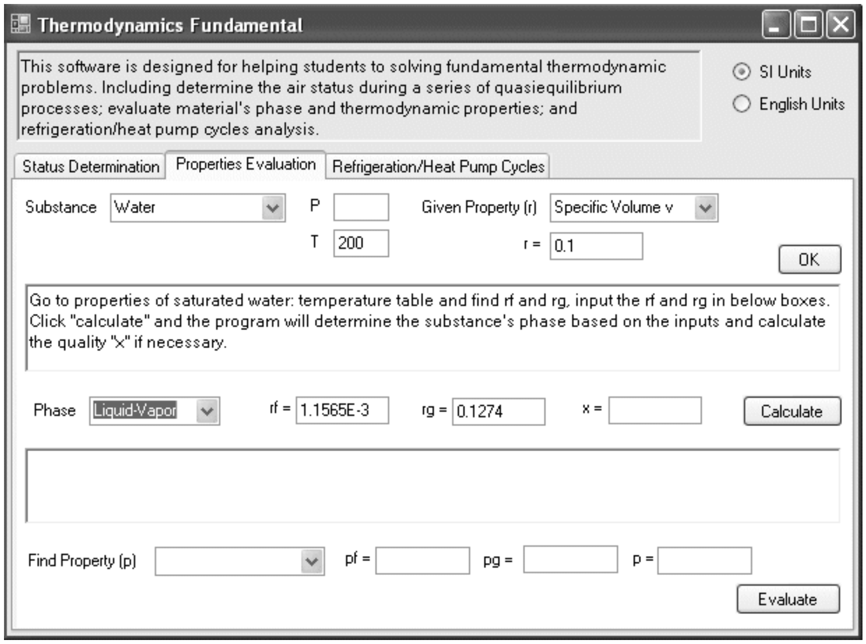

Figure 6. Solve 1) using the interface, step 2

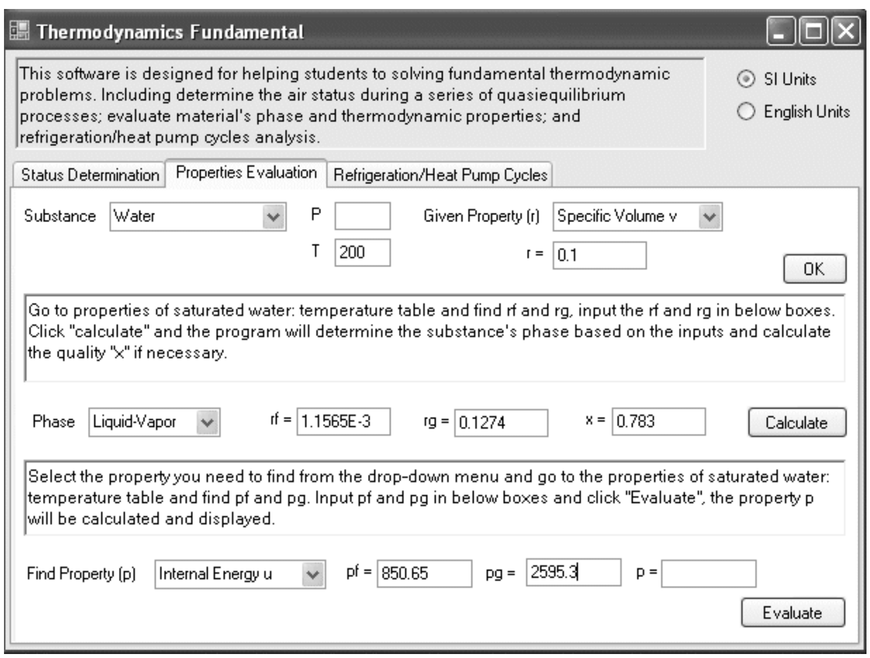

Figure 7. Solve 1) using the interface, step 3

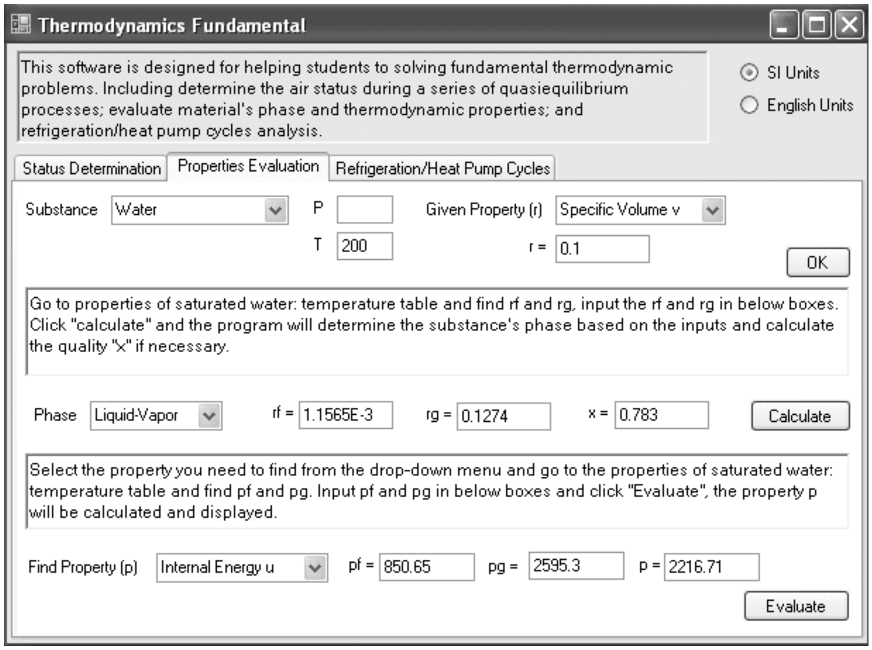

Figure 8. Find solution for 1) using the interface

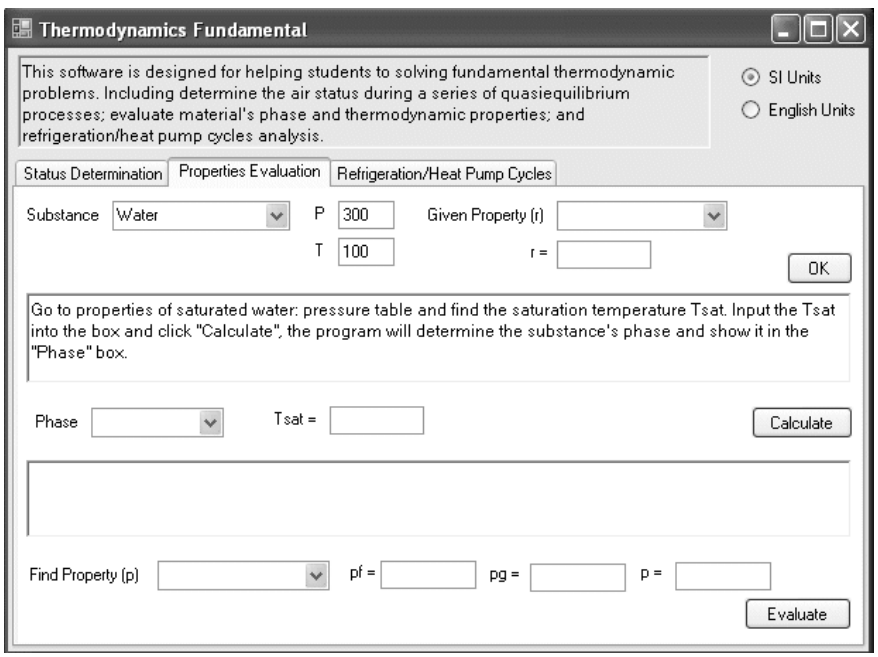

Figure 9. Solve 2) using the interface, step 1

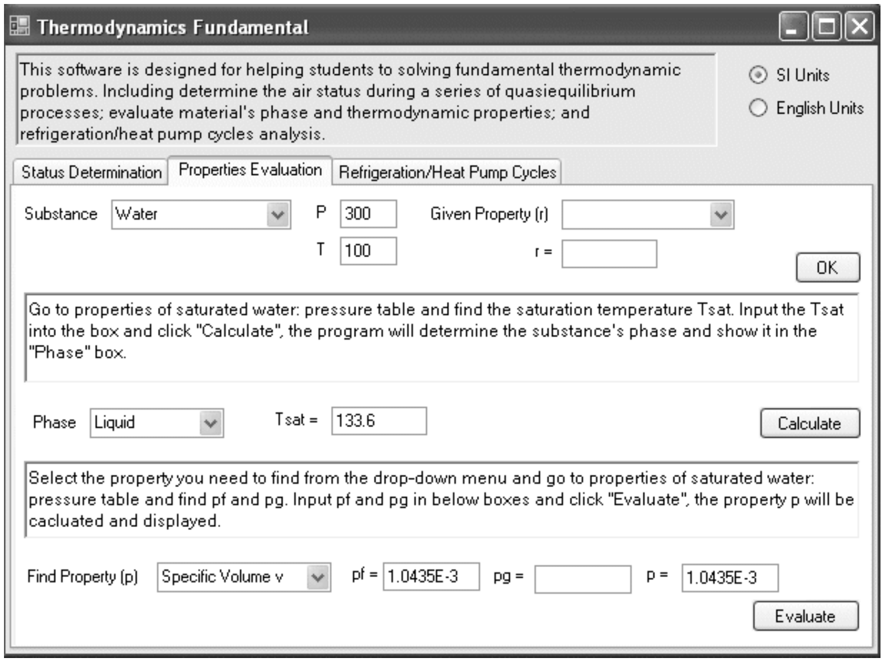

Figure 10. Find solution for 2) using the interface

Analysis of Basic Thermodynamic Cycles

Basic thermodynamic cycles include power cycles, refrigeration cycles, and heat pump cycles. Various thermodynamic cycles play prominent roles in many areas of application. Analyzing these cycles is very difficult because of the presence of complicating effects. A real thermodynamic cycle may have many processes and states. Engineers have to evaluate the characteristics for each process and determine the properties at each state using the method presented in the above section in order to analyze the entire cycle. The presented program only provides basic governing equations for the cycles from the perspective of the conservation of energy principle. Much more comprehensive software needs to be developed to study different cycles in greater detail.

In the following equations, W_{cycle} represents the net amounts of energy transfer by work; Q_{in} represents the heat transfer of energy into the system; and Q_{out} represents heat transfer out of the system. From different cycles, we have:

For power cycle

$$W_{cycle} = Q_{in} - Q_{out}, \text{ thermal efficiency } \eta = W_{cycle}/Q_{in} \quad (7)$$

For refrigeration cycle

$$W_{cycle} = Q_{out} - Q_{in}, \text{ coefficient of performance } \beta = Q_{in}/W_{cycle} \quad (8)$$

For heat pump cycle

$$W_{cycle} = Q_{out} - Q_{in}, \text{ coefficient of performance } \gamma = Q_{out}/W_{cycle} \quad (9)$$

In above equations the W_{cycle}, Q_{in}, Q_{out} can also be replaced by the rate form $\dot{W}_{cycle}$, $\dot{Q}_{in}$, and $\dot{Q}_{out}$, which represent the power or energy rate transferred by work and heat. The program is able to find W_{cycle} ($\dot{W}_{cycle}$), Q_{in} ($\dot{Q}_{in}$), Q_{out} ($\dot{Q}_{out}$), η, β, and γ for these cycles based on the inputs.

Example 3

A heat pump cycle whose coefficient of performance is 2.5 delivers energy by heat transfer to a dwelling at a rate of 20 kW. Determine the net power required to operate the heat pump, in kW.

The solution process of that example can be seen from Figs. 11 and 12.

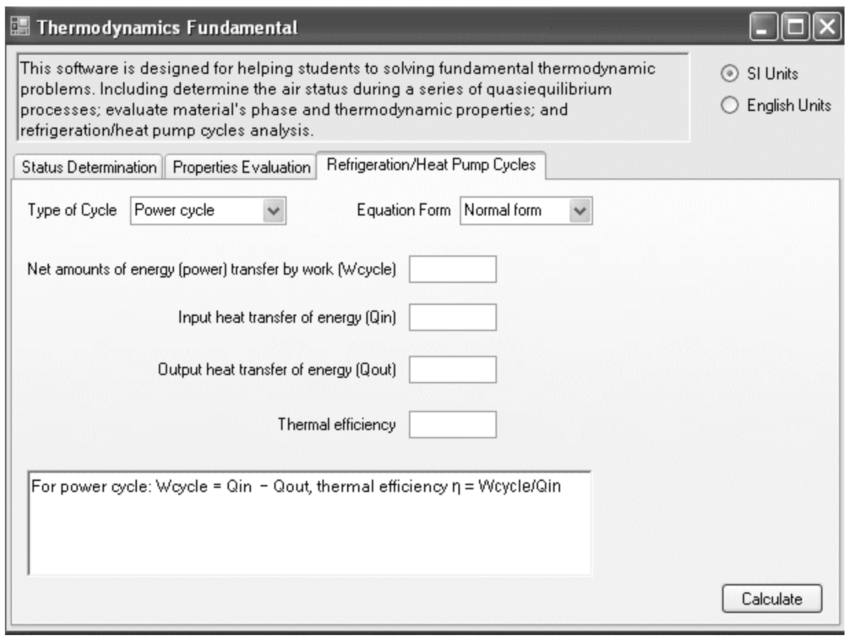

Figure 11. Main interface for analyzing thermodynamic cycles

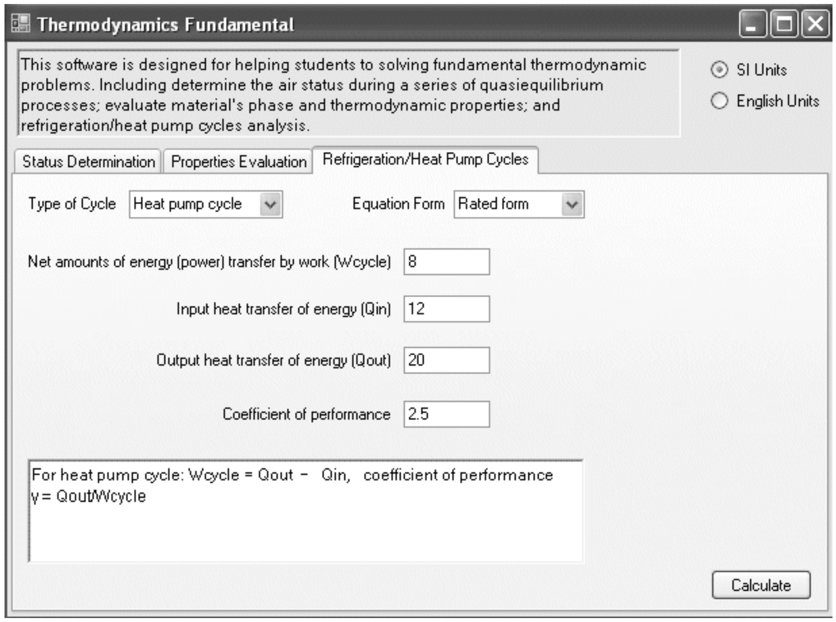

Figure 12. Solve problem 3 using the interface

Discussions and Conclusions

This paper presents courseware that can be used to solve fundamental problems in thermodynamic courses. Theories and algorithms related to the problem solving were implemented in the program, which was developed using C#. As validated by means of three application examples, the developed courseware can be used to solve typical thermodynamic problems, including: determine gas status, evaluate substance's thermodynamic properties, and analyze basic thermodynamic cycles from the perspective of the conservation of energy principle. Graphical user interfaces were designed for the courseware, through which a user can have a friendly conversation to the program. The proposed courseware can help engineering students to better understand basic thermodynamic principles, problem-solving approaches, as well as improving them the capability in solving analytical problems. Because of the advantages and efficiency of the developed courseware, it can be applied in thermodynamic education. Meanwhile, this paper also verifies that development and application of instructional courseware are simple but effective tools in enhancing teaching quality.

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Teaching thermo-chemical equilibrium using a MATLAB algorithm

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Abstract

Computers are an integral part of learning in different fields of education. The ability of scientific computing to solve realistic problems can strengthen engineering education by allowing the students to analyze complex systems. To improve the quality of learning along this path, educators must take a step to make their teaching style flexible and include elements of numerical analysis as an ingredient of upper-class engineering courses. This paper documents our attempt to teach a difficult problem, chemical equilibrium in combustion systems, using a method based on matrix factorization that is very well suited to be implemented in MATLAB. This paper presents our novel numerical algorithm that treats chemical equilibrium beyond the simple balance. By doing so, we emphasize the thermodynamic and detailed nature of chemical equilibrium. These two concepts arise naturally by performing a singular value decomposition of the stoichiometric matrix, avoiding the necessity to specify reaction paths, and providing a lean and easy-to-understand algorithm based on matrix-vector multiplications. A complete MATLAB code is presented, verified and discussed in details. Educational effectiveness is investigated via in-class student surveys. Based on the student evaluations and feedback, it is evident that this module proved beneficial towards developing a sound understanding of the topic. Our results emphasize the benefit of teaching engineering courses from first principle. Educators should refrain from using web applications to teach this fundamental of mechanical engineering and challenge their students to carry out a detailed computational analysis.

Introduction

Computer technology plays a two-fold role in the field of engineering education. On the one hand, using computer software to create multimedia demonstrations in class aids the students in understanding new concepts. Previous research[1,2] has shown that students who learned from teachings supplemented by animations performed better than those who learned through the text-only technique. Using graphics, simulations, animations of concepts and their applications has the potential to explain concepts more clearly and in a shorter time when compared to the conventional lecture-only approach. On the other hand, scientific computing allows the analysis of large, complex engineering problems, involving, for example the solution of coupled nonlinear equations. The advantage of computers in education is, in this second case, to make the lecture less abstract by presenting a realistic analysis.

The present research investigates benefits related to the second issue. The topic under investigation is the definition of thermo-chemical equilibrium, which mechanical and aerospace engineering students learn and apply to determine chemical compositions, flame temperatures, specific impulses of rockets, etc..., in combustion, propulsion and atmospheric modeling classes. In this paper we argue that explaining the concept of thermodynamic equilibrium based on chemical reactions[3] is an uninformative approach for two reasons. First, it does not establish that the equilibrium principle is derived based on purely thermodynamic considerations, where chemical paths play no role. The rationale for its applicability to various stoichiometric balances is that thermo-chemical equilibrium is a detailed balance principle[4], meaning that each subsystem of the mixture is itself in equilibrium. Nonetheless, subsystem balances are neither chemical paths nor reactions and can include, for example, fractional stoichiometric coefficients. Second, it does not identify what information is actually needed for an equilibrium computation, which should include two thermodynamic variables and a number of additional constraints equal to the number of atom types in the mixture. Since these constraints are imposed by the stoichiometry, they are equal in number to the non-zero singular values of the stoichiometric matrix. In this regard, we argue that a proper definition of the number of system constraints is the dimension of the range of the stoichiometric matrix.
The main topic of the present paper is a computational module prepared for teaching chemical equilibrium in a combustion course. The algorithm uses singular value decomposition (SVD) both to define the problem and to solve it through non-linear searches on a (reduced) manifold spanned by the range of the stoichiometric matrix. The numerical operations are cast in a matrix-vector form, leading to a lean presentation and implementation. A similar SVD approach was used by Fox[5] to reduce the finite rate chemistry species into conserved and reactive subspaces. Further, the idea of reducing the search manifold by manipulation of the stoichiometric matrix is similar to the concept of element potentials introduced by Reynolds[6], but more suitable for education because of its definition in terms of matrix-vector products.
In the remainder of this paper a complete MATLAB implementation of the algorithm is presented, verified and discussed. The educational outcomes of this work are analyzed through in class surveys, and, finally, the conclusions are discussed.

Chemical Equilibrium

Combustion of hydrocarbon fuels releases a variety of product species. At high temperature, the products of hydrocarbon combustion are not just represented by the major species (CO_2, O_2, H_2O, N_2). These species dissociate and produce a variety of minor species, which may be important from both the energetic and the environmental stand-points. In this section we briefly discuss the theoretical background and method to calculate the mole fractions of the product species at a given temperature and pressure. This problem is also referred to as *TP* (temperature and pressure), but the outlined solution procedure can be easily extended to *HP* (enthalpy and pressure) or *SP* (entropy and pressure) problems.

Second Law of Thermodynamics

The second law of thermodynamics identifies the equilibrium condition in composition space as the state of maximum entropy of the system. In order for equilibrium to represent a detailed (rather than global) balance, the entropy must be maximal over all the degrees of freedom of the system. For a system at given pressure and temperature, the maximization of the entropy leads to (see Ref. [7])

$$\sum \mu_i \mathrm{d}n_i = \mu^T \ \mathrm{d}n = 0, \tag{1}$$

where μ_i are the species Gibbs functions and $\mathrm{d}n_i$ the changes in mole numbers. Constraints are of stoichiometric nature, and in the absence of any, the only detailed solution would be $\mu_i = 0\ \forall i$, which violates conservation of mass, thus it is discarded.
Stoichiometry constraints on equation (1) are typically expressed in terms of the stoichiometric matrix

$$A\,n = b \Rightarrow A\ \mathrm{d}n = 0, \tag{2}$$

where the matrix A is of size $n_{\text{element}} \times n_{\text{species}}$, and expresses the number of each atomic element in each species molecule. Therefore, the product $A\,n$ counts the total number of elements in the systems, which is set to a constant by imposing equation (2). The evaluation of A can be implemented in MATLAB in terms of the array of strings for the species and elements, as demonstrated in the code fragment reported in Fig. 1.

```
elements={'c','h','o'};
species = {'ch4','o2','co2','co','h2o','h','h2','o','oh','ho2'};
Nel = numel(elements);
Nsp = numel(species);
A=zeros(Nel,Nsp);
for i = 1:Nel
   for j = 1:Nsp
      ip=strfind(species{j},elements{i});
      if ~isempty(ip);
         ip1= min(ip+1,numel(species{j}));
         coe=str2num(species{j}(ip1));
         if ~isempty(coe);
            A(i,j) = coe;
         else
            A(i,j)=1;
         end
      end
   end
```

end

Figure 1. Fragment of code to determine the stoichiometric matrix A in equation (2).

The implementation and manipulation of the stoichiometric constraints renders equilibrium didactically challenging: the Lagrange multipliers strategy discussed in Ref. [7] is effective but cumbersome. We propose a singular value decomposition of the stoichiometric matrix as a viable solution strategy, because of its lean and straightforward implementation. The algorithm starts with identifying the effective number of constraints as the codimension of the nullspace of A ($N(A)$), which is, as a consequence, mapped by the right singular vectors corresponding to zero singular values. Hence,

$$A = USV^T \Rightarrow \mathrm{d}n = V\left(:, n_{\text{element}} + 1 : n_{\text{species}}\right) \mathrm{d}c, \tag{3}$$

where dc is the projection of dn on the nullspace $N(A)$, and the columns of the matrix

$$S_1^T \equiv V\left(:, n_{\text{element}} + 1 : n_{\text{species}}\right)$$

span $N(A)$. Thus, equation (1) becomes,

$$\mu^T S_1^T \mathrm{d}c = \mathrm{d}c^T S_1 \mu = 0 \Rightarrow S_1 \mu = 0, \tag{4}$$

where the implication is supported by the fact that dc can be any element of $N(A)$, which is a consequence of the detailed balancing principle. The MATLAB implementation is simple, i.e.,

```
[U,S,V]=svd(A);
S1 = V(:,Nel+1:end)'.
```

Note that the vector μ contains the unknown mole fractions X, in fact,

$$\mu / \hat{R}T \equiv g^0 / \hat{R}T + \log X + \log p / p_0,$$

where $g^0 \equiv h\text{-}Ts^0$, and p^0 is the pressure at which s^0 is evaluated (typically 1 bar).

We start manipulating eq. (4) by focusing on a TP problem. The unknowns are brought to the left-hand side and the following system is obtained,

$$S_1 \log X = -S_1 \frac{g^0}{\hat{R}T} - S_1 [1,1,\ldots,1]^T \log p / p_0 \equiv v_1. \tag{5}$$

Equation (5) provides $n_{species} - n_{elements}$ equations that are supplemented by equation (2), which is recast in an homogeneous form dependent on the mole fractions as follows,

$$S_2 X = 0, \text{ where, } S_2 \equiv A - \tilde{b}\hat{M}^T A. \tag{6}$$

Here $\tilde{b}$ is the vector of the mole mass ratios of the elements, and $\widehat{M}$ is the vector of the atomic molecular weights; e.g., $\widehat{M} = [12,1,16]^T$ for the MATLAB code in Fig. 1. The matrix S_2 in equation (6) is obviously singular because it does not enforce conservation of mass, and thus one of its rows is replaced by the condition

$$\sum_{i=1}^{n_{\text{species}}} X_i = 1;$$

whereby the system is non-singular, but also non-homogeneous. Finally, we have

$$S_2 X = [1, 0, \ldots, 0]^T \equiv v_2, \tag{7}$$

as second part of the resolvent system.

Each of the two sub-systems is linear; equation (4) in $\log X$ and equation (7) in X. Nonetheless, the combination of the two systems is not linear. Since the dimension (n_r) of the range of S_1 is typically much larger than that of S_2, we find it computationally efficient to reduce equation (4) by parameterizing the variation of its solution with a vector of size equal to the codimension of the range of S_1. Hence, we carry out a singular value decomposition

$$S_1 = L\,K\,R_0^T,$$

and set

$$\log X = N + Rc, \tag{8}$$

where,

$$N \equiv R_1 (S_1 R_1)^{-1} v_1, \tag{9}$$

and

$$R_1 \equiv R_0(:,1:n_r) \text{ and } R \equiv R_0(:,n_r+1:\text{end}). \tag{10}$$

This operation is performed in MATLAB without the need of the matrix inversion as shown in Fig. 2.

```
[L,K,R0]=svd(S1)
N=R0(:,1:nr)*((S1*R0(:,1:nr))\V1);
R=R0(:,nr+1:end);
```

Figure 2. Fragment of code to reduce the dimensions of the solution log X by manipulation of equation (4).

Thus, the search of the solution is restricted to a vector of size equal to the codimension of the range of S_1, which is typically equal to the number of elements. This drastic reduction of the unknown space from (possibly) hundreds to a few elements sharply decreases the computational burden associated with the solution of the non-linear system in equation (7). Another advantage of equation (8) is that it voids the problem with species disappearing from the mixture at high temperature, in which case the Newton update of the original formulation becomes singular because of the problem with $\log(0) \to -\infty$.
The solution of a *TP* problem can be accomplished by a multivariate minimization procedure instead of the Newton method, thus augmenting the solution convergence radius. This outcome becomes important when one uses equilibrium to teach problems with variable parameters, e.g.,

when evaluating Hugoniot curves for detonation waves. Multivariate minimization is implemented in MATLAB using the intrinsic function *fminsearch* as described in Fig. 3.

```
options=optimset('TolFun',1d-9,'TolX',1d-9,'MaxFunEvals',10000);
cv0 = cguess*ones(nv,1);
c = fminsearch(@locfun,cv0,options);disp(c);
X=exp(N+R*c);
   function out=locfun(cv)
      l=N+R*cv;
      resid=b2-Z2*exp(l);
      out = norm(resid);
   end
end
```

Figure 3. Code for the evaluation of chemical equilibrium using a multivariate minimization strategy.

Properties

The evaluation of the mixture properties is an important aspect of the algorithm and comes about in the definition of the potentials g_0. Assuming the mixture composed of calorically perfect gases, the information necessary for the computation of the chemical potential is the temperature dependent heat capacity C_p°, plus the enthalpy and entropy at formation. We find it useful to point students to a website where they can obtain thermodynamic information on a wide variety of gases, so that they can use this knowledge for other problems, beyond the scope of combustion education. On the National Institute of Standards website (http://webbook.nist.gov/chemistry/), the Shomate equation defines the heat capacity in terms of five coefficients A - E, which can be used to evaluate the standard entropy and enthalpy by means of additional integration constants,

$$C_p^\circ = A + Bt + Ct^2 + Dt^3 + E/t^2, \quad (11a)$$

$$h - h_{298K} = \int_{298K}^{T} C_p^\circ \mathrm{d}T, \quad (11b)$$

$$s^\circ - s^\circ_{298K} = \int_{298K}^{T} \frac{C_p^\circ}{T} \mathrm{d}T. \quad (11c)$$

Verification

We have carried out sample computations involving small hydrocarbons (C_5H_{12}, C_3H_8, CH_4 and air, and found that with the initial guess $c = [-20, -20, -20, -20]^T$ the algorithm converges everywhere in the temperature range $T \in [1000 - 3000]K$, and for fuel weight fractions

$W \in [0.05, 0.95]$. The accuracy of the approach is verified against the NASA thermochemical equilibrium code[7] by evaluating the product composition supported by CH_4 + Air burning at 3000 K, 1 bar and with weight fractions $W_{CH_4} = 0.055, W_{O_2} = 0.21$, and, $W_{N_2} = 0.735$. Results reported in table (1) show a good agreement between the two algorithms, also considering that the interpolating polynomials used to define the thermodynamic properties (equation (11)) differ.

Species	NASA	Present
CO	5.9803×10^{-2}	5.9832×10^{-2}
CO_2	2.6807×10^{-2}	2.6956×10^{-2}
H	2.8659×10^{-2}	2.8901×10^{-2}
H_2	3.2837×10^{-2}	3.341×10^{-2}
H_2O	1.0895×10^{-1}	1.096×10^{-1}
N	1.1266×10^{-5}	1.126×10^{-5}
NO	1.4111×10^{-2}	1.4716×10^{-2}
NO_2	2.6669×10^{-6}	2.4375×10^{-6}
N_2	6.5577×10^{-1}	6.5538×10^{-1}
O	1.6799×10^{-2}	1.6847×10^{-2}
OH	3.4207×10^{-2}	3.2225×10^{-2}
O_2	2.2040×10^{-2}	2.2107×10^{-2}

Table 1. Verification of the chemical equilibrium algorithm against the NASA thermochemical equilibrium code[7].

HP algorithm

HP problems are rather important in mechanical/aerospace engineering education because they define flame temperatures, rocket chamber pressures and specific impulses, and the detonation speed according to the Chapman-Jouguet theory. The core algorithm for an *HP* problem is only slightly different from what discussed in the previous sections. The conservation of energy in terms of the mass fraction is written as

$$X^T \left(h - A^T \hat{M} \bar{h}_0 \right) = 0, \tag{12}$$

where h is the vector of molar enthalpies of products and h_0 is the enthalpy of the reactants per unit mass. The *HP* algorithm requires two modifications with respect to the *TP* analog. First, the vector v_1 is not fixed at the beginning of the computations, thus we find useful to rewrite equation (8) as

$$\log X = -R_1 (S_1 R_1)^{-1} S_1 \left(\nu + [1,1,\ldots,1]^T \log p / p_0 \right) + R c = N_0 \nu + R c + N_p, \tag{13}$$

where N_0 should be evaluated before the non-linear search. Note that if the matrix S_1 was full-rank, equation (13) would become

$$\log X = \left(\nu + [1,1,\ldots,1]^T \log p / p_0\right),$$

which we previously identified as the solution for the non-constrained problem. Second, solving the problem as a multivariate minimization is inefficient, because the computer time necessary in evaluating mixture properties ($\nu \equiv \frac{g^0}{\hat{R}T}$ and h) overwhelms the linear algebra time. The large computational time becomes an issue when the algorithm is run with a large set of initial values, as when evaluating the Hugoniot curve for a given fuel in the context of a combustion wave analysis. Therefore, we use the Newton method with solution vector $[c^T, T^T]$, residual,

$$r = \left[\nu_2 - S_2 X, X^T\left(h - A^T \hat{M}\bar{h}_0\right)\right]^T, \tag{14}$$

and Jacobian,

$$J = \begin{pmatrix} J_1 & J_2 \\ J_3 & J_4 \end{pmatrix}, \tag{15}$$

with

$$\begin{aligned} J_1 &\equiv S_2 \mathrm{D}\left[X\right] R, & J_2 &\equiv S_2 \mathrm{D}\left[X\right] N_0 \nu_1 \\ J_3 &\equiv \left(h - A^T \hat{M}\bar{h}_0\right)^T \mathrm{D}\left[X\right] R, & J_4 &\equiv X^T h' + \left(h - A^T \hat{M}\bar{h}_0\right)^T \mathrm{D}\left[X\right] N_0 \nu', \end{aligned} \tag{16}$$

where $D[X]$ is a square matrix having X on the main diagonal and the prime indicates differentiation with respect to the temperature. A sample code for the calculation of the adiabatic flame temperature of a generic hydrocarbon $C_m H_n$ in stoichiometric air is included in Fig. 4. The only module to be added to this program is the *perfgas.m* routine, needed to evaluate the thermodynamic properties of the mixture. This code was validated against data provided in Ref [3] (Appendix B) and results shown in table (2) show that the flame temperatures are evaluated with an error lower than 2 K. No convergence problem was detected when analyzing hydrocarbons with m up to 10.

Fuel	Glassman[3]	Present
CH_4	2226K	2227 K
C_2H_2	2541K	2539K
C_2H_6	2260K	2261K
C_3H_8(L)	2257K	2258K
C_5H_{12}(L)	2262K	2263K
$C_{10}H_{16}$(L)	2308K	2308K

Table 2**.** Verification of the *HP* algorithm against adiabatic flame calculations in normal stoichiometric conditions reported in Ref. [3].

```
function T= Tflame(m,n,Tcold,p)
p0=1; %bar
Nfrac = 3.76; %molar ratio between nitrogen and oxygen in air

%set the problem data
W_F = (m*12+n)/(m*12+n + (m+n/4)*(32+3.76*28)); W_A = 1-W_F;
fuel = ['c',num2str(m),'h',num2str(n)];
W_O = W_A*32/(32+Nfrac*28); W_N = W_A*Nfrac*28/(32+Nfrac*28);

%Mass matrix:
elements={'c','h','o','n'};
species = {fuel,'o2','n2','co2','co','h2o','h','h2','o',...
   'oh','ho2','no','hno','n','no2'};
Nel = numel(elements);Nsp = numel(species);
A=zeros(Nel,Nsp);
for i = 1:Nel;
   for j = 1:Nsp
      ip=strfind(species{j},elements{i});
      if ~isempty(ip);
         ip1 = ip-1+ regexp(species{j}(ip:min(ip+2,end)),'\d');
         coe=str2num(species{j}(ip1));
         if ~isempty(coe)&& ip1(1)-ip <=1;
            A(i,j) = coe;
         else
            A(i,j)=1;
         end;
      end;
   end;
end

%Molar Mass of elements and species
Mel = [12,1,16,14];Msp = Mel*A;

%system matrices
[U,S,V]=svd(A);S1 = V(:,Nel+1:end)';S2 = A;

%RHS vectors
Sp = ones(size(S1,2),1)*log(p/p0);
V2 = W_F/Msp(1)*A(1:4,1)+[0;0;W_O/Mel(3);W_N/Mel(4)];
```

```
%mole-mass of reactants
eta0=[W_F,W_O,W_N]./Msp(1:3);
%enthalpy of reactants (per unit mass)
H0=0;for k=1:3;H0=H0+ eta0(k)*perfgas('h',Tcold,species{k});end

Tguess=1000;cguess = -10*ones(Nel,1);
[X,cv] = NewtonHP(S1,S2,V2,Msp,species,H0,Sp,[cguess;Tguess]);
T=cv(end);

function [X,cva]=NewtonHP(S1,S2,V2,Msp,species,H0,Sp,cguess)
Runi = 8.31447215;  %KJ/Kmole
[L,K,R0]=svd(S1);
nc=size(S1,2);nr=size(S1,1);nv=nc-nr;Nsp = numel(species);
N0=-R0(:,1:nr)*inv(S1*R0(:,1:nr))*S1;R=R0(:,nr+1:end);Np= N0*Sp;
nu = zeros(Nsp,1);h  = zeros(Nsp,1);nu1= zeros(Nsp,1);h1 = zeros(Nsp,1);

Z2=[ones(1,size(S2,2));S2-V2*Msp];
Z2=Z2(1:nv,:);b2=zeros(nv,1);b2(1)=1;
Hi=(Msp*H0)';

cva = cguess;iter=0;
while iter < 5000
   iter=iter+1;
   cv=cva(1:end-1);T=cva(end);
   for k = 1:Nsp;nu(k) = perfgas('g',T,species{k})/(Runi*T);end
   for k = 1:Nsp;h(k) = perfgas('h',T,species{k});end
   Tp=T+.1;
   for k = 1:Nsp;nu1(k) = perfgas('g',Tp,species{k})/(Runi*Tp);end
   for k = 1:Nsp;h1(k) = perfgas('h',Tp,species{k});end
   h1=(h1-h)*10;nu1=(nu1-nu)*10;
   X=min(max(exp(N0*nu+R*cv+Np),1d-18),1);
   resid = [b2-Z2*X;-X'*(h-Hi)];
   if norm(resid) < 1d-8;break;end;
   J=[Z2*diag(X)*[R,N0*nu1];(X'.*(h-Hi)')*R,X'*h1+(X.*(N0*nu1))'*(h-Hi)];
   cva = cva + min(max(J\resid,-10),10);
end
```

Figure 4. Complete code to evaluate the adiabatic flame temperature of a generic hydrocarbon C_mH_n in stoichiometric air at the given pressure and temperature.

Educational approach and results

We first introduced the topic of chemical equilibrium to the students with a verbal lecture that emphasized the concepts of singular value decomposition and projection over finite dimensional vector fields. Then, we used a computer connected to a projector to explain the same concepts using MATLAB. The code was explained to the students line-by-line. The students were given a demo on how to use the code to obtain results. Homework was assigned where the students were asked to perform two tasks. a) Validate the code by comparing the results of the SVD procedure to the NASA thermo-chemical equilibrium code[7]. b) Solve a series of problems involving thermo-chemical equilibrium.

The analysis of the educational outcomes focused on the following issues:

1. Student keenness in using advanced linear algebra concepts to solve problem.
2. Ease with which students can learn the tool.
3. Ease with which students can apply the tool.
4. Student's learning performance with the aid of the tool.

Student Feedback

Students were asked to give their feedback, by answering a questionnaire, so that we could assess if the use of computer technology to teach this topic was beneficial. The questionnaire contained the following questions.

On a scale of 1 to 5, 1 being the lowest and 5 being the highest, rate the following:

Q_1 How well did you understand the principle of chemical equilibrium in combustion?

Q_2 How helpful was the MATLAB program in understanding the principle of chemical equilibrium?

Q_3 What is your level of experience with MATLAB?

Q_4 How good would your understanding be if you were explained only the theory behind the principle of chemical equilibrium?

Q_5 To what extent do you think that computer aided teaching can replace just lecturing?

Q_6 How helpful do you think it would be to apply this computer aided teaching technique to other topics?

The feedback was anonymous and the students were given a week to answer all the questions at home.

Survey Results

Thirteen of the fifteen students enrolled in the class responded to the survey. The responses to the six questions listed in the previous section are shown in Fig. 5. Overall, the students considered the present computer approach to teaching combustion useful. Only one student strongly disagreed with the teaching method, and he marked both questions Q_2 and Q_6 with a score of one. In his comments such a student remarked that he previously took a combustion course at another university, that he understood chemical equilibrium well (the Q_1 score was 4), and that he would have preferred an approach based on an existing graphic user interface (GUI) program (the NASA CEA code[7]); in other words, he deemed modifying an existing program provided to the class by the instructor “frustrating” and “futile”. Based on these and other comments made in person to the instructor, we conclude that having previously being taught the subject with a different approach made him reject our alternative explanation. We also remark that the student has a strong visual and global approach to learning[2], which explains his preference for a GUI computer program. His learning style might interfere with the analytical computational approach to teaching proposed here.

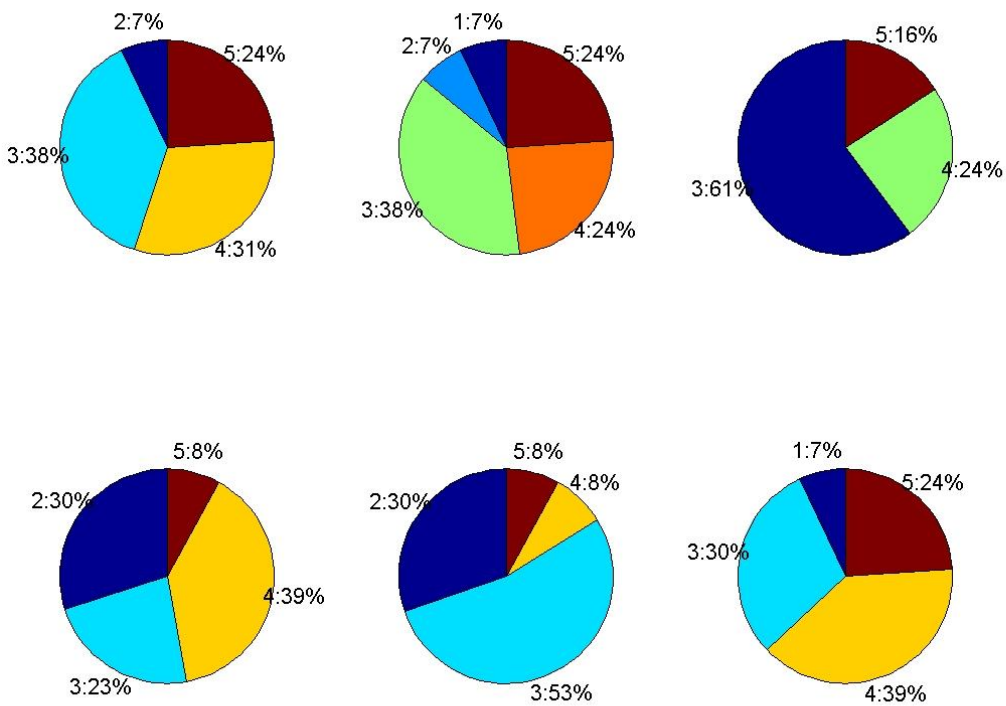

Figure 5. Results of student surveys. The six questions are analyzed independently and displayed in increasing order from left to right, top to bottom. The first number close to each pie segment refers to the score (1 lowest, 5 highest), the second number to the percentage of students agreeing with that score.

The correlation coefficient matrix based on the survey answers is shown in table (3). As expected, questions Q_2 and Q_6 are strongly correlated. Surprisingly, question Q_3 (i.e., MATLAB knowledge) is negatively correlated with both Q_2 and Q_6, which indicates that students with weak prior MATLAB knowledge are willing to learn this language and use it to solve engineering problems. Further, the strong negative correlation between Q_4 and both Q_2 and Q_6

indicates that students thought that the MATLAB approach helped them learning the theory.

Question	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
Q_1	1	0.5	0.24	0.08	0.17	0.22
Q_2	0.5	1	-0.2	-0.44	0.28	0.81
Q_3	0.24	-0.2	1	0.36	-0.06	-0.37
Q_4	0.08	-0.44	0.36	1	0.12	-0.45
Q_5	0.17	0.28	-0.06	0.12	1	0.32
Q_6	0.22	0.81	-0.37	-0.45	0.32	1

Table 3. Correlation coefficient based on the answers to questions Q_1 - Q_6 reported in this section.

Summary and Conclusions

We propose a MATLAB program based on singular value decomposition (SVD) of the stoichiometric matrix to explain the equilibrium composition of high temperature combustion. The teaching of equilibrium should focus on two aspects 1) that it is a purely thermodynamic rather than kinetic principle 2) that it represents a detailed rather than global balance. The proposed formulation accomplishes these objectives by eliminating reaction paths, and reducing the degrees of freedom of the system to the vector basis spanning the nullspace of the stoichiometric matrix: detailed balance implies maximization of entropy over these degrees of freedom.

The proposed use of SVD to impose the atom conservation constraints and to reduce the size of the unknown (search) manifold leads to a simple implementation that involves only matrix-vector products, suitable for engineering education.

From the evaluation of the student feedback, we found that 48% of the students found the computer aided teaching either helpful or very helpful. A follow-up test proved that the students had understood the concept well. Regardless of their previous experience with MATLAB, a majority of students found it easy to understand a provided code and modify it towards learning the chemical equilibrium principle. Hence, we conclude that the use of computer technology as an aid to traditional teaching methods can help the students understand concepts more easily and remember them for a longer time.

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Behavior of Internal Energy and Enthalpy of Fluids Along Isotherms and Isentropic Lines in the Compressed Liquid Region

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Abstract

It is a common practice to approximate the thermodynamics properties of fluids in the compressed liquid regions from their saturation properties at the given temperature. Most thermodynamics textbooks state that the specific volume, specific internal energy, and specific entropy in the compressed liquid region are functions of temperature only and are independent of pressure. Recent examination of current practice in approximating compressed liquid properties has shown that the specific internal energy of fluids exhibits growing dependency on pressure with increases in temperature. Analysis was done to show that the effect of pressure on specific internal energy and specific enthalpy is much less pronounced along the isentropic lines than those along the isotherms. The behavior of specific internal energy and specific enthalpy for four compressed fluids along isothermal and isentropic lines were compared. The four fluids (water, ammonia, methane, and propane) were examined at subcritical temperatures and pressures ranging from saturation values to five times their critical pressures. Analysis showed that using the saturation properties at the given specific entropy as opposed to temperature is more accurate in approximating the specific internal energy for a fluid in the compressed liquid region. Moreover using the saturated properties for specific internal energy and specific volume at the given entropy, the specific entropy can be more accurately approximated. The behaviors of specific internal energy and specific internal energy along isotherms and isentropic lines are examined for water ammonia, methane, and propane in the compressed liquid region. It is shown that the effect of pressure on the internal energy of the compressed liquid is much greater along isotherms than those along isentropic lines.

Introduction

Thermodynamic properties of fluids in the compressed liquid region are usually approximated from the saturated liquid properties. In most thermodynamics textbooks [1-9] it is assumed that specific volume, specific internal energy, and specific entropy of fluids in the compressed liquid region are functions of temperature only and pressure effects are negligible. Therefore, the following expressions are presented in the textbooks to approximate these properties at a given temperature and pressure.

$$v(T,p) \cong v_f(T) \tag{1}$$

$$u(T,p) \cong u_f(T) \tag{2}$$

$$s(T,p) \cong s_f(T) \tag{3}$$

where, v, u, and s are specific volume, specific internal energy, and specific entropy, respectively, and the subscript, f, denotes saturated liquid properties.

The following equation is also given in the thermodynamics textbooks [1-9] for the approximation of specific enthalpy in the compressed liquid region

$$h_{app}(T,p) = h_f(T) + v_f(T)[p - p_{sat}(T)] \tag{4}$$

The second term in the right hand side of Eq. (4) represents the effect of pressure on the specific enthalpy in the compressed liquid region and its deviation from the saturation state due to pressure increase along an isotherm. Therefore the second term in the right hand side of Eq. (4) represents the correction factor. Usually this correction factor is very small and can be neglected, unless the pressure, p, is much larger than the saturation pressure, p_{sat}. For example for water in the range of temperatures between 50 ^oC and 325 ^oC, the error in approximation of h (T, p) by h_f (T) is less than 5% as long as ($p-p_{sat}$) is less than 10 MPa. Therefore, in many practical applications the specific enthalpy in the compressed liquid region can be approximated simply by

$$h_{app,f}(T,p) \approx h_f(T) \tag{4a}$$

Equation (4) is based on the following consideration [10-12]. Enthalpy is defined as

$$h \equiv u + p\,v \tag{5}$$

and in a differential format

$$dh \equiv du + pdv + vdp \tag{6}$$

Integrating Eq. (6) along an isotherm from saturation pressure to a given pressure results in the following relationship:

$$\int_{h_f}^{h(p)} dh)_T = \int_{u_f}^{u(p)} du)_T + \int_{v_f}^{v(p)} pdv)_T + \int_{P_{sat}}^{P} vdp)_T \tag{7}$$

Or

$$h(T,p) = h_f(T) + u(T,P) - u_f(T) + \int_{v_f}^{v(p)} pdv)_T + \int_{P_{sat}}^{P} vdp)_T \tag{8}$$

Approximations of specific volume and specific internal energy by Eqs. (1) and (2) suggest that:

$$\int_{u_f}^{u(p)} du)_T = \int_{v_f}^{v(p)} p dv)_T = 0 \quad \text{and} \quad v(T,p) \cong v_f(T)$$

Therefore, Eq. (7) reduces to

$$\int_{h_f}^{h(p)} dh)_T = v_f \int_{P_{sat}}^{P} dp)_T \tag{9}$$

Integration of Eq. (9) and the rearrangement of terms will result in Eq. (4). The second term on the right hand side of the Eq. (4) represents the correction to h_f (T), considering the effect of the pressure.

Kostic [13, 14] demonstrated that for sub-cooled water, the pressure correction term in Eq. (4) improves the accuracy of the approximation only at low temperatures, but contributes to larger errors at high temperatures and pressures. He also showed that the correction term is not necessary at intermediate pressures and temperatures. In fact he has shown that adding the correction term results in larger errors. Kostic [14] showed that for water at 4 ^oC and 100 MPa, the error in approximation of h (T, p) by Eq. (4a) is as high as 85% while the error reduces to5.2% if h(T, p) is approximated by Eq. (4). It was shown that the error in approximation of h (T, p) of water at 150 ^oC and 100 MPa by Eqs. (4) and (4a) were 6.1% and 9.4%, respectively. At temperatures above 200 ^oC, it was shown that the approximation of h (T, p) by Eq. (4a) is more accurate than the one approximated by Eq. (4). For example for water at 300 ^oC and 100 MPa, the error in approximation of h(T, p) by Eq. (4) is 10.9% while using Eq. (4a) for approximation, the error reduces to 1.2 %.

A reproduction of the data points presented by Kostic [13, 14] is shown in Table 1, displaying the enthalpy and internal energy of water at 260 ˚C. The first row below the table heading (where pressure is equal to 4.688 MPa) represents the saturated liquid properties. The headings in Table 1 are defined by the following relations:

$$\Delta u = u(T,p) - u_f(T) \tag{10}$$

$$v_f \Delta p = v_f(T)[p - p_{sat}(T)] \tag{11}$$

$$\Delta h_f = h(T,p) - h_f(T) \tag{12}$$

$$\Delta h_{app} = h(T,p) - h_{app}(T,p) \tag{13}$$

where, h_{app} is the approximation of h (T, p) by Eq. (4).

Table 1 shows that along the 260 ˚C isotherm, the approximations of enthalpy by Eq. (4a), h(T, p) = h_f(T), are more accurate than those obtained from Eq. (4). For example, at 50 MPa, h(T, p) – h_f(T) = 3.8 kJ/kg (0.3% error) while h(T, p) – h_{app} = -52.4 kJ/kg (4.6% error). It also shows that internal energy, u(T, p), of liquid water at 260 ˚C varies with pressure. For example u_f at 260 ^oC is equal to 1128.4 kJ/kg. However, the value of u at 260 ^oC and 50 MPa is 1078.1 kJ/kg. These results suggest that at 260 ^oC, pressure has a greater influence on the internal energy than the enthalpy of fluid in the compressed liquid region.

Table 1 Specific volume, internal energy, and enthalpy of liquid water at 260 ^oC. Saturated liquid properties are highlighted

p	h (T, p)	Δh_f	h_{app}	Δh_{app}	v(T, p)	u(T, p)	Δu	$v_f \Delta p$
[MPa]	[kJ/kg]				[m^3/kg]	[kJ/kg]		
4.688	1134.4	0.0	1134.4	0.0	0.00128	1128.4	0.0	0.0
5	1134.3	-0.1	1134.8	-0.5	0.00127	1127.9	-0.5	0.4
10	1133.7	-0.7	1141.1	-7.4	0.00126	1121.1	-7.3	6.7
15	1133.4	-1.0	1147.4	-14.0	0.00126	1114.6	-13.8	13.0
20	1133.5	-0.9	1153.7	-20.2	0.00125	1108.6	-19.8	19.3
30	1134.3	-0.1	1166.1	-31.8	0.00123	1097.4	-31.0	31.7
50	1138.2	3.8	1190.6	-52.4	0.0012	1078.1	-50.3	56.2

*Δh_f, Δh_{app}, Δu, and $v_f\, \Delta P$ are defined by Eqs. (10) through (13)

With Kostic's observation report on compressed liquid water, subsequent investigations [10-12] were conducted to further examine the behavior of other substances in the compressed liquid region. The studies in [10-12] examined the behavior of properties of ammonia, propane, methane, R134a, and R-22 in the compressed liquid region. In these studies the fluid property behaviors in the compressed liquid were similar to those for water. The studies showed that, along isotherms, the dependency of internal energy on pressure cannot be ignored in compressed liquid. The data presented in these studies revealed that with the increasing temperatures towards the critical point, the error in approximation of v, u, s, and h by Eqs. (1), (2), (3), and (4), respectively, increase. Table 2 shows the percentage errors in approximation of properties by Eqs. (1) through (4) at highest temperature and pressures of fluids examined in [10-12]

Table 2 Percentage error in approximation of properties by Eqs. (1) through (4)

Fluid	**T, ^{o}C**	**P, Mpa**	**Error in v_{app}**	**Error in u_{app}**	**Error in h_{app}**	**Error in s_{app}**
Ammonia	30	100	11.%	21%	18%	18%
Propane	20	21	8%	12%	11%	9%
Methane	-135	10	4%	17%	14%	16%
R-134-a	50	70	23%	14%	16%	10%
R-22	30	60	16%	13%	14%	10%

The results in Table 2 suggest that one must be cautious in using Eqs. (1) through (4) for the approximation of properties in the compressed liquid region at higher temperatures. In general, the data in [10-12] showed that along an isotherm, the values of v, u, and s decrease with increasing pressures. At low temperatures close to the triple point the errors in approximated properties are less than 2% in the range of pressures from saturation point to five times the critical pressure. Therefore, Eqs. (1), (2), (3), and (4), produce good approximation results only at lower temperatures close to triple point temperatures.
In an example in an earlier study [12] it was shown that with increasing temperature and pressure, the first term and the last term on the right hand side of Eq. (7) cannot be ignored. The

example considered water at 200 ^oC and 100 MPa, where the actual value of h (T, p) = 903.40 kJ/kg. At the given temperature and pressure the following values were used to evaluate each term on the right hand side of Eq. (8): v (T, P) = 0.0010826 m^3/kg, u (T, p) = 795.14 kJ, h_f (T) = 852.27 kJ/kg, v_f (T) = 0.0011565 m^3/kg, and h_f (T) = 850.47 kJ/kg. The results of calculation for each term on the right hand side of Eq. (7) are presented below.

$$\int_{u_f}^{u(p)} du)_T = u(T,p) - u_f(T) = -55.33, kJ/kg,$$

$$\int_{v_f}^{v(p)} pdv)_T \approx p_{ave}[v(T,p) - v(T)] \approx -3.75, kJ/kg,$$

$$\int_{p_{sat}}^{p} vdp)_T \approx v_{ave}[p - p_{sat}] \approx 110.21, kJ/kg,$$

where, p_{ave} is the linear average value of p and p_{sat}. Substituting values in Eq. (8) yields the following results.

$$h(T,p) = 852.27 - 55.33 - 3.75 + 110.21 = 903.4, kJ/kg$$

The resulting value is the same as the actual value of h at 200 ^oC and 100 MPa. .

The results in the above example shows that $\left. \lfloor u(p,T) - u_f(T) \rfloor \right|_T \prec 0$, and at the given temperature and pressure the magnitude of change in internal energy is large enough that its value cannot be ignored in the approximation equations. Also, it is clear that $\int_{v_f}^{v(p)} pdv)_T \prec 0$, because v decreases with the increasing pressure and $\int_{P_{sat}}^{P} vdp)_T \succ 0$. This example demonstrated that at the given temperature, u (T, p) is not only a function of temperature since the value of [u (T, p) – u_f (T)] is significant enough that pressure effects cannot be ignored.

In another example in the earlier study [12], it was shown that for water in the compressed liquid region, the pressure has smaller affect on the values of u and v along the isentropic lines than those along isotherms. The example again considered water at 200 ^oC and 100 MPa. The approximations of v (T, p) and u (T, p), using Eqs. (2) and (3) resulted in 6.83% and 6.96% errors, respectively. At T = 200 ^oC, s_f (T) = 2.3305 kJ/kg.K, v_f (s) = 0.0011565 m^3/kg, and u_f (s) = 850.47 kJ/kg. At p = 100 MPa and s = s_f (T) = 2.3305 kJ/kg.K T (s, p) = 214.3 ^oC, v (s, p) = 0.001098 m^3/kg, and u(s, p) = 853.22 kJ/kg. In this example, the deviations of v (s, p) and u (s, p) from their saturation properties along the isentropic line of s = 2.3305 kJ/kg.K are5.3 % and 0.3%, respectively. These deviations are lower than those evaluated earlier for the 200 ^oC isotherm. This is especially true for the specific internal energy, u. Based on this example, it was suggested that in the compressed liquid region, the influence of pressure along an isentropic line on specific internal energy is less than that along an isothermal line. Therefore, it was suggested that the following expression is more accurate in approximating the internal energy of fluids in the compressed liquid region than that obtained from Eq. (2).

$$u(s,p) \cong u_f(s) \quad (14)$$

The specific enthalpy is defined by Eq. (5). Since the specific internal energy in the compressed liquid region can be approximated accurately by Eq. (14), then specific enthalpy along an isentropic line can be approximated using the following relationship

$$h(s,p) \cong u_f(s) + p v_f(s) \quad (15)$$

This paper examines the validity of the arguments presented above to show that the effect of pressure on internal energy and enthalpy is much less pronounced along the isentropic lines than those along the isotherms.

Comparison of the Behavior of Specific Internal Energy an Enthalpy in the Compressed Liquid Region

The behavior of the internal energy and enthalpy of water, ammonia, methane, and propane in the compressed liquid region are examined in this section. The examination includes the comparison of the behavior of these properties along isotherms and isentropic lines for subcritical temperatures and pressures ranging from saturation to five times critical pressures. The results provide valuable insight to initiate a more accurate approximation of internal energy and enthalpy in the compressed liquid region.

The current approximation of internal energy and enthalpy along isotherms are achieved through the application of Eqs. (2) and (4), respectively. To examine the behavior of these properties one might consider the following fundamental thermodynamic relations.

$$du = Tds - Pdv \quad (16)$$

and

$$dh = Tds + vdP \quad (17)$$

Integrating Eqs. (16) and (17) along isentropic lines from the saturation state to a given state in the compressed liquid region, results in the following relationships.

$$u(s,p) = u_f(s) - \int_{v_f}^{v} Pdv \Big)_s \quad (18)$$

and

$$h(s,p) = h_f(s) + \int_{P_{sat}}^{P} vdp \Big)_s \quad (19)$$

Assuming constant specific volume, Eq. (19) reduces to

$$h(s,P) = h_f(s) + v_f \left[P - P_{sat}\right]_s \quad (20)$$

The National Institute of Standards and Technology (NIST) Thermophysical Properties Software [15, 16] was used to generate property values for v (T, p), u (T, p), s (T, p), and h (T, p). The NIST website provides a thermodynamic property databases for a wide range of substances, covering 74 different fluids. The program uses equations for the thermodynamic and transport properties to calculate the state points of the fluid or mixture.

Behavior of Specific Internal Energy

For several isotherms, the departures of specific internal energy of compressed liquid water from their saturated states are plotted versus ($P-P_{sat}$) in Fig. 1. The figure indicates that for water, the absolute values of [u (T, P) - u_f(T)] increase with rising pressures and temperatures. The deviation exceeds 150 kJ/kg for temperatures above 325 ^{o}C and pressures greater 100 MPa. Similarly, departures of specific internal energy of compressed liquid water from their saturation states along isentropic lines are plotted in Fig. 2. Table 3 lists the saturation temperatures corresponding to the values of constant entropy lines shown in Fig. 2. A comparison of the deviations presented in Figs. 1 and 2 indicate much smaller deviations along isentropic lines than those along the isotherms. The figures show that the absolute deviations along isotherms are larger than 150 kJ/kg at high temperatures and pressures, while deviations along isentropic lines are always lower than 10 kJ/kg. The second term on the right hand side of Eq. (16) represents the deviations presented in Fig. 2. Figures 1 and 2 really compare the accuracy of approximation of specific internal energy in the compressed liquid region, using Eq. (2) and Eq. (15), respectively.

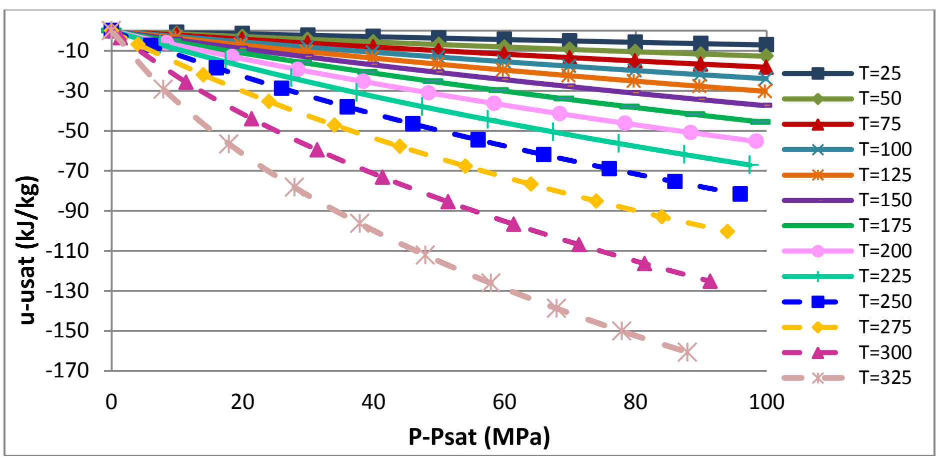

Fig. 1 Departure of specific internal energy from the saturation state along isotherms, water in the compressed liquid region.

The accuracies of the approximations of u (T, P) of compressed liquid water by Eq. (2) are displayed in Fig. 3. In the range of pressures and temperatures presented, Fig. 3 shows that the percentage errors in the approximations of u (T, P) by Eq. (2) are less than 13%. The accuracy of the prediction of u(s, P) from Eq. (14) for water in the compressed liquid region is shown in Fig. 4. The figure shows that error in approximation of internal energy by Eq. (14) is less than 1.6 % for water in the compressed liquid region. This supports the argument that second term in the right hand side of Eq. (18) can be ignored. The reason for this is that the change in specific volume is negligible and hence $\int_{v_f}^{v} P dv$ can be ignored in the approximation of u (s, P).

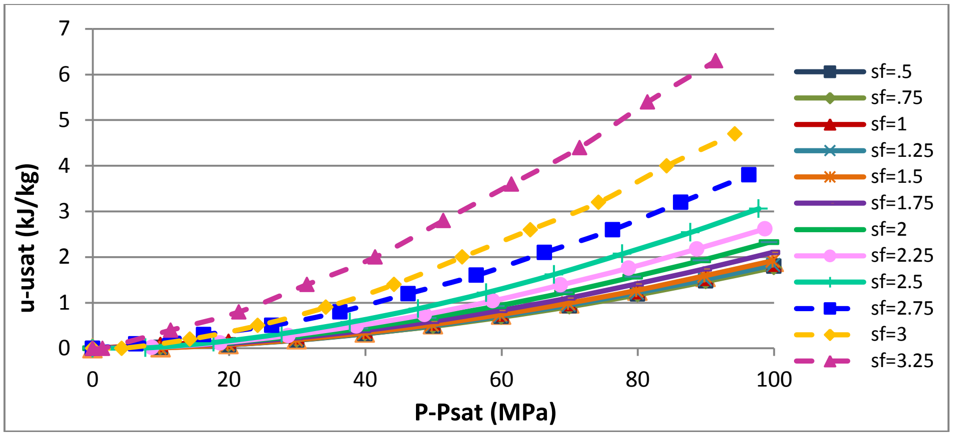

Fig. 2 Departure of specific internal energy from the saturation state along isentropic lines, water in the compressed liquid region.

Table 3 Relationship between temperature and entropy of saturated liquid water.

s, kJ/kg.K	T_{sat}, °C	s, kJ/kg.K	T_{sat}, °C
0.5	34.6	2.0	165.8
0.75	53.6	2.25	191.5
1.0	73.7	2.5	218.1
1.25	95.0	2.75	245.2
1.50	117.4	3.0	272.6
1.75	141.0	3.25	299.5

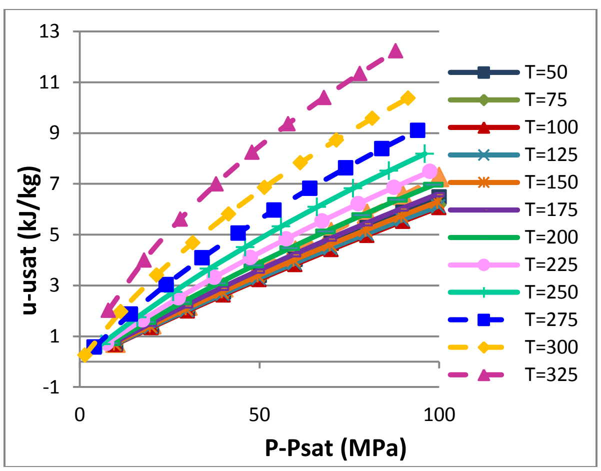

Fig. 3 Accuracy of the approximation of u (T, P) from Eq. (2) for water in the compressed liquid region.

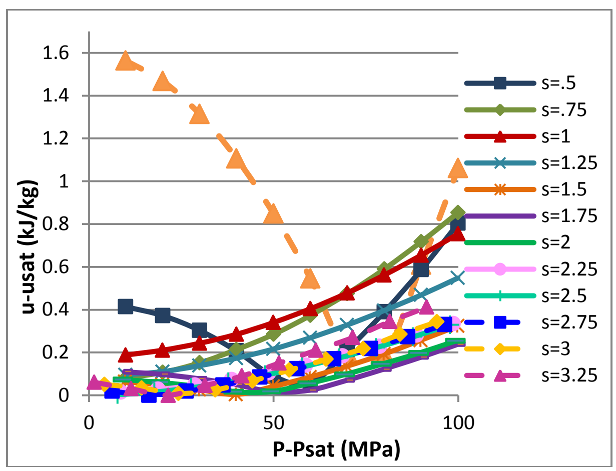

Fig. 4 Accuracy of the approximation of u(s,p) from Eq. (15) for water in the compressed liquid region.

Specific internal energy departures of compressed liquid ammonia from their saturated states are plotted versus ($P-P_{sat}$) in Fig. 5 for several isotherms ranging from -50 °C to 75 °C. For each temperature, the pressure variation is between the saturation pressure and 60 MPa. Similar to water, Fig. 5 indicates that deviation of the actual values of u (T, P) from u_f (T) increases with increasing pressures and temperatures. Similarly, the departures of specific internal energy from the saturated liquid states along isentropic lines are plotted in Fig. 6. Table 4 provides the corresponding values of saturation temperatures for the isentropic lines shown in Fig. 6. A comparison of Figs. 5 and 6 indicates that deviations of specific internal energy along isentropic lines are much less than those along the isotherms. Figure 5 shows that the deviations of internal energy from their saturation state exceed 90 kJ/kg for temperatures above 75 ^{o}C and pressures above 60 MPa, while Fig. 6 shows that deviations along isentropic lines are less than 7 kJ/kg at temperature less than 96 ^{o}C and pressures less than 60 MPa.

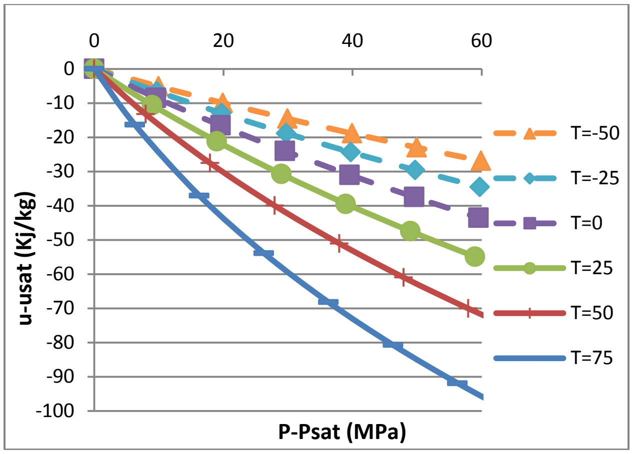

Fig. 5 Departure of specific internal energy from the saturation state along isotherms, ammonia in the compressed liquid region.

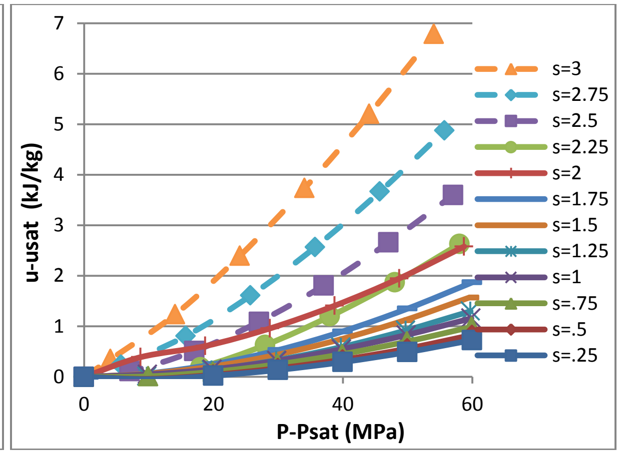

Fig. 6 Departure of specific internal energy from the saturation state along isentropic lines, ammonia in the compressed liquid region.

Table 4 Relationship between temperature and entropy of saturated liquid ammonia.

s, kJ/kg.K	T_{sat}, ^{o}C	s, kJ/kg.K	T_{sat}, ^{o}C
0.25	-65.8	1.75	16.9
0.5	-53.4	2.0	32.5
0.75	-40.44	2.25	48.7
1.0	-27.0	2.5	65.0
1.25	-12.9	2.75	81.2
1.50	1.70	3.0	96.9

A comparison of the figures 5 and 6 indicate that deviations of internal energy in the compressed liquid region from its saturated liquid states are much smaller along isentropic lines than those along the isotherms. For the same range of pressures, the maximum deviations along isentropic lines are less than 7 kJ/kg as compared to 100 kJ/kg along isotherms.

Figure 7 exhibits the accuracy of the approximation of u (T, P) for compressed liquid ammonia by Eq. (2). It shows that for the given range of pressures and temperatures, the percentage errors in the approximation of u (T, P) from Eq. (2) are less than 30%. The accuracy of the approximating internal energy of ammonia in the compressed liquid region by using Eq. (14) is shown in Fig. 8, which shows that error in approximation of internal energy from Eq. (14) is less than 1.5 % in the given ranges of temperatures and pressures.

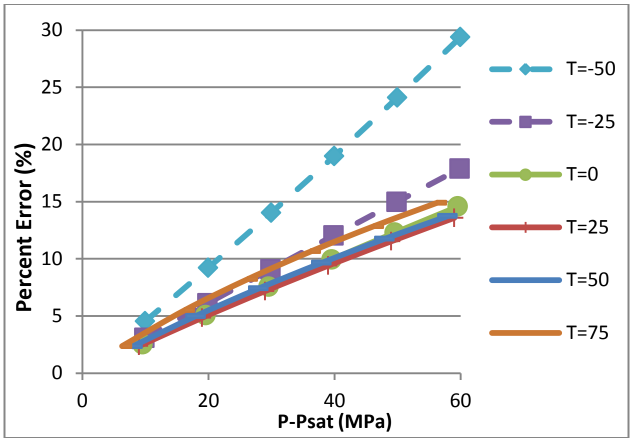

Fig. 7 Accuracy of the approximation of u (T, P) from Eq. (2) for ammonia in the compressed liquid region.

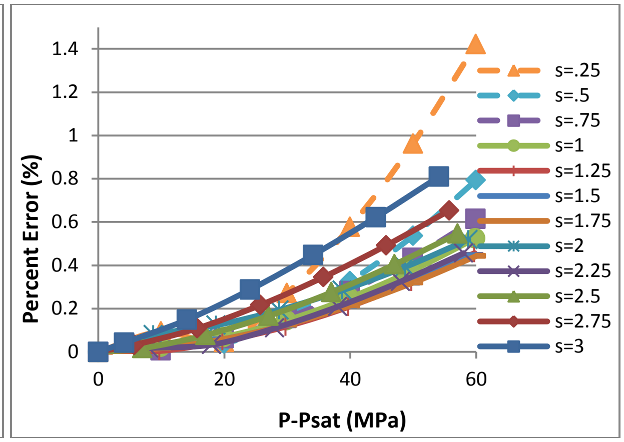

Fig. 8 Accuracy of the approximation of u (s, P) from Eq. (15) for ammonia in the compressed liquid region.

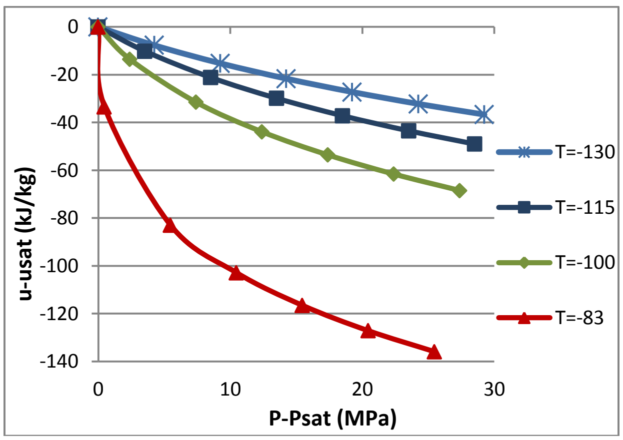

Fig. 9 Departure of specific internal energy from the saturation state along isotherms, methane in the compressed liquid region.

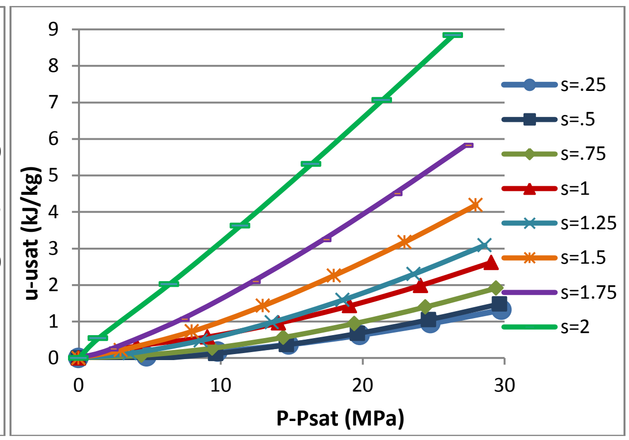

Fig. 10 Departure of specific internal energy from the saturation state along isentropic lines, methane in the compressed liquid region.

For several isotherms ranging from -130 ^{o}C to -83 ^{o}C, specific internal energy departures of compressed liquid methane from their saturated states are plotted versus ($P-P_{sat}$) in Fig. 9. For each temperature, the pressure variation is between the saturation pressure and 30 MPa. Similar to water and ammonia, Fig. 9 shows that absolute deviation of u (T, P) from u_f (T) increases with increasing pressures and temperatures. Similarly, the departures of specific internal energy from theirs saturated liquid states along isentropic lines are plotted in Fig. 10. Table 5 provides the corresponding values of saturation temperatures for the isentropic lines shown in Fig. 10. A comparison of Figs. 9 and 10 indicates that deviations of specific internal energy along isentropic lines are much less than those along the isotherms. Figure 9 shows that the absolute deviations of internal energy from their saturation state exceed 140 kJ/kg for temperatures above -83 ^{o}C and pressures above 20 MPa, while Fig. 10 shows that deviations along isentropic lines are less than 9 kJ/kg at temperature less than -90 ^{o}C and pressures less than 30 MPa.

Table 5 Relationship between temperature and entropy of saturated liquid methane.

s, kJ/kg.K	T_{sat}, °C	s, kJ/kg.K	T_{sat}, °C
0.25	-153.2	1.25	-116.5
0.5	-144.5	1.50	-107.0
0.75	-136.4	1.75	-98.0
1.0	-126.1	2.0	-90.2

Figure 11 exhibits the accuracy of the approximation of u (T, P) for compressed liquid methane by Eq. (2). It shows that for the given range of pressures and temperatures, the percentage errors in the approximation of u (T, P) from Eq. (2) are less than 62%. The accuracy of the approximating internal energy of methane in the compressed liquid region by using Eq. (14) is shown in Fig. 12, which shows that error in approximation of internal energy from Eq. (14) is less than 3 % in the given ranges of temperatures and pressures.

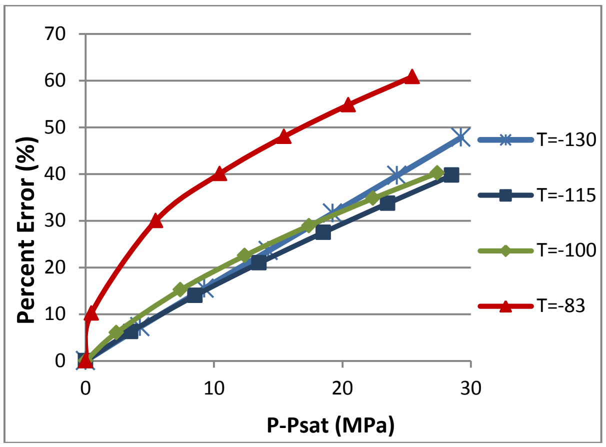

Fig. 11 Accuracy of the approximation of u (T, p) from Eq. (2) for methane in the compressed liquid region.

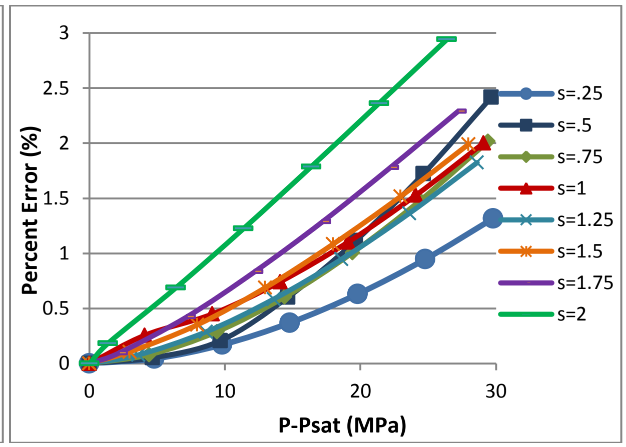

Fig. 12 Accuracy of the approximation of u (s, p) from Eq. (15) for methane in the compressed liquid region.

Specific internal energy departures of compressed liquid propane from their saturated states are plotted versus ($P-P_{sat}$) in Fig. 13 for several isotherms ranging from -160 °C to 80 °C. For each temperature, the pressure variation is between the saturation pressure and 30 MPa. Similar to previous three fluids, Fig. 13 shows that the absolute deviation of u (T, P) from u_f (T) increases with rising pressures and temperatures. Similarly, the departures of specific internal energy from the saturated liquid states along isentropic lines are plotted in Fig. 14. Table 6 provides the corresponding values of saturation temperatures for the isentropic lines shown in Fig. 14. A comparison of Figs. 13 and 14 indicates that deviations of specific internal energy along isentropic lines are much less than those along the isotherms. Figure 13 shows that the deviations of internal energy from their saturation state exceed 60 kJ/kg for temperatures above 80 °C and pressures above 25 MPa, while Fig. 14 shows that deviations along isentropic lines are less than 7 kJ/kg at temperature less than 80 °C and pressures less than 30 MPa.

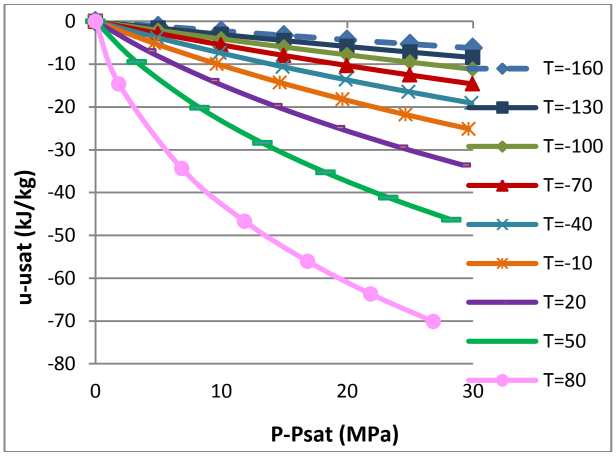

Fig. 13 Departure of specific internal energy from the saturation state along isotherms, propane in the compressed liquid region.

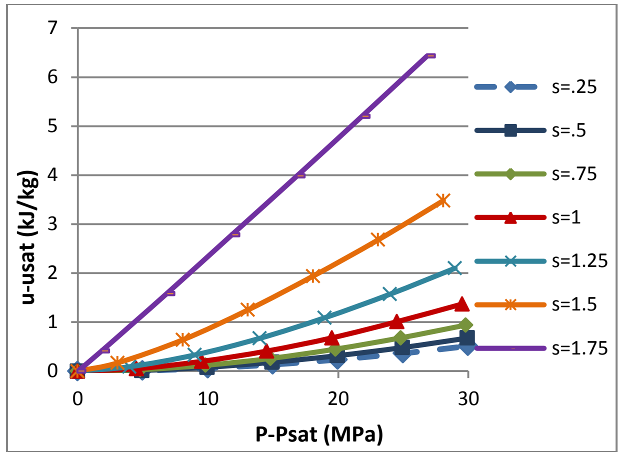

Fig. 14 Departure of specific internal energy from the saturation state along isentropic lines, propane in the compressed liquid region.

Table 6 Relationship between temperature and entropy of saturated liquid propane.

s, kJ/kg.K	T_{sat}, ^{o}C	s, kJ/kg.K	T_{sat}, ^{o}C
0.25	-77.1	1.25	27.8
0.5	-53.0	1.50	55.4
0.75	-27.1	1.75	80.8
1.0	0	2	96.5

Figure 15 shows the accuracy of the approximation of u (T, P) for compressed liquid propane by Eq. (2). It shows that for the given range of pressures and temperatures, the percentage errors in the approximation of u (T, P) from Eq. (2) are less than 60%. The accuracy of the approximating internal energy of propane in the compressed liquid region by using Eq. (14) is shown in Fig. 16, which shows that error in approximation of internal energy from Eq. (14) is less than 2.2 % in the given ranges of temperatures and pressures.

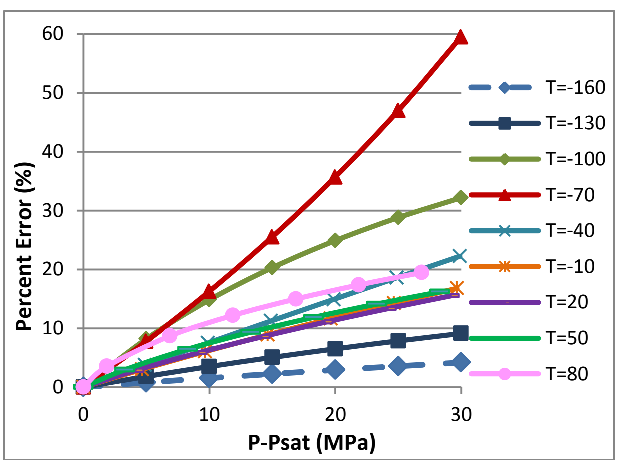

Fig. 15 Accuracy of the approximation of u (T, P) from Eq. (2) for propane in the compressed liquid region.

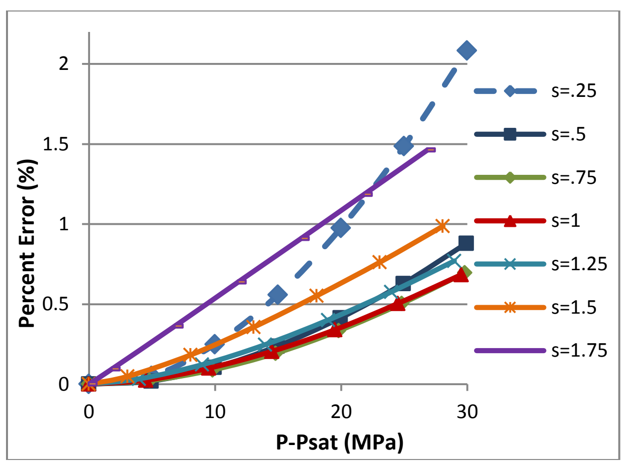

Fig. 16 Accuracy of the approximation of u (s, p) from Eq. (15) for propane in the compressed liquid region.

Behavior of Specific Enthalpy

For several isotherms, ranging between 50 ^oC and 325 ^oC, specific enthalpy departures of compressed liquid water from their saturated states are plotted versus ($P-P_{sat}$) in Fig. 17. The figure shows that for water at low temperature, the deviation of h(T, P) from $h_f(T)$ increases with rising pressures. Therefore, it makes sense that at low temperatures, the correction term in the right hand side of Eq.(4) improves the accuracy of the approximation. The lines representing specific enthalpy at low temperatures display a linear behavior along each isotherm. Equation (4) also represents a linear function. However with the increasing temperatures, the deviations of h (T, P) from h_f (T) become smaller. Figure 17 shows that at some temperature between 250 ^oC and 300 ^oC the slope of the curves changes from positive to negative. For temperatures above 275 ^oC, Fig. 17 shows that with the increasing presure, the specific enthalpy first decreses, reaches a minium value, and then increases. Therefore, while the specific enthlpy decreases with the increaing pressure, the correction term in Eq. (4) will increase the error of approximation, instead of improving it.

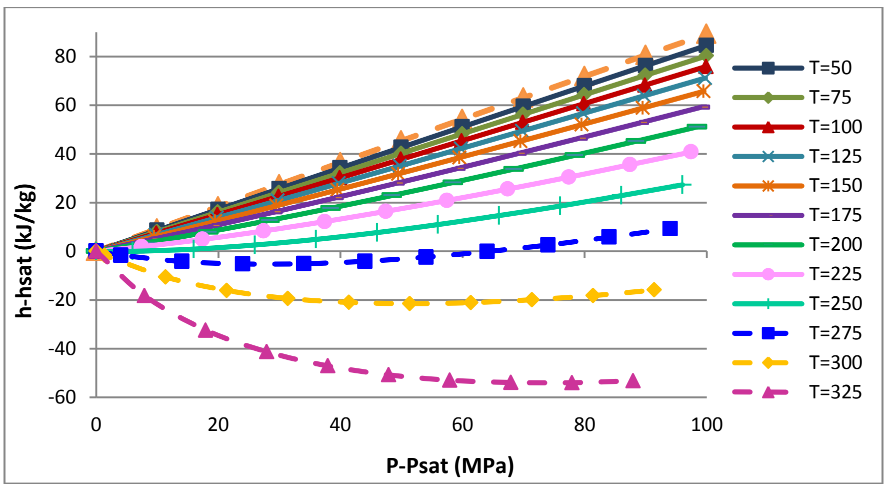

Fig. 17 Departure of specific enthalpy from the saturation state along isotherms, water in the compressed liquid region.

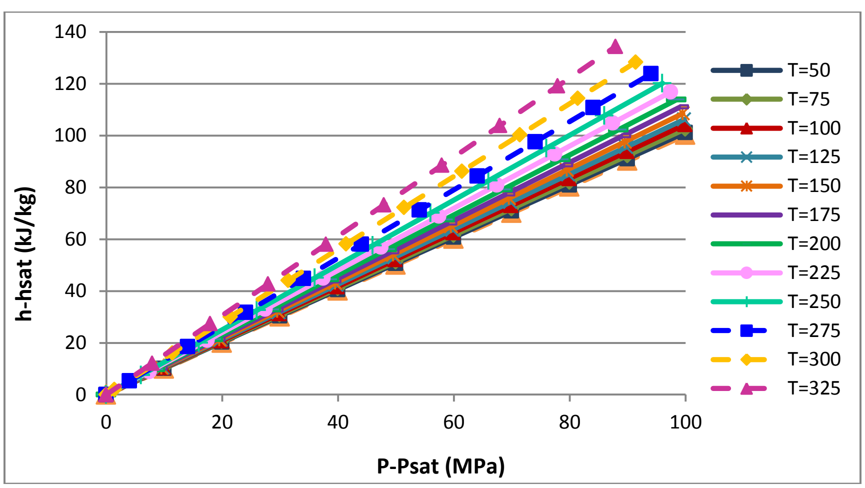

Fig. 18 Departure of specific enthalpy from the saturation state along isotherms based on Eq. (4), water in the compressed liquid region.

Figure 18 shows the departures of h_{app} (T, P) from h_f (T), as calculated from Eq. (4), for water in the compressed liquid region. In other words, Fig. 18 presents the calculated values of second term in the right hand side of Eq. (4). By comparing Figs. 17 and 18, it can be seen that the behavior of enthalpy departure curves are similar only at low temperatures. These figures confirm the impracticality of Eq. (4) for the approximation of the enthalpy of water in the compressed liquid region, especially at high temperatures and pressures.

For water in the compressed liquid region, departures of specific enthalpy from the saturation states along isentropic lines are displayed in Fig. 19 as functions of (p- p_{sat}). The relationship between the entropies presented in Fig. 19 and saturation temperatures were presented earlier in Table 3. Approximations of specific enthalpy of compressed liquid water by Eq. (15) and Eq. (20) practically yield exactly the same values. Departures of specific enthalpy of compressed liquid water from their saturated state, calculated using Eqs. (15) and (20) are plotted in Fig. 20 versus (p – p_{sat}). Figures 19 and 20 display very similar behaviors and very close values.

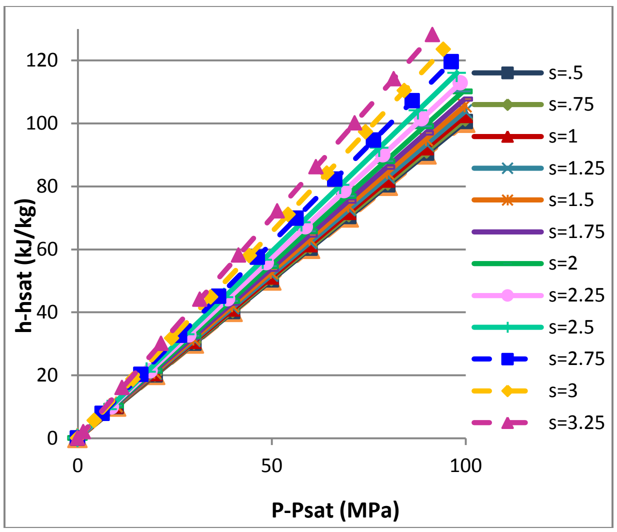

Fig. 19 Departure of specific enthalpy from the saturation state along isentropic lines, water in the compressed liquid region.

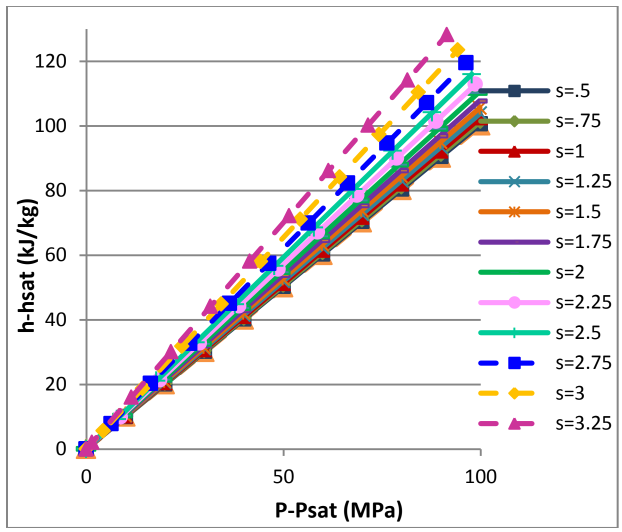

Fig. 20 Departure of specific enthalpy from the saturation state along isentropic lines, based on approximation Eqs. (15) and (20), water in the compressed liquid region.

The accuracies of Eqs. (4), (4a), (15), and (20) in approximating the specific enthalpy of water in the compressed liquid region are presented in Figs. 21 through 24. Figure 21 shows the accuracy of Eq. (4a) for the approximation of h (T, P) of water in the compressed liquid region. This figure shows that Eq. (4a) is reasonably accurate for the approximation of enthaly of compressed liquid water only if the pressures are close to saturation state or temperatures in the range of 200-325 ^{o}C. The accuracey of the approximation equation sharply decreases with the rising pressures at low temperatures. The approximation error can reach a value of 45% for the range of temperatures and pressures presented in Fig. 21.

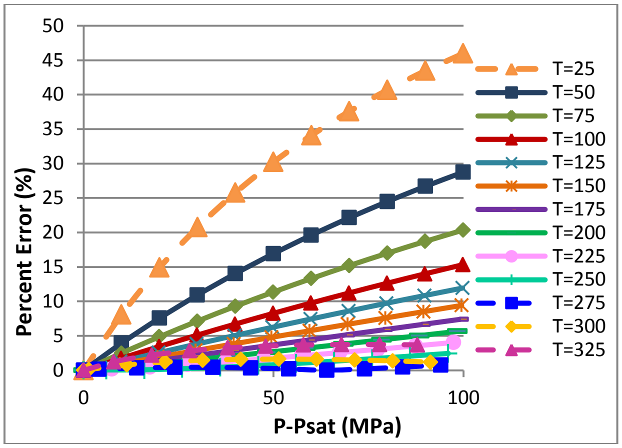

Fig. 21 Accuracy of Eq. (4a) for the approximation of specific enthalpy of water in the compressed liquid region.

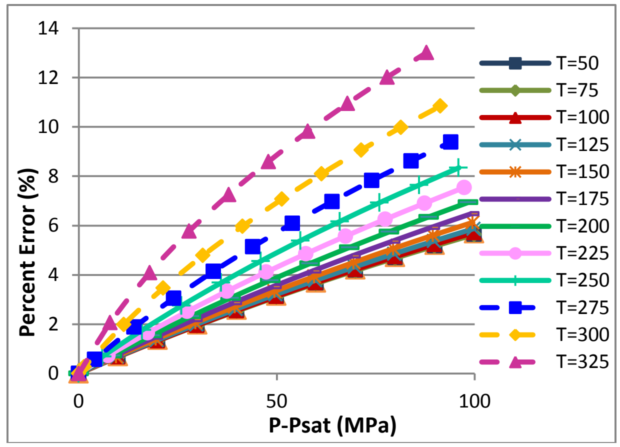

Fig. 22 Accuracy of Eq. (4) for the approximation of specific enthalpy of water in the compressed liquid region.

Figure 22 shows the accuracy of the Eq. (4) in the approximation of enthalpy of water in the compressed liquid region. This figure shows that the correction term in the right hand side of Eq.(4) makes contribution to the accuracey of approximations of enthlpy only at low temperatures. A compresson of the percentage error figures shown in Figs. 21 and 22 verifies the earlier studies that the correction term in Eq. (4) increases the error of approximation for temperatures exceeding 200 ^{o}C.

The acurracy of Eq. (15) in predicting the enthalpy of the water in the compressed liquid region is presented in Fig. 23. The figure shows that Eq. (15) can approximate the entalpy of water in the compressed liquid region quite accurately in a wide range of pressures an temperatures. The figure shows the error in approximation of enthalpy of compressed liquid water by Eq. (15) is less than 1.4 % in a wide range of pressures and temperatures. Figure 24 shows the accuracy of Eq. (20) in approximating the enthalpy of compressed liquid water. Figures 23 and 24 indicate that both Eq. (15) and Eq. (20) are quite accurare in approximating the specific enthalpy of compressed liquid water and the accuracies of both equations are very similar.

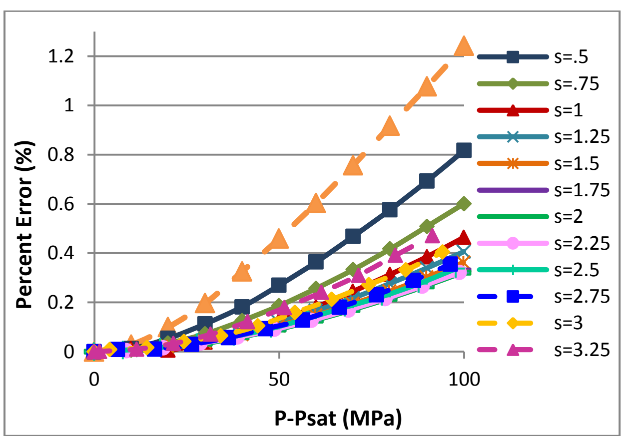

Fig. 23 Accuracy of Eq. (15) for the approximation of specific enthalpy of water in the compressed liquid region.

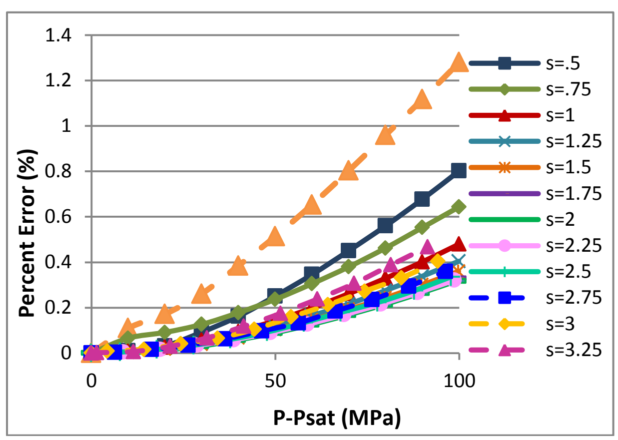

Fig. 24 Accuracy of Eq. (20) for the approximation of specific enthalpy of water in the compressed liquid region.

For several isotherms, ranging between -50 ^{o}C and 75 ^{o}C, the departures of specific enthalpy of compressed liquid ammonia from their saturated states are plotted versus (P-P_{sat}) in Fig. 25. Similar to compressed liquid water, the figure shows that for ammonia at low temperatures, the deviation of h (T, P) from h_f (T) increases with rising pressures and the lines representing specific enthalpy display a linear behavior along each isotherm. Hence, the correction term in the right hand side of Eq.(4) improves the accuracy of the approximation. Again with the increasing temperatures, Fig. 25 shows that the deviations of h (T, P) from h_f (T) become smaller and the isothermal lines display non linear behavior. Figure 25 indicates that at temperatures near and above 75 ^{o}C, the specific enthalpy departures first decreses with the increasing presures, reache a minium value, and then increases. Therefore, while the specific enthlpy drops to values below the sturation property with the increaing pressure, the correction term in Eq. (4) will add positive values to the saturation propertiy, increasing the error of approximation.

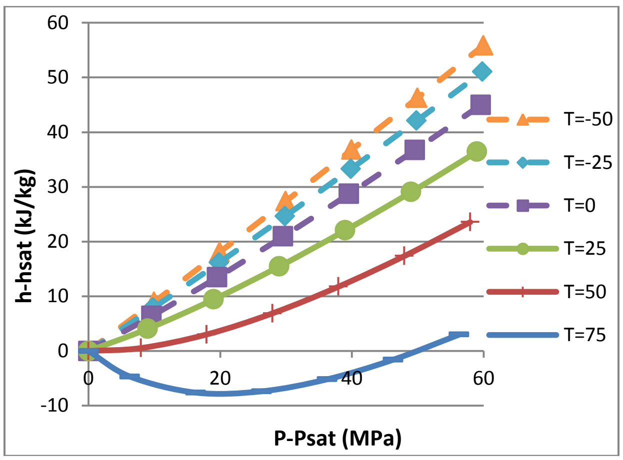

Fig. 25 Departure of specific enthalpy from the saturation state along isotherms for compressed liquid ammonia.

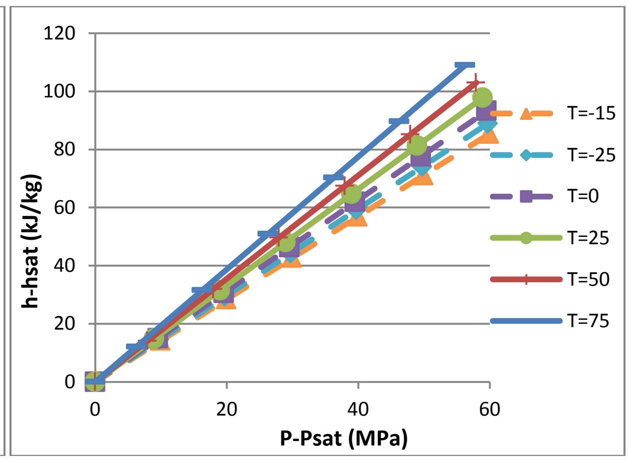

Fig. 26 Departure of approximated specific enthalpy, based on Eq. (4), from the saturation state along isotherms for ammonia in the compressed liquid region.

Figure 26 shows the departures of h_{app} (T, P) from h_f (T), calculated from Eq. (4), for ammonia in the compressed liquid region. The comparison of Figs. 25 and 26 indicates that the behavior of enthalpy departure curves is similar only at low temperatures. These figures confirm the impracticality of Eq. (4) for the approximation of the enthalpy of ammonia in the compressed liquid region, especially at high temperatures and pressures.

For ammonia in the compressed liquid region, departures of specific enthalpy from the saturation states along isentropic lines are displayed in Fig. 27 as functions of (p- p_{sat}). The corresponding values of saturation temperatures to the specific entropies presented in Fig. 27 were presented earlier in Table 4. Similar to water, approximations of specific enthalpy of compressed liquid ammonia by Eq. (15) and Eq. (20) practically yield exactly the same values. Departures of approximated values of specific enthalpy of compressed liquid ammonia from their saturated states, calculated using Eqs. (15) and (20) are plotted in Fig. 28 versus (p – p_{sat}). Figures 27 and 28 display very similar behaviors with nearly identical values for specific enthalpies, h (s, p).

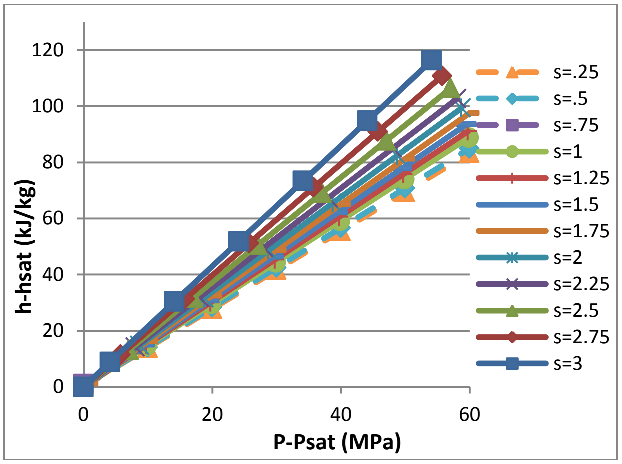

Fig. 27 Departure of specific enthalpy from the saturation state along isentropic lines for ammonia in the compressed liquid region.

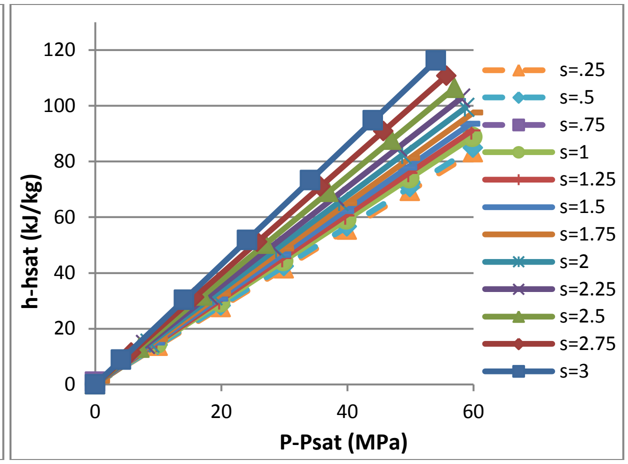

Fig. 28 Departure of specific enthalpy from the saturation state along isentropic lines, based on approximation Eqs. (15) and (20), ammonia in the compressed liquid region.

The accuracy of Eq. (4a) in approximating specific enthalpy of ammonia in the compressed liquid region is shown in Fig. 29. Similar to water, Eq. (4a) is reasonably accurate (less than 5%) for the approximation of enthalpy of compressed liquid ammonia at elevated temperatures (50-75 ^{o}C) or pressures close to saturation state. The accuracy of Eq. (4a) in predicting the enthalpy of ammonia in the compressed liquid region decreases with the decreasing temperatures. At temperatures below -50 ^{o}C, the approximation error can exceed 30% at pressures near 60 MPa.

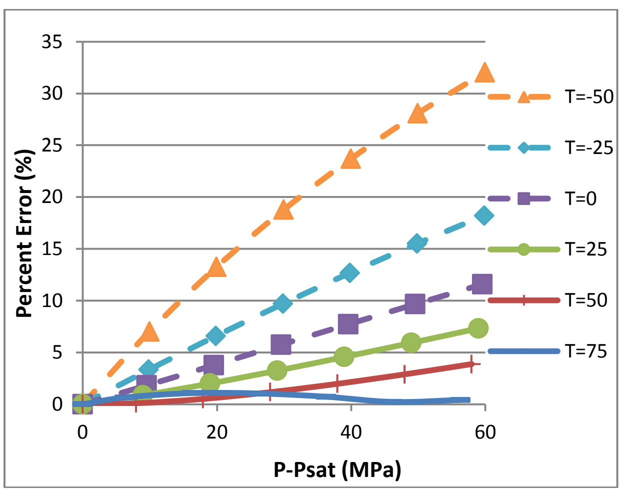

Fig. 29 Accuracy of Eq. (4a) for the approximation of specific enthalpy of ammonia in the compressed liquid region.

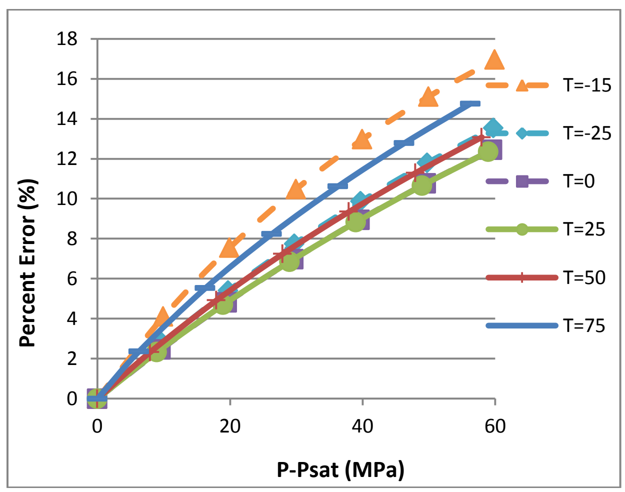

Fig. 30 Accuracy of Eq. (4) for the approximation of specific enthalpy of ammonia in the compressed liquid region.

The accuracy of the Eq. (4) in the approximation of enthalpy of ammonia in the compressed liquid region is displayed in Fig. 30. This figure shows that the correction term in the right hand side of Eq.(4) contributes to the accuracey of approximations of enthlpy of compressed liquid ammonia only at low temperatures. A comparison of the percentage errors presented Figs. 29 and 30 suggestes that the correction term in Eq. (4) in fact increases the error of approximation for temperatures exceeding 25 ^{o}C.

The acurracy of Eq. (15) in predicting the enthalpy of the ammonia in the compressed liquid region is displayed in Fig. 31. The figure shows that Eq. (15) can approximate the entalpy of ammonia in the compressed liquid region quite accurately in a wide range of pressures and temperatures. The figure shows the error in the approximation of enthalpy of compressed liquid ammonia, using Eq. (15), is less than 1.8 % in a wide range of pressures and temperatures. Fig 32 shows that the accuracy of Eq. (20) in approximating the enthalpy of compressed liquid ammonia is very similar to that obtained from Eq. (15).

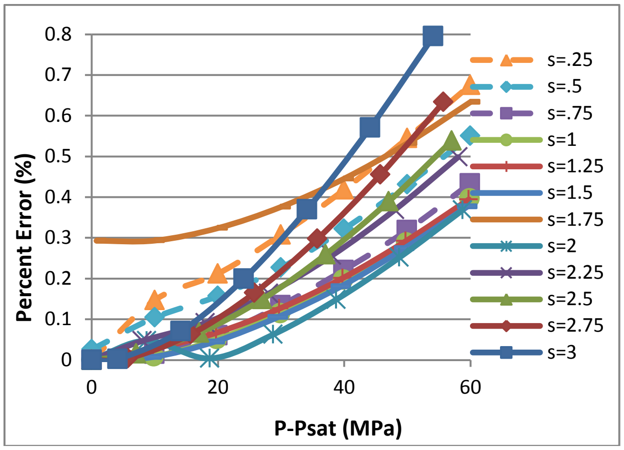

Fig. 31 Accuracy of Eq. (15) for the approximation of specific enthalpy of ammonia in the compressed liquid region.

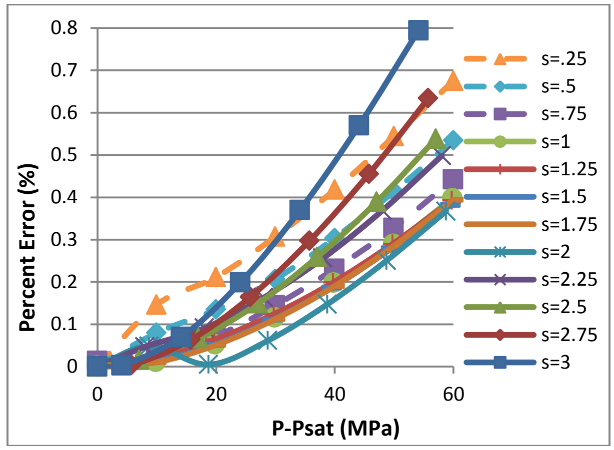

Fig. 32 Accuracy of Eq. (20) for the approximation of specific enthalpy of ammonia in the compressed liquid region.

For several isotherms, ranging between -150 ^oC and -85 ^oC, the departures of specific enthalpy of compressed liquid methane from the saturated states are plotted versus ($P-P_{sat}$) in Fig. 33. Similar to compressed liquid water and ammonia, the figure shows that for methane at low temperatures, the deviation of h (T, P) from h_f (T) increases with rising pressures and the lines representing specific enthalpy display a linear behavior along each isotherm. Hence, the correction term in the right hand side of Eq.(4) improves the accuracy of the approximation. With the increasing temperatures, Fig. 33 shows that the deviations of h (T, P) from h_f (T) become smaller and the isothermal lines display non linear behavior. At temperatures near and above -100 ^oC, the specific enthalpy departures first decreses with the increasing presures, reache a minium value, and then increases. Therefore, while the specific enthlpy drops to values below the sturation property with the increaing pressure, the correction term in Eq. (4) will add positive values to the saturation propertiy, increasing the error of approximation.

Figure 34 shows the departures of h_{app} (T, P) from h_f (T), calculated from Eq. (4), for methane in the compressed liquid region. The comparison of Figs. 33 and 34 indicates that the behaviors of enthalpy departure curves are similar only at low temperatures. These figures confirm the impracticality of Eq. (4) for the approximation of the enthalpy with increasing temperatures towards critical temperature.

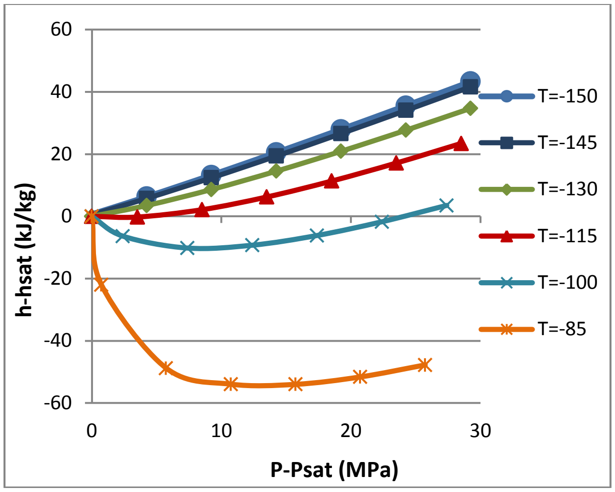

Fig. 33 Departure of specific enthalpy from the saturation state along isotherms for compressed liquid methane.

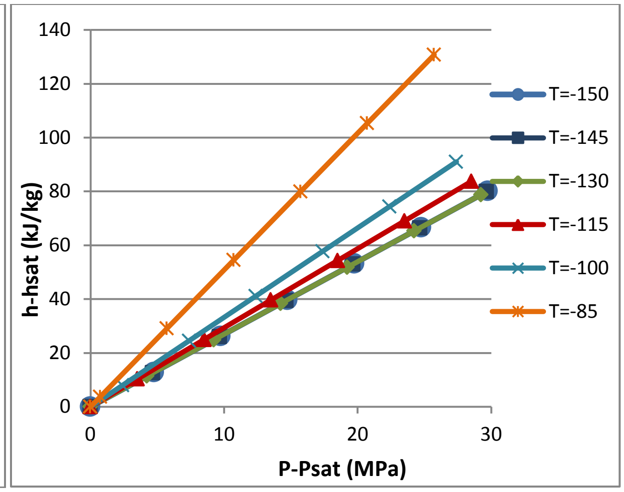

Fig. 34 Departure of approximated specific enthalpy, based on Eq. (4), from the saturation state along isotherms for methane in the compressed liquid region.

For methane in the compressed liquid region, departures of specific enthalpy from the saturation states along isentropic lines are displayed in Fig. 35 as functions of ($p- p_{sat}$). The corresponding values of saturation temperatures to the specific entropies presented in Fig. 35 were presented earlier in Table 5. Similar to water and ammonia, approximations of specific enthalpy of compressed liquid methane by Eq. (15) and Eq. (20) practically yield exactly the same values. Departures of approximated values of specific enthalpy of compressed liquid methane from their saturated states, calculated using Eqs. (15) and (20) are plotted in Fig. 36 versus ($p – p_{sat}$). Figures 35 and 36 display exactly similar behaviors with nearly identical values for specific enthalpies, h (s, p).

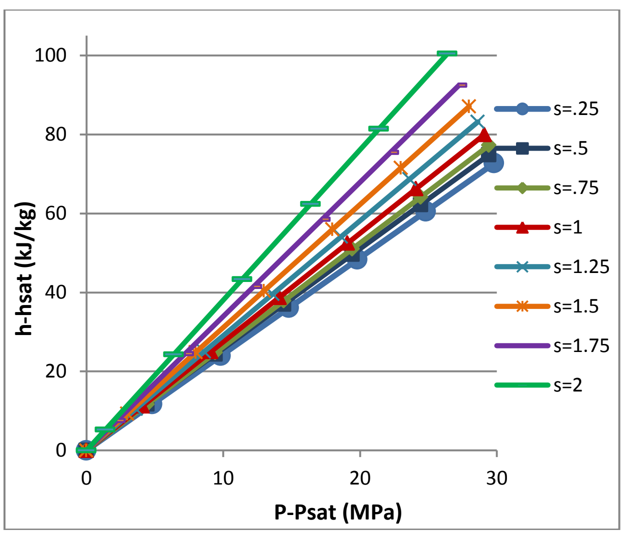

Fig. 35 Departure of specific enthalpy from the saturation state along isentropic lines for methane in the compressed liquid region.

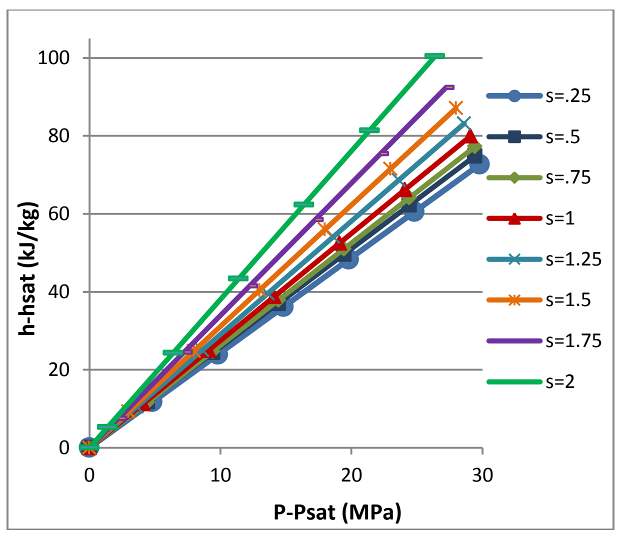

Fig. 36 Departure of specific enthalpy from the saturation state along isentropic lines, based on approximation Eqs. (15) and (20), methane in the compressed liquid region.

The accuracy of Eq. (4a) in approximating specific enthalpy of methane in the compressed liquid region is presented in Fig. 37. The figure shows that Eq. (4a) is reasonably accurate (less than 10% error) for the approximation of enthalpy of compressed liquid methane only at some elevated temperatures or pressures close to the saturation states. The accuracy of Eq. (4a) in predicting the enthalpy of compressed liquid methane decreases with the decreasing temperatures. At temperatures below -145 ^{o}C, the approximation error can exceed 40% at pressures near 30 MPa.

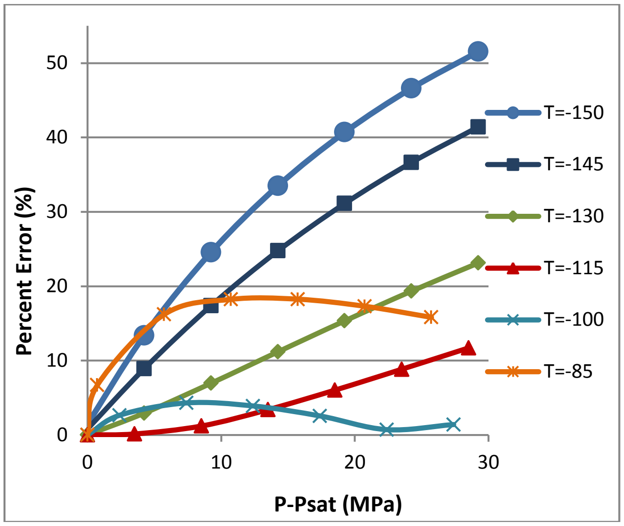

Fig. 37 Accuracy of Eq. (4a) for the approximation of specific enthalpy of methane in the compressed liquid region.

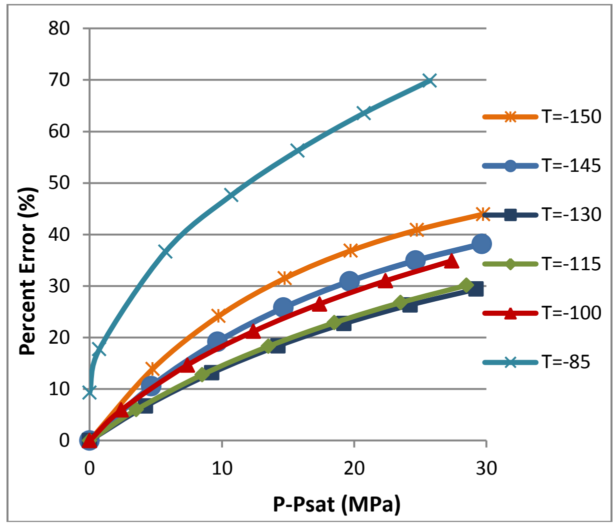

Fig. 38 Accuracy of Eq. (4) for the approximation of specific enthalpy of methane in the compressed liquid region.

The accuracy of the Eq. (4) in the approximation of enthalpy of compressed liquid methane is displayed in Fig. 38. This figure shows that the correction term in the right hand side of Eq.(4) contributes to the accuracey of approximations of enthlpy of compressed liquid methane only at low temperatures. But the error in approximation can exceed 20%, even at low temperature. A comparison of the percentage errors presented Figs. 37 and 38 suggestes that the correction term in Eq. (4) in fact increases the error of approximation for several temperatures.

The acurracy of Eq. (15) in predicting the enthalpy of the compressed liquid methane is displayed in Fig. 39. The figure shows that Eq. (15) can approximate the entalpy of methane in the compressed liquid region quite accurately in a wide range of pressures and temperatures. The figure shows the error in the approximation of enthalpy of compressed liquid methane, using Eq. (15), is less than 3 % in a wide range of pressures and temperatures. Fig 40 shows that the accuracy of Eq. (20) in approximating the enthalpy of compressed liquid methane is very similar to that obtained from Eq. (15).

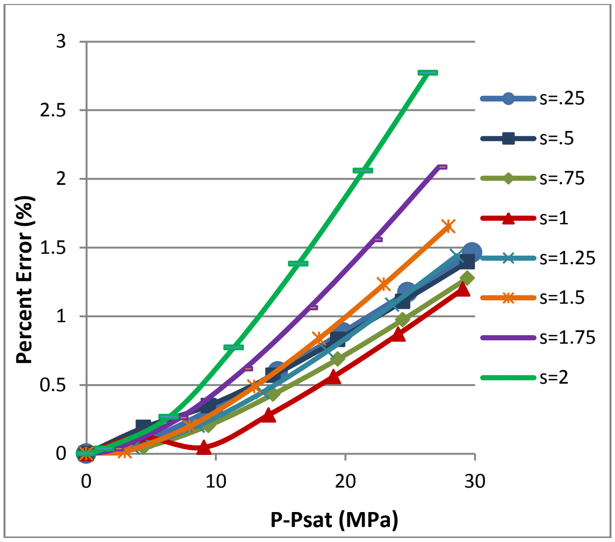

Fig. 39 Accuracy of Eq. (15) for the approximation of specific enthalpy of methane in the compressed liquid region.

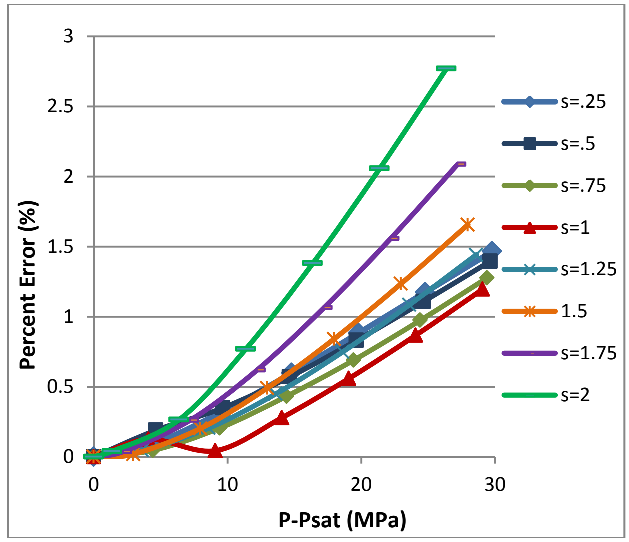

Fig. 40 Accuracy of Eq. (20) for the approximation of specific enthalpy of methane in the compressed liquid region.

For several isotherms, ranging between -160 °C and 80 °C, the departures of specific enthalpy of compressed liquid propane from the saturated states are plotted versus (P-P_{sat}) in Fig. 41. Similar to other three fluids, the figure shows that for methane at low temperatures, the deviation of h (T, P) from h_f (T) increases with rising pressures and the lines representing specific enthalpy display a linear behavior along each isotherm. Hence, the correction term in the right hand side of Eq.(4) improves the accuracy of the approximation. With the increasing temperatures, Fig. 41 shows that the deviations of h (T, P) from h_f (T) become smaller and the isothermal lines display non linear behavior. At temperatures near and above 50 °C, the specific enthalpy departures first decreses with the increasing presures, reache a minium value, and then increases. Therefore, while the specific enthlpy drops to values below the sturation property with the increaing pressure, the correction term in Eq. (4) will add positive values to the saturation propertiy, increasing the error of approximation.

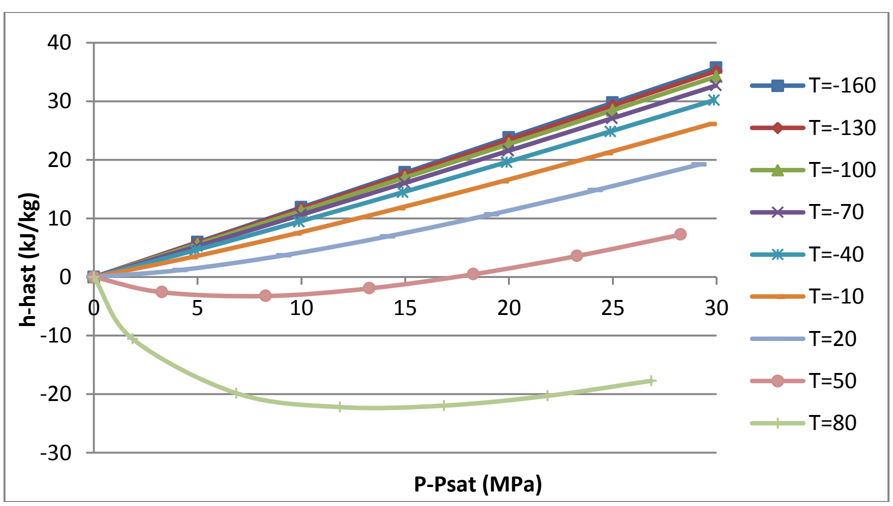

Fig. 41 Departure of specific enthalpy from the saturation state along isotherms for compressed liquid propane.

Figure 42 shows the departures of h_{app} (T, P) from h_f (T), calculated from Eq. (4), for propane in the compressed liquid region. The comparison of Figs. 41 and 42 indicates that the behaviors of enthalpy departure curves are similar only at low temperatures. These figures confirm the impracticality of Eq. (4) for the approximation of the enthalpy with increasing temperatures towards critical temperature.

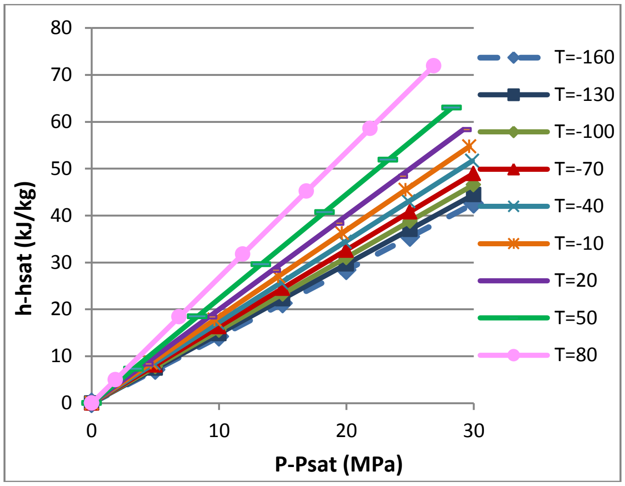

Fig. 42 Departure of approximated specific enthalpy, based on Eq. (4), from the saturation state along isotherms for propane in the compressed liquid region.

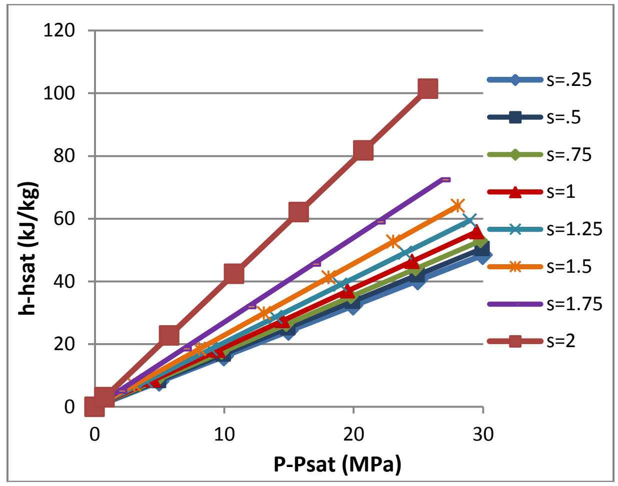

Fig. 43 Departure of specific enthalpy from the saturation state along isentropic lines for propane in the compressed liquid region.

For propane in the compressed liquid region, departures of specific enthalpy from the saturation states along isentropic lines are displayed in Fig. 43 as functions of (p- p_{sat}). The corresponding values of saturation temperatures to the specific entropies presented in Fig. 43 were presented earlier in Table 6. The approximated specific enthalpy departure from saturated states, calculated from Eq. (15) and Eq. (20) along isentropic lines, are plotted versus (p- p_{sat}) in Figs. 44 and 45, respectively. The curves in Figs 43 through display similar behavior. The values of specific entropy departures in Fig. 45 are slightly closer to the values on Fig. 43than those in Fig. 44. This suggests that Eq. (20) provides slightly more accurate approximation of specific enthalpy for compressed liquid propane than the approximation achieved, using Eq. (15).

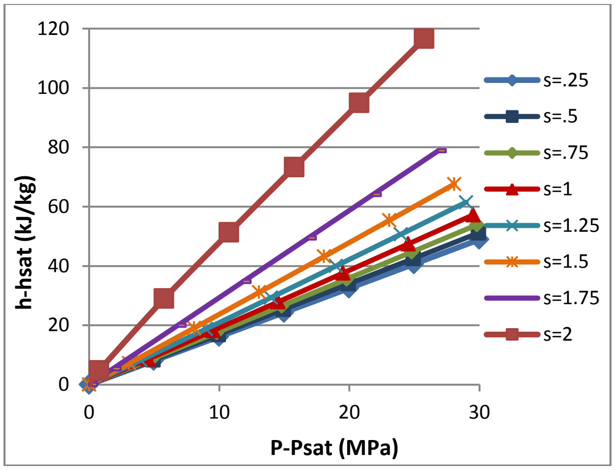

Fig. 44 Departure of approximated specific enthalpy from the saturation state along isentropic lines, based on approximation Eq. (15) for propane in the compressed liquid region.

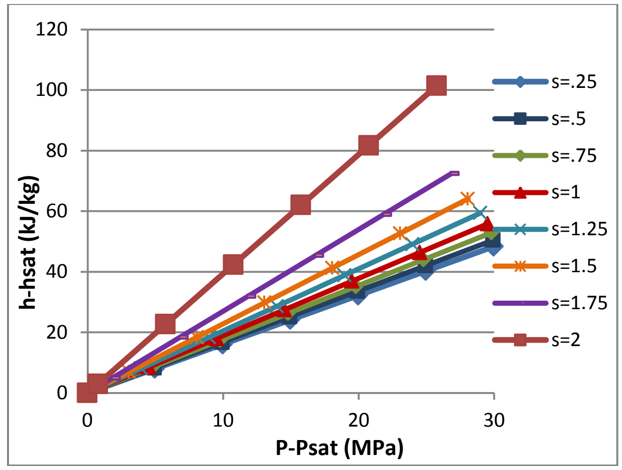

Fig. 45 Departure of approximate specific enthalpy from the saturation state along isentropic lines, based on approximation Eq. (20), propane in the compressed liquid region.

The accuracy of Eq. (4a) in approximating specific enthalpy of propane in the compressed liquid region is presented in Fig. 46. The figure shows that Eq. (4a) is reasonably accurate (less than 10% error) for the approximation of enthalpy of compressed liquid methane only at temperatures above 20 ^{o}C or pressures very close to the saturation states. The accuracy of Eq. (4a) in predicting the enthalpy of compressed liquid methane decreases with the decreasing temperatures. At temperatures below -70 ^{o}C, the approximation error can exceed 45% at pressures near 30 MPa.

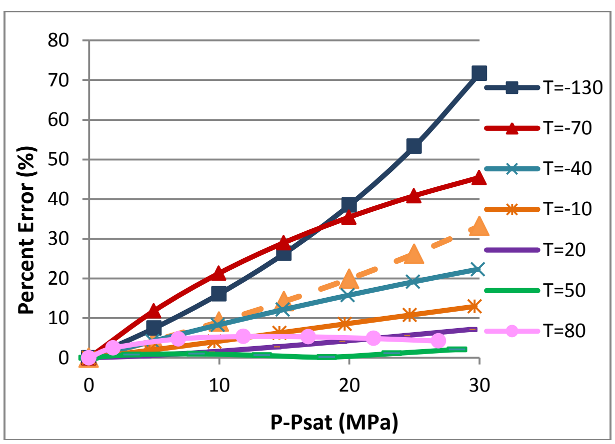

Fig. 46 Accuracy of Eq. (4a) for the approximation of specific enthalpy of propane in the compressed liquid region.

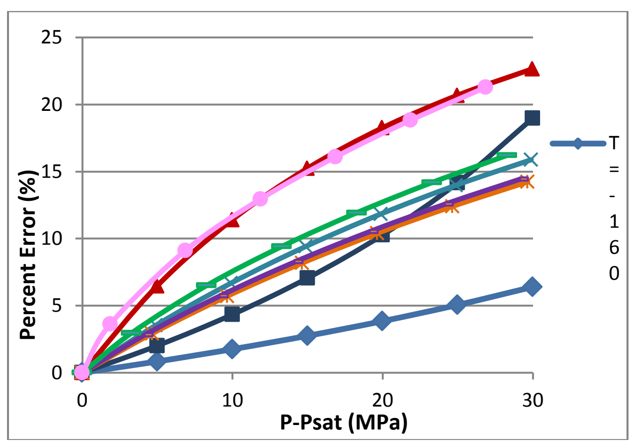

Fig. 47 Accuracy of Eq. (4) for the approximation of specific enthalpy of propane in the compressed liquid region.

The accuracy of the Eq. (4) in the approximation of enthalpy of compressed liquid propane is displayed in Fig. 47. This figure shows that the correction term in the right hand side of Eq.(4) contributes to the accuracey of approximations of enthlpy of compressed liquid methane only at very low temperatures. For example the approximation error is less than 7% at a temperature at -160 ^{o}C or below for pressures up to 30 MPa. A comparison of the percentage errors presented

Figs. 46 and 47 suggestes that the correction term in Eq. (4) in fact increases the error of approximation at higher temperatures.

The acurracy of Eq. (15) in predicting the enthalpy of the compressed liquid propane is displayed in Fig. 48. The figure shows that Eq. (15) can approximate the entalpy of compressed liquid propane in quite accurately in a wide range of pressures and temperatures. The figure shows the error in the approximation of enthalpy of compressed liquid methane from Eq. (15) is less than 8 % in a wide range of pressures and temperatures. Fig 49 shows that the accuracy of Eq. (20) in approximating the enthalpy of propane in the compressed liquid region. In this case the maximum approximation error is less rhan 6%, indicationg that Eq. (20) is slightly more accurate than Eq. (15) in approximating the specific entropy of compressed liquid propane.

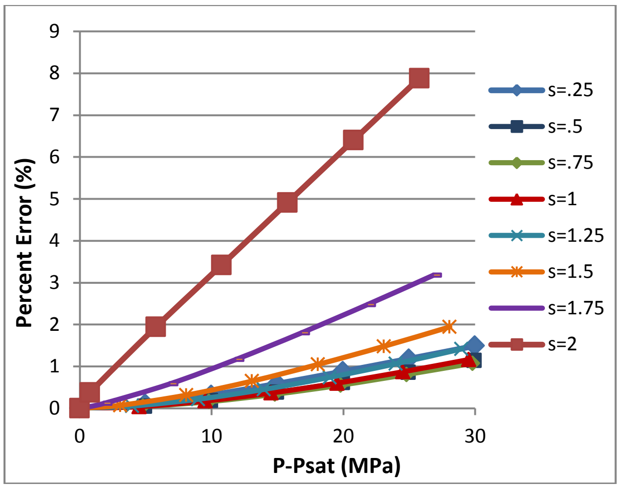

Fig. 48   Accuracy of Eq. (15) for the approximation of specific enthalpy of propane in the compressed liquid region.

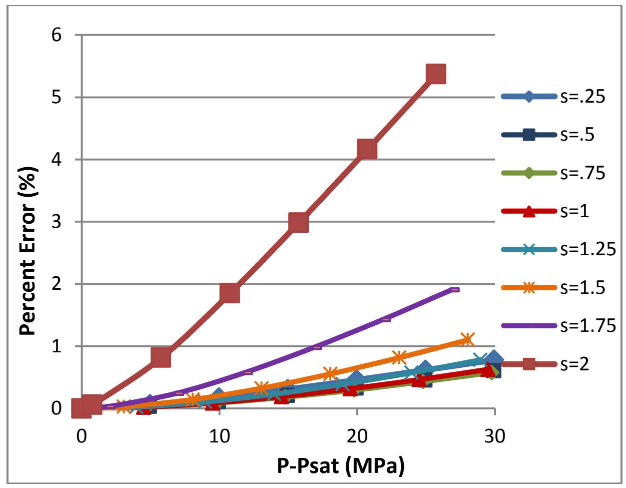

Fig. 49   Accuracy of Eq. (20) for the approximation of specific enthalpy of propane in the compressed liquid region.

Applications in Thermodynamic Courses

Discussions on the results of this study in thermodynamic courses are beneficial to students taking thermodynamics courses both at undergraduate and graduate levels. At the undergraduate level the instructors can use the results of this study to highlight the limitations of Eqs. (1) through (4) in approximating the thermodynamic properties of substances in the compressed liquid region. At the graduate level a more detailed analytical discussion, similar to those described in this paper, can be used to explain the reasoning for the limitations on using Eqs. (1) through (4) for the approximation of properties. In addition, projects can be assigned at the graduate level for students find ways to improve the accuracy of approximations from saturation properties.

Summary

The behaviors of specific internal energy and specific internal energy along isotherms and isentropic lines are examined for water ammonia, methane, and propane in the compressed liquid region. It is shown that the effect of pressure on the internal energy of the compressed liquid is much greater along isotherms than those along isentropic lines. It is shown that Eq. (14) is much more accurate than Eq. (2) in approximating the internal energy of fluids in the compressed liquid region. Similarly, equation (15) and (20) yield much more accurate approximation of specific enthalpy in the compressed liquid region than those obtained from Eq. (4).

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Educational Methodology Applied to Aircraft Design

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Abstract

The purpose of this document is to evaluate and promote the methods of education in the STEM fields by reporting a particular overview of the results and accomplishments in an aeronautical vehicle design class project. In this experience, a development of individual effort and studies lead to a very important process of collaborative effort (an essential quality required in the industry). In aircraft design, a process is executed such that all the disciplinary studies of aeronautics are applied to produce together one single concept for a vehicle to be built followed by more detailed planning phases. The design is first of all achieved by creating a conceptual shape of the aircraft made by a convergence of variables that best fit the subjected mission requirements. The following seven steps give an overview of the conceptual design for an aircraft: 1) Analysis, 2) Integration, 3) Iteration, 4) Convergence, 5) Solution Space Screening, 6) Solution Space Visualization, and 7) Risk Assessment. Beginning with the mission requirements, an Analysis directed by all the disciplines provides values that contribute to the configuration of the vehicle as well as the specifications produced. Integration combines the findings and calculations in the analysis and assemblies it into one whole. Iteration recreates the process of analysis by reapplying the flight parameters in an iterative process. The Iteration process ends when these values arrive at Convergence and remain fixed for the rest of the design. This provides a visual Solution Space Screening, which provides the constraints of the vehicle in design. The Solution Space Visualization represents the available combination of parameters which provide an optimal design visually. This area is finally evaluated and any risks are assessed of the point chosen from the design space. Thus this paper will demonstrate the validation of this aircraft by recreating the design process to the World War II German Fighter, Messerschmitt Bf 109. Reverse engineering essentially serves as the first step in analysis where an initial set of parameters regarding the intentions of the plane are used. Parametric sizing, steps 2 to 6, essentially serves as a critical procedure of sizing the aircraft to the desired mission capabilities. The guideline for this sizing is

explained by Laurence Loftin's method of aircraft development documented in his work of *Subsonic Aircraft: Evolution and the Matching of Size to Performance*. This is important to any application of aircraft design where the knowledge gained by the Capstone students is utilized through combining the different elements during the years of study and is demonstrated in this collaborative work.

Introduction

Education in engineering has become a nation-wide concern against the rising global competition in the fields of Science, Technology, Engineering, and Mathematics (STEM) advancements. The concern is due to the forecasted inability of the United States to maintain economic leadership if the students, teachers, and professionals are not at the same stride of the international community in STEM education. Although the majority of these concerns should be targeted at the early stages of education that inspire and motivate the development of the STEM influence, the focus here lies on the existing undergraduate engineering university student. This student's academic course work, which was taken over the years, is applied not only to the capstone design project but also to the collaborative effort that will bring the best out of an organized group. This is one aspect in education that will generally not be initially taken into consideration in the educators' curriculum.

To accomplish a nation with strong STEM foundation, advanced levels of thinking must be achieved instead of following learned procedures in the classroom. A creative mind in conjunction of STEM initiatives will enable this nation to become an international leader in the scientific fields. This paper will present the overall procedure carried in the senior vehicle design project of reverse engineering of the World War II fighter planes by utilizing available historical resources and applying methods of group execution to arrive at a conceptual design of the aircraft. A method of aircraft design will be implemented to the aircraft based on the flight mission requirements that the fighter planes were required to maintain. The handling of the student group will also be evaluated. It is intended to showcase the strength of research of previous history to eliminate and understand the errors committed in the past and to demonstrate the necessity of effective team dynamics in the designing process.

Aircraft Design Procedure

In the aircraft design process, there are three main phases in which the creation of a flight vehicle is reached. These are generally considered to be the Conceptual Design, Preliminary Design, and Detailed Design. The analysis required in the designing of an aircraft implements a multi-disciplinary approach that integrates various elements involved.

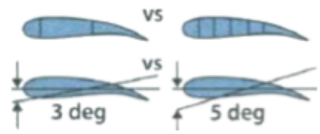
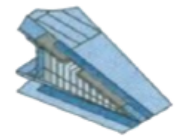
	Phase 1 **Conceptual Design**	**Phase 2** **Preliminary Design**	**Phase 3** **Detailed Design**
			
Known	Basic Mission Requirements Range, Altitude, & Speed Basic Material Properties σ/ρ E/ρ $\$/lb$	Aeroelastic Requirements Fatigue Requirements Flutter Requirements Overall Strength Requirements	Local Strength Requirements Producibility Functional Requirements
Results	**Geometry**: Airfoil Type, R, t/c, λ, Δ **Design Objectives**: Drag Level, Weight Goals, Cost Goals	Basic Internal Arrangement Complete External Configuration *Camber & Twist Distribution* *Local Flow Problems Solved* Major Loads, Stresses, Deflections	Detail Design *Mechanisms* *Joint Fittings and Attachments* Design Refinement as Result of Testing
Output	**Feasibility Design**	**Mature Design**	**Shop Designs**
TRL	**2-3**	**4-5**	**6-7**

Table 1. Three phases of aircraft design (Nicolai, 2010).

In the Conceptual Design phase, the initial configuration of the aircraft is made without scrutinizing on many of the details. Essentially the basic flight and mission requirements are addressed at this stage, such as if the plane being design is intended for certain cargo or payload requirement, high or low speed, and maneuverable capabilities. Such requirements allow determining the definition of wingspan, sweep, and basic dimensions of the aircraft that will fulfill the mission requirements. There no major constraints in this phase leading to generally making the design of a low Technology Readiness Level (TRL). However this TRL will increase with realistic implementations of available technology. Basic calculations are made in this phase to accomplish all general flight conditions.

Preliminary Design becomes more of a detailed analysis of the model created conceptually through the first phase of design. This stage will verify phase 1 as well as provide more detailed aspects of the flight vehicle. The engine and intake configurations are selected or confirmed at this point of stage. The structural overviews are assessed at this point such as aeroelastics, fatigue, and flutter analysis. Refined weight estimates are made and a more thorough performance analysis is conducted. Dynamic stability and control analysis influences are determined and six-degrees-of-freedom (6-DOF) rigid aircraft simulations are conducted to establish flight control requirements and handling quality levels. If the aircraft is highly flexible (such as a high aspect ratio wing, a high fineness ratio fuselage, low fuselage damping), the simulation might require consideration of more than six degrees of freedom in order to examine the coupling of the rigid aircraft modes and the flexible aircraft modes.

In the Detailed Design phase, the product reaches a fixed state in which no more modifications are made to the design of the aircraft. The modifications made in this phase are applied to the detailed components of the aircraft that do not necessarily contribute significantly to the design. Such components include mechanisms, joints, fittings, and attachments in the structure. It is important that from this point on the design changes be kept to a minimum because the cost of making a change is large once the drawing hits the shop floor (Nicolai 2010). Interior layout is detailed with respect to location and mounting of equipment, hydraulic lines, ducting, control cables, and wiring bundles.

For the scope of the assigned project, only the conceptual design phase is taken into consideration not only for the specifics of the assignment, but also to refrain from making ambiguous studies and analysis of the aircraft. To remain in a conceptual design approach, calculations can be made by using the general geometry and configuration of the aircraft. Any form of high-ordered detailed analysis by utilizing advanced computing tools is such as Computational Fluid Dynamics (CFD) viewed as over-ambitious, yet possible.

Team Methodology

The intended approach of the assembled team is to separate into groups in order to specialize in the main disciplines, to obtain concentrated data, and to efficiently master each criterion. The proposed subject criteria are accepted and agreed upon by the team, which include the following concentrations: Aerodynamics, Propulsion, Controls, Structure and Performance. In addition, two critical areas of interest that required detailed attention are studied: Aircraft Sizing (utilizing Loftin's method) and Risk/Certification. Assuming there will be enough documentation available, Risk will undertake any documented errors or maintenance necessities that will give understanding to the structure and function of the plane. Certification will analyze documentation regarding regulations for flight at the given era.

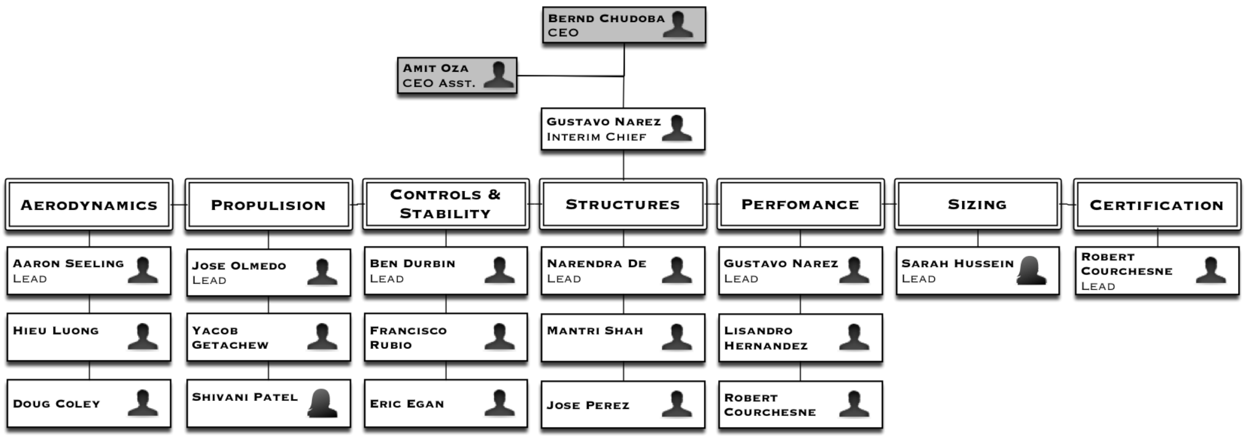


Figure 1. Design team diagram with team members and position within chosen criterion.

Aerodynamics

The aerodynamics group will specialize in tradition aerodynamic topics related to the results of normal and shear stress distributions applied to plane including coefficients of lift, drag, and moments applicable to any given dynamic pressure value. The group will decide on an implementation of measuring such values. Process possibilities include Thin Airfoil Theory, to find correlations in data, or advanced DATCOM programming.

Propulsion

The propulsion group will work to analyze the propulsion aspects surrounding mainly the propeller and power plant of the aircraft. Other topics of concern to be shared among performance are fuel consumption of the piston engine and temperature effects. Specifications of the engine must be considered as initial configuration elements of the aircraft, leaving not much room to change variables. Thus the available technology at the time must be correctly applied.

Controls

The controls group will overlook the control surfaces of the aircraft that operate the trim and flight maneuverability overall. Even though in the sizing approach in Loftin's procedure stability and controls are not included, this group will overlook the stability of flight in all the conditions (climb, cruise, combat, etc.)

Structure

The structure group will be dedicated to find structural information of the plane that dictate the force loads during flight and calculate the maximum forces and stress the aircraft can retain. This group will as well provide a CAD model to demonstrate stress distributions.

Performance

The performance group will examine the range and mission capabilities of the aircraft. Topics to be covered include lift-drag ratio, endurance, climb & descent, and flight envelope considering both optimal flight conditions as well as maximum capabilities. A great amount of collaboration with the other groups will be required to validate available information with the analytical approach of these values.

Mission Profile

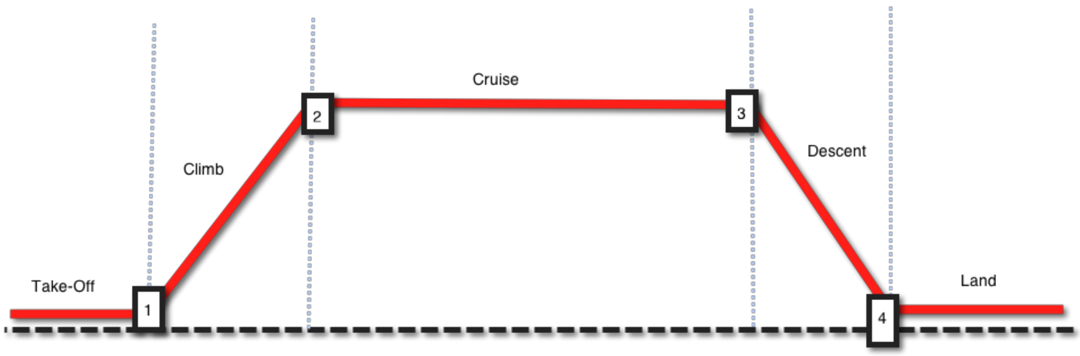


Figure 2. Mission profile requirements calculated for the Bf 109.

To begin with, a simple approach demonstrates the range of the Bf 109 and the specifications of a mission requiring a quick climb rate to cruising altitude and long range until fuel is out. This simple profile description will provide a demonstration for the endurance abilities for the aircraft in a simple manner of calculating several points in the path of the mission profile.

It is intended for the mission profile to be nice and simple by calculating the points for each segment of the profile (points 1, 2, 3, and 4).

A mission profile code is made to accommodate and organize these values in an input/output manner in order to facilitate the change in variables provided by other disciplines, or where different situations are to be investigated. This is not intended to substitute the Loftin sizing method, but merely to describe the instantaneous mission depiction.

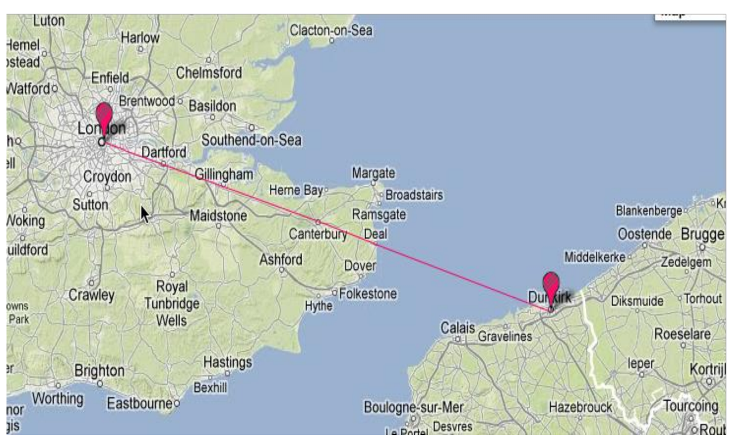


Figure 3. Mission example displaying Dunkirk to London capable by the Bf 109

An example to which this mission profile may be applied is the

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distance from Dunkirk, France to London. The values calculated for this mission profile demonstrated the capabilities in which this fighter aircraft is seen to be capable of accomplishing.

The distance between the two cities is approximately 182 kilometers (114 miles). While the Bf 109 E variations are documented as having a range capability of 650 kilometers (410 miles).

Project Overview

The instructions and description for this project are presented in this section. Four main objectives that are required for this assignment are

- Reverse-engineer three WWII Fighter missions and vehicles using design approach by Loftin.
- Validate individual missions segments using existing data.
- Develop a complete Conceptual-Design-Level study identifying the vehicle solution space for the mission selected.
- Produce a rendering of the vehicle.

The overall purpose of this project for MAE 4350 Vehicle Design Course is to execute a literature overview and analyze, based on calculations and historical data, the military aircraft in World War II era. An emphasis is made on applying the information of the past as well as becoming completely knowledgeable of the aircraft. The aircrafts used in combat at the time were regarded as vehicles of high performance. Due to the nature of military information, all data available were not accessible or public. Yet, in the past 70 years, much documentation has been made accessible to the public through intensive research on the Internet and in printed books from libraries.

The three aircrafts that will be studied by the MAE 4350 Vehicle Design class are the German *Messerschmitt Bf 109*, the British *Supermarine Spitfire*, and the United States' *P-51 Mustang*. The students in the senior design course are divided into three groups and each organization focuses on one of the three aircrafts assigned for the project; each organization consisting of about 13-16 individuals per group.

It is intended for the aircraft to be analyzed and evaluated through gathered data, essentially to conceptually reverse engineer the aircraft. A historical overview is required to fully comprehend the design and expectations of the assigned aircraft. Modifications or design enhancements of the aircraft will demonstrate the ability of the appointed senior design group to take a capstone approach and apply the acquired knowledge to the collected information of the designated aircraft.

This project will provide the senior design capstone student with the ability to specialize in a criterion of the aircraft presented and, through a collaborative effort, demonstrate the ability to analyze an aircraft numerically (all specifications and extremities of the original design) as well as understand the primary conceptual functions of the aircraft.

Figure 4. World War II era fighter planes, in this picture from left to right are the Messerschmitt Bf 109, British Spitfire, and P-51 Mustang.

Loftin's Parametric Approach

It is intended to implement a design approach by following the procedure outlined by Laurence Loftin in his publication *Subsonic Aircraft: Evolution and the Matching of size to Performance.* Loftin's guided procedure in the parameterizing and development of aircraft arrives at a solution space that visually demonstrates the optimal design configurations for the mission and operation of interest. This information found in his documentations is to be applied through the original available data from the aircraft to make an analysis based on the configurations. This will be seen through the outcome of the process and the change of the fighter plane's configuration. The differences between the iterated outcome values from Loftin and the original specs available of the aircraft will be an error that is intended to be analyzed. The result of this error will be explained as either due to optimization of the aircraft or true error in the initial input values used of the known aircraft data.

Chapters II, III, and IV in Loftin's document focus on the development of Jet Engine Propulsion aircraft while the following chapters V, VI, and VII are designated for the development of the Propeller-Driven aircraft. Although many subjects are generally the same, such as aerodynamics and structural forces, Loftin takes this into account in regards to the propulsion system and provides a procedure in the parameterization of the propeller blade.

Literature Review

The intention of the Messerschmitt Bf 109 is to replace the current line of fighter planes at the time in the 1930's, which for the German nation at the time included the Arado Ar 68 and the Heinkel He 51 as shown in Figure 3. The Arado Ar 80 design was a relatively conservative open-cockpit monoplane, with the characteristic (Nicolai 2010) forward-set vertical fin. On the other hand, the Heinkel He 112 was a relatively portly aircraft, featuring the Günther brothers' signature elliptical wing planform as first seen on the He 70.

Figure 5. Arado Ar 68 (top) and Heinkel He 51 (bottom).

The biplanes were well out performed by the design of Willy Messerschmitt in 1933 when the Luftwaffe desired to make the substitution. This out-performance was seen from the prototype of the new monoplane itself.

The requirements imposed by the Luftwaffe included for a capability of 400 km/h at 6000 meters, climbing to the 6000 meters in 17 minutes and an operational service of 10,000 meters.

Some of the features that brought about innovating differences were the incorporation of the enclosed cockpit, which was something that many pilots found strange at the time but demonstrated to have great benefits for the design. Retractable landing gear was another major improvement compared to the Arado's and the Hinkel's fixed landing gear.

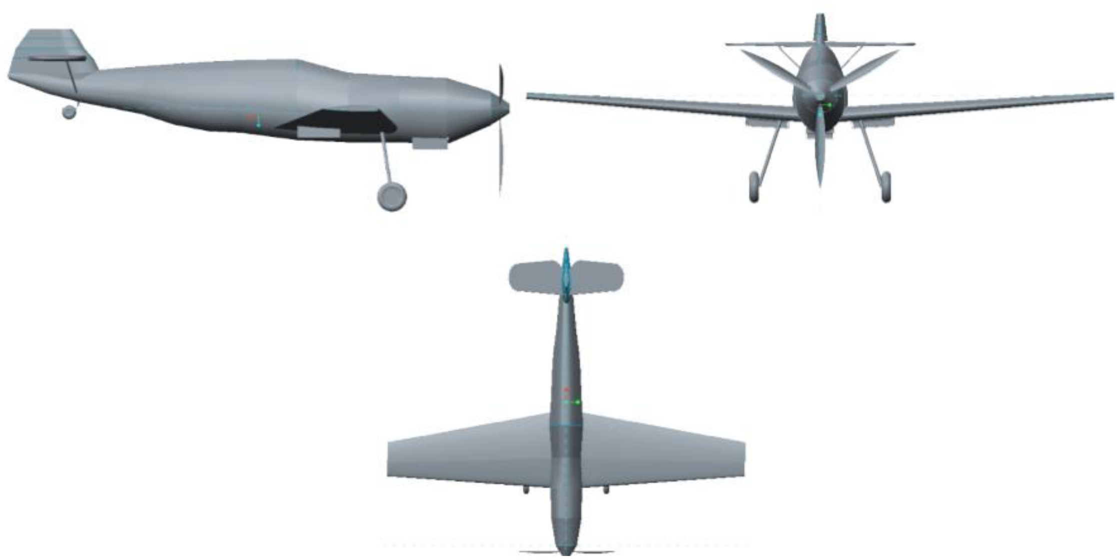

Figure 6. Messerschmitt Bf 109 Variant E model renderings from CREO 2.0

Educational Applications and Experience

The Aerospace Engineering Capstone program at the University of Texas at Arlington exposes the senior student to a more realistic level of application based on the knowledge and methodologies acquired as an undergraduate. It is not until this point in the final year that the student applies higher levels of thinking to arrive at designing success. Methodology, which is not expressed traditionally in any required course within the curriculum of engineering, is now a key developmental process for the success of the project.

The explanation of learning capabilities and process has been for years modeled in Bloom's Taxonomy (Forehand 2010). General courses will for the most part cover the two lower parts of the pyramid diagram, in Figure 7. Remembering and Understanding. Remembering is the capability of recalling the information without much high order process. Comprehension is the understanding of the information. Educators who are familiar with Bloom's Taxonomy, or any other effective learning techniques, will request the students to employ their understanding to valid conceptual applications.

As for Applying, it implements solving problems preceding the recalling and understanding levels. Higher order of thinking proceeds, as Analyzing and Evaluating.

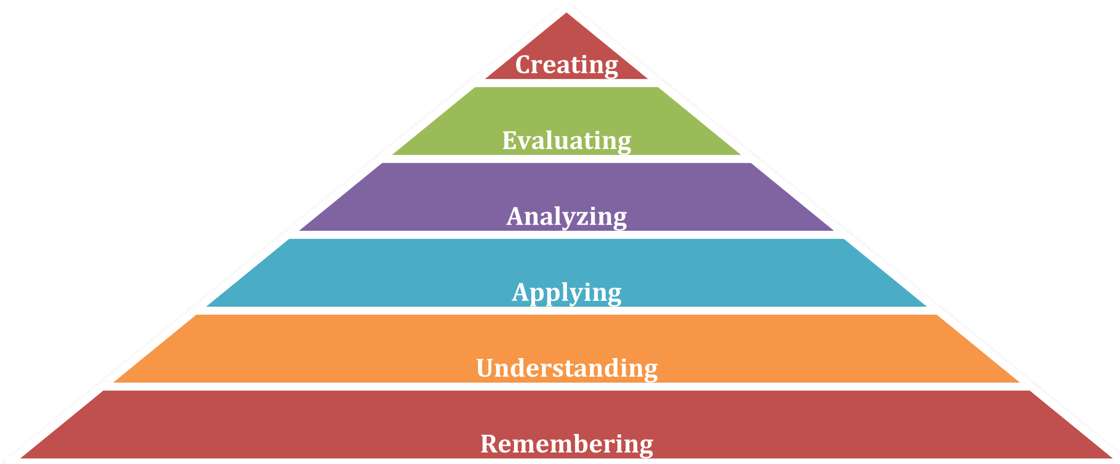

Figure 7. Bloom's Taxonomy overviewing thinking levels of information beginning basic remembering to elaborate composition.

The ability to create is considered the highest level of thinking. It is defined simply as the ability to put elements together to form a coherent or functional whole, organized into elements of a new pattern or structure. It is the Creative level in Bloom's Taxonomy which the student is exposed to by the senior capstone project. With the exception of the extracurricular lab assistant or intern student in the field of engineering, this level of execution may be unfamiliar to the scholar. It is not until the exiting capstone course that the composing of these conceptual designs are created.

In aircraft design, there is a general procedure that heavily utilizes the concepts of Creating in Bloom's Taxonomy. The method consists of seven clear steps required to effectively produce an aircraft. It provides the ability to assess the possible configurations, that would meet the mission and the design constraints, and the risk involved with the selection of an intended flight operation. The steps, as shown in Figure 8, are in the following order: 1) Analysis, 2) Integration, 3) Iteration, 4) Convergence, 5) Solution Space Screening, 6) Solution Space Visualization, and 7) Risk Assessment.

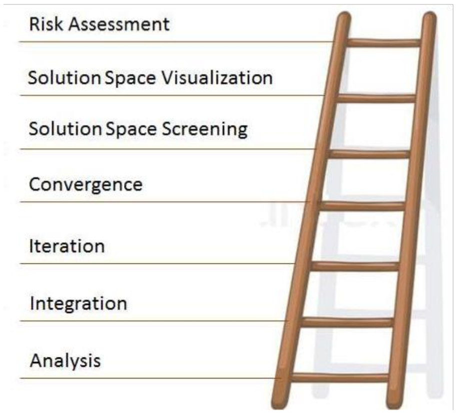

Figure 8. The seven step conceptual design procedure.

Analysis is the step in the design method that involves the general studies of aerospace engineering: aerodynamics, propulsion, controls and stability, structures, and aircraft performance. This is mainly the focus of general undergraduate courses. Thus for the beginning capstone student, Analysis is the only step with certain familiarity.

Integration is the step which takes all the separate disciplines of the design and builds them into a parametric calculation code. For example, calculating the values of aerodynamic drag at certain velocities contribute to an assessment of power required by the propulsion system for operation at the desired speed. This interchangeability of calculations between the disciplines may alter the design configurations indefinitely if continued. Thus, it is necessary to implement a Convergence step that will, as the name indicates, converge on specific values that dictate the configuration of the design based on an iterative process of calculation.

After a convergence is reached satisfying the constraints of the design configuration, solution space assessment is implemented to visually demonstrate the possible configurations of the aircraft, ideally based on parametric sizing values. The parametric sizing values for the project are considered to be Wing Loading (lbf/ft^2) and Power Loading (lbf/hp). This was applied following Loftin's procedure of fixing the calculations in terms of Wing Loading, and output values of Power Loading for each required design configuration or constraint. The purpose of Solution Space Screening and Visualization is to view the optimal point of performance for the design. In the Solution Space generated from the project, in Figure 9, the Match Point is the optimal configuration of the design in which the Wing Loading of the aircraft will provide the most Power Loading values based on the input parameters.

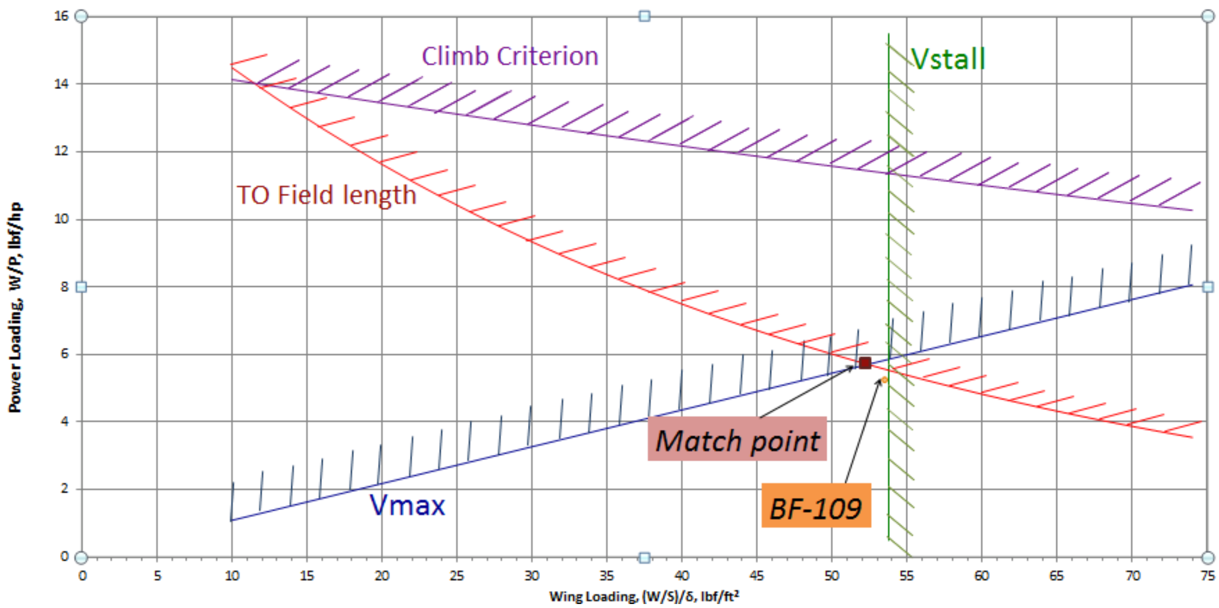

Figure 6. Solution Space Visualizing-The Matching Chart obtained from the AVD project for the Messerschmitt Bf 109 aircraft.

This point is seen at the corner of the Take-off Field Length and the Max Velocity constraints within the solution space. The solution space is recognized in the bottom portion of the graph where no hash markings are present. The point marked as BF-109 corresponds to the actual Wing Loading based on historical values. This is seen to be very near the Match Point approximation. This is considered appropriate for the German World War II fighter since performance is prioritized over the cost, compared to general aviation at the time. Although the design methodology utilized originally for the aircraft at the time is unknown, this parametric analysis concurs the decision to ultimately perform at great high magnitude.

Some of the risks that would be addressed in viewing the Solution Space are costs and safety considerations. Although performance is desired at optimal settings, designing the aircraft to such extent may consequently create safety complications. Such would be an example of risk that is taken by choosing the specific design point in the Solution Space. Although in this project the aircraft was not itself designed from scratch, but rather compared to the original parameters and assessed for the accuracy of the Loftin's sizing techniques, it served as an impressive example and valuable experience of the aircraft design process.

Concluding Remarks

Arriving at a Solution Space becomes the Creation-Level of thinking in Bloom's Taxonomy. It is not until that point in the design process is reached that the aircraft begins to take shape physically and tangibly. The design point is selected from the Solution Space by cautiously evaluating the risk. This has been demonstrated in previous years in all the Capstone Aerospace Vehicle Design courses. It is only with this level of critical thinking that engineering solutions to the relevant problems in the world can be addressed.

In encouraging these levels of thinking at earlier stages in the academic careers of students, the rate of processing information will be more and more effective with the development of these abilities. In the age of information where there is not enough time to fully grasp all available quantities, much less retain it, the individual becomes suppressed by the Remembering and Understanding stages. With correct influence from the educators, the mental capacities will increase in cognitive thinking and follow the stride the international community.

In intense academic competition, a framework is set to define right and wrong. To lose the fear and to think simply without the concern of being right or wrong is something that is lacked in many educational systems today. As demonstrated in the Solution Space with an infinite amount of valid configurations, the Match Point is not necessarily the only possibility or the selected configuration for that matter. The point in the Solution Space is obtained after analysis and evaluation of the selected configuration designs.

The exposure thus far in the Vehicle Design Course has, from personal experience, allowed the teams to become proficient with the process of designing. Even though the chief engineer in the project selects the final point of design, this process requires a full collaborative effort of every individual in the team. With such an effort, arduous feats can be accomplished through the contribution of critical thinkers organized to achieve specific objectives.

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A Recent Experience in Utilization of Online Resources in Teaching Undergraduate Dynamics

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Abstract

Undergraduate Engineering Dynamics (ENGR 2302) is one of the challenging courses in both Engineering and Engineering Technology curricula. Variety of topics related to Engineering Mechanics is covered in this course with varying degrees of difficulty students perceived to develop their understandings of the course topics. In particular, the relationship between force and potential Energy and physical meaning and significance of "Conservative forces" are among topics that typically undergraduate students struggle with in developing their understanding of mechanical systems dynamics. A recent experience gained by the author in teaching the course is discussed and examples are provided to help instructors who teach this course either online or in person.

Nomenclature:

m	*mass*	***U***	*Work done on an object by a force*
v	*velocity*	***F***	*Force*
V	*Potential Energy*	***r***	*displacement*
T	*Kinetic Energy*	***A***	*Area*

Introduction

Engineering Dynamics (ENGR 2302) course is a required course in both Mechanical Engineering Technology and Mechanical and Energy Engineering programs at University of North Texas. Author has taught the course for several semesters and would like to share with readers his experience gained in teaching the course. Among topics covered in the course, the one that appears to present a challenge to some students is the concept of "conservative forces" versus "non-conservative forces." The topic is covered in all respected and popular textbooks[1-4] in a nearly similar fashion. For example, Bedford and Fowler[1] states that if all forces that do work on an object are conservative the equation (1) can be applied:

$$\tfrac{1}{2}\,\boldsymbol{m v_1^2} + \boldsymbol{V_1} = \tfrac{1}{2}\,\boldsymbol{m v_2^2} + \boldsymbol{V_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

They further indicated that frictional forces are not conservative.
Hibbeler[2] qualifies a conservative force by stating "If the work done by a force is independent of the path and depends only on the force's initial and final positions on the path, then we can classify this force as a conservative force." He suggests writing conservation of energy equation as:

$$\boldsymbol{T_1} + \boldsymbol{V_1} + (\textstyle\sum \boldsymbol{U_{1\text{-}2}})_{noncons.} = \boldsymbol{T_2} + \boldsymbol{V_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where $(\sum \boldsymbol{U_{1\text{-}2}})_{noncons.}$ represent work done by all non-conservative forces such as frictional forces.

Gray et al.[3] offers a similar approach as Hibbeler did but Beer et al.[4] states that "for any conservative force we can write:"

$$\oint \mathbf{F} \cdot d\mathbf{r} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where the close circle indicates that the path is closed. Considering the mathematics proficiency of Mechanical engineering Technology students or even Mechanical Engineering ones, the concept of Green's Theorem where equation 3 originates from would be new to them and will have a challenge digesting it. So an easier understanding approach needs to be introduced to students in Mechanical discipline. Based on author's teaching experience, once the concept of conservative force is introduced along with the force–potential energy relationshiop given in equation 4 will ease understanding of the concept.

$$\boldsymbol{F} = -\,\partial \boldsymbol{V} / \partial \boldsymbol{r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Equation (4) presents a definition of Force in terms of Potential Energy and can be used to effectively demonstrate the physical significant of conservative forces as shown below.
A hypothetical plot of a potential Energy- Distance relationship can be as shown in Figure 1.

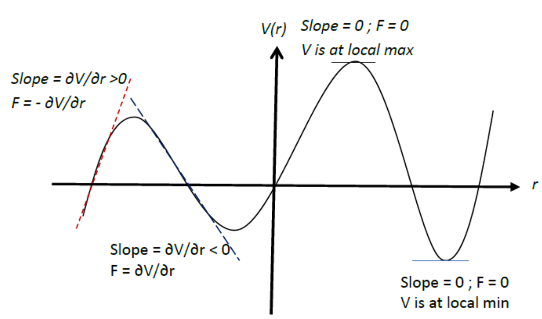

Figure 1: A hypothetical potential Energy (*V*) –Distance (*r*) relationship.

Assuming a ball is placed on the positive slope section of the plot (Figure 1) and since the force acting on the ball will be having negative value ($\partial V/\partial r > 0$) the ball will move to the left (left movement is given arbitrary sign of negative and ball movement to the right is considered positive). Alternatively, if a ball is placed on the negative slope of the plot (Figure 1), the ball will experience a positive force ($\partial V/\partial r < 0$) and will be moving to the right. At either local maximum or local minimum shown in Figure 1 the ball will not experience any force due to the fact that slope is zero in both cases ($\partial V/\partial r = 0$). The only difference between the two extreme equilibrium positions of maxima or minima will be that at the local maxima position, the ball will be in an "unstable" equilibrium position whereas at the local minima position the ball will be at the stable equilibrium.

Equation (3) is actually the heart of Green's Theorem that is given as follows:
Let C be a peicewise-smooth, simple closed curve that bounds a region R in the plane[5]. If P and Q have continuous partial derivatives on an open set that contains R, then

$$\int_c Pdx + Qdy = \int_R\int \{(\partial Q/\partial x) - (\partial P/\partial y)\} dA \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Equation (5) represents a closed curve region that for a conservative vector field represent a circle if the integral equals zero as equation (3) indicated but if it is a non-zero for a vector field such as (*F*=*yi* –*xj*) it can represent a non closed circle such as a spiral shown bellow (Figure 2)

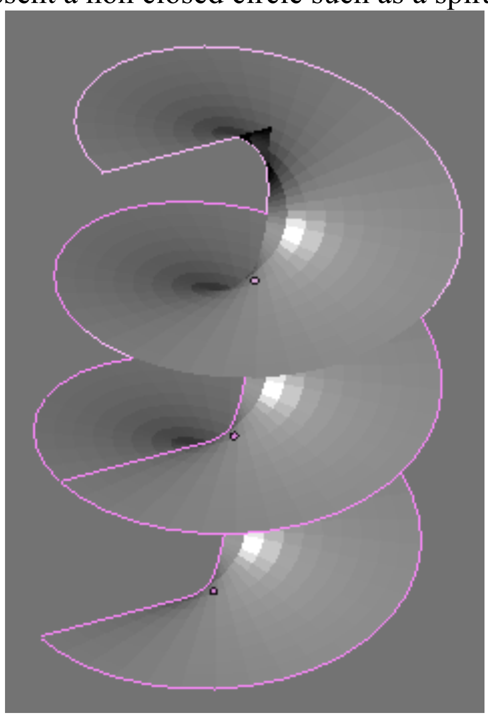

Figure 2: Spiral force function represented by (*F*=*yi* –*xj*)[6].

The best test to determine whether a vector field is conservative is to determine whether the curl of the function is equal to zero or not. All conservative forces meet the following condition:

$$\nabla x F = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where $\nabla = (\partial/\partial x + \partial/\partial y + \partial/\partial z)$ is just an operator and $F = F_x\, i + F_y\, j + F_z\, k$ is the force vector. For example, while $F = (3x^2 - 2xy)i - x^2\, j$ is conservative, $F = (x - xy^2)i + x^2yj$ is nonconservative because the curl of the former is equal to zero where as that of the later is not.

$$\nabla x F = \text{Curl of F} = \begin{vmatrix} i & j & k \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ 3x^2 - 2xy & -x^2 & 0 \end{vmatrix} = (0)i + (0)j + (-2x+2x)k = 0$$

($\therefore$ conservative)

$$\nabla x F = \text{Curl of F} = \begin{vmatrix} i & j & k \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ x - xy^2 & x^2y & 0 \end{vmatrix} = (0)i + (0)j + (2xy + 2xy)\, k = 4xy\text{k} \neq 0$$

($\therefore$ nonconservative)

Summary and Conclusions

In summary, we have described the conservative and nonconservative vector fields in relation to dynamic systems to be included in Engineering Mechanics Dynamics (ENGR 2302) course. Green Theorem is utilized to best describe the mathematics behind the concept and a relatively easy test based on the curl of a given vector field is highlighted to be used in determining whether a vector field is continuous or noncontinuous. In addition, a relationship between force vector field and its potential energy was described for a ball that is physically located in an uphill or downhill slope as shown in Figure 1 so that students can intuitively understand the main concept by following the direction of a force the ball feels. The force exerted on the ball located at a slope indicated the potential energy associated with the ball causing to move the ball to the right or left depending on whether the ball is located on the uphill or downhill slope type. Such a simple explanation along with mathematical backing of the topic should fully educate Engineering and Engineering Technology students on this important topic that may have been chosen to either not fully or lightly explain it in a given ENGR 2302 course.

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The Implementation of Take Home Laboratories Using the NI myDAQ

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Abstract

Every year, new technologies are been discovered, and they affect us in many different ways. They change the way we live, move, think, and learn. Kids these days are very familiar with computers, gaming consoles, the internet, and cell phones. For them, things like encyclopedias, chalk boards, and trigonometric tables are ancient history. That is the reason why they consider the internet the place where most, if not all necessary information can be found. We need to remember that the internet was introduced to the public in the 1990s. That means that most of the kids graduating from high school have been interacting with the internet since they were born. The question is: How we take advantage of all these new technologies to improve, or captivate the attention of this new generation of students in the classrooms and laboratories? We all know that online learning is becoming more and more popular. However, in engineering, learning is not limited to lecture; there are multiple laboratories that require sometimes expensive pieces of equipment. For that reason, the teaching community has been studying different ways to develop online laboratories. The department of electrical engineering at UT Tyler has decided to take a step forward and start testing new technologies that can be used to teach a linear circuit laboratory remotely. In order to keep control and reduce any possible negatives effects from this implementation, it was decided to create a laboratory in which the students will be working experiments in the laboratory, and they will complement their learning by working additional experiments at home. In this paper, the results from such implementation and some examples of the exercises given to the students will be presented.

Introduction

Online learning, that is a word that many of us don't want to hear. For some people, it means a lot of work and efforts preparing the best lecture possible in order to teach a course. It needs to be understood that Online Learning should not be the same in every field. If we consider lectures in the field of social sciences, they may require a big amount of graphs, pictures, tables, and diagrams, in arts, they may require audio, high-quality images, and video. However, it is a different story when STEM courses are considered. Even between the fields that compose the STEM area, there are remarkable differences between the teaching styles. For example, in math, they will need to develop mathematical procedures and make graphs; on the other hand, in chemistry, they may need pictures, videos and some mathematical procedures. For that reason, online teaching techniques need to be adapted for each specific case in order to satisfy all the course requirements. This does not mean that this knowledge cannot be used to develop courses in other areas, but it needs to be carefully analyzed to see whether it will work for the other courses.

Every year, new technologies are been discovered, and they affect us in many different ways. They change the way we live, move, think, and learn. Kids these days are very familiar with computers, gaming consoles, the internet, and cell phones. For them, things like encyclopedias, chalk boards, and trigonometric tables are ancient history. That is the reason why they consider the internet the place where most, if not all necessary information can be found. We need to remember that the internet was introduced to the public in the 1990s. That means that most of the kids graduating from high school have been interacting with it since they were born. Many instructors keep wondering why teaching techniques that used to work 10 years ago are not working as good with this generation of students. Many believe that is related to the way that kids learn now days. For that reason, we need to take advantage of all these new technologies to improve, or captivate the attention of this generation of students in the classrooms and laboratories.

It is well known that in engineering, learning is not limited to lecture; there are multiple laboratories that require sometimes expensive pieces of equipment. For that reason, the teaching community has been studying different ways to develop online laboratories. The department of electrical engineering at UT Tyler has decided to take a step forward and start testing new technologies that can be used to teach a linear circuit's laboratory remotely. In order to keep control and reduce any possible negatives effects from this implementation, it was decided to create laboratory procedures in which the students will be working in experiments inside the laboratory, and they will complement their learning by working additional experiments at home. Some options were studied, and for this purpose, it was decided that the NI myDAQ was the best suited for our necessities. It is realized that this is not the only system capable of this, but for the department of electrical engineering was the most suitable option. The reason is that currently, National Instruments software (Multisim, Ultiboard, LabView) is used all over the curriculum. For this course, the students were required to buy their own NI myDAQ to allow them to perform the experiments at home. At the end of the semester it was found that the students enjoyed the possibility of working the experiments at home and even testing their own circuits.

Previous Work

Engineering courses present great challenges when online lectures or laboratories are developed. Typically, they require considerable amounts of mathematical procedures, proofs and hands-on experience. This imposes a big burden for the professor who is preparing the course. Universities have invested considerable amounts of time and efforts in developing them. The objective is to develop an efficient way to transfer knowledge remotely. Some of these efforts include: videotaping lectures and posting these videos on the web so that students will be able to access them at any time[1], webcasting or video-conferencing lectures so that students will be able to have some level of interaction with the professor[2-3], posting lecture materials like PowerPoint's and lecture notes for the students[4-6], remote laboratories that will allow students to make laboratory practices from any place[7-10]. There are also studies focused on the impact of web-based courses on different groups of students[11].

From all these approaches, the work done by Melkonyan and Chesnutt are the most related to this paper. In the work done by Melkonyan, they used a NI ELVIS in conjunction with the EMONA DATEx board to develop remote laboratory architecture for a radio-communications course. The professor or teaching assistant will need to prepare the experiment before hand, and the students will login from their computers to perform measurements in the previously assembled experiment. The measurements were performed using a LabView Interface and by physically observing the setup with the help of a webcam. It is evident that this approach presents a good solution to provide hands-on experience to the students in communications, by allowing them to observe and manipulate the inputs and outputs of the experiment. However, this system does not allow the students to learn from assembling the system. It is well known that they learn more by making mistakes and debugging the circuit. On the other hand, Chesnutt decided to use the NI myDAQ to provide some hands-on experience to students taking Electric Circuit Theory courses. In this case, they used it to assign homework problems related to the topics seen during the lecture. Definitely, this is a good approach to provide physical demonstration to the concepts covered in the lecture.

All these methodologies were studied and analyzed, and it was decided to include the myDAQ in the Linear Circuit Analysis course, not as a replacement to the current lab procedures and equipments, but as an addition to the current content. The rationale is to provide the students with the opportunity to work with real and virtual laboratory equipment. Even in some cases the results obtained using the physical equipment were compared against the results obtained using the myDAQ.

Linear Circuits Analysis Laboratory

The Linear Circuits Analysis Laboratory is composed eight laboratories. Each of them designed to enhance the student understanding in linear circuits and laboratory equipment. From the eight laboratories, a total of four labs required the use the myDAQ to perform measurements. A list of topics that include the use of myDAQ is shown below.

- Introduction to myDAQ
- Voltage, Current and Resistance
- Thevenin Resistance and Thevenin Equivalent

- Operational Amplifiers

It needs to be noted that all eight laboratories require the used of physical equipment, and only those four laboratories contained extra experiments that require the student to work from home.

The very first myDAQ laboratory familiarizes the students with the unit and the different virtual instruments. They learned about the multiple inputs and outputs available and how to use them. In the second myDAQ laboratory, the students learned how to use the virtual Digital MultiMeter (DMM) and how to measure current, voltage and resistance. The students were given one DC circuit and one AC circuit. From both circuits, they were required to measure voltages and currents. On the AC circuit, they were also asked to use the Virtual O-Scope to observe the voltage at different points in the circuit and measure its frequency and amplitude. On the next laboratory, the students were given an AC circuit, and they were asked to find the Thevenin equivalent using the myDAQ. The last laboratory required the students to build and observe the characteristics of a Difference Amplifier using the myDAQ. For all laboratories, the students were asked to submit a report that includes the work made in the laboratory, and the work made using the myDAQ. Figures 1 and 2 are examples of the circuits given to the students to build and test in myDAQ.

In addition to the laboratory procedures, this course contains two practical exams. The purpose of these is to enforce the understanding of the laboratory procedures, and the use of laboratory equipment. The used of the myDAQ was included in the second practical exam. The students were required to build and test a High-Pass filter given some specifications. They measured the amplitude of the signal at the output of the filter for different frequencies.

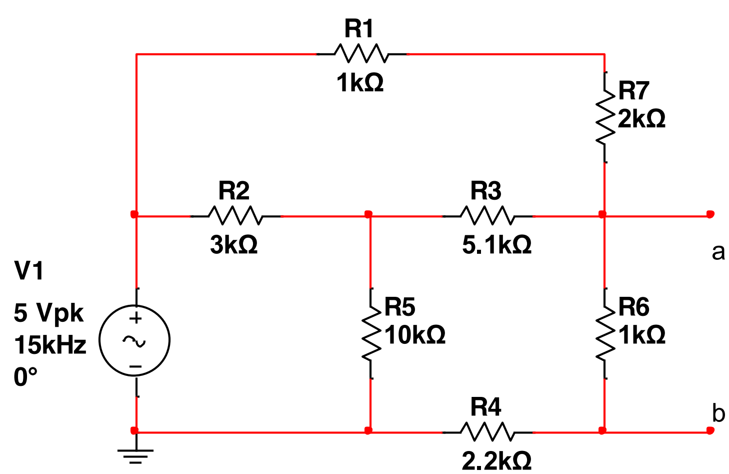

Figure 1. Circuit used in myDAQ to find the Thevenin Equivalent

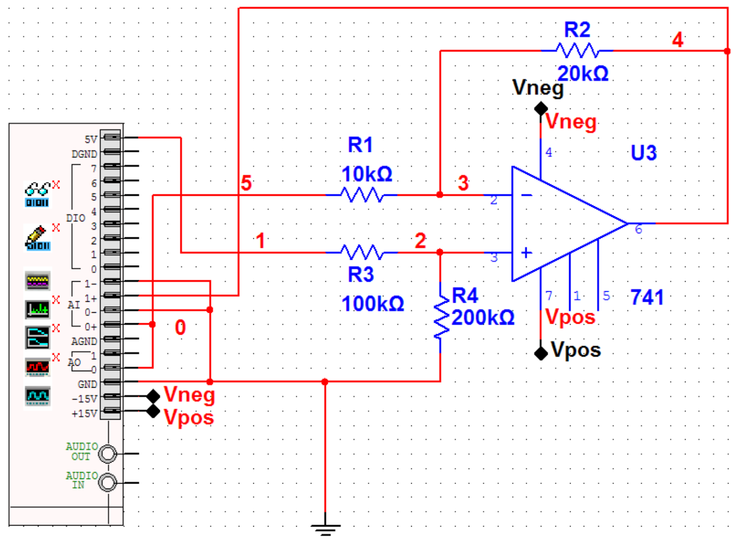

Figure 2. Difference amplifier built using the myDAQ

Results and Comments

By the end of the semester, the students were given a course evaluation survey in which they assess different aspects of the course. One of the sections included the rating of the usefulness of the myDAQ. The average rating for the myDAQ was 3.4/5.0. The instructor considers that the rating was low compared to other elements of the course, because of some problems faced with the equipments at the beginning of the semester. For example, a couple of myDAQs were not working properly, and students never informed the professor about this problem until last week of the semester. The instructor responsible for the course has decided to include an extra laboratory in which the students will check every component of the Data Aquisition Card to ensure the proper functionally of the unit. It is expected that this will reduce the number of problems, and it will create a smother experience for the students. The instructor has also decided to include more experiments that require the use of myDAQ. By doing this the faculty expects to improve the acceptance of this new equipment and technology.

In summary, the implementation of the myDAQ can be considered a success. However, more work is required in order to make the experience more enjoyable for the students, so they can appreciate the advantages of virtual instruments and the ability to perform the experiments at home. By next year, it is expected that an update in regard to this course will be presented.

Conclusions

In the Spring of 2012, the department of electrical engineering decided to include the NI myDAQ as part of the equipment for the Linear Circuit Analysis Laboratory. This was the first time in the department that something of this nature was attempted. The myDAQ was used to assign take home laboratory to the student, so they can work the experiments from home. During this first implementation, it was observed that the students enjoyed the opportunity of working laboratory experiment from home. However, a couple of problems related to the functionally of the unit were observed. In order to avoid problems in the future, an extra laboratory will be added, designed to test the functionally of the unit. It is expected that the laboratory will be offered again during the spring of 2013, and more experiments related to the used of the myDAQ will be included.

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Feasibility Study of a Thrust Vector Control Transport

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Abstract

Thrust Vectored Control (TVC) has the potential to advance the design of commercial transports. This research evaluates the feasibility of a TVC commercial transport concept in three phases; (1) thrust vectoring technology review, (2) parametric sizing of a TVC transport, and (3) stability and control (S&C) FAA certification & safety assessment of the proposed transport. The baseline selected for the study is the long-haul wide-body mission (325 PAX, 8,000nm at M0.85) represented by the B777-300ER. The baseline B777-300ER as well as the modified TVC B777 are sized and compared. The results show a 17% increase in L/D, a 17% reduction of empty weight, a 27% decrease in fuel weight and an 18% decrease in Direct Operating Cost (DOC) from the TVC B777 to the baseline. The S&C analysis shows that the aircraft needs to be flown unstable in order to reduce the control power burden on the engines. It also shows that directional control in cross wind is the most design-constraining flight condition (DCFC) and that the vehicle is uncontrollable with one engine out. Further work is necessary to mature this first generation B777-TVC transport concept into a certifiable thus safe next generation transport.

Introduction

The commercial transport is approaching a fuel burn performance plateau with the typical Tail Aft Configuration (TAC) wing-tube-empennage design. Over its 92 year history, there have been two significant performance paradigm shifts. One in the 1950's, caused by propulsion upgrades with the dawn of the jet age. The other in the late 2000's, caused by the significant weight reduction from full composite structures. NASA projects a need for an additional 70% decrease in fuel burn performance within the next 30 years (N+3), see Figure 1. This demand requires another paradigm shift. The Thrust Vector Control (TVC) commercial transport offers potential to contribute to such innovation because of the significant weight and drag reduction benefits it provides. This paper describes the feasibility of this technology. The first section is a TVC review which includes a literature survey of TVC technologies and a description of effect of removing empennages. The second section is a parametric sizing study that compares the performance of a TVC transport to a convention transport if both are sized to a typical commercial transport mission. The third section evaluates the ability of the vehicle to perform maneuvers required for FAA certification.

CORNERS OF THE TRADE SPACE	N+1 (2015)*** Technology Benefits Relative to a Single Aisle Reference Configuration	N+2 (2020)*** Technology Benefits Relative to a Large Twin Aisle Reference Configuration	N+3 (2025)*** Technology Benefits
Noise (cum below Stage 4)	- 32 dB	- 42 dB	- 71 dB
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance Aircraft Fuel Burn	-33%**	-50%**	better than -70%
Performance Field Length	-33%	-50%	exploit metroplex* concepts

*** Technology Readiness Level for key technologies = 4-6
** Additional gains may be possible through operational improvements
* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

Figure 1. NASA Subsonic Transport System Metrics1

TVC Technology Review

Thrust vectoring is the deflection of the thrust line in order to create multi-dimensional forces and moments which can enhance aircraft performance and control. It is quite different from differential thrust which involves varying magnitude of thrust of multiple engines. TVC systems can be classified based on actuation mechanism, control axes and operation scheme.

TVC Classification

There are three mechanisms for actuating TVC, namely: external actuation, internal actuation and fluidic actuation. External actuation is the least efficient mechanism. It involves either gimbaling the entire engine or adding deflection devices post-nozzle such as paddles, buckets or flaps. Internal actuation involves controlling the shape of the engine nozzle to produce a desired thrust vector deflection. It is the most efficient TVC mechanism; Ikaza2 claims up to a 7% off-design thrust improvement because of the ability to vary nozzle exit area while thrust vectoring. Fluidic actuation is an experimental mechanism in which TVC is achieved by using a secondary fluid stream to manipulate the primary jet stream3 (See Sparks[4], Mason[5], Gu[6], Sobester7).

The control axes classification of TVC is based on the number of rotational axes (pitch [P], roll [R], yaw [Y]) that are effected. For example, Lockheed Martin's F-22 Raptor is a PTVC because the thrust vector effects only pitch control. On the other hand, The F-16 VISTA with its single Multi-Axis Thrust Vectoring (MATV) nozzle is a PYTVC. It corresponds that a single 2-D nozzle allows single axis control, one 3-D nozzle allows 2-axis control and multiple nozzles allow for 3-axis control.

Gal ‘Or8 gives the operational classification of TVC systems as pure and partial systems. Pure TVC aircraft use only vectored thrust for the entire flight control force. Partial TVC aircraft use a mixture of both thrust vectoring as well as aerodynamic devices for control. This current study examines the feasibility of TVC to by evaluating the feasibility of a pure PYTVC commercial transport (i.e. a tailless commercial transport). Other than some model aircraft and missiles, there are no manned pure TVC aircraft in service9; however, there are many aircraft with partial TVC.

Applications of TVC Technology

TVC has predominantly been used in fighter aircraft for increased maneuverability (e.g. F-22, JSF and Su-37); and for Vertical or Short Take-Off and Landing (VTOL/STOL) capability (e.g. AV-8A Harrier). Some experiments have demonstrated the feasibility of a pure PYTVC fighter (tailless fighter) using the X-31A as a test-bed9[-12]. The results show many benefits for military application with the benefit of reduced cross section area as the key one.

Gal ‘Or[13-14] explores the use of partial TVC to increase the safety of commercial transports. This concept has been proven by successful flights of a partial TVC B727[15] and the patents[16-18] for its TVC technology. NASA also has successful tests of Propulsion Controlled Aircraft (PCA) with MD11 and B747 testbeds[19-21]. Although those experiments use differential thrust control not TVC, they are relevant to the general concept of control augmentation of commercial vehicles using thrust.

Finally, Steer[22] proposes the use of partial TVC on a second generation Supersonic Commercial Transport (SCT). The idea is to improve low speed performance where aerodynamic controls stall and augment supersonic controllability when aerodynamic controls lose effectiveness. There has not been a proposal for a pure PYTVC commercial transport as has been for fighter aircraft; however, such a vehicle will provide benefits as well as unique challenges.

Benefits and Challenges of a PPYTVC Commercial Transport

The benefits of a pure PYTVC commercial transport include:

- Significant weight reduction from removal of empennages.
- Overall drag reduction from removal of tail surface area.
- Trim drag reduction from elimination of induced drag due to tail lift (note that trim drag is not entirely eliminated because of induced drag from the additional wing lift required to counter engine trimming forces. This is a consequence of the stable Tail-Aft configuration [TAC]).
- Improved stall performance and spin recovery due to independence from aerodynamic control effectiveness.

- Decrease in takeoff speed and takeoff field length.

The major challenges include:

- Negative public perception of radical designs.
- Fatality if all engines fail.
- Thrust requirement increase for control power demands.
- Propulsion weight increase from TVC modifications.
- Specific fuel consumption increases from mixed flow turbofan compared to high bypass unmixed turbofan.

The implications of these merits and demerits in a total system context are quantified in the next section via a parametric sizing study.

Parametric Sizing of A TVC Commercial Transport

Parametric sizing is the determination of the size/scale of a vehicle required to meet desired design and mission specifications. The value of the TVC transport is assessed by comparing its predicted performance and cost to a baseline commercial transport. Both vehicles need to be sized to same baseline mission in order to consistently compare them. *AVDSizing* is used in this study to accomplish this task.

Description of *AVD*^{Sizing}

AVD^{Sizing} is a methodology and tool that arrives at a vehicle, given a set of design parameters and mission specifications, by converging multiple disciplines including aerodynamics, propulsion, trajectory, weights, volume and cost. The tool is a FORTRAN 90 program developed by Coleman[23] based on a process developed by Czyzs[24, 25]. The modular design of *AVD*^{Sizing} allows for quick adaption of disciplinary methods to handle new design problems such as a TVC commercial transport. A Nassi-Schneiderman diagram of the sizing logic is shown in Figure 2 and the methods that have been used for this study are given in Table 1.

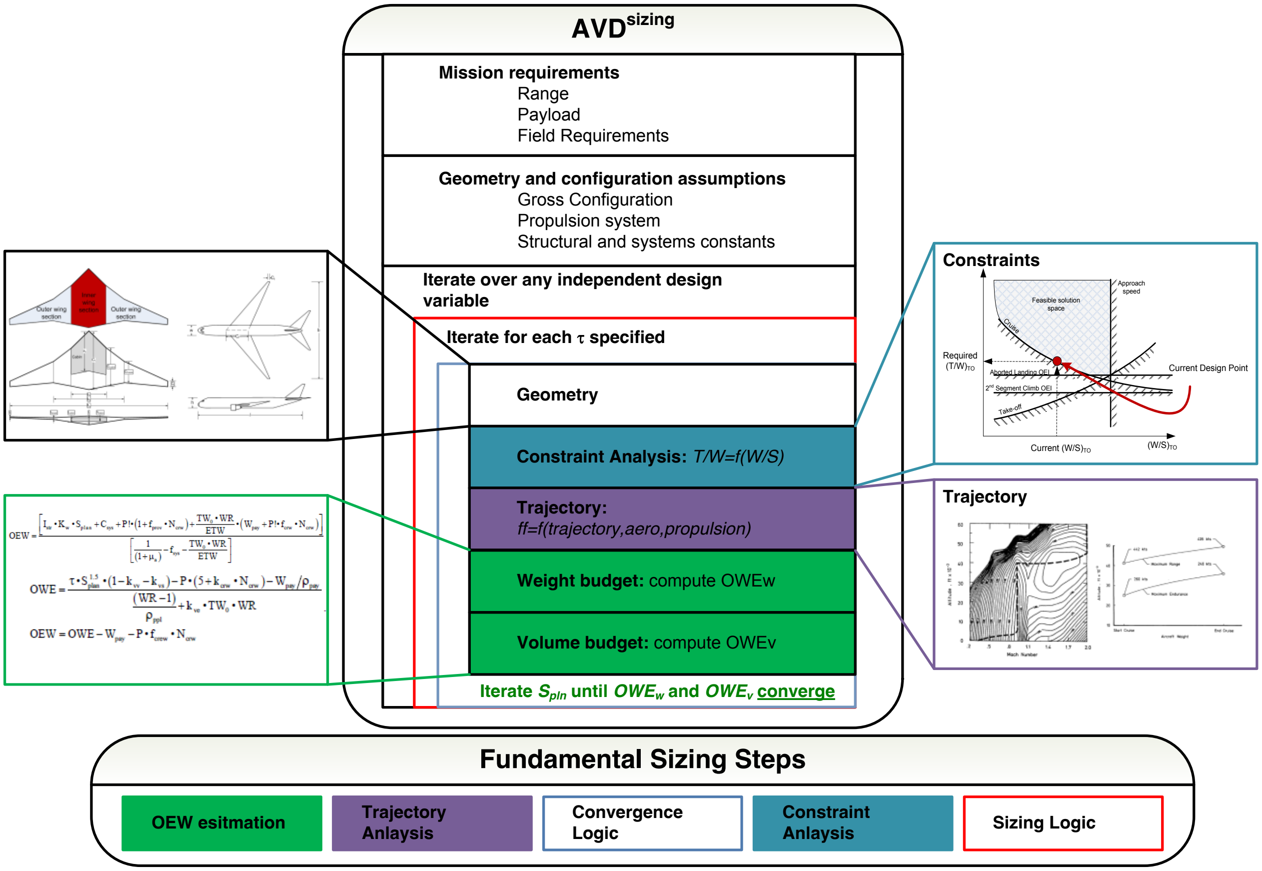


Figure 2. Nassi-Schniderman of *AVD*^{Sizing} Logic

Table 1. Disciplinary Methods Summary

DISCIPLINE	METHOD TITLE	DESCRIPTION	REFERENCE
Geometry	Transonic TAC	Parametric equations for the geometry of a TAC transport	Coleman[23]
	Modified Tail-Volume Coefficient	Parametric equations for the empennage geometry a TAC transport based on its main wing shape	Morris[26]
Aerodynamics	Subsonic Skin Friction Estimation	Construction of the skin friction drag coefficient using an equivalent flat plate method	Smith[27]
	Subsonic partial laminar skin friction estimation	Computation of the skin friction coefficient based on a given transitional Reynolds number for partial laminar flow airfoils.	Roskam[28]

	Drag Due to Flaps and Landing Gear	Typical drag coefficients for flaps effects in take-off and landing configurations	Roskam[29]
	McDonnell Aircraft Company Wave Drag Approximation	Drag rise as a function of Mach no. based on an approximation of the area distribution to the sear hack body.	Coleman[23]
	Induced Drag	Mach number corrections from Vought wind-tunnel testing to the induced drag method presented in DATCOM	Vought[30]
	Lift Curve Slope	3-D wing lift curve slope for strait tapered wings	Hoak[31]
	Maximum Landing Lift Coefficient	Value maximum lift coefficient selected based on similar aircraft	Roskam[29]
	Lift to Drag Ratio	Computes the L/D for a given location on the drag polar	Vinh[32]
Propulsion	Turbofans, Turbojet, and Turboprop SFC variation	Statistical regressions for SFC values for High bypass turbofans, Low bypass turbofans, Turbojets and Turboprop engines	Mattingly[33]
	Turbofans, Turbojet, and Turboprop Thrust lapse	Statistical regressions for thrust lapse values for High bypass turbofans, Low bypass turbofans, Turbojets and Turboprop engines	Mattingly[33]
	Turbofan Engine Preliminary Design Tool	Statistical regression for turbofan weight, dimensions and performance	Svoboda[34]
Performance	Stall Speed Representation	wing loading requirements calculation from lift coefficients at various stall speeds	Roskam[29]
	Landing Distance Representation for FAR 25 aircraft	Approach speed, stall speed and landing wing loading (W/S) requirements calculation from given design landing field length and lift coefficient	Roskam[29]
	Take-off Distance Representation for FAR 25 aircraft	Take-off thrust-to-weight ratio (T/W) requirement calculation from design Take-off field length and lift coefficient	Roskam[29]
	Take-off to Climb performance matching for FAR 25 aircraft	T/W and W/S requirements for flight segment between take-off and climb.	Coleman[23]
	Climb performance matching for FAR 25 aircraft	All Engines Operable (AEO) and One Engine Inoperable (OEI) Climb T/W requirements calculation for take-off and balked landing.	Loftin[35]

	Cruise Matching	T/W and W/S requirements for cruise.	Coleman[23]
	Time to Climb	T/W as a function of W/S and initial climb speed and cruise altitude. Initial climb speed and cruise altitude are solved for iteratively during performance matching	Coleman[23]
	Climb Requirements for Jet Powered Aircraft	T/W as a function of W/S and initial climb speed and cruise altitude. Initial climb speed and cruise altitude are solved for iteratively during performance matching.	Roskam[29], Coleman[23]
	Range and Time to Descent	Assume power reduced to flight idle (power off) the flight path angle, rate of descent range covered and time of descent from cruise altitude is computed.	Roskam[36]
	Maximum Velocity Constraint for Jet Powered Aircraft	T/W requirement for a given wing loading and time to climb	Roskam[29]
	Ceiling Requirements for Jet Powered Aircraft	T/W as a function of W/S and initial climb speed and cruise altitude. Initial climb speed and cruise altitude are solved for iteratively during performance matching	Roskam[29]
	Initial Fuel Weight Estimation	Fuel fractions calculations for each mission segment based on typical values or from the Breguet range and endurance equations with assumed L/D and SFC.	Roskam[29]
Stability and Control	Approximate Trim Solution 1	Simplified 2-D (Lift and pitching moment) trim solution to compute the corresponding basic (untrimmed aircraft) lift and the longitudinal control effectors (LoCE) lift contributions.	Coleman[23]
	Approximate Trim Solution 2	A combination of DATCOM and Torenbeek methods for estimating both the zero lift pitching moment and distance from the c.g. to the wing body aerodynamic center. For use with the Approximate Trim Solution 2.	Hoak[31], Torenbeek[37]
Weight and Volume	V-N diagram and structural limits for FAR 25 aircraft	Construction of the maneuvering and guest V-N diagram based on design trend for FAR 25 commercial transports.	Roskam[38]
	Convergence Empty Weight Estimation	method for estimating the converged empty weight based on volume and mass based on Czysz[25]	Coleman[23]

Wing Structure Group Weight Fraction Method	Estimation of structural weight fraction in terms of ultimate load factor, wing dimensions, and Max Take-off Gross Weight, Max Zero Fuel Weight	Nicolai[39]
Fuselage Mass Estimation	Fuselage mass based on basic geometry and structural constraints	Howe[40]
Tail Structure Group Weight Fraction Method	Estimation of structural weight fraction in terms of ultimate load factor, wing dimensions, and Gross Weight.	Torenbeek[37]
Raymer cargo/ transport aircraft Nacelle Weight Method	Empirical weight estimation for turbojet and turbofan engines	Raymer[41]
Torenbeek Commercial Transport Landing Gear Weight	Empirical landing gear weight estimation for transport type aircraft	Torenbeek[37]
Power Plant Mass Estimation	Correction factor to dry propulsion system weight for installation (nacelles, pods, cowlings, propeller, etc.)	Howe[40]
Refined Hydraulic and/or Pneumatic Group Weight Method	Estimation of Hydraulic systems weight in terms of gross-take-off weight	Roskam[38]
Refined Instrumentation Group Weight Method	Estimation of instrumentation, aviation and electrical n weight in terms of number of engines, pilots, PAX, take-off weight, empty weight	Roskam[38]
APU Weight Method	Typical weight fraction values for APU weight.	Roskam[38]
Furnishings Weight Method	Furnishing weight based on correlation with maximum zero fuel weight	Roskam[38]
Baggage Handling Equipment Weight Method	Empirical correlation for baggage and cargo handling equipment for use in military and commercial freighters	Roskam[38]
Operational Items Mass Estimation	Mass estimation for operating items including crew personal items, safety equipment, freight equipment, water and food, residual fuel	Howe[40]

`Cost	Life Cycle Cost	Life Cycle cost is estimated from the summation of Research, Development, Testing and Engineering Cost (RDTE), Acquisition cost (ACQ),Operations Cost (OPS), and Disposal (DISP)	Roskam[42]
	RAND DAPCA IV RDT&E and Production Cost Model	DAPCA is comprised of Cost Estimating Relationships (CER's) for RDT&E and production broken down by, (1) Engineering (2) tooling (3) manufacturing (4) quality control (5) development support (6) flight-testing and (7) manufacturing material costs.	Hess[43]
	Manufacturing and Acquisition Cost	Build-up of manufacturing and acquisition costs	Roskam[42]
	Direct Operating Cost for Commercial Airplanes: DOC	An adaptation of ATA-method which decomposes direct operating cost into 5 components, (1) Flight (2) Maintenance (3) depreciation (4) landing fees, navigation fees, registry taxes, and (5) financing direct operating costs	Roskam[42]
	Block Mission for Commercial Transports	This method estimates the block, range, speed and time for DOC computation purposes	Roskam[42]

Baseline Mission

A mission derived from the B777-300ER has been selected to test the feasibility of the TVC commercial transport. It is a long-haul wide-body mission to fly 325 PAX a range of 8,000nm at a cruise speed of M0.85. This mission is selected because its long cruise segment can benefit from the weight and drag reduction TVC offers. Table 2 summarizes this design mission.

Table 2. Summary of Baseline Mission

Mission Specification	
Crew weight	
Crew	
(1-Captin, 1-1st officer, 14 cabin attendents)	1472 kg (3,250 lbs)
Payload weight	
Maximum (175 lbs passenger + 40 lbs cargo)	
370 pax (3-cabin), 33,770 kg cargo	69853 kg (154,000 lbs)
Design Passengers (325 pax, 6,474 kg cargo)	38168 kg (84,150 lbs)
Range	

Design	14075 km (8,000 nm)
Velocity	
Design Cruise Speed	0.85 M
Altitude (m)	
Max operating	12,200 m (40,000 ft)
Take-off field length (TOGW)	< 3,048 m (1,000 ft)
Landing field length (max landing weight)	< 1,767 m (5,780 ft)
Fuel reserves	926 km (500 nm)

Sizing Results

Baseline B777-300ER Sizing

AVD^{Sizing} produces a solution space of converged vehicles sized to mission by varying design independent variables such as aspect ratio (AR) and Kuchemann slenderness parameter (τ), see Figure 3. The shaded area represents the unfeasible design space due to the landing wing loading constraint. The design point can be selected from any number of objective functions. In this instance, minimum Direct Operating Cost (DOC) is used for. Table 3 compares the selected design point and the B777-300ER reference[44]. The errors are within acceptable limits for the conceptual design phase, thus the baseline vehicle is validating the methodology.

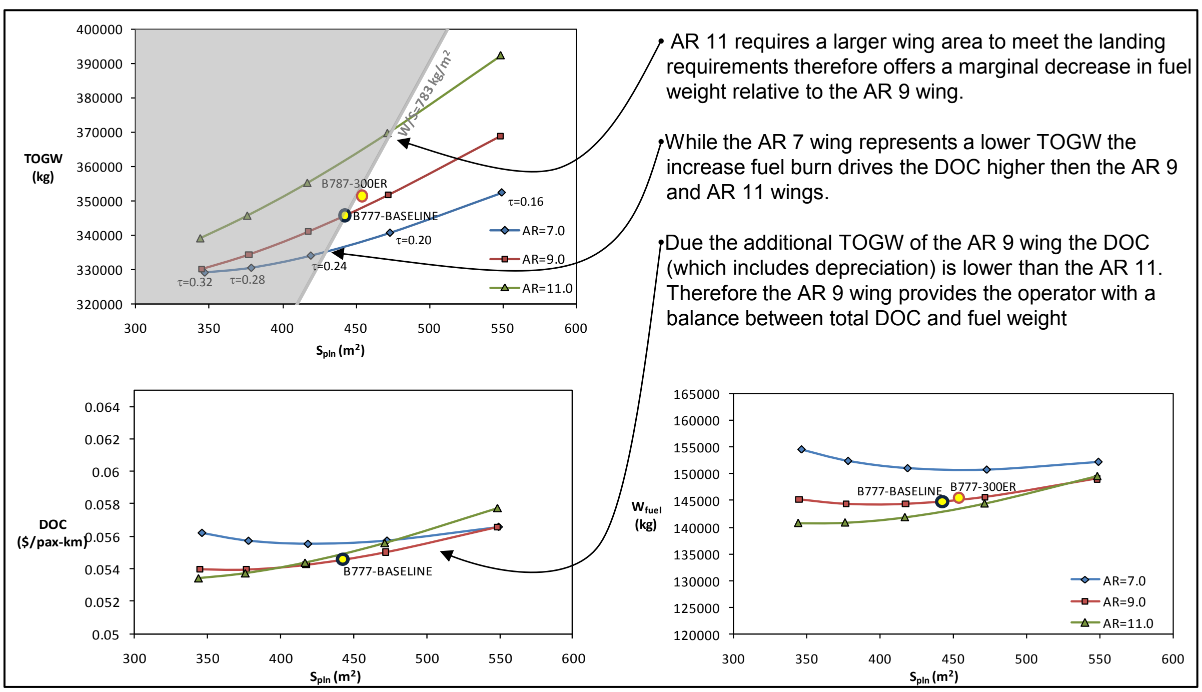
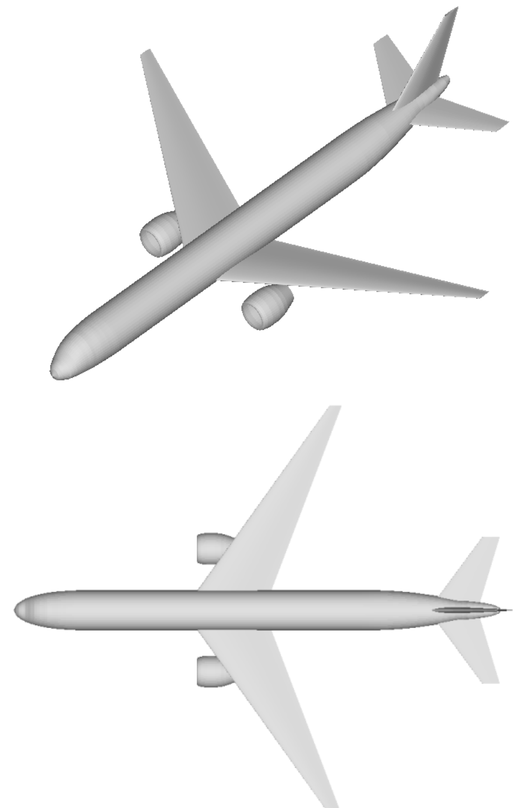


Figure 3. Baseline Solution Space

Table 3. Validation of Baseline B777-300ER Design Point

	B777-300ER	DESIGN POINT	% error	Design Point Geometry
Geometry				
τ		0.21		
AR	9.25	9.00	-2.69%	
S_{pln} (m^2)	454.00	457.49	0.77%	
b (m)	64.8	64.17	-0.98%	
l_{fus} (m)	73.08	74.78	2.32%	
d_{fus} (m)	6.20	6.20	0.00%	
Weight				
TOGW (kg)	351535	359357	2.22%	
W_{fuel} (kg)	145538	148503	2.04%	
MLW (kg)	251290	256868	2.22%	
$(W_{PAY})_{design}$ (kg)	38168	38168	0.00%	
OEW (kg)	167829	172686	2.89%	
Aero-Propulsion				
ff	0.414	0.413	-0.18%	
Thrust (kN/engine)	514	548	6.62%	
$Alt_{cruise\ avg}$ (m)		10722		
L/D_{cruise}		17.46		
SFC_{cruise} (/hr)	0.56	0.56	-0.20%	
Cost				
DOC ($/pax-km)		0.07260		
Unit price ($ M)	202	205	1.67%	

B777-TVC Sizing

The TVC modifications made to the baseline B777-300ER are summarized in Figure 4. The assumptions for DOC calculations are shown in Table 4. Figure 5 shows a comparison between the B777-TVC and B777-300ER. The removal of the empennage results in an overall reduction in weight and wetted surface area (S_{wet}) which leads to an increase in lift-to-drag (L/D) aerodynamic efficiency. This improvement in efficiency allows for the selection of an AR = 7 wing which is lighter and has better stability characteristics. This translates into a 27% decrease in fuel burn for the mission. In addition, the direct operating cost (DOC) decreases by 12%. However, the cost of such state-of-the-art research and development offsets and DOC reduction and causes an increase in unit price. These results show that, if certifiable, the B777-TVC is worth an investment. The issue of airworthiness is addressed in the next section.

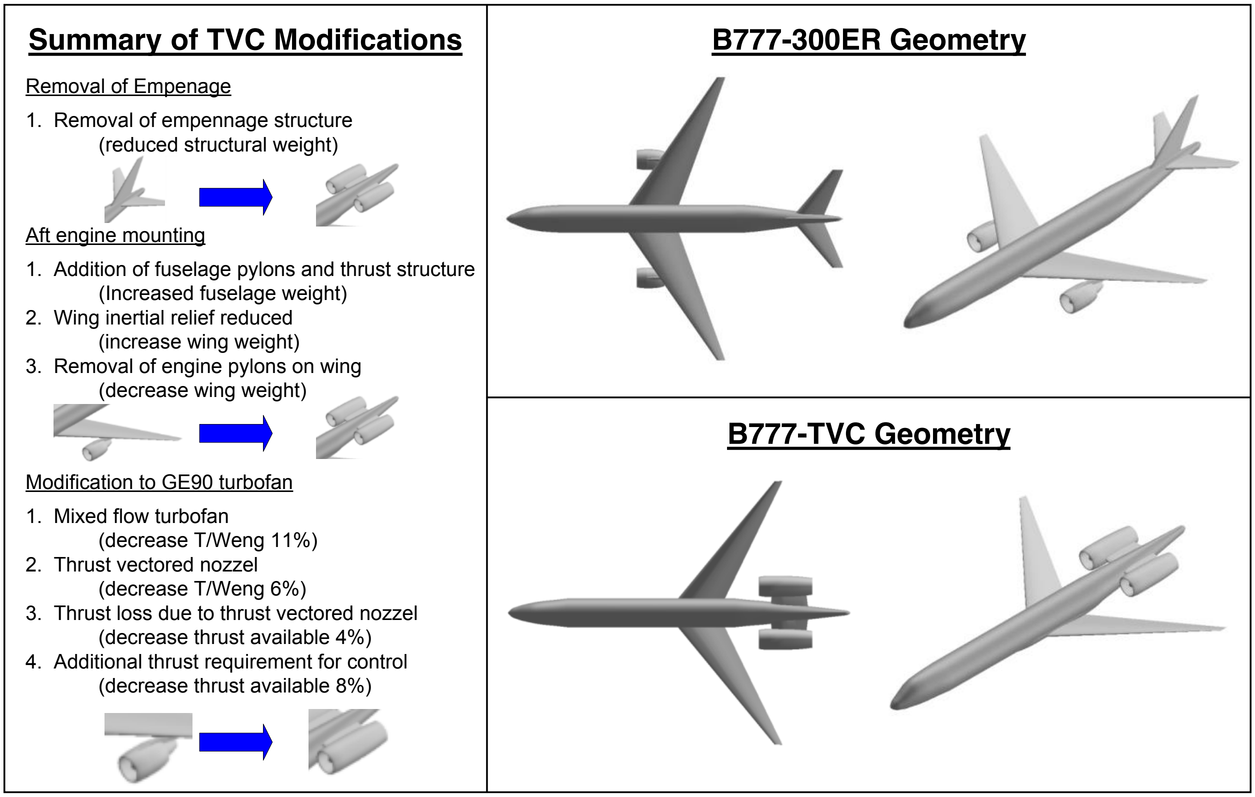


Figure 4. Summary of TVC Modification

Table 4. Direct Operating Cost Calculation Assumptions

Weighting Factor	
Fuel Cost	$5.00/gal
Annual hull insurance rate	0.05
Crew Cost	
Captin	$85,000/yr
1st Officer	$50,000/yr
Attendants	$32,000/yr
System Development Complexity Factors [F x RTDE cost]	
Propulsion Thrust vectored control	1.20
Flight control System (Baseline and statically stable TVC)	1.25
Flight control System (unstable TVC)	1.50
System maintenance Complexity Factors	
Propulsion Baseline Time-Between Overalls [ΔTBO]	16,000 hrs
Propulsion Thrust vectored control [ΔTBO]	-4,000 hrs

Depreiation factor	0.85
Depriation time frame	20 yrs

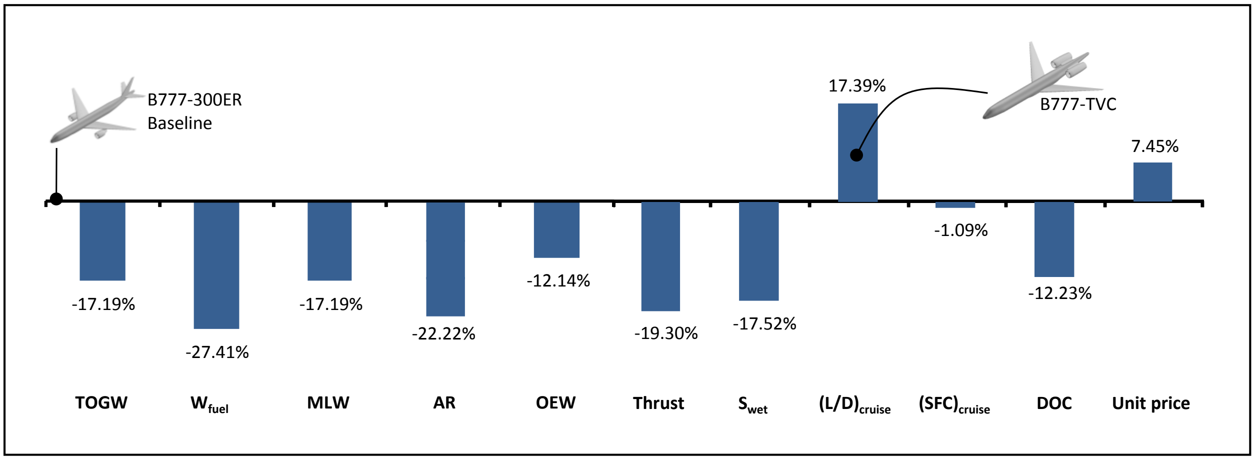


Figure 5. B777-TVC and B777-300ER Comparison

Stability and Control (S&C) FAA Certification & Safety Assessment

The TVC commercial transport needs to meet the Federal Aviation Administration[45] (FAA) and the Joint Aviation Authorities[46] (JAA) regulations in order to be commercially viable. Chudoba[47] translates these regulations into a comprehensive list of Design Constraining Flight Conditions (DCFCs) for sizing aircraft control effectors. The identification of these DCFC's is part of the control power evaluation methodology and simulation tool *AeroMech*[47].

Description of *AeroMech*

AeroMech is an aircraft configuration independent stability and control methodology and tool for conceptual design which provides a means of properly sizing Control Effectors (CEs) such as ailerons early in the design process. The tool is a FORTRAN 90 program written by Coleman[48] based on Chudoba's[47] methodology. Figure 6 shows the structogram of the methodology as it has been implemented.

TVC sizing results provide the required aircraft input data. Subset DCFCs are selected from Chudoba's[47] comprehensive list. Since the aircraft has a traditional wing, the typical stall conditions are critical. The vehicle is engine thrust controlled; therefore, high altitude and high speed conditions, which typically do not size aerodynamic control effectors, are considered. This is because engine thrust limits are reached at these conditions. Figure 7 shows the critical corners of the flight envelope for consideration in assessing the control power of a (TVC) aircraft. A modified version of Digital DATCOM[49] provides aerodynamic prediction at these conditions.

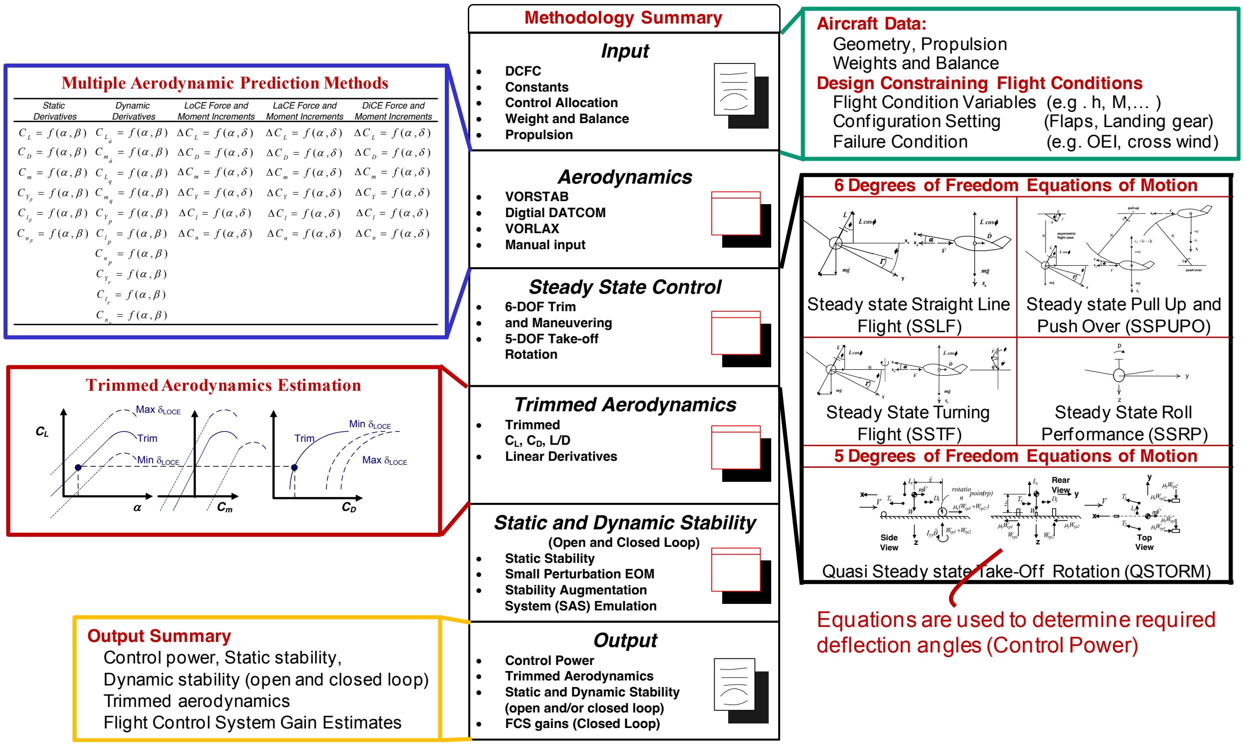


Figure 6. Nassi-Schniderman Diagram of *AeroMech* Methodology

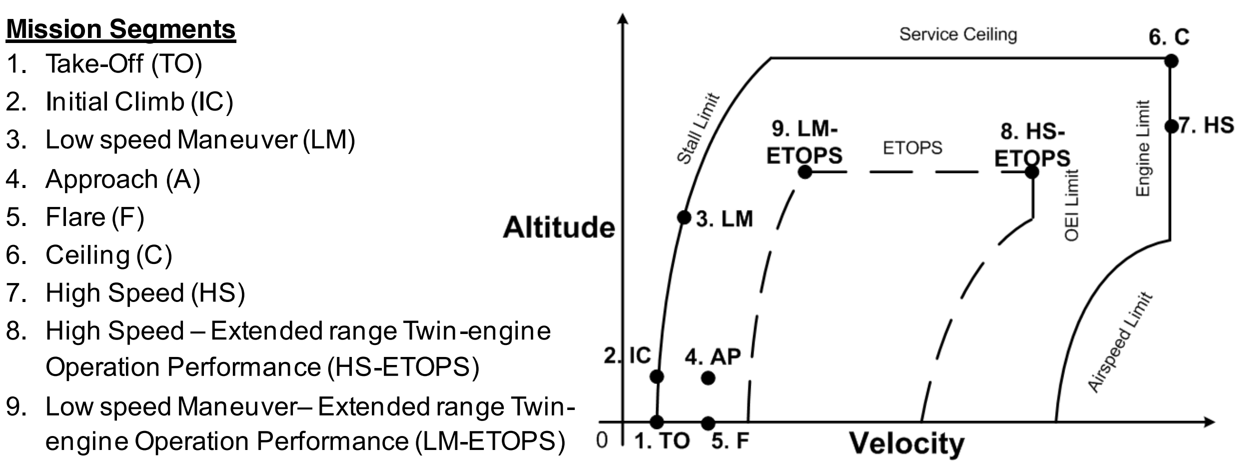


Figure 7. Critical Corners of the Flight Envelope for a TVC transport

TVC Control Power Assessment Results

A summary of observations and recommendations from the TVC commercial transport steady state control power analysis are provided with Table 5.

Table 5. Summary of TVC Transport Control Power Assessment Results

Test Cases	Observations	Recommendations
Statically stable configuration (HS)	Large SM travel between forward and aft cg locations.	Use a fuel transfer system to keep the cg at the forward location
	Insufficient control power for almost all the maneuvers.	Increase LoCE control power by relocating the wings
Wing Location Trades (HS)	There are control power issues at extremely negative SM	Increase the thrust requirement for cruise in a later sizing study
	The most control power is available at -5% SM	Assess control power at off design conditions using the -5% SM wing location
	Insufficient thrust available at -5% SM	
Stall Performance (IC, LM)	Longitudinal Control Effectors (LoCE) saturate during most of the maneuvers in both conditions	Redesign the wing to delay the pitch break
		Use an angle of attack limiter to constrain angle of attack to safe pitching moment regions
Crosswind Performance (A, F)	Only the LaCEs saturate during the approach	Resize the ailerons for more lateral control power
	Both the LoCE and LaCE saturate during the landing flare	Relocate engines for more directional control power
		Add undersized rudders
Engine Limit Conditions (C, HS-ETOPS, LM-ETOPS)	Insufficient thrust available for all the maneuvers with the HS-ETOPS pull-up being the most demanding	Use the thrust requirement for the HS-ETOPS pull-up to size the engines
	The LM-ETOPS condition suffers from the same pitch break problems as the stall conditions	Wing redesign or an angle attack limiter is required to curb the pitching moment problem near stall

The results show that a pure pitch & yaw thrust vector controlled commercial transport cannot fly statically stable at design cruise. The demand on the engine to provide thrust and trim the large pitching moment of the wing is too large. A -5% Static Margin (SM) is the optimum for the vehicle. The statically unstable version performs marginally in stall and cross wind conditions. The biggest limitation for the vehicle is cruise with OEI and at max ceiling with all AEO. The engine thrust in these conditions is insufficient for control. There are too many expensive workarounds required to make the pure pitch & yaw thrust vector controlled commercial transport work; however, a partial TVC option with aerodynamic controls would eliminate these problems.

Summary

A feasibility study of a Thrust Vector Control (TVC) commercial transport including a TVC technology review, a parametric sizing study as well as a safety certification assessment is given. The review has various TVC classification schemes and technologies that motivate the discussion. The parametric study show that there are great benefits in aerodynamic efficiency, weight reduction and fuel burn performance which makes the TVC commercial transport worth an investment. However, the safety and certification assessments indicate that a TVC transport with pure pitch yaw thrust controls without a tail is not a safe aircraft. The recommendation from this study is that a combination of TVC and smaller aerodynamic controls devices could provide the revolution in commercial transport performance.

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Forecasting the Green Potential for General Aviation Aircraft

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Abstract

The paper presented here is a specification and evaluation study to determine the potential of general aviation electric aircraft technology towards the green technology revolution. It forecasts the solution space for electric aircraft industrial capability. For this purpose, a sizing process has been adopted to demonstrate a long-range planning capability for electric general aviation aircraft. This study examines five case studies, all based on the Ryan NYP and Lancair-IV: the aircraft are sized for four unique technology packages including two different internal combustion engine, one all-electric, and one hybrid-electric powertrains. In this way the design sensitivities can be adopted to generate lessons learned for green transportation. The paper concludes with a forecast that provides design and mission recommendations, followed by a breakdown for practical electric powertrain technology options.

Introduction

Study Motivation

This year marks the 85th anniversary of the 1927 Charles Lindbergh Transatlantic crossing from New York to Paris. This iconic event represented a first for the world, and has since grown to represent a cultural phenomenon that defines the very spirit of exploration. In terms of technological progress, the *Spirit of St. Louis* (Ryan NYP aircraft) was a clever experiment in forecasting that came to embody the extreme in 1920s general aviation structural, aerodynamic, and propulsion aircraft technology. In short, the *Spirit of St. Louis* was the 'X-Prize'-equivalent for the pioneering days of aviation. As such to commemorate this achievement, the grandsons of Charles Lindbergh and the Ryan NYP designer Donald Hall along with the Aerospace Vehicle

Design (AVD) Laboratory have decided to define a modern challenge to honor the 1927 design and operator team to better understand the impact of state-of-the-art technology on advanced aircraft performance.

It would not be a stretch to say that since the 1950s there have been no significant gains in general aviation (GA) operations and technology. This study hopes to re-energize this conversation by identifying the electric general aviation (GA) transportation potential, see Figure 1, and its corresponding impact on what missions may be possible. The green transportation revolution has taken root in the automotive industry; gains in electric powertrain technology are being announced on an almost daily basis. While these technologies are nowhere near the scale required to benefit commercial transports, they may be well suited to deliver technology solutions towards environmentally friendly and economic GA operation that is certifiable.

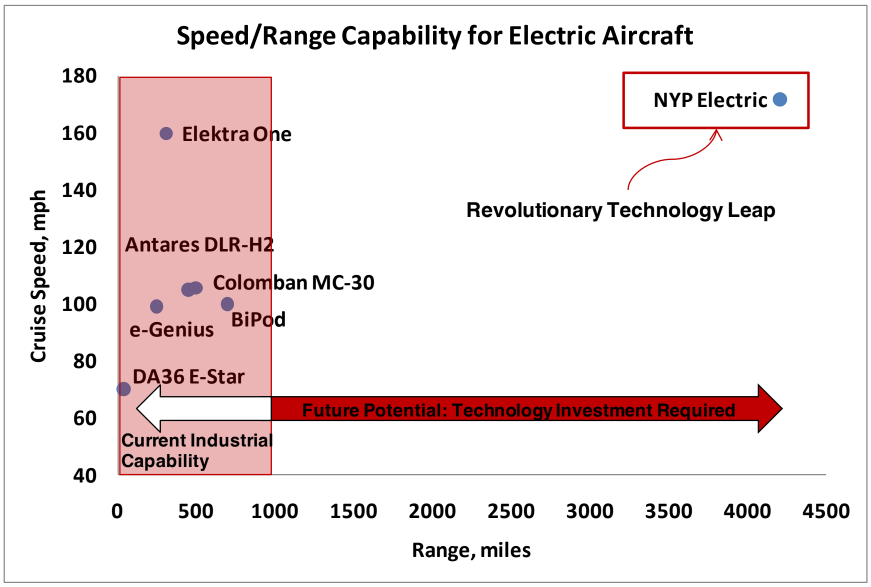

Figure 1. Electric GA Aircraft Transportation Potential

Study Objectives

The principal objectives of this study are as follows: to develop an electric GA technology roadmap to identify this *new industry* potential, and to explore the transition of such technology into operational and practical hardware applications. The investigation itself is limited to the formulation of first-order forecasting projections and the application of a systematic product development life-cycle methodology. An existing generic design-synthesis methodology has been customized to support futurist strategizing and decision-making aimed at exploring the feasibility of an (a) *all-electric GA aircraft*, and (b) *hybrid-electric GA aircraft* implementations for flight with associated present and future powertrain technologies.

Research Strategy

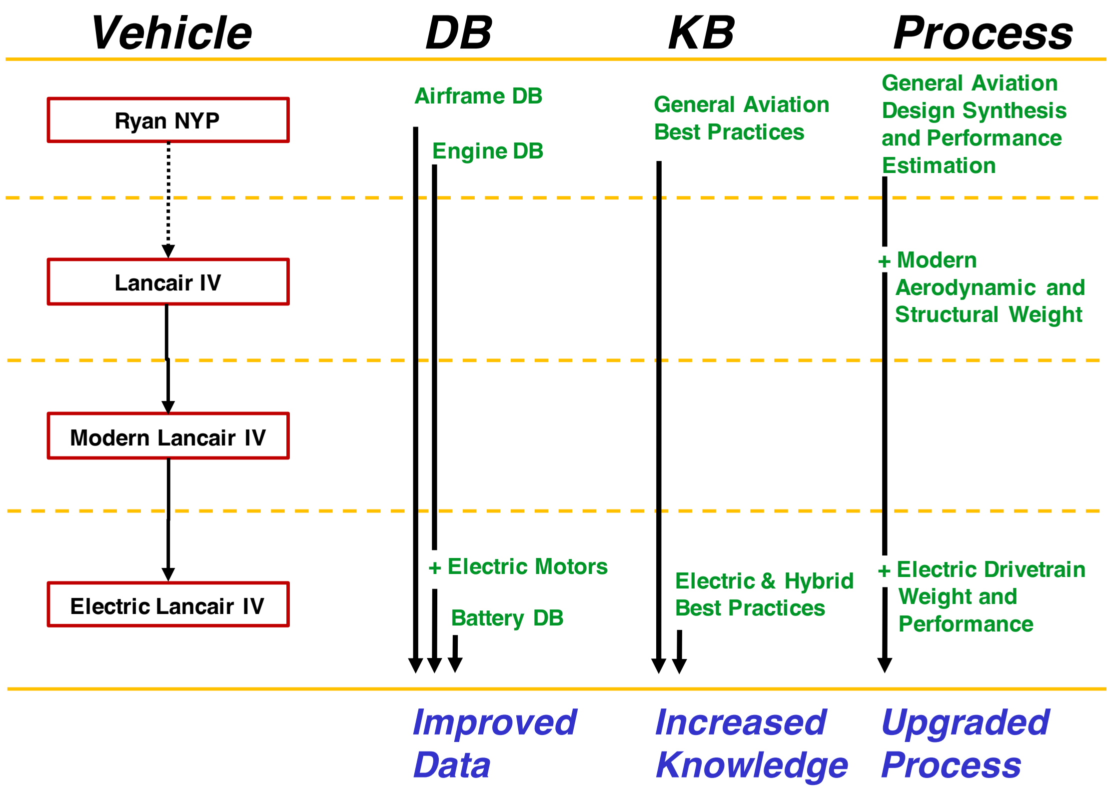

Figure 2. Buildup of Parametric Sizing Evaluation Process

The study has been organized into three distinct phases: Phase 1: preparatory activities; Phase 2: configuration, concept and technology identification; and Phase 3: advanced planning activities.

Phase 1
Tasks include to propose a challenge, research strategy definition, operational requirements definition, reference vehicle definition, all-electric and hybrid electric disciplinary technology matrix identification, and multi-disciplinary aircraft configuration matrix identification.

Phase 2
Tasks include review of all-electric and hybrid electric disciplinary technology potential, and aircraft parametric sizing to configuration layout studies.

Phase 3
Tasks include prioritized technology matrix, and prioritized configuration and concept matrix.

Methodology

In order to evaluate the technical feasibility of each configuration and technology combination, it is required to employ a state-of-the-art forecasting system consisting of the AVD Laboratory methodology and software packages (a) data-base system, AVD^{DBS}, (b) knowledge-base system, AVD^{KBS}, and the (c) parametric sizing methodology, AVD^{SIZING}. Figure 2 illustrates the research strategy consisting of the four distinct research vehicle case studies. Each vehicle required to customize the forecasting methodology accordingly.

DB/KB System Summary

A key component enabling the development of all-electric/hybrid electric flight vehicles is effective management of knowledge-generation and knowledge-preservation activity. As illustrated before, the research approach implemented places emphasis on elevating the understanding with regards to project aims and objectives, overall resulting in an informed and structured approach. In the present context, the research challenge is best formulated with the question: How to efficiently synchronize the understanding available with the understanding required to specify feasible all-electric/hybrid electric flight vehicles with the technical resources, team support and time available? Due to the limited timeframe available, the DB and KB assistances have become indispensable to expedite the learning process. Work prepared for this study includes:

- DB System – GA airframe DB, GA engine DB, powertrain DB, electric motor DB, battery DB, and controller and inverter DB.
- KB System – GA Aircraft (disciplinary and multi-disciplinary analysis methods/process library and lessons learned), all-electric powertrain system (disciplinary and multi-disciplinary analysis methods/process library, and lessons learned), hybrid-electric powertrain system (disciplinary and multi-disciplinary analysis methods/process library, and lessons learned).

AVD Sizing Process Summary

This 'best practice' sizing approach has been developed through a thorough review of parametric sizing processes and methods from the 1960s to present for subsonic to hypersonic vehicles [4]. With this framework in place, the available solution space is identified (if available) for each mission, configuration and technology combination, see Figure 3.

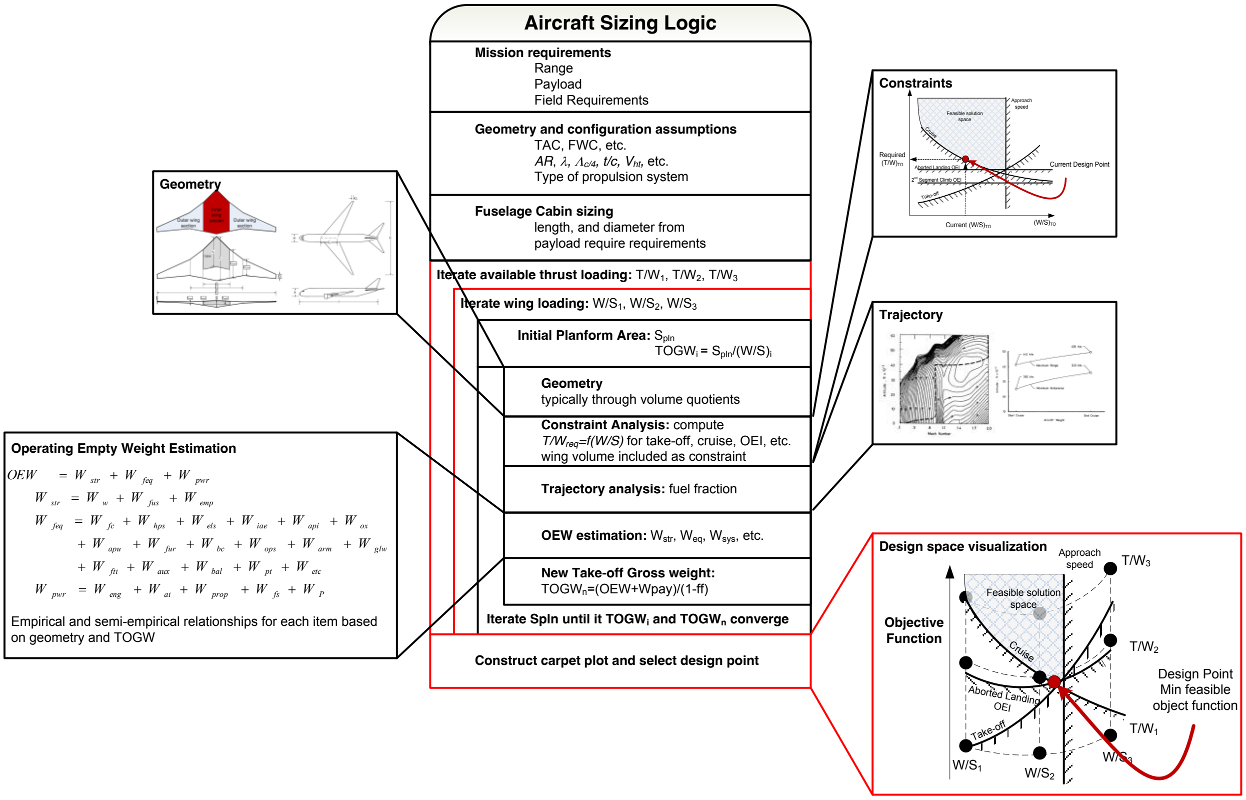

Figure 3. Parametric Sizing Methodology

For this study, each solution space is developed using a classical wing loading trade. For each wing loading the complete vehicle is converged to meet the range requirement with the lowest power loading requirement resulting from performance constraints. In this instance take-off, climb, landing, cruise and maximum velocity at sea-level (SL) are used as performance constraints and the FAR Part 23 regulations determines the climb and balanced field length requirements. In addition to sizing the wing and propulsion system, the code also calculates the corresponding geometry internally: (1) nose nacelle is sized to house the engine, (2) an additional fuselage section is added for extra battery volume, and (3) the tail cone and empennage are sized to provide a given volume quotient.

Electric Aircraft System Components

Top-Level Description of Selected All-Electric and Hybrid-Electric Powertrains

Figure 4 illustrates the all-electric powertrain used in this study. This configuration with battery, controller and inverter, electric motor, and propeller is similar to the lower performance system employed by the electric Cessna 172.

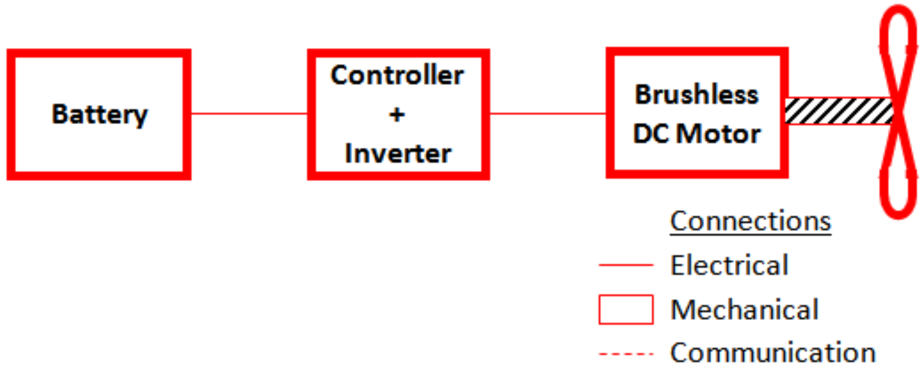

Figure 4. Conceptual Design of All-Electric Powertrain System

Figure 5 illustrates the hybrid-electric powertrain used in this study. This configuration utilizes an internal combustion engine, battery, motor and inverter, controller and inverter, electric motor, and propeller. It is based on the system used by the Chevy Volt.

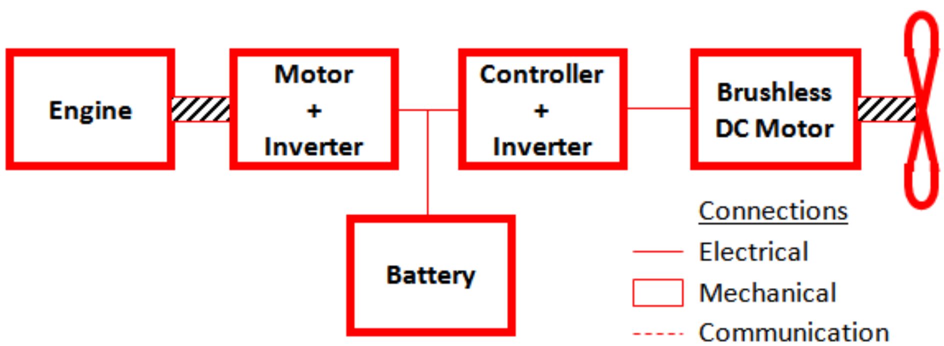

Figure 5. Conceptual Design of Hybrid-Electric Powertrain System

Top-Level Description of Near-Term and Long-Term Battery Technology

Figure 6 describes the specific energy to weight fractions for the Lithium-Polymer, Zinc-Air, and Lithium-Air batteries studied for this paper.

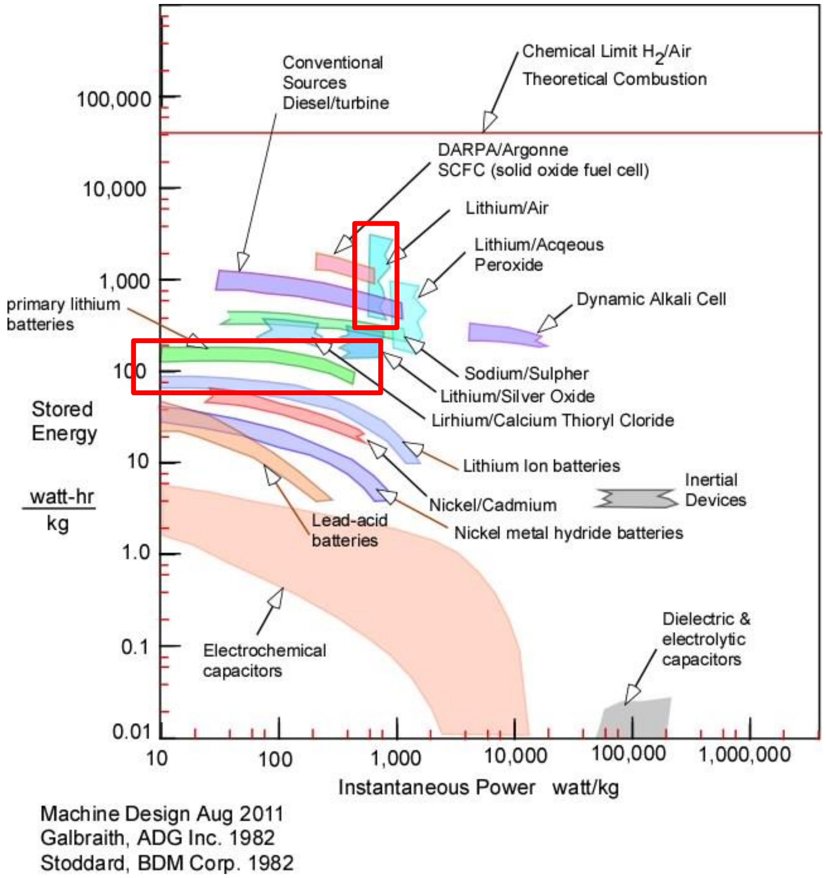

Figure 6. Overview of Battery Specific Energy to Weight Fraction vs. Instantaneous Power Rating

Design Sensitivities Influencing GA Electric Aircraft Design

This portion of the study is intended to arrive at a proof of concept design aimed at the formulation of a technology roadmap. As such, the first step has been to determine the design sensitivities driving the electric GA aircraft solution space. Figure 7 illustrates the steps taken to build the necessary understanding in typical GA operations versus green GA operations. A brief summary regarding the organization of the case studies and top-level lessons learned follows:

- Step 1 – Re-engineer the original Ryan NYP. This represents the industrial capability and technological limit for 1920s GA aircraft. While this case does not directly contribute to the forecast it was critical to validating and calibrating the initial design synthesis system for GA application. In addition, it produced a parametric understanding of the original NYP design and operation.
- Step 2 – Re-engineer the existing Lancair-IV. This represents the modern industrial capability and technology limit for GA aircraft. The Lancair IV was selected due to its

payload and range capability in addition to the aerodynamically and structurally efficient airframe. It represents a validated baseline technology-level to which the aircraft developed in Steps 3 and 4 are sized.

- Step 3 – Engineer the Modern Lancair-IV NYP (baseline) and Electric Lancair-IV NYP. These aircraft are individually sized along the original Ryan NYP range and the Lancair-IV technology-level to assess the potential for all-electric and hybrid-electric aircraft. During the course of Step 3 evaluation it was realized that the Electric Lancair-IV NYP mission is not possible under current technology projections; thus, the shorter range Route 66 has been selected as the baseline mission instead.

The following sections will discuss the case studies, results, and more detailed lessons learned on a mission-by-mission basis.

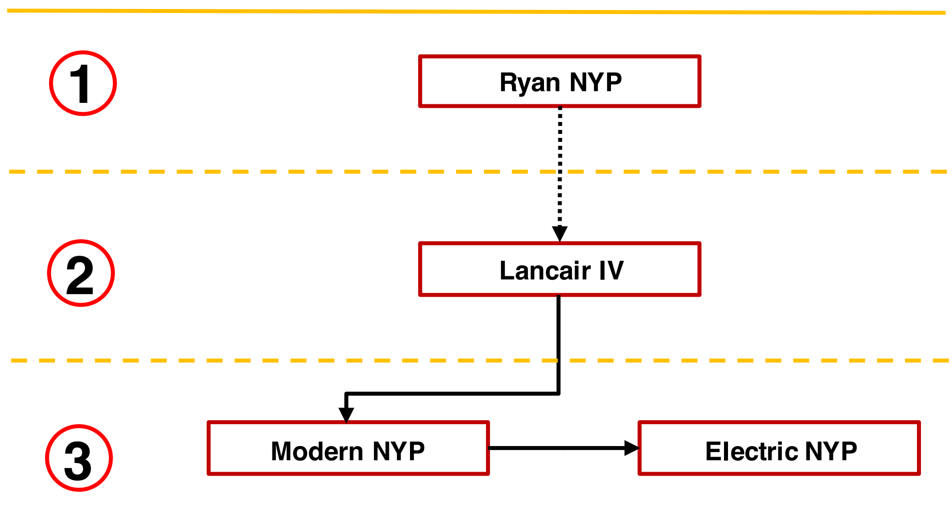

Figure 7. Overview of GA Aircraft Design Sequence

Step 1 – Ryan NYP

Although the Ryan NYP was not a revolutionary aircraft configuration for its time, its operational capability was ground-breaking. It was comprised mostly of existing hardware retrofitted with just enough performance-enhancing features to ensure the vehicle's operational limits would satisfy the New York to Paris mission. The design team chose the Ryan M-2 airframe to serve as the basis for the aircraft configuration with modifications to wing and fuselage.

Mission

The Ryan NYP 1927 race course, figure 8 and 9, is defined as follows:

- New York (Roosevelt Field) to Paris (Le Bourget Field)
- Range: 5,800 km (3,660 nm)
- Duration: 33 hours 30 minutes
- Ave Speed: 107 m.p.h.
- Payload: survival gear
- Operational Capability: average weather, robust design, and FAR 23/25 safety standards

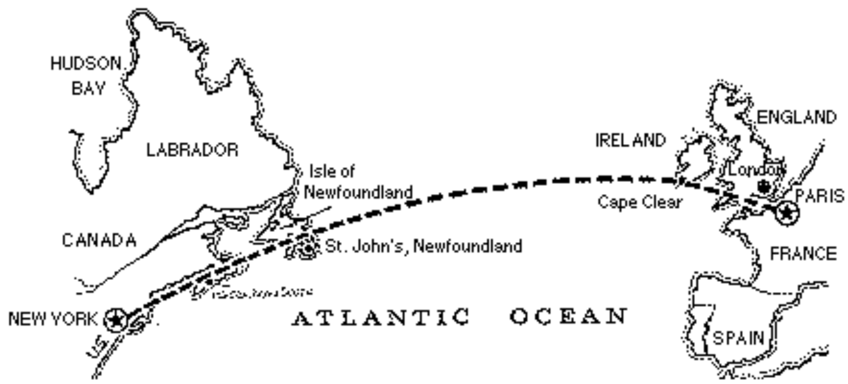

Figure 8. Overview of 1927 Race Course

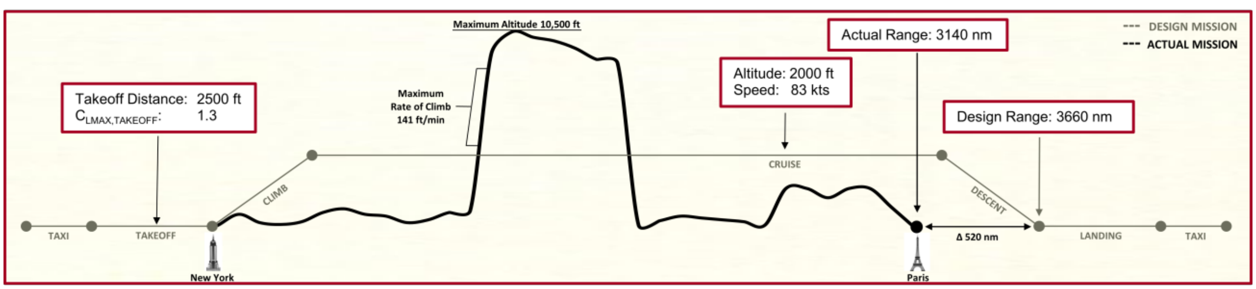

Figure 9. Specification of Ryan NYP Operational Mission

Vehicle Summary

Figure 10 summarizes the physical geometry, aerodynamic, weights, and performance characteristics for the Ryan NYP aircraft.

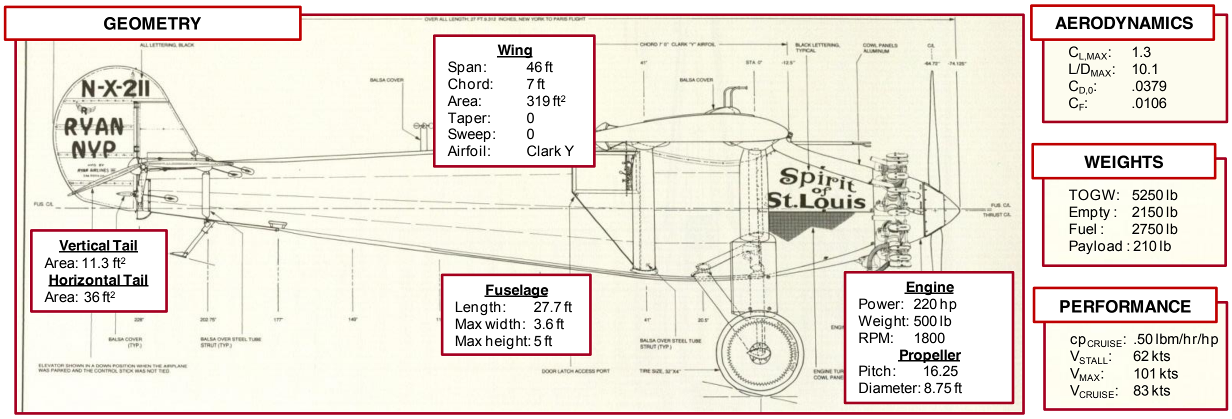

Figure 10. Overview of Ryan NYP Aircraft

Figure 11 details the unique design qualities for the Ryan NYP aircraft that will influence modeling the geometry, weights and materials, performance, aerodynamic, stability and control, and propulsion systems.

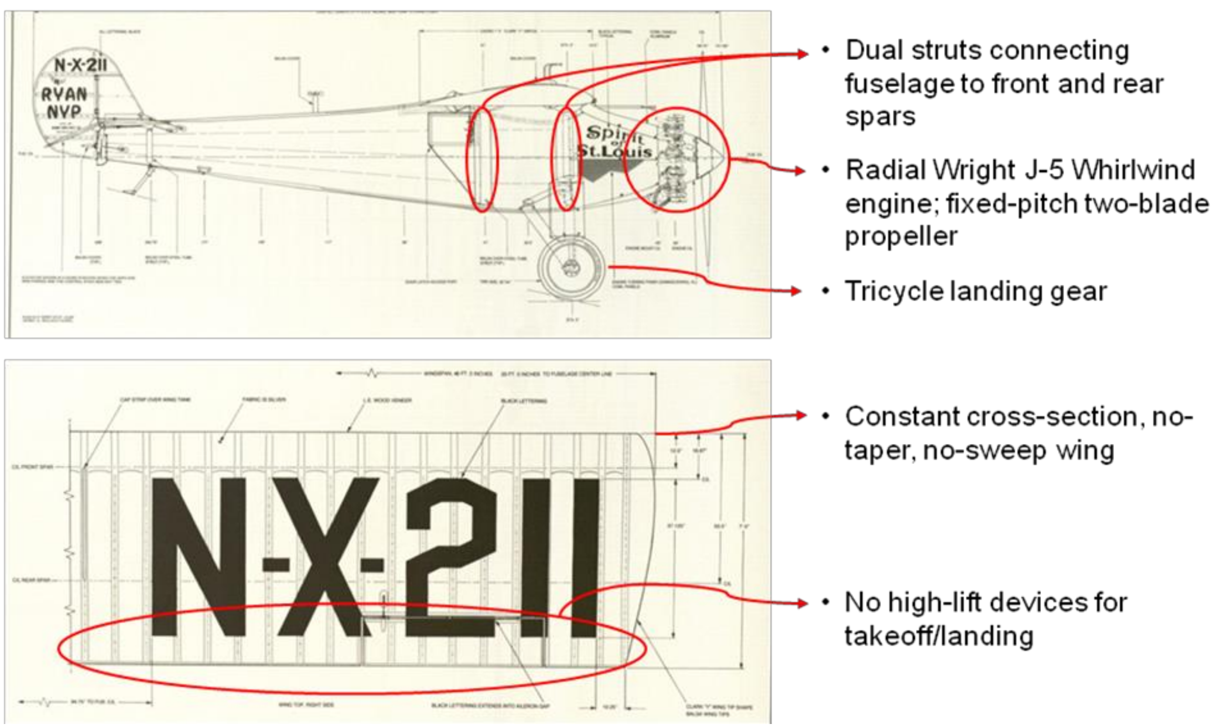

Figure 11. Defining Characteristics of the Ryan NYP Aircraft

Design Trade Space

Figure 12 illustrates the feasible and unfeasible solution space due to sizing. It compares the

Reverse Engineered Ryan NYP (red dot) to the Original Ryan NYP (green dot). Additionally, the effects of wing loading (blue line) are shown for variable take-off gross weight (TOGW) and planform area (S_{pln}).

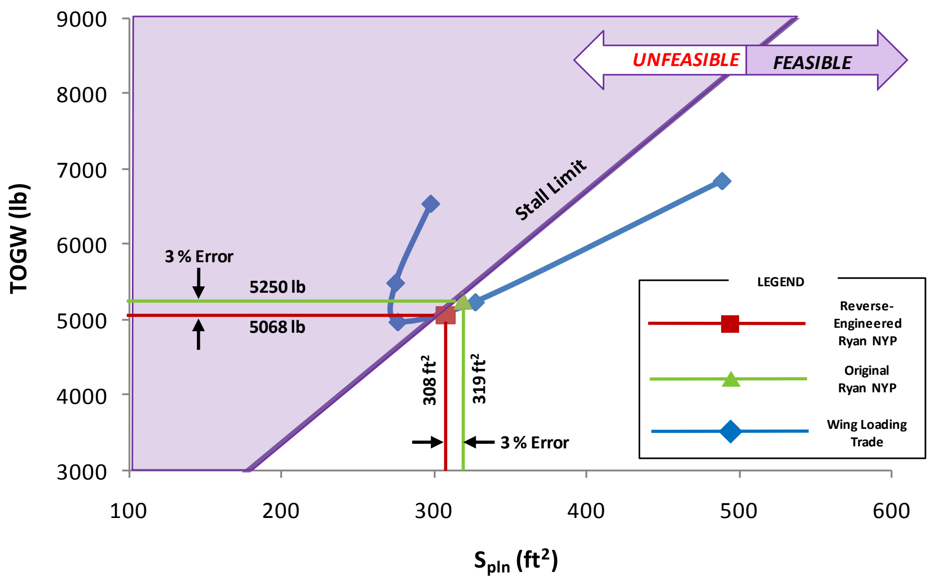

Figure 12. Solution Space of the Ryan NYP Aircraft

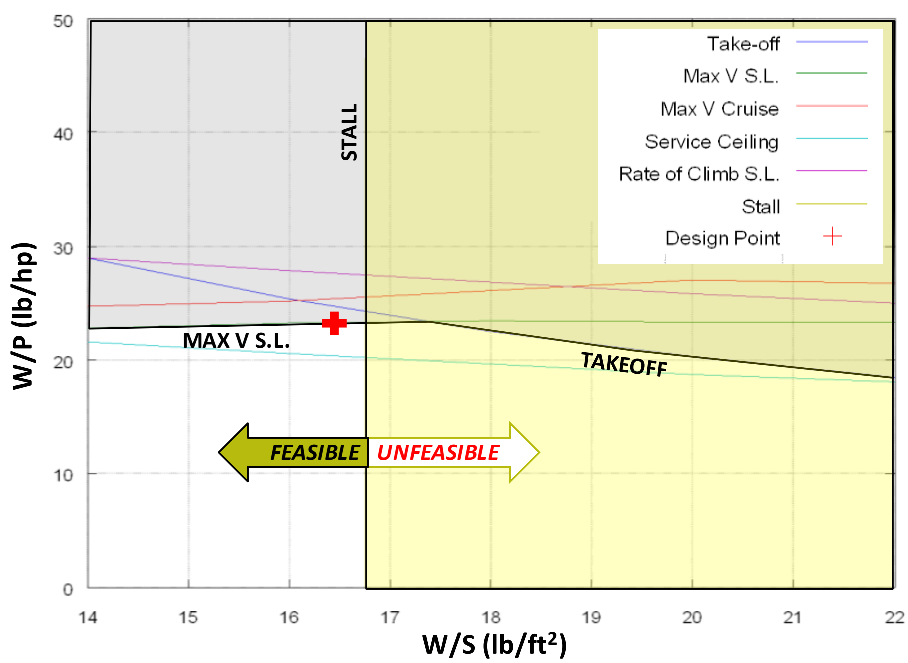

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Figure 13. Performance Matching Requirements of the Ryan NYP Aircraft

Figure 13 displays the results from performance matching for feasible and unfeasible design regions. It compares the wing loading (TOGW/S_{pln}) and power loading (TOGW/P) requirements from each mission segment (takeoff, climb, cruise, etc.) to decide the minimal design requirements to complete the mission

Design Summary

Table 1 compares the original Ryan NYP data with the calculated (design point) Ryan NYP as obtained from the design trade space. The sizing results match the original Ryan NYP within an acceptable margin of error. Note that the error during validation does not exceeds five percent.

Table 1. Design Summary for Actual Ryan NYP vs. Calculated Ryan NYP

Design Summary			
	Design Point	NYP	%Error
Geometry			
Spln (ft^2)	307.96	319.00	-3%
AR	6.63	6.63	0%
b (ft)	45.19	46.00	-2%
dp (ft)	8.75	8.75	0%
RPM	1893.32	1800.00	5%
Weight			
TOGW (lb)	5068.32	5250.00	-3%
Wfuel (lb)	2612.59	2750.00	-5%
Woil (lb)	140.00	140.00	0%
Wpay (lb)	210.00	210.00	0%
OEW (lb)	2105.73	2150.00	-2%
Structure (lb)	1219.49	1200.00	2%
wing (lb)	418.04		
ht (lb)	87.44		
vt (lb)	36.43		
fuselage (lb)	472.49		
naccelle (lb)	36.86		
landing gear (lb)	168.23		
engine (lb)	494.15	500.00	-1%
Performance Matching			
Range (nmi)	3660.00	3660.00	0%
ff	0.52	0.52	-2%
L/D	10.06	10.10	0%
Cd0	0.04	0.04	4%
cp (lbm/hr/hp)	0.51	0.51	0%
np cruise	0.76	0.76	0%
p sea level (hp)	217.42	222.46	-2%
w/s (lb/ft^2)	16.46	16.46	0%
w/p (lb/hp)	23.31	23.60	-1%
w/s stall (lb/ft^2)	16.75		
Pbl	1.81		

The lessons learned from this case study include:

- Wing loading (TOGW/S_{pln}) is the primary sizing design driver for design point selection.
- The stall wing loading constraint is a function of the slow stall speed and the lack of high-lift devices.
- Although low performance for modern day, the Ryan NYP pushed the boundaries of field performance possible for its technology and configuration.

Step 2 – Lancair IV

The Lancair IV was selected as the modern day state-of-the-art in GA aircraft technology due to its payload and range capability. It additionally possesses an aerodynamically and structurally efficient airframe to support a wide variety of missions.

Mission

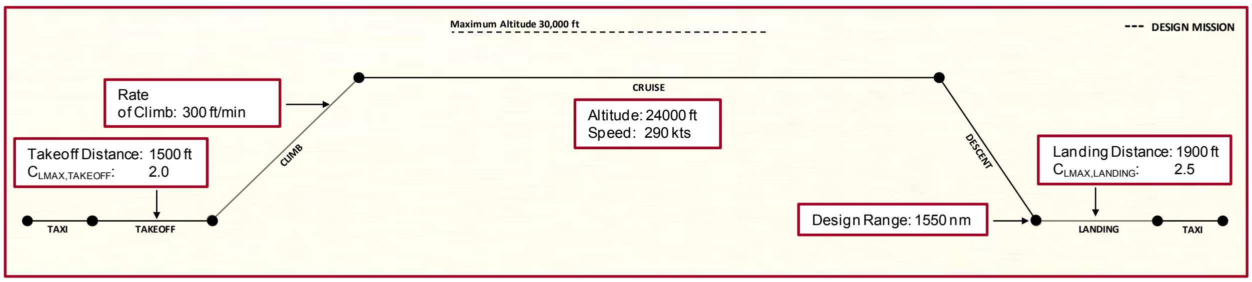

Figure 14. Specification of Lancair-IV-P NYP Operational Mission

The Lancair-IV-P mission, see Figure 14, is defined as follows:

- Range:2,870 km (1,550 nm)
- Ave Speed: 290 kts.
- Payload: 4 Passengers
- Operational Capability: average weather, robust design, and FAR 23/25 safety standards

Vehicle Summary

Figure 15 summarizes the physical geometry, aerodynamic, weights, and performance characteristics for the Lancair-IV-P aircraft.

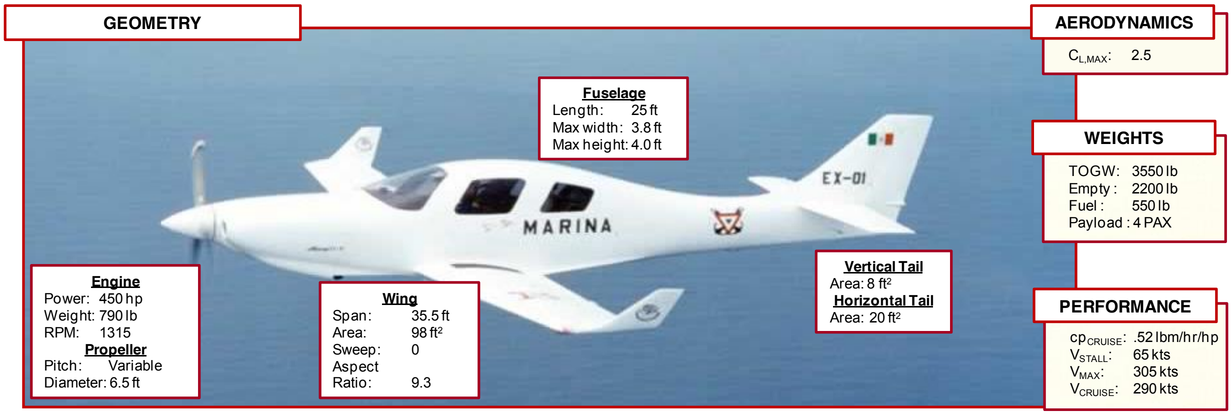

Figure 15. Overview of Lancair-IV-P Aircraft

Figure 16 details the unique design qualities for the Lancair-IV aircraft that will influence modeling the geometry, weights and materials, performance, aerodynamic, stability and control, and propulsion systems.

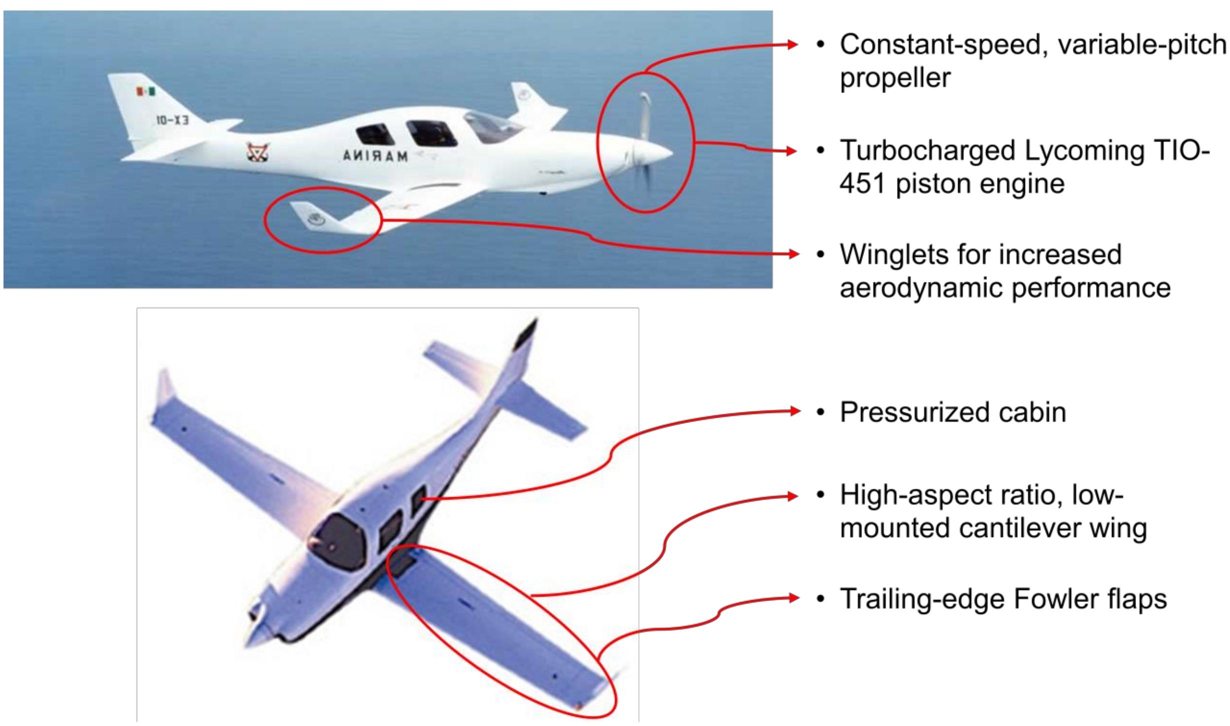

Figure 16. Defining Characteristics of the Lancair-IV Aircraft

Design Summary

Table 2 compares the actual Lancair-IV data to the calculated (design point) Lancair-IV-P as obtained from the design trade space. The sizing results match the Lancair-IV within an acceptable margin of error. Note that the error during validation does not exceeds five percent.

Table 2. Design Summary for Actual Ryan NYP vs. Calculated Ryan NYP

Design Summary			
	Design Point	Lancair IV	%Error
Geometry			
Spln	101.41	98.00	3%
AR	9.29	9.29	0%
b	30.69	30.17	2%
d prop	6.31	6.33	0%
rpm prop	2706.91	2700.00	0%
Weight			
TOGW	3673.06	3550.00	3%
Wfuel	681.14	660.00	3%
Wpay	890.00	890.00	0%
OEW	2101.93	2000.00	5%
Performance matching			
Range	1347.00	1347.00	0%
ff	0.185	0.186	0%
L/D	14.00		
cp	0.52		
np (cruise)	0.90		
hp	360.36	350.00	3%
w/s	36.22	36.22	0%
w/p	10.19	10.14	0%
Pbl	2.88	2.78	3%

The lessons learned from this case study include:

- The simulation capability now exists to model Lancair-IV-level aircraft technology for the remaining case studies.

Step 3 – Engineer the Modern Lancair-IV NYP (baseline) and Electric Lancair-IV NYP

The modification of a Lancair-IV similar aircraft into a Modern Lancair-IV NYP requires very little change in the design of the aircraft. The primary considerations, see Table 3, include: cruise at a lower velocity (150 kts), reduced payload (1 passenger), and inclusion of a fuselage fuel tank.

This sizing model is used as a baseline for all of the electric aircraft trades. Note that these requirements have been re-examined for each trade and they have been relaxed if they over constrain the aircraft. For example, the short field length of the Lancair IV is a fallout of the 350 hp required for a 290 kt cruise speed. For this challenge, such a large cruise speed is unnecessary and thus the field length has been increased to a larger value to reduce take-off power requirements.

Table 3. Mission Summary for Original Ryan NYP and Original Lancair-IV vs Modern and Electric Lancair-IV NYP

		Ryan NYP	Lancair IV	Lancair NYP	
Mission	Payload	1 PAX	4 PAX	4 PAX	🔴
	Range	3660 nmi	1550 nmi	3660 nmi	🟡
Performance	Cruise Speed	83 kts	290 kts	150 kts	◐
	Cruise Altitude	2000 ft	24,000 ft	24,000 ft	🔴
Propulsion	Fuel Consumption	.50 lbm/hr/hp	.52 lbm/hr/hp	.52 lbm/hr/hp	🔴
	Engine Weight	2.27 lb/hp	1.75 lb/hp	1.75 lb/hp	🔴
	No.of Propeller Blades	2	4	2	🟡
Aerodynamics	Maximum Lift Coefficient	1.3	2.5	2.5	🔴

🟡 Ryan NYP Value 🔴 Lancair IV Value ◐ Intermediate Value

Mission

Aside from the changes listed in the preceding section, the mission and operational conditions are unchanged from that of the actual Lancair-IV.

Vehicle Summary

The design assumptions for the Modern Lancair-IV include:

Drivetrain Concept:
- Internal Combustion Engine (ICE) for taxi, take-off, climb, cruise, loiter, and landing

Structures:
- Aluminum/fiberglass structure

Systems:
- Pressurized cabin and battery compartment
- Assumed 200 lbs for pressurization systems

- Retractable landing gear

Configuration and Aerodynamics:

- Similar to original Lancair-IV geometry
- Conventional airfoil (no natural laminar flow)

The design assumptions leading to the all-electric Lancair-IV are:

Drivetrain Concept

- Pure electric configuration for taxi, take-off, climb, cruise, loiter, and landing
- Different battery technologies are traded to determine maximum ranges
- DC brushless motor (UQM PP-200) with 1.28 peak hp/lb loading
- Spur gear box
- 3 blade variable pitch propeller

Structures:

- Aluminum/fiberglass structure

Systems:

- Pressurized cabin and battery compartment
- 200 lbs assumed for each pressurization system (from Lancair IV-P)
- Retractable landing gear

Configuration and Aerodynamics:

- Same configuration as modern Lancair-IV NYP
- Conventional airfoil (no natural laminar flow)

The design assumptions for the hybrid-electric Lancair-IV include:

Drivetrain Concept:

- Battery supplies power for taxi, take-off, climb and landing
- ICE supplies power for cruise and loiter
- ICE sized and optimized for improved fuel efficiency during cruise operation
- Different battery technologies are traded
- DC brushless motor (UQM PP-200) with 1.28 peakhp/lb loading
- Spur gear box
- 3 blade variable pitch propeller

Structures:

- Aluminum/fiberglass structure

Systems:

- Pressurized cabin and battery compartment
- Assumed 200 lbs for pressurization systems
- Retractable landing gear

Configuration and Aerodynamics:

- Same configuration as modern Lancair-IV NYP
- Conventional airfoil (no natural laminar flow)

Design Trade Study 1 – Modern Lancair-IV NYP (baseline) and All-Electric Lancair-IV NYP

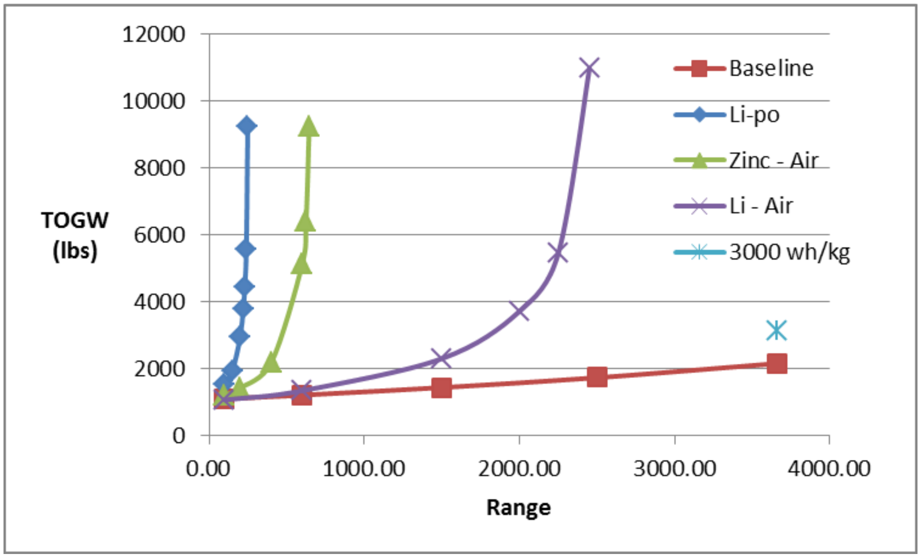

Figure 17. Solution Space for the Modern Lancair-IV NYP (baseline) and All-Electric Lancair-IV NYP

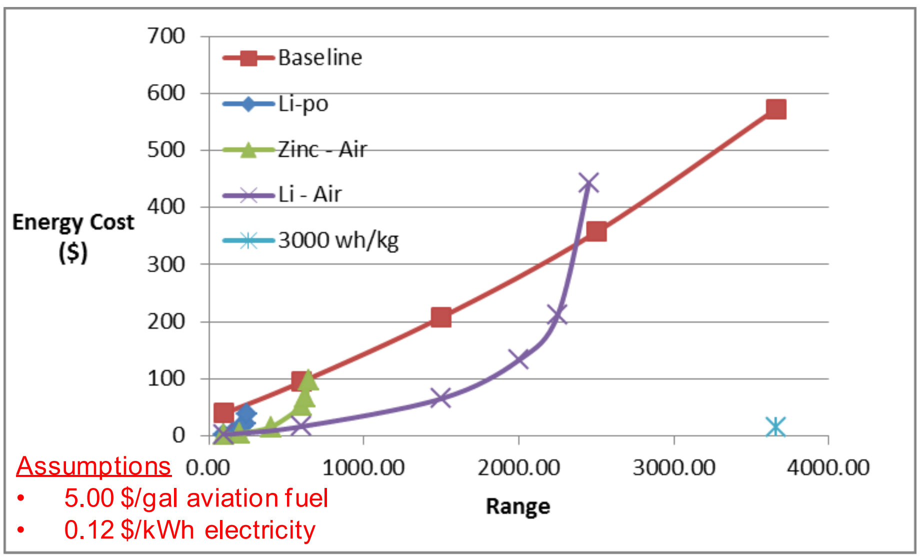

Figure 18. Economic Space for the Modern Lancair-IV NYP (baseline) and All-Electric Lancair-IV NYP

A design summary of the all-electric trade study results in Figure 17 follow:

- Excessive battery weight, a fixed mass system without a cruise climb cause, TOGW,

planform area, and power requirements to grow exponentially as range increases.
- Asymptotic behavior begins when the battery fraction ($W_{battery}$/TOGW) exceeds 40%.
- The Battery-only powertrain specific energies limit design to Li-Po < 100 nm, Zinc – Air < 400 nm, and Li- Air < 2000 nm.
- 3,000 Wh/kg energy density is required to a maintain $W_{battery}$/TOGW at 0.40 for 3660 nm.

As can be expected, the all-electric Lancair-IV NYP outperforms the energy costs of the modern Lancair-IV NYP with almost every battery option, see Figure 18. However, none of the aircraft can complete the *Spirit of St. Louis* mission. The economic benefit of batteries could be significant when compared to the hydrocarbon baseline if the efficiency of the powertrain components can be improved.

In terms of technical lessons learned it is suggested that an ICE-hybrid electric powertrain could be used to increase range or the operational range must be reduced to less than 2000 nm.

Design Trade Study 2 – Modern Lancair-IV NYP (baseline) and Hybrid-Electric Lancair-IV NYP

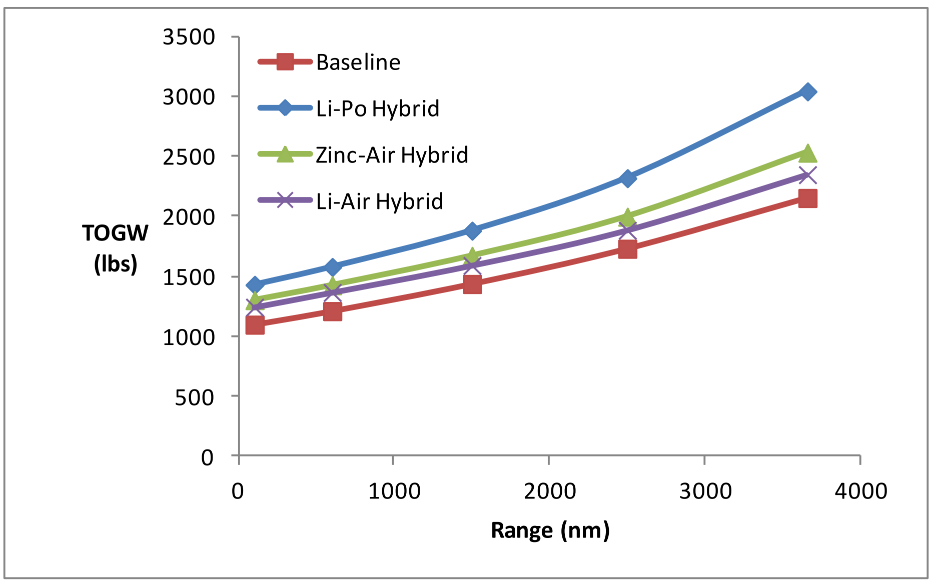

Figure 19. Solution Space for the Modern Lancair-IV NYP (baseline) and Hybrid-Electric Lancair-IV NYP

Figure 19 illustrates the design results from the hybrid-electric trade study. The following conclusion can be formulated:

- All hybrid-electric aircraft are heavier than the Modern Lancair-IV NYP baseline.

- The TOGW increase is due to the aircraft having both ICE and electric powertrain component.

Using the results of a simplified cost model, see Figure 20, it is shown that:

- Li-Po hybrid energy cost breaks even in the 1500 - 2500 nm range.
- For the transatlantic range, Zinc-Air and Li-Air hybrids have reduced energy costs over the baseline aircraft.

Therefore, it is it is not technically feasible for the hybrid-electric aircraft to provide a benefit over electric aircraft over current GA operation. Although a mission range between 1,500 – 2,500 nm could be more economical in the near future, such cost savings are not offset by the direct operating cost (DOC).

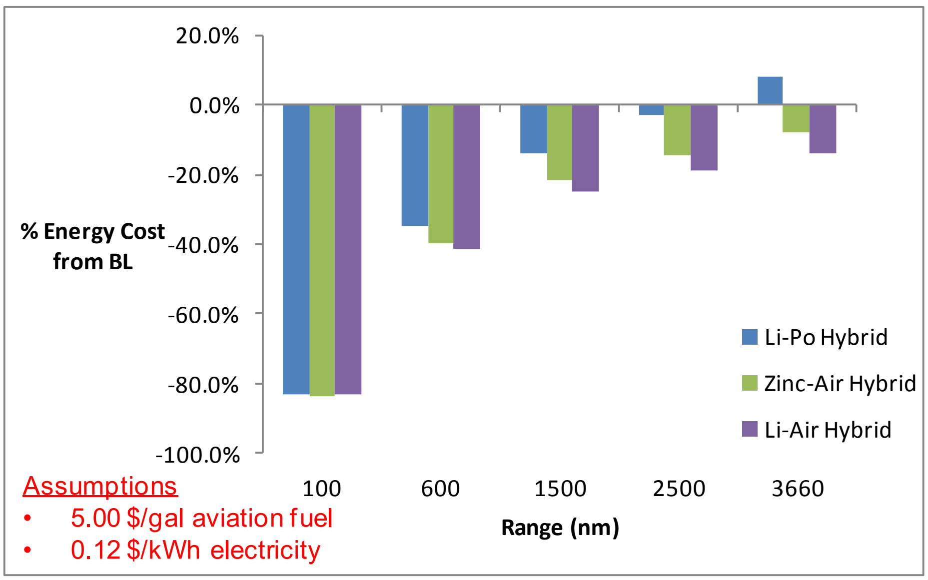

Figure 20. Economic Space for the Modern Lancair-IV NYP (baseline) and Hybrid-Electric Lancair-IV NYP

Electric General Aviation Technology Roadmap

At this point of the study the lessons learned from the individual case studies are tied together in order to arrive at an overall forecast model, culminating in a technically feasible design space for green GA aircraft. Having understood the design sensitivities for all-electric and hybrid-electric aircraft, the approach has been to explore the solution space with the principal design driver battery specific energy (Wh/kg). Note that the following analysis, like in the previous chapter, is based on resizing aircraft to the Lancair-IV aircraft technology-level.

Mission Description and Mission Assumptions

Developing the solution space for electric technology potential, four mission segments have been selected, see Figure 21. The shortest design range (150 nm) is estimated as the minimum distance required to make a GA vehicle market feasible. Increasing the range to 800 nm represents the typical operational range for a hydrocarbon GA aircraft. The third range, 1,500 nm, represents Route 66-type mission. Finally, the maximum distance considered is 3,500 nm which is inspired by the Modern NYP challenge.

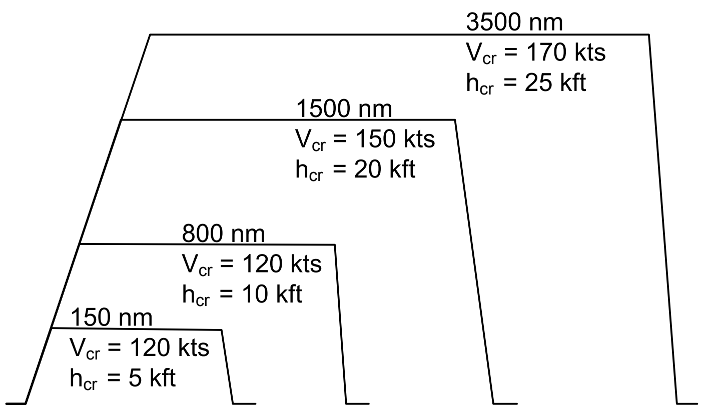

Figure 21. Solution Space Mission Profiles

Table 4. Solution Space Mission Requirements

Mission Requirement	
Payload*	
Crew	1 crew, 180 lbs
Emergency Gear	70 lbs
Range	
R	Variable
h_{cr}	Variable
Reserve endurance	0 hr
Velocities	
Vs	65 kts
$V_{cr\ design}$	Variable
$V_{cr\ max}$	Variable
Load Factor	
$n_{max/min}$	+4.4/-4.4
Take-off	
S_{to} <	2700 ft
h_{to}	Sea-Level
R/C_{sl} >	300 ft/min
Landing	
S_L <	1900 ft

h_L	Sea-Level
W_L/TOGW	1

*Cabin volume sized for 4 pax, based on Lancair IV-P

Table 4 summarizes the operational requirements used to maintain standard flight operation and FAR Part 23 constraints for the solution space. In this formulation, cruise velocity and altitude is variable for a given wing loading in order to efficiently fly at L/D_{max} during cruise.

Technology Potential Solution Space Definition

Effect of battery specific energy on design range

For the given four mission design ranges, the battery energy density is varied between 100 Wh/kg and 3000 Wh/kg, see Figure 22. The lowest specific energy for each mission represents the convergence limit. Consequently, for the required design range, no mathematical solution could be determined as a function of balancing mass, volume, wing area, power, etc. within the mission constraints.

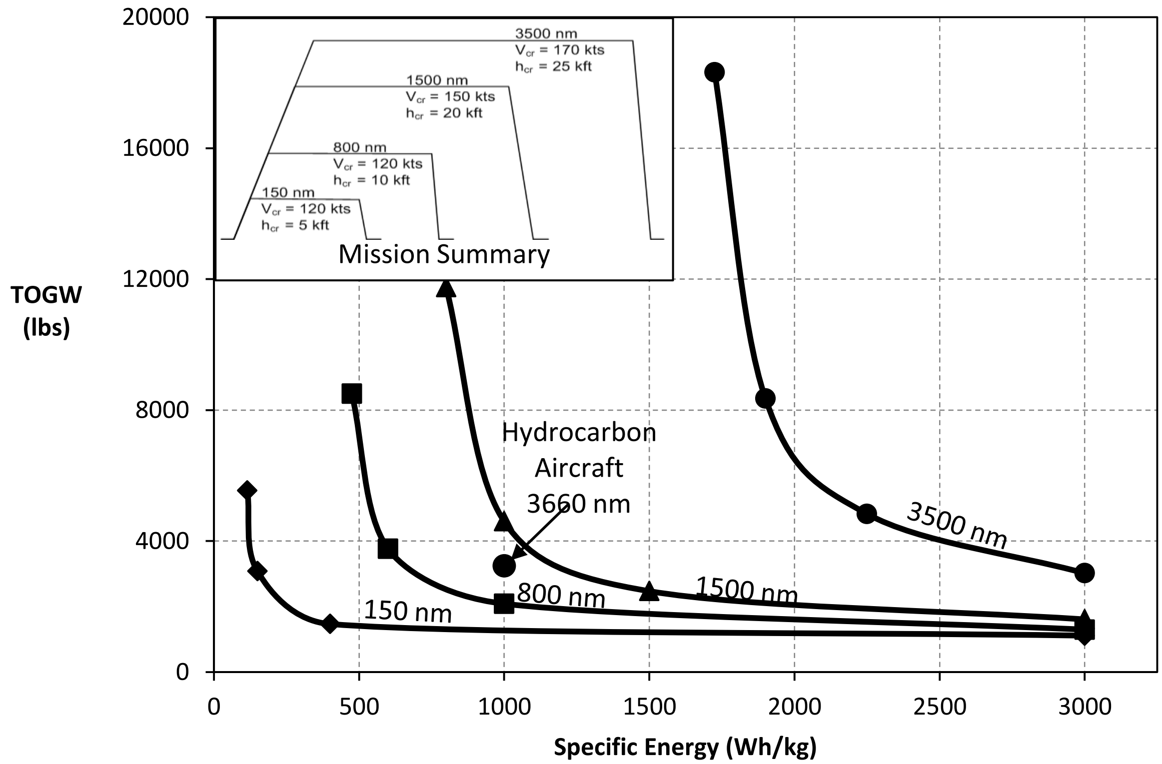

Figure 22. Vehicle TOGW as a function of battery specific energy (Wh/kg) for each design

ranges.

Effect of TOGW on design range

On the opposite axis the TOGW for each range contour approaches an asymptotic value as the specific energy decreases. Unlike the variable mass system found in hydrocarbon aircraft, the fixed battery mass employed for electric aircraft negates the benefit of fuel burn during cruise-climb. Therefore, at a certain specific energy the inert mass of the used batteries forces the TOGW, power requirements, and wing area to unsuccessfully converge on a design point for the fixed mission requirements. It is generally found that a battery mass fraction (W_{bat}/TOGW) greater than 50% results in this effect.

Effect of battery technology on design range

When comparing these curves to projected specific energies of various battery technologies, it becomes clear that small low range aircraft (approximately 100 to 200 nm) could be produced with Li-Po batteries (and currently are). Increasing the range to the 500 to 800 nm range bracket, Zn-Air or Li-S could be possible battery solutions. And finally, increasing the range requirement beyond 1,000 nm requires battery technology on the order of Li-Air projects. A 3,500 nm class vehicle cannot realistically meet the mission constraints with any of the batteries shown in Figure 22. A specific energy of 2,000 to 2,500 Wh/kg would be required simply to carry enough energy for the flight, not considering the specific power (Wh/kg) required from the propulsion system.

Design Recommendations

Considering the asymptotic nature of the vehicle mass of concept, practical combinations of range and specific energy would occur in the region with milder mass gradients. As such, establishing a transition line through each mass curve gives an approximate region for feasible combinations of range and specific energy for the specified missions, see Figure 23.

Comparing this feasible region with the projected specific energy of future battery technology, it is clear that Li-Air scale batteries are required for ranges above 800 nm but fail to allow for a feasible 3,500 nm aircraft. Clearly, the full NYP range mission, that initially founded this study, may not be possible in the foreseeable future. A practical electric aircraft solution space would likely be on the scale of 800-1,500 nm.

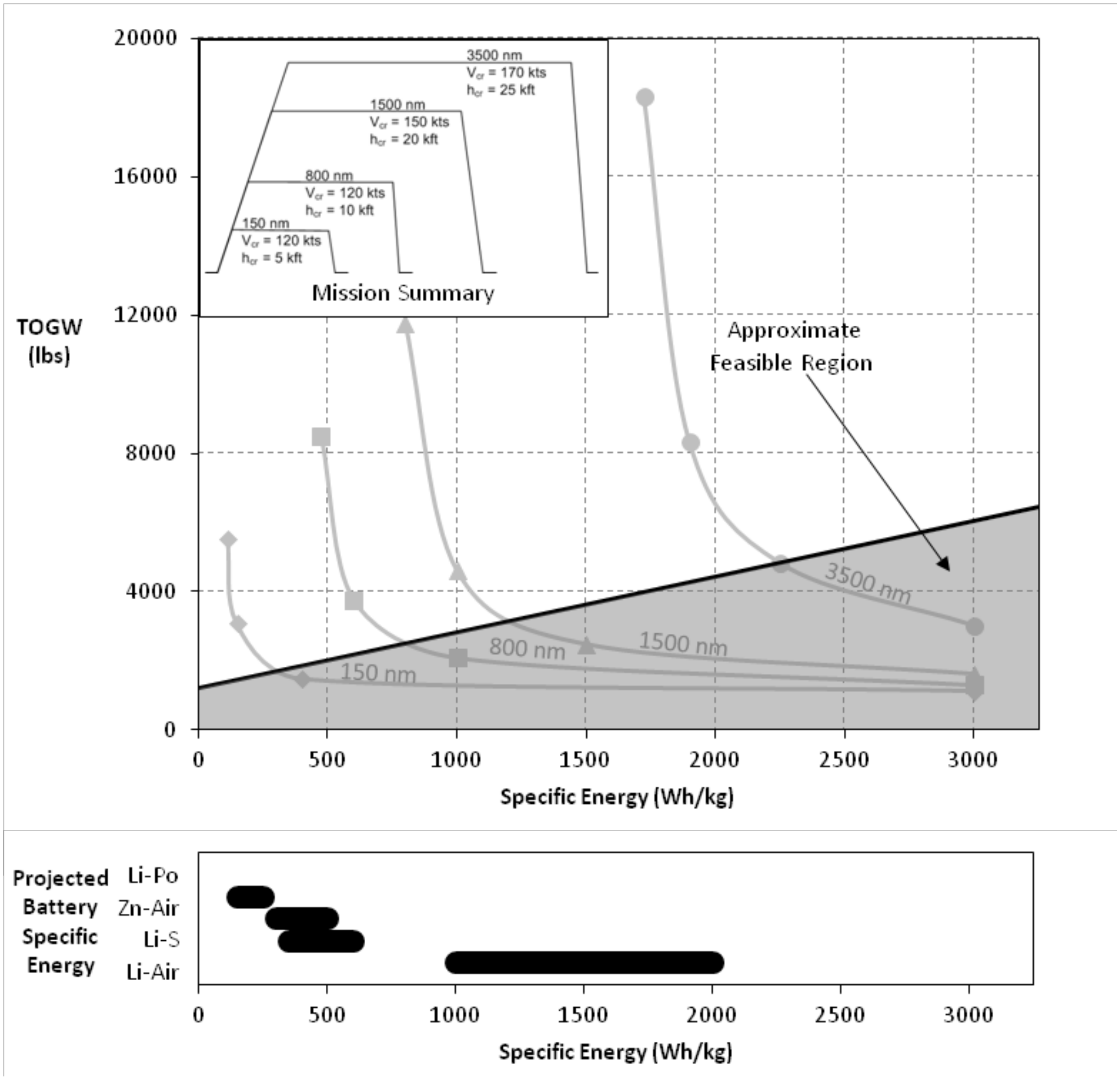

Figure 23. Locus of asymptotic transition points denoting minimum specific energy required as a function of range.

Summary and Conclusions

The principal conclusions can be drawn from the contour charts in the preceding chapter. Electric batteries are technology constrained for transatlantic flight (3,500 nm) in the foreseeable future. The twin penalties of fixed mass (dead weight) and lower energy density relative to hydrocarbon fuels lead to an exponential increase in total mass for electric aircraft.

However, the wide spread use of electricity could provide a significant cost saving over more expensive hydrocarbon fuel and thus for lower range missions, electric power stored via chemical batteries could be a cost effective energy alternative. Electric vehicles benefit from the fact that electricity is mass-produced, thus cost effective despite the fact that any electric aircraft tends to be heavier compared to the hydrocarbon equivalent. Not having a battery-technology breakthrough in sight, it is required to keep the practical design range below the critical value. It is possible to increase the structural and aerodynamic efficiency to somewhat offset the propulsive efficiency loss of chemical batteries, however, the key is increasing battery energy density.

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Solution Space Screening of a Hypersonic Endurance Demonstrator

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Abstract

The Solution Space Screening for a Hypersonic Endurance Demonstrator program was a two and one-half month study to:

- Demonstrate the Aerospace Vehicle Design (AVD) Laboratory sizing process applied to a fast turnaround project by using a dedicated knowledge-harvesting approach coupled with a unique sizing methodology to represent the first step in the conceptual design phase.
- Identify and visualize the solution space available for a hypersonic endurance (20 to 30 min) demonstrator that employs an air-breathing propulsion system.
- Propose prospective baseline vehicle(s) based on (1) available industry capability and (2) high-priority research (technology) required.
- Demonstrate a best-practice product development and technology forecasting environment that integrates the key team members, including (1) manager (decision maker), (2) synthesis specialist (integrator), and (3) technologist (disciplinary researcher).

In an effort to increase the air-breathing endurance capability of current hypersonic research aircraft (i.e., X-43, 7 seconds; X-51, 5 minutes), the NASA Langley Research Center (LaRC) Vehicle Analysis Branch (VAB) has tasked the Aerospace Vehicle Design (AVD) Laboratory at the University of Texas Arlington (UTA) with exploring the technical and operational solution space for a 20 minute to 30 minute cruise endurance demonstrator operating at Mach 6 to Mach 8. The primary challenge has been to explore that portion of the available industry capability that will require future technology complementation, with the aim of arriving at a technically feasible demonstrator within a given time frame and

budget. Consequently, this study necessitated the use of a simulation capability to assess and visualize the physical design drivers and sensitivities of the operational and technical domain.

The overall goal of the project has been the development of a concept for an airbreathing hypersonic endurance flight vehicle to increase our existing understanding and knowledge-base regarding air-breathing propulsion, associated thermal protection systems (TPS), and any operational peculiarities of long-duration hypersonic flight (e.g., maintenance, turnaround, practical range, etc.).

This report introduces the AVD Laboratory's product development and technology forecasting methodology as applied to the problem introduced above. Because the focus of this activity has been on the exploration of the available solution space, a unique screening process has been employed to assess the implication of (a) the mission, (b) the baseline vehicle, and (c) the operational scenarios on key research objectives to be defined.

This study concludes that an air-launched, liquid-hydrogen-fueled, 30 minute Mach 6 demonstrator (with 10 minute Mach 8 capability) provides the largest feasible solution space of the trades that have been examined (i.e., largest design margins with lowest technical risk) when compared with a kerosene-fueled equivalent.

Mission Requirements and Research Objective

The overall objective of this study is to explore and visualize the technical solution space for a hypersonic endurance demonstrator.

The NASA VAB operational and technology requirements for this demonstrator are:

- scramjet test vehicle
- reusable
- unmanned
- multiple aircraft (at least three test articles)
- entry into service circa 2020

To evaluate the technical feasibility of such a research vehicle, the following mission requirements are selected by NASA VAB:

- design speed: Mach 6 to 8 (possibly Mach 12)
- maximum endurance: 20 to 30 minutes
- payload: test instrumentation
- fuel selection: hydrogen or kerosene
- operation: straight line or point-to-point

The broad direction specified by VAB in June 2010 translates into a large *n*-dimensional design trade space. Please note that the VAB-defined design mission is considered a starting point only, thus the mission itself is a variable. Since the targeted flight regime is novel terrain for the designer, it is essential to trade flight vehicles capable of satisfying alternative missions. Clearly, the sizing exposure will iteratively enable the designer to define and justify a feasible baseline mission and baseline vehicle combination.

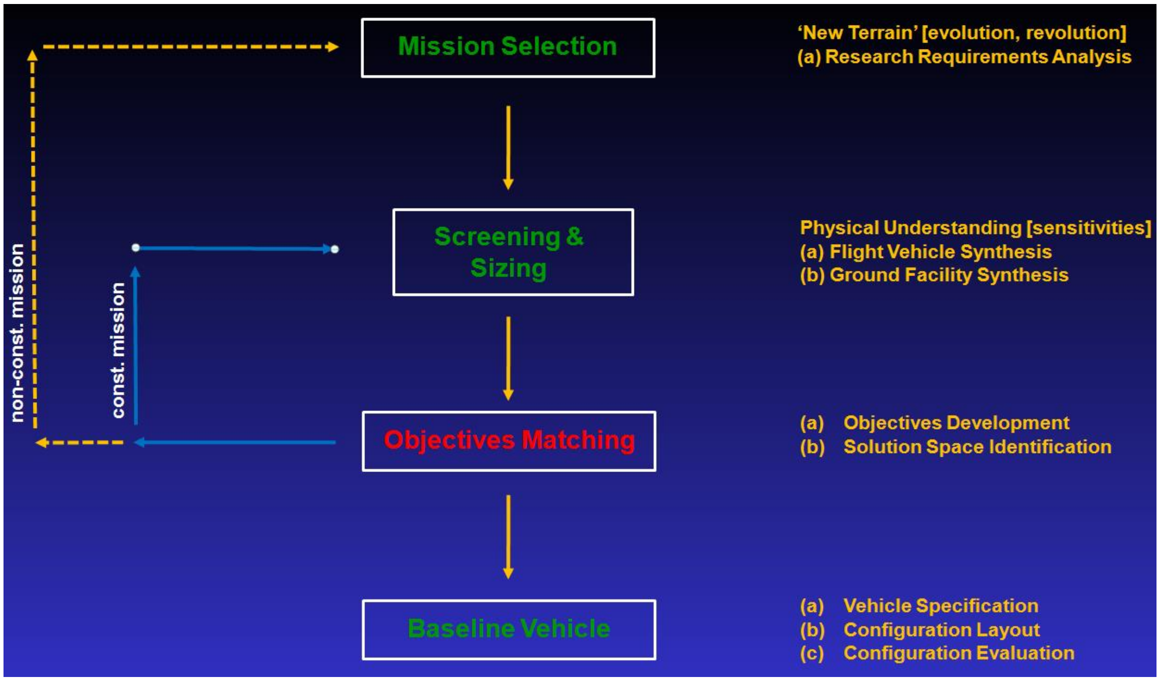


Figure 1. Iterative nature of the mission & objectives & baseline vehicle(s) selection process.

Figure 1 illustrates the iterative nature of the mission selection process. The unknown-terrain nature of a 20 to 30 minutes air-breathing demonstrator requires a modification of the traditionally utilized product development procedures. As shown in this figure, the AVD Laboratory screening & sizing methodology is the primary tool utilized to arrive at a (a) baseline mission which harmonizes with (b) the overall research objectives and (c) the baseline vehicle.

The sizing team is tasked to execute alternative missions resulting in prospective baseline vehicle(s). Throughout the sizing phase, the involved mindsets (*managerial* (M), *synthesis* (S), *technology* (T)) are successively gaining physical insight into the characteristic of the product. Consequently, true product understanding is evolving while the solution space alternatives are perturbed. The mission-trading needs to happen during the *parametric sizing* (PS) phase, an essential task before a baseline objectives catalogue can be formally defined. Clearly, the traditional notion of pre-defining the mission and objectives is not feasible with a product of such novel characteristics. The screening & sizing approach becomes the enabling means to arrive at a balanced set of (a) mission, (b) objectives, and (c) baseline vehicle(s).

Due to project time constraints, the present research undertaking excludes the research objectives development and matching step. Figure 2 illustrates the finally implemented baseline vehicle development sequence for the present study by omitting the *objectives matching* step shown in Figure 2. It is recommended to formally complement the existing study at a later step by including the *objectives matching* logic as an essential ingredient supporting decision-making.

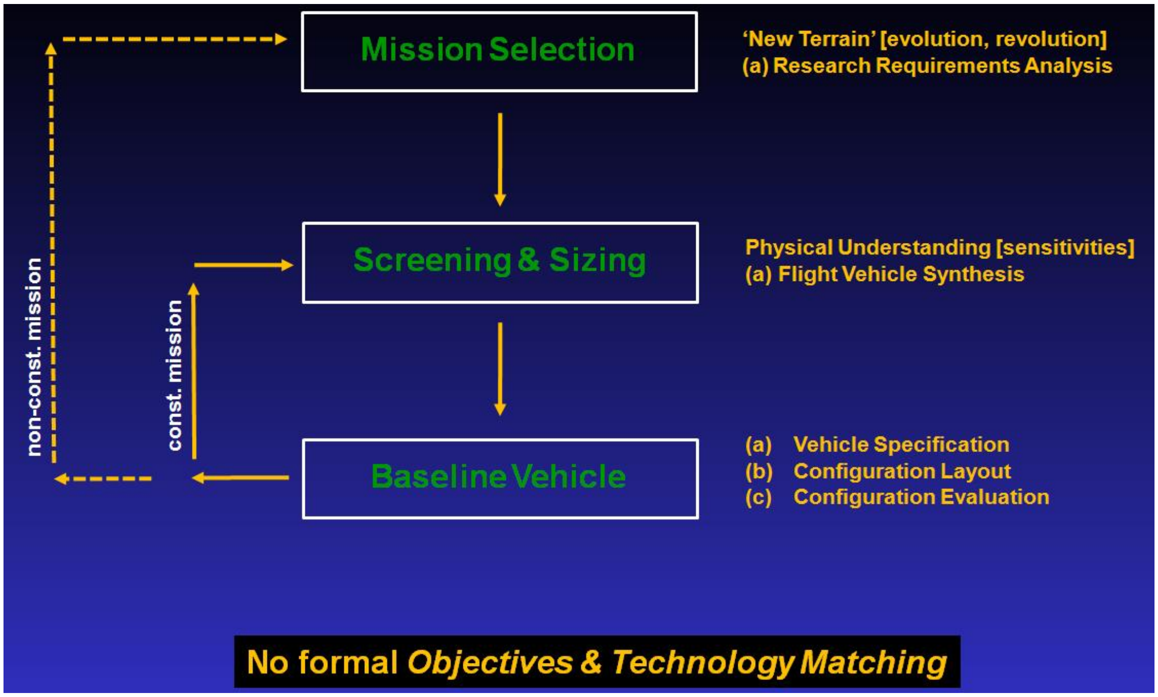


Figure 2. VAB/AVD Laboratory baseline vehicle development sequence.

Data-Base and Knowledge-Base Review of Hypersonic Demonstrators

A key component enabling the development of hypersonic flight test vehicles is effective management of the knowledge-generation and knowledge-preservation activity. As illustrated before, the research approach implemented places emphasis on elevating the understanding with regards to project aims and objectives, overall resulting in an informed and structured approach. In the present context, the research challenge is best formulated with the question: How to efficiently synchronize the *understanding available* with the *understanding required* to specify a feasible air-breathing hypersonic demonstrator with the technical resources, team support and time available? Due to the limited timeframe available, the DB and KB assistances have become indispensable to expedite the learning process.

The scope and complexity of the present research undertaking is seen as *catalyst opportunity*, which translates into a chance to evaluate past and present data and knowledge for its utilization in the context of a technically demanding demonstrator with not seen-before performance capability. Table

1 lists high-speed flight vehicles of direct relevance in the context of a future endurance testbed.

The following two sub-chapters present the flight vehicle conceptual design data-base (DB) and knowledge-base (KB) as developed and utilized for the present research undertaking. The main flight vehicle research & design work is directly benefitting from this dedicated DB & KB foundation.

Table 1. Past Hypersonic Demonstrator Projects and Programs

Start Date	End Date	Project/Program	Organization	Description
1952	1968	X-15	North American/NASA/USAF	Mach 6 to 8 rocket powered hypersonic research vehicle. 3 test vehicles, 199 flights
1957	1959	Griffon 02	Nord Aviation	Manned ramjet demonstrator
1962	1971	D-21	Lockheed	Mach 4 ram-jet UAV launched from the SR-71
1964	1965	MHCV	Lockheed	*Manned Hypersonic Cruise Vehicle*, some description of a demonstrator
1967	1968	UHTV	Vought	*Universal Hypersonic Test Vehicle*, flexible and modular hypersonic test vehicle
1967	1969	X-15 Delta	North American/NASA	Delta wing X-15
1969	1970	HYFAC	MAC/NASA	*HYpersonic FACilities* study, 32 rocket/air-breather configurations explored
1969	1969	X-15 SERJ	Marquardt	*Super Charged Ejector Ramjet* (RJ) X-15
1969	1969	X-15 Scram	Boeing	Scramjet (SJ) X-15
1970	1972	IGV	MAC/USAF	Incremental growth vehicle
1972	1972	PPD Scramjet Test Vehicle		*Propulsion Performance Demonstrator*, vertical takeoff cone with four scramjets around its periphery; rocket acceleration to test speed
1975	1977	X-24C NHFRF	Lockheed/NASA	*National Hypersonic Flight Research Facility*, B-52 launched, Mach-4.8 70,000 lbs vehicle; envisioned as a X-15 type flight operation
1976	1980	ASALM	Martin	Hydrocarbon fuel air-launched cruise missile
1980	1981	SLRV		*Shuttle Launch Research Vehicle*, Mach 8 aerodynamic configuration demonstrator
1985	1985	RSFTP		*Ramjet/Scramjet Flight Test Program*, M 4-7 F-15 launched vehicle
1989	1990	HYPAC	MBB	Sänger demonstrator study
1990	1995	BMFT	MBB/UK/UT/Dornier/MTU	Hypersonic technology program, HYTEX and RADUGA D2
1996	2004	X-43A	NASA LaRC/NASA Dryden	Scaled hypersonic scramjet demonstrator
1999	1999	SSTO Demonstrator	Hyper Tec	RBCC hypersonic demonstrators based on HYFAC Studies
1999	1999	Trailblazer	NASA Glenn	Modification of the NASA wing body to include RBCC and TBCC
2000	2002	X-43B	NASA LaRC/NASA Dryden	Reusable combined cycle demonstrator
2001	2002	X-43C	NASA LaRC/NASA Dryden	Hydrocarbon variant of the X-43A, RJ/SJ
2002	Present	HYFLY	Boeing/DARPA	Mach 6 ramjet powered cruise missile demonstrator
2003	Present	X-51A	Boeing	Scramjet propulsion research vehicle
2005	2007	X-43D	NASA LaRC/NASA Dryden	HYFLITE III, M 12 variant of the X-43A
2007	2007	HyCAUSE	DARPA/ADST	2-stage sounding rocket for hypersonic propulsion demonstration
2007	2008	Falcon HTV-3X	Lockheed/DARPA	TBCC hydrocarbon hypersonic demonstrator

Overall and Reduced Trade Space

The challenge of designing a 20 to 30 minutes hypersonic endurance demonstrator is embodied in the fundamentally unknown vehicle solution space and solution topography. Based on the best understanding available at the outset, it is required to define an initial or 'start' trade-space by taking relevant constraints and requirements into account.

Table 2. Overall Trade-Space Concepts, Categories and Options

CONCEPT/CONFIGURATION	CATEGORIES	TOTAL TRADE OPTIONS	SELECTED TRADES
Mission Concept	Mach number and duration	design Mach 6	design Mach 6
		design Mach 8	design Mach 8
		design Mach 12	
		test duration	0 to 30 minutes
	test range options	point-to-point	point-to-point
		fly-back	fly-back
Staging Configuration	SSTC	integrated booster, propellant and oxidizer tanks	
	TSTC	air launch	air launch
		expendable booster	expendable booster
		oxidizer drop tanks	
	MSTC	any combination of TSTC options	
Operations Concept	launch	HTO	
		VTO	
	recovery	HL	
Hardware Concept	lift & volume supply	lifting body	lifting body
		wing body	
	propulsion concept: (accelerator engine)	RKT	RKT
		TJ	
		RBCC	
		PDE	
	propulsion concept: (cruise engine)	SJ	
		dual mode RJ/SJ	dual mode RJ/SJ
		RKT	
	fuel selection	hydrogen	hydrogen
		methane	
		kerosene	kerosene
	primary & secondary controls	aerodynamic	
		mix	mix

It is to be expected that this initial trade-space, with associated constraints & requirements, will naturally mature during the configuration exploration phase. The configuration exploration phase is tasked to identify two primary solution-space areas of significance: (a) the solution space area based on presently available industry capability, and (b) the solution space area requiring prospective future technologies. Dependent on the establishment of overall project objectives (technology development, low-cost & risk demonstrator, etc.), the physical understanding generated will help to refine the initial trade-space scope.

Clearly, the early identification of the *correct* trade-space and technology combinations requires using logic, organization and transparency before any baseline design can be selected. This approach will provide the greatest insight into the design problem within the time assigned.

The process of rectifying thus reducing the theoretical trade-space available consists of: **(a)** Formulate a classification scheme for the design options available. **(b)** Focus the DB/KB development and team learning on relevant design trade-studies. **(c)** Harmonize pre-selected trades with VAB's team's long-term research objectives.

Table 2 presents the overall trade-space adopted classification scheme addressing (1) *mission concept*, (2) *staging configuration*, (3) *operations concept*, and (4) *hardware concept*. If all of the options shown in this general trade-space Table 2 would be executed, the total number of trades would exceed $90{,}000^+$ cases.

Applying the DB/KB lessons-learned and harmonization with VAB's research objects further allows reducing and focusing the trade-space:

1. ***Mission Concepts*****:** Mach 6 and Mach 8 design trades are given priority; point to point and fly-back options are explored. Mach 12 has been eliminated.

2. ***Staging Configurations and Operational Concepts*****:** HyFAC (Reference 3) determined that air-launch and vertical take-off provide the largest research value for a hypersonic demonstrator relative to horizontal takeoff and single-stage vehicles. Air-launch and vertical takeoff with a booster allow for smaller and lighter demonstrators which can focus on testing the high-speed regime. Consequently, the trades selected will focuse on air-launch and vertical takeoff options.

3. ***Hardware Concepts*****:** Alternative vehicle concepts have been grouped as follows:

    a. *Lifting body* - for this speed range, the lifting body provides improved volumetric efficiency over wing bodies; therefore, the lifting body has been selected as the sole volume supply option (Reference 3, 4).
    b. *Off-the-shelf accelerator rocket* – the off-the-shelf rocket motor (low risk item) is selected to accelerate the ramjet to start Mach number.
    c. *Dual-mode ramjet cruise engine* - the dual mode ramjet/scramjet is selected to allow for testing of both modes with a single vehicle.
    d. *Fuel selection limited to liquid hydrogen and kerosene* - the fuel selection is determined by the operational vehicle envisioned; for possible reusable TSTC launch vehicles, hydrogen appears to be the most likely choice. Kerosene appears to be an operationally practical option for a military hypersonic point-to-point vehicle. Consequently, both options (hydrogen and kerosene) are explored.

The above reasoning is reducing the overall trade-space to 10 trade studies, consisting of a constant test vehicle concept (lifting body, dual mode ramjet/scramjet, horizontal landing) with varying (a) design Mach number, (b) endurance, and (c) launch concept. The reduced trade-space is introduced with Table 3 and Figure 3.

Table 3. Summary of Design Trades Executed

	MISSION				**STAGING CONFIGURATION**		**OPERATIONS CONCEPT**		**HARDWARE CONCEPT**		
	Atmospheric			Test Range Options	TSTC		Launch		Fuel Selection		
Trade #	design Mach 6	design Mach 8	test duration	point-to-point	air launch	expendable booster	HTO	VTO	hydrogen	kerosene	dual fuel
1	x		0 - 30 min	x	x		x		x		
2		x	0 - 30 min	x	x		x		x		
3	x		0 - 30 min	x	x		x			x	
4		x	0 - 30 min	x	x		x			x	
5	x		0 - 30 min	x	x		x				x
6		x	0 - 30 min	x	x		x				x
7	x		0 - 30 min	x		x		x	x		
8		x	0 - 30 min	x		x		x	x		
9	x		0 - 30 min	x		x		x		x	
10		x	0 - 30 min	x		x		x		x	

For each individual trade study, the total system design solution space is identified and visualized with the AVD Laboratory parametric sizing program AVD^{sizing}. This 'best practice' sizing approach has been developed through a thorough review of parametric sizing processes and methods from the 1960s to present for subsonic to hypersonic vehicles, see Reference 5. With this framework in place, the available solution space is identified considering both technical and operational constraints.

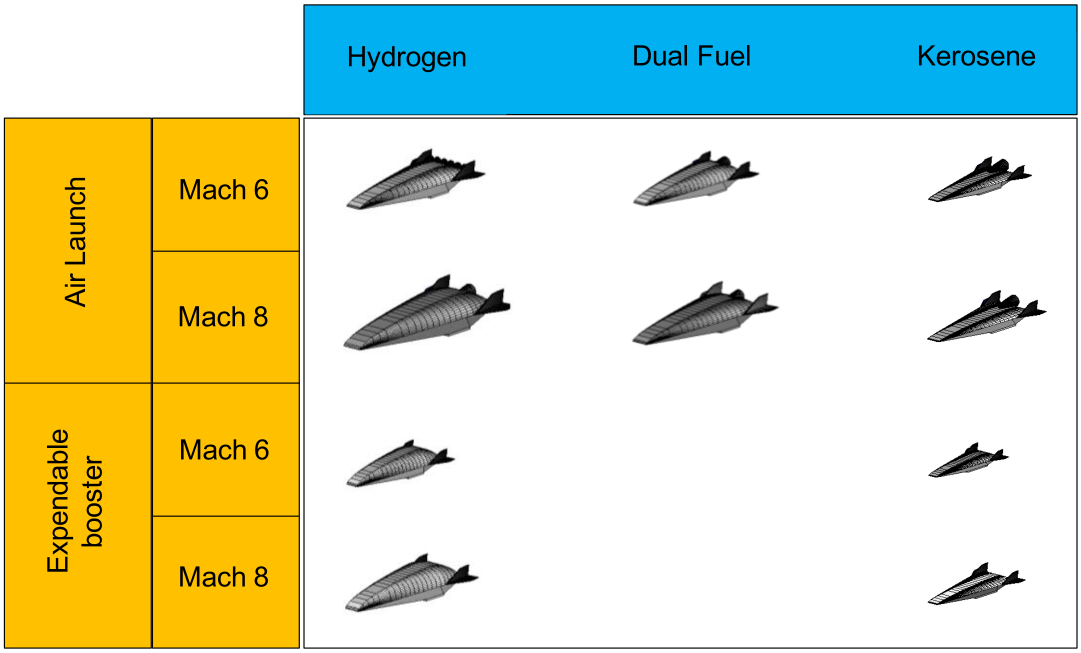


Figure 3. Reduced trade-space explored.

Parametric Sizing and Solution Space Screening

AVD Sizing Process Summary

AVD^{sizing} is a constant mission sizing process capable of first-order solution space screening of a wide variety of conventional and unconventional vehicle configurations. Solution space screening implies an overall focus on visualizing multi-disciplinary design interactions and trends. AVD^{sizing} is based on the *Hypersonic Convergence* sizing approach for transonic to hypersonic vehicle applications as developed at formerly McDonnell Aircraft Company between 1970 and 1990, see Reference 6. The modular process implemented with AVD^{sizing} relies upon a robust disciplinary methods library for analysis and a unique multi-disciplinary analysis (MDA) sizing logic and software kernel enabling data storage, design iterations, and process convergence. The integration of the disciplinary methods library and the generic multi-disciplinary sizing logic enables the consistent evaluation and comparison of radically different flight vehicles, see References 7, 8. The flight vehicle configuration independent implementation of AVD^{sizing} allows for rapid parametric exploration of the complete flight vehicle system via a convergence check to mission. Figure 4 visualizes the top level sizing process implemented.

At the heart of the process is the weight and balance budget. The results from the geometry, performance constraint and trajectory modules (weight ratio, required T/W ratio, and vehicle geometry) are provided to a weight & volume available and required logic. For a given vehicle slenderness parameter $(\tau = V_{total}/S_{pln}^{1.5})$, the planform area is iterated through the total design process until weight & volume available equal weight & volume required.

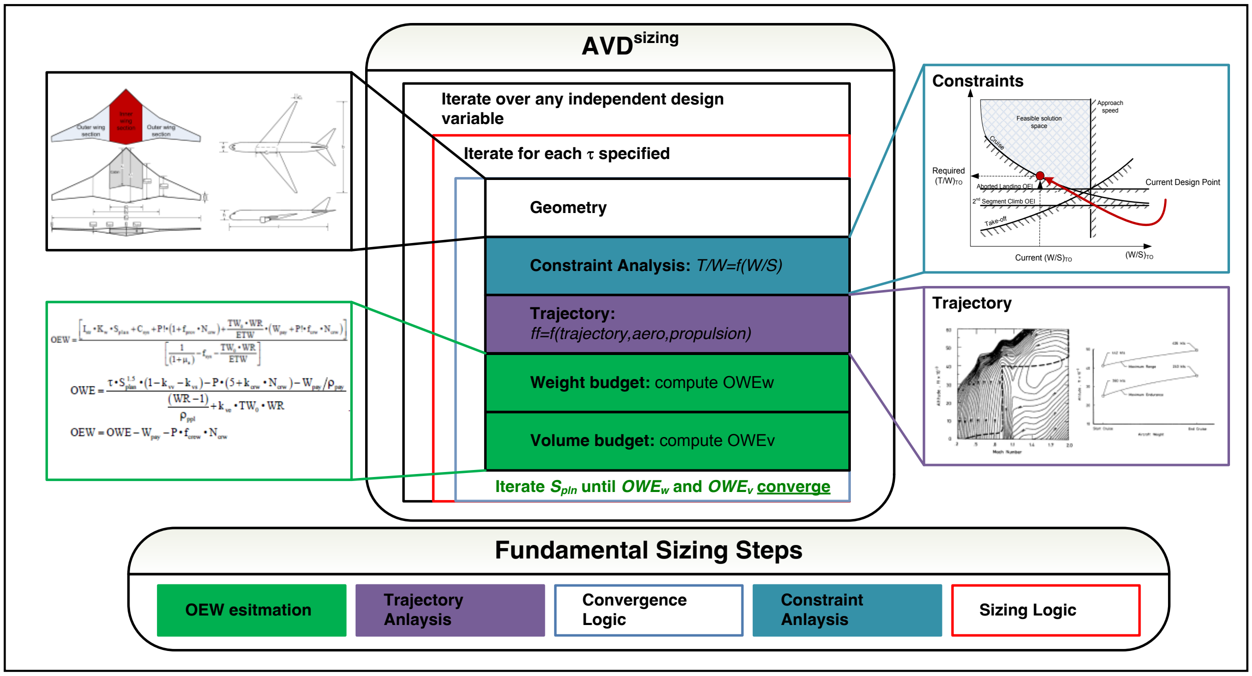


Figure 4. AVDsizing methodology visualized via Nassi-Schneidermann structogram.

Disciplinary Methods Library Overview

The following methods are utilized from the disciplinary methods library for this hypersonic demonstrator study, see Reference 5. The methods selected are of consistent first-order nature, including empirical, semi-empirical and reduced-order analytical types. Table 4 summarizes the disciplinary methods used for this study.

Table 4. Summary of Disciplinary Methods

DISCIPLINE	METHOD TITLE	DESCRIPTION	REFERENCE
Geometry	Planform	Vehicle length, span and spatular width for current planform area based on constant leading edge sweep and c/s.	Czysz [6]
	Bottom Surface	Total volume and dimensions determined from non-dimensional engine constants.	Appendix A
	Top Surface	Total volume, dimensions and wetted area computed for a compound elliptical cross-section. Top surface height determined from specified slenderness parameter.	Appendix A

Aerodynamics	Drag Polar	McDonnell-Douglas empirical correlations (circa 1970) based on vehicle slenderness, frontal area and wetted area with spatular corrections from Pike. $C_{D_0} = f(\tau, c/s, S_{wet}, S_{front}, Mach,\ Configuration)$ $L' = f(Mach, Configuration)$	HyFAC [3] Pike [10]
	Lift-Curve Slope	McDonnell-Douglas empirical correlations (circa 1970) of all-body hypersonic vehicles. $C_{L_\alpha} = f(Mach, Configuration)$	HyFAC [3]
	Maximum Lift (low speed)	FDL-7 wind tunnel data.	FDL-7 report
Propulsion	Scramjet - Modified 1-D Cycle Analysis	1-D stream thrust analysis with corrections inlet spillage drag. RSM from Bradford used for truncated SERN nozzle performance.	Heiser and Pratt [12], Bradford [13]
	Ramjet – Marquardt Data	Representative data from Marquardt study (circa 1960).	Marquardt [14]
	Rocket – Pratt & Whitney Method	Analytic off-design performance estimation of rocket thrust and I_{sp} based on ideal rocket equation.	Czysz [6]
Performance	Landing	Wing loading requirement for given stall speed and maximum trimmed lift coefficient.	Coleman [5]
	Trajectory	2-D energy integration method (altitude and velocity), constant q trajectory to cruise velocity, cruise climb, maximum L/D descent.	Appendix A
Stability and Control	Trim effects	Engine cowl location effect on trim drag.	HyFAC [3] Czysz [6]
Weight and Volume	Hypersonic Convergence Weight and Volume Budget	Empirical weight and volume estimation of structure, systems, payload and propellant.	Appendix A

Description of Solution Space Visualization

The overall product solution space consists of individually converged total flight vehicle design points. For a fixed vehicle slenderness parameter (τ), the complete weight breakdown and trajectory are computed for every individual vehicle planform iteration. The process is repeated until the weight and volume required meet the weight and volume available, see Figure 5.

A vehicle geometry solution space contour or topography is determined by varying the vehicle slenderness and re-converging each design point. The operational mission solution space is created by varying cruise time and re-converging each solution contour. The result is a continuous carpet plot comparing individually converged flight vehicle solutions based on structural index, I_{str}, and *TOGW*, see Figure 6. The structural index, I_{str}, is a metric of the structural efficiency of the concept, and is defined as structural weight per unit wetted area. This parameter will be further discussed when addressing the description of the solution space constraints.

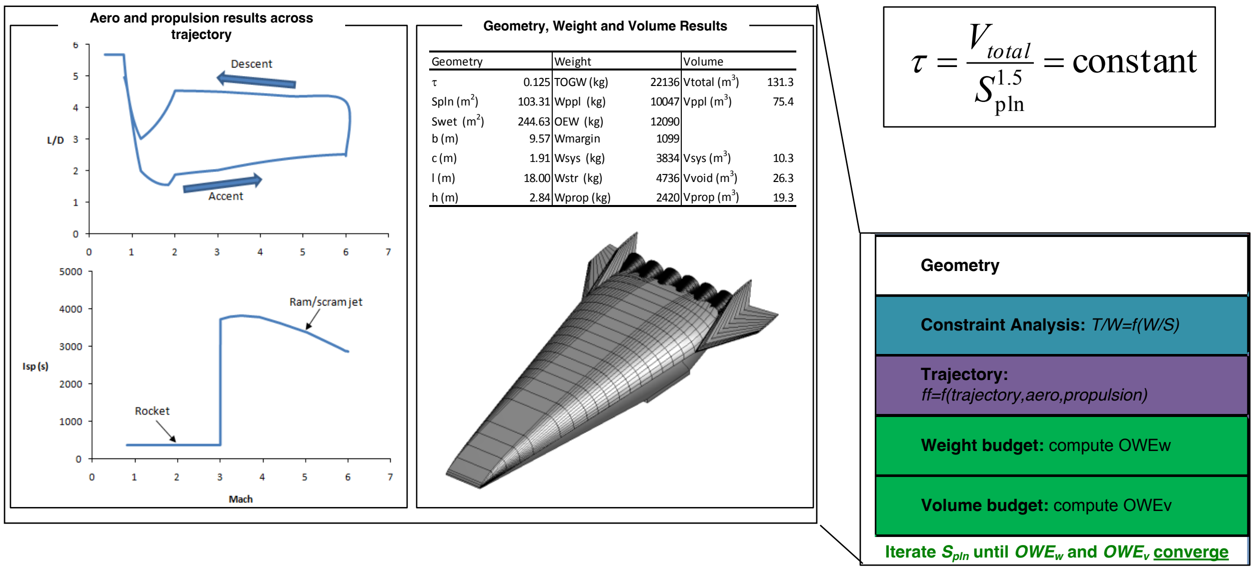


Figure 5. Each design point represents a converged complete hypersonic vehicle (Example: Mach-6, 30 minutes, cruiser configuration).

Solution Space Constraint Description: Having generated a carpet plot consisting of individually converged flight vehicles of varying vehicle slenderness (τ) and cruise time, the next step is to superimpose the aborted landing constraint, the thrust minus drag (*T-D*) constraint and the structural technology level available (I_{str}). The landing constraint is computed from the prescribed approach speed, which translates to the required 1g stall speed and required stall wing loading. Additionally, mapping the required wing loading to the *TOGW* and I_{str}, the *T-D* constraint can be added to the solutions, see Figure 7.

The *T-D* constraint represents the highest τ allowable which will still have positive acceleration during the ascent portion of the trajectory. If the vehicle is stouter (reduced planform area and increased vehicle height), then this limits the wave drag increase and the reduced capture area results in negative thrust, see Figure 7.

Figure 7 represents the structural weight per wetted area required to converge the configuration to each specific slenderness value (τ). When superimposing relevant material and structural concept technology levels onto the vehicle structural index carpet plot, the left boundaries of the solution space are determined. For vehicle slenderness parameters which require structural indices beyond this limit, the structural and shingle material are not feasible, see Figure 8. Figure 9 documents the structural indices utilized to derive the technology solution space boundaries pertinent to the flight mission.

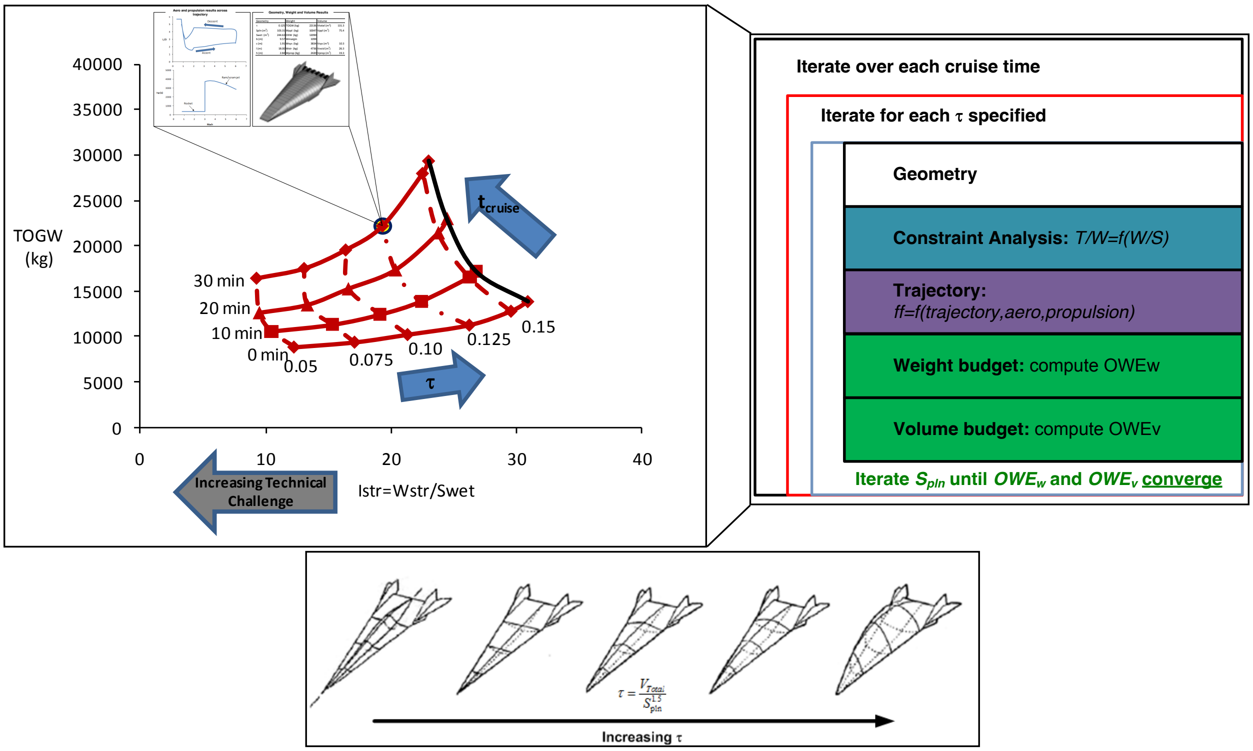


Figure 6. Solution space plot of TOGW and Istr for varying vehicle slenderness and cruise time.

The final constraints of relevance for identifying the solution space include: (a) launch vehicle load capability, (b) geometry limits for the carrier (air-launch) aircraft, and (c) expendable booster staging options. Options for the air-launched carrier vehicle are the B747-100SCA and B-52H; both options have been explored as possibilities. The B-52H employs an under wing mount constrained by: (a) the maximum load of the pylon, and (b) the geometric boundaries between the fuselage and inboard engine, the test vehicle wing and engine exhaust plum. The X-24C was intended to be the largest vehicle to possibly fit under the B-52H wing mount. Therefore, the X-24C's *TOGW*, length and width represent a guide for the maximum capability of the B-52H air-launcher for this investigation, see Figure 10. The B747-SCA is a modified B747-100 designed to carry the Space Shuttle Orbiter. For this study, the *OEW*, length and span of the Space Shuttle Orbiter are used as a guide for the maximum air-lift capability of the B747-SCA, see Figure 11.

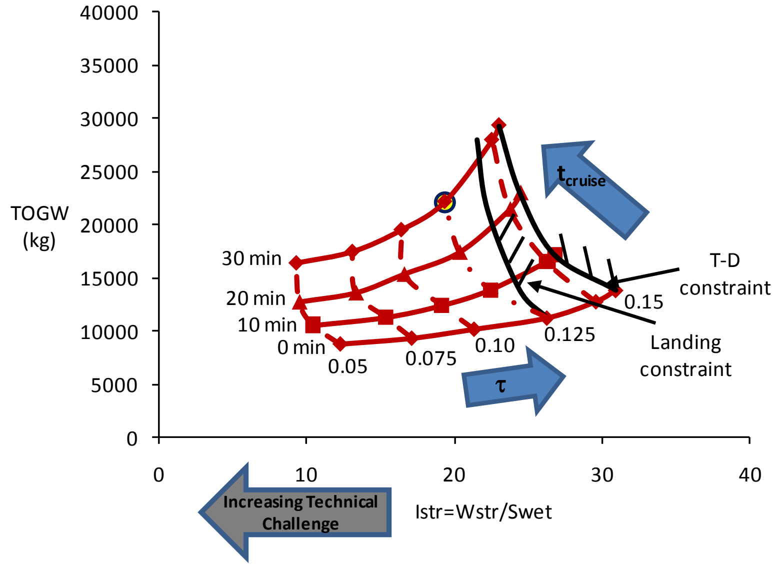


Figure 7. Landing and T-D constraints imposed on the solution space. For the Mach 6 demonstrator, the landing constraint is more constraining than T-D.

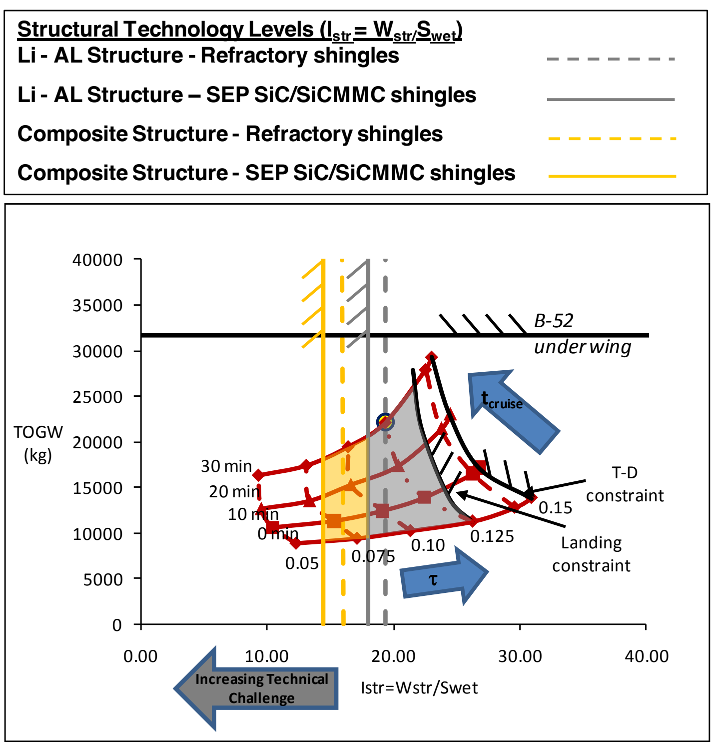
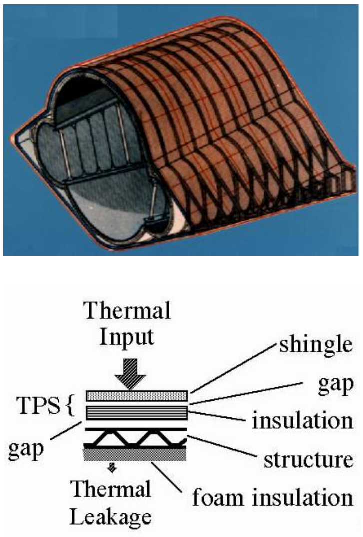


Figure 8. Superposition of structural indices provides the final constraint to determine the technical solution space.

Integral fuel Tank Structural constant (MAC circa 1970)



Break-down of industrial capability index

	Li-AL structure		Composite strucutre	
Integral Hydrogen Fuel tank				
	Refractory shingles	Advanced schingles	Refractory shingles	Advanced schingles
	kg/m^2	kg/m^2	kg/m^2	kg/m^2
Shingle	6.30	4.88	6.30	4.88
Insulation	4.39	4.39	4.39	4.39
Structure	7.08	7.08	3.61	3.61
Foam insulation	1.61	1.61	1.61	1.61
total	***19.38***	***17.97***	***15.92***	***14.50***
Integral Kerosene fuel tank				
	Li-AL structure		Composite strucutre	
	Refractory shingles	Advanced schingles	Refractory shingles	Advanced schingles
	kg/m^2	kg/m^2	kg/m^2	kg/m^2
Shingle	6.30	4.88	6.30	4.88
Insulation	4.39	4.39	4.39	4.39
Structure	7.08	7.08	3.61	3.61
Foam insulation	0.00	0.00	0.00	0.00
total	***17.77***	***16.36***	***14.31***	***12.89***

Figure 9. Definition of structural capability indices used for this study. (Ref 6)

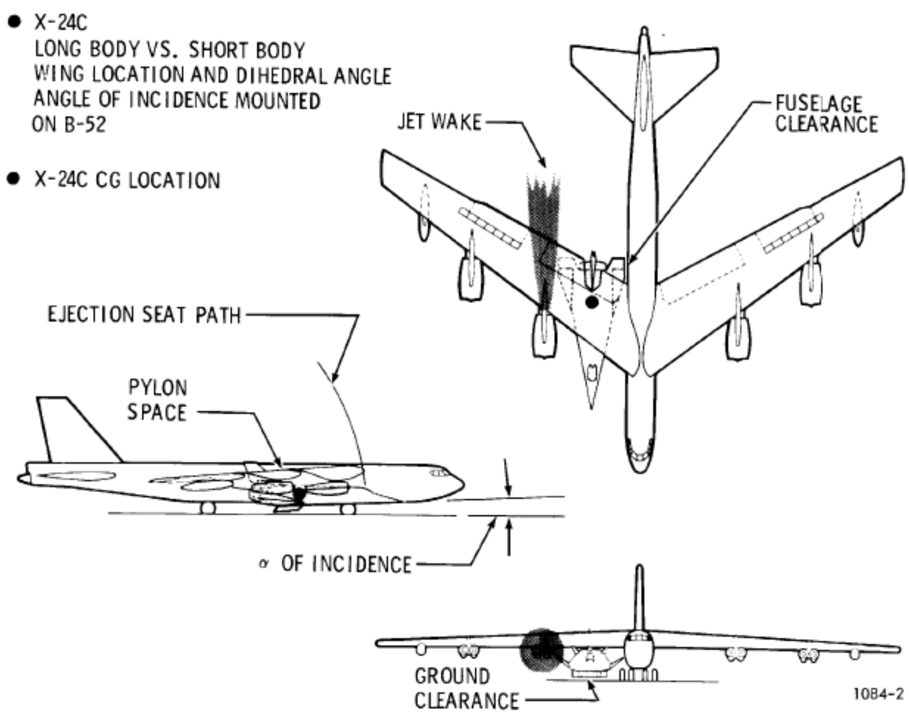


Figure 10. B-52H under-wing mount geometric constraints. (Ref 15)

B747-100SCA	**B-52H**
	
Design Payload: Space Shuttle	Design Payload: X-24C
Payload =78,000 kg	Payload = 31,751 kg
$Span_{limit}$ = 23.79 m	$Span_{limit}$ = 7.3 m
$Length_{limit}$ = 37.24 m	$Length_{limit}$ = 17.3 m

Figure 11. Summary of B747-SCA and B-52H constraints for the hypersonic demonstrator study. (Ref 15,16)

M55A1	**Castor 120**	
		Payload equals payload to orbit plus weight of upper stages Velocity and altitude referenced to first stage separation point
Minotaur I – 1^{st} Stage	Taurus XL – 1^{st} Stage	Both boosters are currently in production
Payload =13,116 kg	Payload = 19,046 kg	
Vel_{sep} = 1,510 m/sec	Vel_{sep} = 2,209 m/sec	
Alt_{sep} = 33 km	Alt_{sep} = 41 km	

Figure 12. Summary of Minotaur I and Taurus XL 1^{st} stage constraints for the hypersonic

When considering expendable boosters as the launch method for the hypersonic demonstrator, the boosters are found to fit the hypersonic demonstrator options as the 2nd-stage of either the *Minotaur I* or *Taurus XL* launch vehicles. These representative boosters are selected based on their maximum payload weight, separation velocity and separation altitude, see Figure 12. The maximum payload weight capacity of the booster 1st stage is taken to be the maximum payload to orbit, plus the weight of the upper stages.
During the screening process, each solution space is bounded by operational factors and technology factors for landing, *T-D*, and structural index. Next, the carrier/launch vehicle constraints are examined to determine the appropriate air-launch vehicle options for each trade.

Solution Space Screening

The selection of the trade-space and the accompanying trade-matrix results in a solution space screening activity overall consisting of two (2) launch options, two (2) cruise Mach numbers, and three (3) fuel combinations. The solution space deliverables for each option are visualized relative to each other with Figure 13. For each trade, the cruise time will be increased from 0 min to 30 min in increments of 10 min while vehicle slenderness is varied, generating the distinct solution space carpet plot. Since Figure 13 compares discrete flight vehicle types (launch method, Mach number, fuel), note that the ten (10) identified and visualized trade solution spaces demonstrate regions of operational and technical feasibility with a varying TOGW y-axis scale. In total, 237 flight vehicle design solutions have been converged.

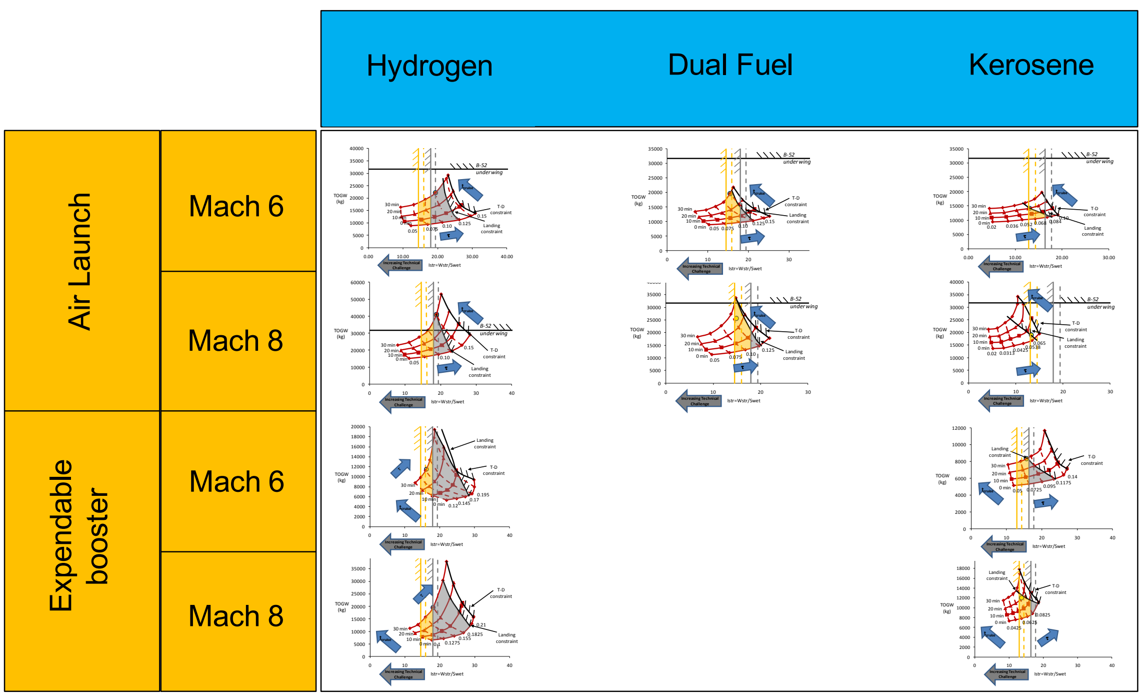


Figure 13. Relative comparison of solution spaces for each design trade explored.

Solution Space Comparison and Baseline Selection

Using the results of this study, two endurance hypersonic demonstrators have been identified as prospective baseline vehicles for research and development, concept formulation and definition, and system development efforts. It has been determined that the goal of first flight within the 10 to 20 year time span can be achieved with reasonable confidence using mostly existing industrial capability. Required technology development efforts would primarily focus on scramjet engine requirements for (a) a hydrogen-based, and/or (b) a kerosene-based operational infrastructure.

In summary, the current research undertaking has covered and delivered sensitivity trends for launch and staging options, accelerator motor selection, ramjet/scramjet fuel selection, material concept and configuration arrangement, all measured against the operational mission (i.e. cruise time, speed requirement). Considering the broadness of these engineering options evaluated, the value of parametric sizing (PS) on physical understanding and system-level decision-making has been demonstrated. Clearly, parametric sizing utilizes the first principles mindset and tools to answer how changes within the mission, operational scenario and overall research objectives influence the design 'hardware' requirements, thus the decision-making process. The recommendations and conclusions of the solution space trade analysis follow.

Solution Space Screening

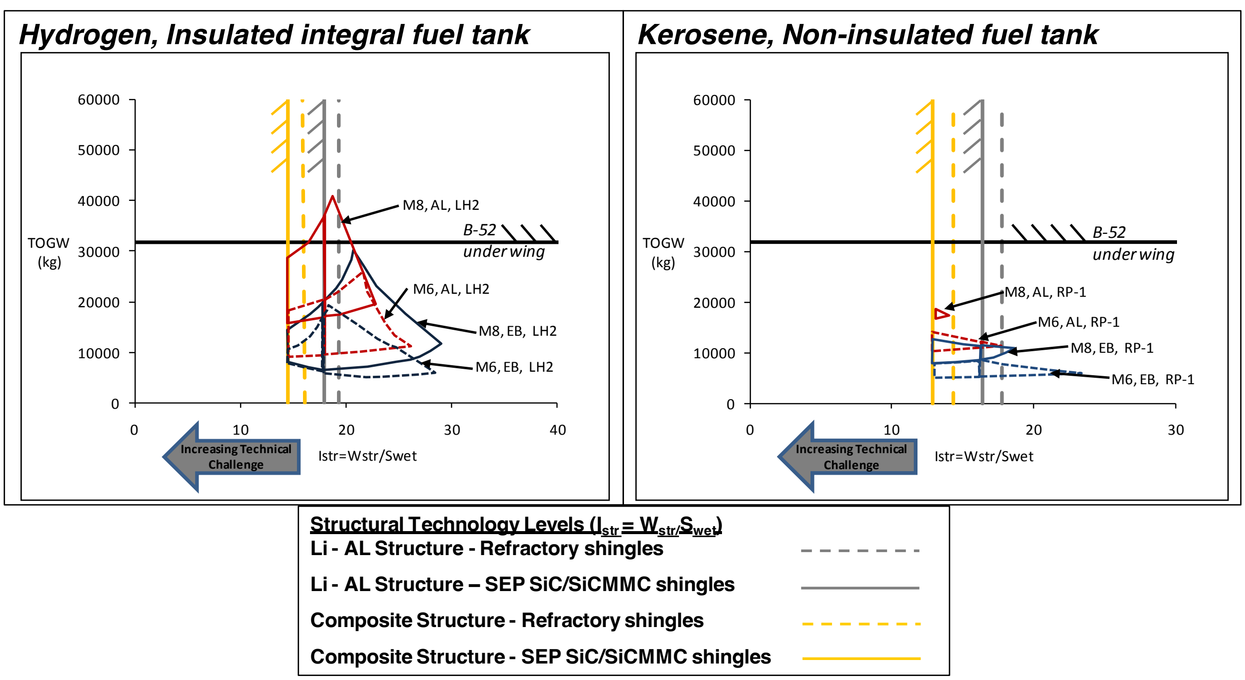


Figure 14. Hydrogen-fueled vehicles allow for a larger technical solution space compared to kerosene-fueled vehicles.

A. Design-Level Summary

A direct comparison of the hydrogen and kerosene demonstrator trade space illustrates that hydrogen vehicles have a larger feasible design space relative to kerosene equivalents, see Figure 14. Comparing *kerosene vehicles relative to hydrogen vehicles*, the kerosene designs show larger sensitivity to landing constraints due to increased vehicle density (which increases wing loading) and the requirement for a lighter structure to compensate for reduced fuel I_{sp} values. Comparing *hydrogen vehicles relative to kerosene vehicles*, the trade-off between fuel weight density and energy density characteristics yields a higher total system benefit for hydrogen.

B. Mission-Level Summary

In order to explore the hypersonic design relationships at mission level, Figure 14 superimposes the outer contours of the hydrogen and kerosene solution spaces. Both design spaces, with decreasing maximum *TOGW*, include (a) M=8 Air-Launch, (b) M=6 Air-Launch, (c) M=8 Expendable Booster, and (d) M=6 Expendable Booster. This discussion centers on the cruise time constraint equal to 30 min (positive curve at the top of the trade space). For the hydrogen-based demonstrators, the individual solution spaces offer a vehicle point-design each that meets the operational limit while having the largest structural technology margin compared to kerosene equivalents. The M=8 Air-Launch option could be considered the higher risk solution for the 30 minutes cruise mission. For the kerosene-based demonstrators, only the M=6 Expendable Booster trade offers a feasible 30 minutes endurance solution. The remaining trades do not present feasible solutions for the 30 minutes demonstrator due to structural constraints. This shows that overall vehicle feasibility is dependent on not-yet-available structural industry capability, thus requiring future structures technology developments.

Design Point Comparison

The following discussion reviews the converged baseline vehicle design points selected from the hypersonic flight vehicle design solution space screening activity. For more information regarding the demonstrator selection for individual hydrogen- and kerosene-fuel trades, please refer to the earlier sections. Figure 15 presents the short-list overview of prospective baseline vehicle configuration-, speed- and fuel combinations. Table 5 and Table 6 are summarizing the general 'parametric' design characteristics for the feasible baseline vehicle options utilizing either hydrogen or kerosene fuel.

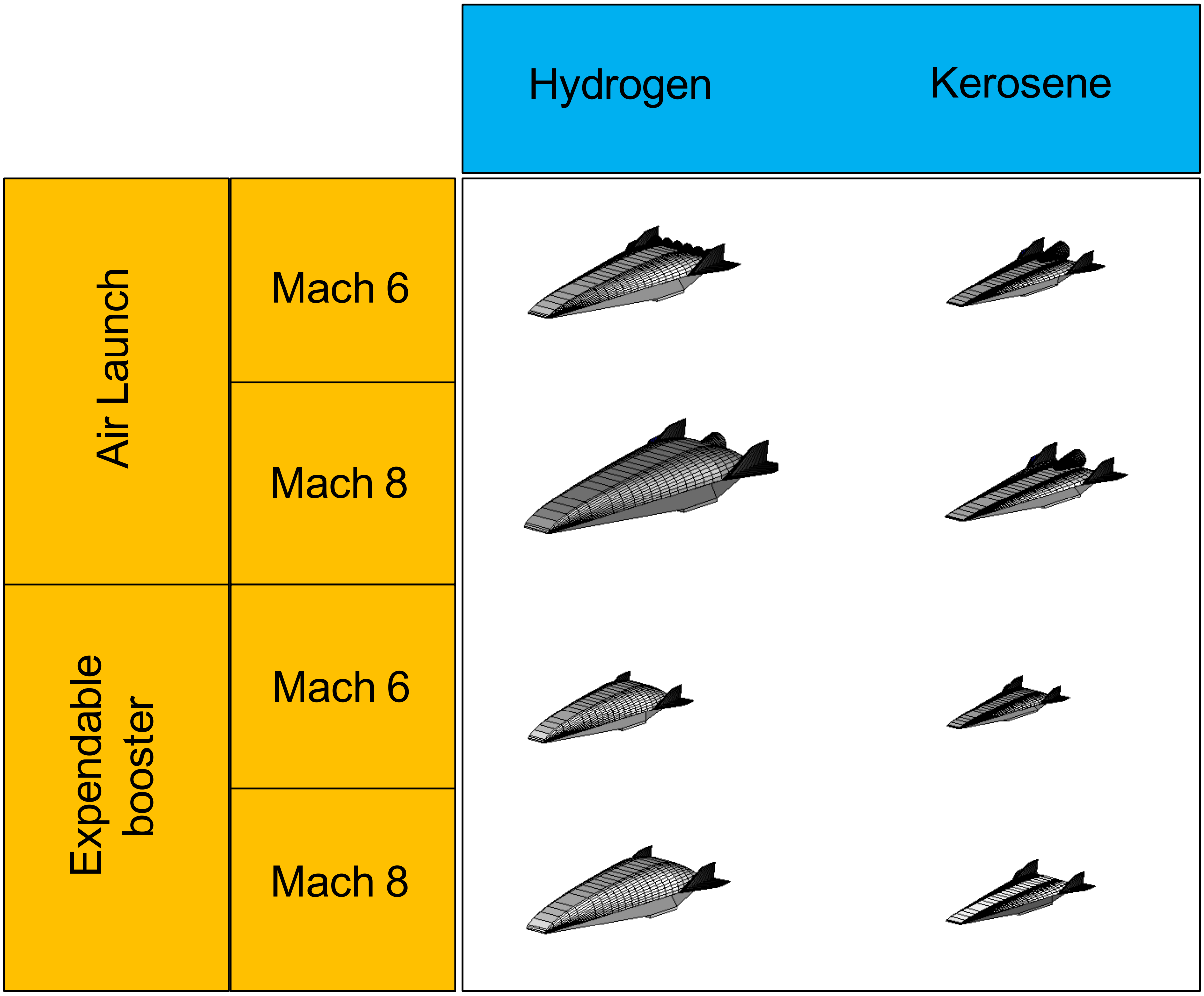


Figure 15. Configuration geometry of proposed hydrogen and kerosene hypersonic baseline vehicle designs.

Table 5. Design Characteristics for Hydrogen-Based Suggested Vehicle Selection

	Mach 6, Air-Launch, LH_2		Mach 8, Air-Launch, LH_2		Mach 6, Expendable Booster, LH_2		Mach 8, Expendable Booster, LH_2	
t_{cruise}	30 min		30 min		30 min		30 min	
Down range	4060 km	2190 nm	6300 km	3402 nm	4120 km	2224 nm	6000 km	3239 nm
TOGW	22136 kg	48802 lbs	40900 kg	90170 lbs	25635 kg	25364 lbs	19577 kg	43160 lbs
W_{ppl}	10047 kg	22149 lbs	20821 kg	45903 lbs	3757 kg	8283 lbs	7423 kg	16365 lbs
OEW	12090 kg	26653 lbs	20079 kg	44267 lbs	7709 kg	16995 lbs	12153 kg	26793 lbs
τ	0.125		0.15		0.175		0.1825	
S_{pln}	103.3 m^2	1112 ft^2	161.2 m^2	1735 ft^2	63.5 m^2	683.5 ft^2	95.67 m^2	1230 ft^2
B	9.57 m	31 ft	11.95 m	39 ft	7.5 m	25 ft	9.2 m	30 ft
L	18 m	59 ft	22.48 m	74 ft	14.1 m	46 ft	17.32 m	57 ft
L/D cruise	2.46		2.31		1.88		1.98	
***Isp cruise* (s)**	2613 s		2246 s		2600 s		2248 s	
Trkt	453 kN	102 klbs	1015 kN	228 klbs				
Nrkt	7 at 64.7kN each		1 at 1015 kN each					

Table 6. Design Characteristics for Kerosene-Based Suggested Vehicle Selection

	Mach 6, Air-Launch, RP-1		Mach 8, Air-Launch, RP-1		Mach 6, Expendable Booster, RP-1		Mach 8, Expendable Booster, RP-1	
t_{cruise}	20 min		4.5 min		30 min		20 min	
Down range	3480 km	1880 nm	3270 km	1770 nm	4523 km	2442 nm	5640 km	3045 nm
TOGW	14191 kg	31287 lbs	19013 kg	41917 lbs	8345 kg	18398 lbs	12027 kg	26515 lbs
W_{ppl}	7715 kg	17009 lbs	10627 kg	23429 lbs	3536 kg	7796 lbs	6074 kg	13391 lbs
OEW	6476 kg	14277 lbs	8386 kg	18488 lbs	4809 kg	10602 lbs	5953 kg	13124 lbs
τ	0.07		0.0675		0.085		0.075	
S_{pln}	58.4 m^2	628 ft^2	76.7 m^2	826 ft^2	34.75 m^2	374 ft^2	51.28 m^2	552 ft^2
b	7.19 m	24 ft	8.24 m	27 ft	5.55 m	18 ft	6.74 m	22 ft
l	13.53 m	44 ft	15.51 m	51 ft	10.44 m	34 ft	12.68 m	42 ft
L/D cruise	3.79		3.39		4.08		3.92	
***Isp cruise* (s)**	943 s		753 s		970 s		732 s	
Trkt	512 kN	115 klbs	512 kN	115 klbs				
Nrkt	1 at 512 kN each		1 at 512 kN each					

Baseline Vehicle Description

While feasible options for both, the hydrogen-fueled and kerosene-fueled vehicles, exist, the selection of the fuel type alone is not a sufficient indicator for demonstrator feasibility. The selection criteria for the fuel type are primarily determined by the required operational vehicle characteristics, in this case being a robust air-breathing propulsion system flying test bed. Clearly, additional criteria are needed to measure the risk and benefit merits of this demonstrator vehicle. At this point we ask the simple question: *"If a hydrogen fueled scramjet is required, what demonstrator is recommended?"* and *"If a kerosene-fueled scramjet is required, what demonstrator is recommended?"*

- ***Selection Criteria***
  - ***Versatility***
    (largest flexibility in operation)
    - ***Mach 8, air-launch, 30 min***
  - ***Growth capability in concept***
    (sensitivity to increase in scale)
    - ***Mach 6, air-launch, 30 min***
  - ***Design confidence***
    (largest technology margins)
    - ***Mach 6, air-launch, 30 min***
  - ***Limitations***
    (Hydrogen demonstrator)
    - ***B747-100 carrier required for air-launch***
    - ***Operational limitation of Hydrogen (relative to Kerosene)***

- ***Selection***
  - ***Mach 6, 30 min cruise, air launch with Mach 8, 10 min cruise capability (the solutions spaces overlap)***
  - ***B747-100 air-launch (planform constrained on the B-52)***
  - ***RL-10 rocket accelerator***
  - ***Li-Al structure***

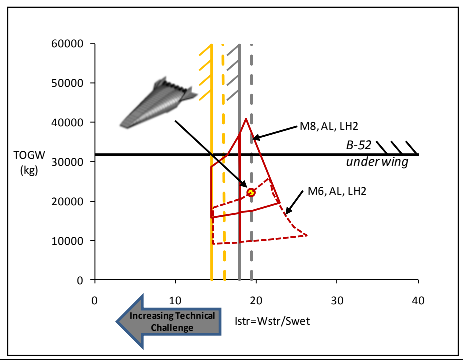


Figure 16. The Mach 8 air-launched case represents the largest operational flexibility while Mach 6 air-launched has larger growth capability and design confidence. Since M6 30 min and M8 10 min solution curves overlay, it appears that the M6 30 min vehicle could perform the Mach 8 mission for 10 minutes.

For each fuel requirement, trade-studies will have to address the following four qualitative metrics:

1. *Versatility* Which vehicle represents the largest flexibility of its operational capability?
2. *Growth Capability* Which vehicle is the least sensitive to scale? In other words, which vehicle is least sensitive to changes in structural capability which are assumed for this study?

3. *Design Confidence* Which vehicle has the largest technology margins and allows for a design point which has sufficient margin in terms of structural technology, *T-D* and landing distance?
4. *Limitations* Which vehicle has any perceived limitations that would hinder development?

If *hydrogen scramjet testing* is required, assessment results are presented with Figure 16:

Observing that the Mach 6, 30 minutes vehicle can perform the Mach 8 mission for 10 minutes, this scenario provides a compromise which will allow for both, the endurance and speed requirements to be accomplished at a lower risk option compared to the Mach 8, 30 minutes vehicle. Consequently, the selection of this particular baseline design provides a superior design margin and a concept less sensitive to structural and propulsion technology requirements.

- ***Selection Criteria***
  - ***Versatility (largest flexibility in operation)***
    - ***Mach 6, expendable, 30 min***
  - ***Growth capability in concept (sensitivity to increase in scale)***
    - ***Mach 6, expendable, 30 min***
  - ***Design confidence (largest technology margins)***
    - ***Mach 6, expendable, 30 min***
  - ***Limitations (Kerosene demonstrator)***
    - ***High level of structural technology required***
    - ***Operation of Kerosene at high temperatures***

- ***Selection***
  - ***Mach 6, 30 min cruise***
  - ***Composite structure (possible aluminum)***
  - ***M55A1 Expendable Booster***

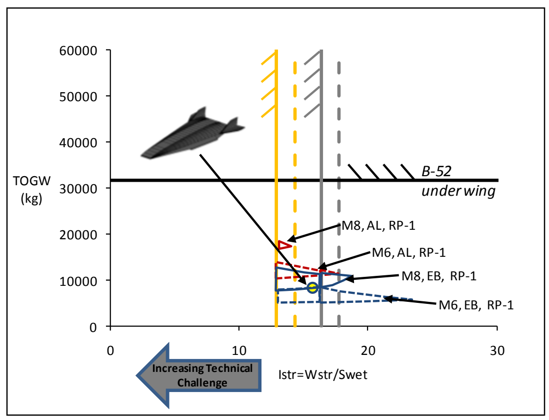


Figure 17. The Mach 6 kerosene-fuel expendable booster trade is the only trade-study which allows for 30 minutes cruise endurance.

If *kerosene scramjet testing* is required, assessment results are presented with Figure 17:

Given the increased density of kerosene (which increases *W/S* and causes the landing constraint to increase) accompanied with a reduced energy density, the required structural technology must increase to compensate. This leaves the Mach 6, 30 minutes vehicle as the only viable technical option for kerosene scramjets. Furthermore, it is important to note that the Mach 6, 30 minutes solution overlays with the Mach 8, 0 minutes cruise time solution. Consequently, the Mach 6, 30 minutes research vehicle can accelerate to Mach 8, but it will not have sufficient fuel for 30 minutes but 10 minutes cruise endurance.

Summary and Conclusions

This report documents a parametric sizing study performed to develop a program strategy for (1) research and development (R&D) and (2) procurement of a next-generation hypersonic air-breathing endurance demonstrator. In the context of the present research undertaking, the AVD Lab team has utilized the *parametric sizing* (PS) tool to measure sensitivities and classical figures-of-merit for the manager [M], synthesis specialist [S], and technologist [T]. The systematic approach applied (**screening & sizing**) is utilized to iteratively harmonize the relationships amongst: (a) mission selection, (b) research objectives definition, and (c) baseline vehicle(s) characterization. The above outlined process arrives at a justification package able to characterize the suggested baseline hypersonic vehicle design.

Design Lessons Learned

Beyond the two primary recommendations communicated in Section VI, several design lessons have been learned through the course of this project which are worthy of note.

- *LH_2 fuel* allows for a larger technical solution space relative to the kerosene option.
- *Air-launch* from the B-52 is limited due to under-wing geometry (planform) constraints rather then under-wing load limitations.
- *Selection of scramjet fuel* is not driven by technical feasibility of the demonstrator test-bed but requirements specified by the operational aircraft.
- *Air-launch and expendable booster launch* are both viable options with LH_2.
- *Launch arrangement* should be based on flight rate requirement and associated operating cost.
- *Off-the-shelf accelerator rocket motors* are available, thereby reducing overall development program costs and initial program risks.
- *Landing constraints*, driven by the abort mission, tend to constrain the solution space.
- *Dual fuel option* marginally decreases size of vehicle, relative to the 30 min LH_2 variant.
- A *reduced cruise time* Mach 8 mission could represent an off-design point for the Mach 6 demonstrator (Merlin thrust class rocket is no longer required).

It is felt that each of the lessons learned require attention before a selection of confidence can be made for a baseline vehicle and moving forward with the design.

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Development of Advanced Commercial Transport Aircraft Configurations Through the Assessment of Past, Present, and Future Technologies

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Abstract

NASA's *Subsonic Fixed Wing Project* has organized its research portfolio into three areas; N+1 represents concepts and technologies for the next generation B737/A320 sized transports; N+2 represents hybrid-wing-body concepts and related technologies; N+3 represents subsonic and supersonic concepts and technologies beyond hybrid-wing-body in the 2025+ timeframe. The initiation of this study by the NASA Langley Research Center is timely given the historically significant changes currently being witnessed with: (1) *technology* (configuration, materials, propulsion), (2) *economics* (rising energy costs), (3) *social* (mobility), (4) *environmental* (noise, emissions, fuel consumption), (5) *market* (return on investment, job stability). Consequently, the historically established air transportation projections of transport capacity growth may become obsolete, thereby demanding a paradigm-shift towards future robust air transportation scenarios. Thereby the United States must be prepared to lead this *Air Transportation Revolution* by timely delivering industry technology solutions throughout the air transportation continuum.

Introduction

The principal objectives of this study are as follows:
To perform advanced strategic planning for N+3 commercial transport aircraft concepts and technologies (large long haul) to assist technologists, researchers, and managers at NASA LaRC, NIA, and other US centers in decision-making.
To transition such selected technology portfolio into future operational and practical industry hardware applications.

As such, the effort is limited to the formulation and first-order application of a systematic product development life-cycle methodology. A generic methodology has been developed to support research portfolio planning and its execution for *evolutionary* and *revolutionary* N+3 generation commercial subsonic large long haul aircraft concepts and associated with past, present, and future technologies.

This study investigated in total 5 case studies for 5 unique technology portfolios, 1 market segments (Boeing B777-300ER, 335 PAX), and 2 design scenarios (variable altitude, fixed altitude [27 kft]). Primary technologies under consideration included (Reference 1):

N+0
Tail-aft configuration
Aluminum structure, high bypass turbofan, partial laminar aerodynamics.

N+1
Tail-aft configuration
Composite structure, next generation high bypass turbofan, increased laminar aerodynamics.

N+2
Thrust vector control
Composite structure, next generation high bypass turbofan with thrust vectoring capability, increased laminar aerodynamics.

Blended wing body
Composite structure, next generation high bypass turbofan, increased laminar aerodynamics.

N+3
Tail-aft configuration + strut-braced wing
Composite structure, next generation high bypass turbofan, natural laminar aerodynamics.

Tail-aft configuration + truss-braced wing
Composite structure, next generation high bypass turbofan, natural laminar aerodynamics.

Consequently the sizing process developed for this project has demonstrated the robustness to consistently assess configuration and technology options to allow more informed decision-making. The case studies themselves did prioritize technology benefit matrix at the technology level.

Overall Study Methodology

The study has been organized into three distinct phases with individual work elements or tasks defined for each:

Phase I Preparatory Activities (Reference 2)

Task 1 – Research Strategy Definition
Objective is to formulate, discuss, harmonize, and adopt research ground rules for the 12 month study. Particular emphasis is directed towards collaboration with the main three NASA LaRC organizations: APPO, SACD, and RTD.

Task 2 – Operational Requirements Definition
This task primarily interacts with NASA LaRC APPO and SACD. The objective is to define generic operational aircraft mission requirements to be expected in the 2025+ timeframe. This requires defining a range of likely mission scenarios, from today's transportation mission to tomorrow's transportation revolution.

Task 3 – Reference Vehicle Definition
Appropriate reference aircraft need to be selected for the mission requirements. Those vehicle(s) serve as the datum to which any development needs to be compared to.

Task 4 – Disciplinary Technology Matrix
This task primarily interacts with NASA LaRC RTD. Past, present, and future disciplinary technologies are surveyed, organized, and documented with the expectation towards completeness. A technology matrix emerges as a working document, representing the current state-of-the-art understanding available.

Task 5 – Multi-Disciplinary Configuration Matrix
This task primarily interacts with NASA LaRC SACD and RTD. Multi-disciplinary past, present, and future aircraft configurations and concepts are defined, surveyed, and documented in this matrix. Throughout Tasks 4 and 5 two grouping schemes emerge which allow a consistent characterization of technologies and arbitrary aircraft configurations and their subassemblies. The main benefit of this categorization materializes when utilized as a 'virtual design-toolbox'. Each subassembly can be assigned to a set of physical characteristics. Then, different configuration- and concept-scenarios (outside the box) can be explored first order assuming different levels of technology for a given mission specification.

The outcome of Phase I will be a report documenting Tasks 1 to 5, including meeting protocols and a detail plan for the remainder of the 12 month research study.

Phase II Configuration, Concept and Technology Identification

Task 6 – Disciplinary Technology Potential
This task primarily interacts with NASA LaRC RTD. The objective is to assess the disciplinary development limits theoretically possible. This will define for each discipline (e.g., aerodynamics) an equivalent to the 'minimum energy limit line'. Questions that need to be asked

include “what is the minimum drag possible, maximum L/D possible, smallest wetted surface area possible, etc”. This task challenges the technologist to first identify the physical limit and then to review the options as to how to access the idling performance potential assuming risk from low (could be) to high (might be).

Task 7 – Parametric Sizing (PS) Phase
This task primarily interacts with NASA LaRC SACD and RTD. The conceptual design (CD) phase can be conveniently subdivided into three distinct sub-phases: (a) Parametric Sizing (PS) Phase [technical and economic design solution space identification], (b) Configuration Layout (CL) Phase [identification of alternative design solutions resulting in configuration trade matrix], and (c) Configuration Evolution (CE) Phase [quantification and identification of baseline aircraft]. Tasks 7 and 8 are only concerned with the first two CD phases, being the PS and CL phases. The PS (Parametric Sizing) Phase first identifies the available solution space for the given mission specification. This solution space is, at this point, not yet populated by distinct point designs, but it rather identifies the feasibility of the mission by assuming a specific technology level.

Task 8 – Configuration Layout (CL) Phase
This task primarily interacts with NASA LaRC SACD and RTD. The two matrices from Tasks 4 and 5 are utilized to the full during the CL (Configuration Layout) Phase. The CL Phase represents the true ‘outside the box’ creative opportunity, which identifies an array of competing design solutions which are located inside the solution space. Sensitivity studies are the primary means to identify the potential of individual technologies, aircraft configurations and concepts.

The report deliverable for Phase II documents Tasks 6 to 8. Transparency is provided as to how technology, configuration and concept sensitivities are generated. The main research effort needs to be invested into Tasks 7 and 8.

Phase III Advanced Planning Activities

Task 9 – Prioritized Technology Matrix
This task primarily interacts with NASA LaRC RTD. The technology matrix generated during Task 4 collects, interprets, and implements the research results (technology sensitivities leading to prioritization) generated throughout Phase II.

Task 10 – Prioritized Configuration Matrix
This task primarily interacts with NASA LaRC SACD. The configuration matrix generated during Task 5 collects, interprets, and implements the research results (technology sensitivities leading to prioritization) generated throughout Phase II.

Task 11 – Demonstration of Configuration Evaluation (CE) Phase
This task primarily interacts with NASA LaRC APPO, SACD, and RTD. The AVD Lab next

generation life-cycle synthesis methodology AVDS is demonstrated with an advanced design case study. The relevance of this 'design control center' to all three NASA LaRC organizations is emphasized. The conceptual design level design case study covers the complete simulated life-cycle from mission definition to accident investigation.

Task 12 – Strategic Recommendations
The deliverables of the 12 month effort are guidelines defined for (a) technology planning, (b) configuration planning, (c) concept planning. Justification is provided throughout leading to prioritized recommendations.

Data-Base, Knowledge-Base and Parametric Process

A key component enabling the development of revolutionary transport aircraft is effective management of the knowledge-generation and knowledge-preservation activity. As illustrated before, the research approach implemented places emphasis on elevating the understanding with regards to project aims and objectives, overall resulting in an informed and structured approach. In the present context, the research challenge is best formulated with the question: How to efficiently synchronize the *understanding available* with the *understanding required* to specify an *evolutionary* and *revolutionary* N+3 generation commercial subsonic large long haul aircraft concept with the technical resources, team support and time available? Due to the limited timeframe available, the DB and KB assistances have become indispensable to expedite the learning process.

The following two sub-chapters present the flight vehicle conceptual design data-base (DB) and knowledge-base (KB) as developed and utilized for the present research undertaking. The main flight vehicle research & design work is directly benefitting from this dedicated DB & KB foundation.

Flight Vehicle Data-Base

The first step in efficiently utilizing existing aircraft design knowledge has been a systematic literature survey, which in itself has been an ongoing effort throughout the existence of the *AVD Laboratory* and of course during the current research period. Source for accessing normal and radical design data and knowledge have been (a) public domain literature, (b) institution and company internal sources, and (c) expert advice. For efficient handling of design related data and information, a dedicated computer-based aircraft conceptual design data-base (DB) has been set up, see Figure 1. Reference 3 presents the literature DB file-structure. This system handles disciplinary and inter-disciplinary literature relevant for conceptual design (methodologies, flight mechanics, aerodynamics, etc.), interview-protocols, flight vehicle case study information (descriptive-, historical-, numerical information on conventional and unconventional flight vehicle configurations), simulation and flight test information, etc. The overall requirement for the creation of the DB has been simplicity in construction, maintenance, and operation, to comply with the underlying time constraints.

A detailed description of the DB is beyond the scope of the present discussion. The system has become a steadily growing, comprehensive, and effective working tool. Clearly, the quality of such system is only as good as the degree of completeness, actuality, and familiarity by the user. The DB has matured to be the central instrument for managing aircraft design data and information. However, the true potential of this system for utilizing design data and information has been opened up by proceeding as follows:

1. availability of a *reference list* containing meaningful entries; (*DB*)
2. availability of these references as a *hardcopy* on the table; (*DB*)
3. utilization of time to *absorb* the data & information; (*DB*)
4. *review, select, classify, subtract, and document* the data & information provided; (*DB*)
5. *extraction, combination and utilization* of data/ information in a pre-defined manner. (*KB*)

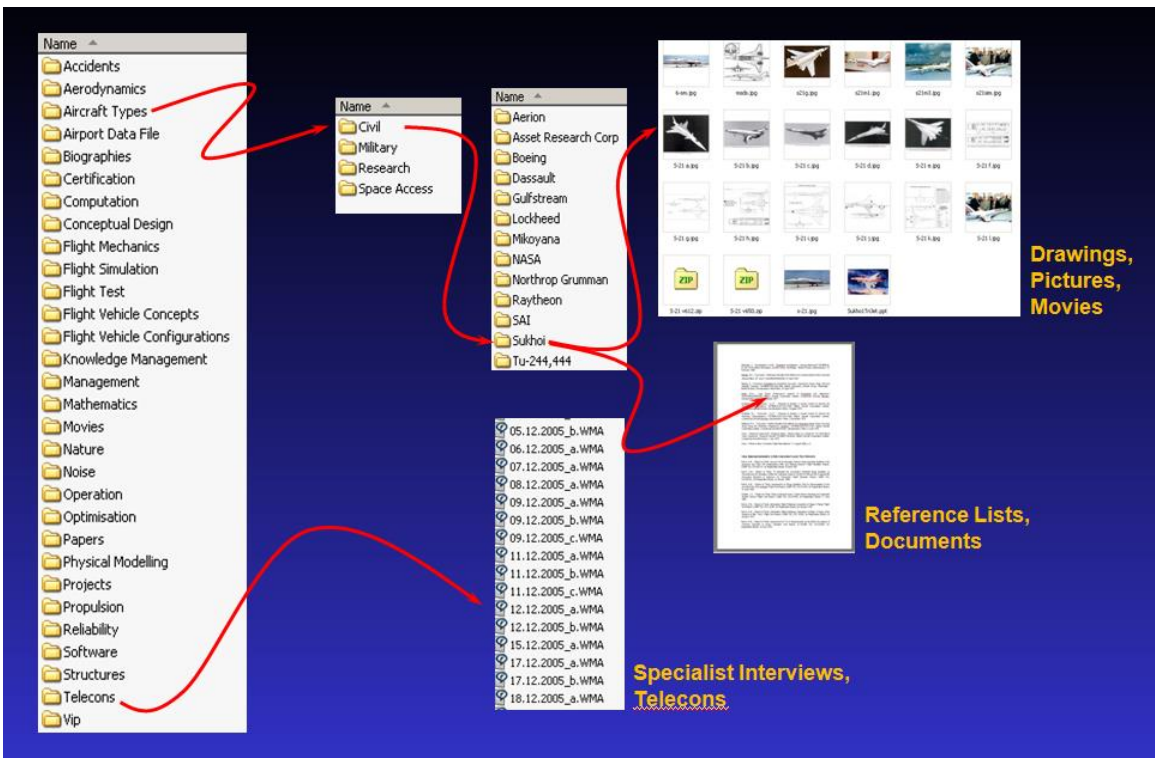

Figure 1. Dedicated AVD Laboratory DB and organization scheme. (Reference 1)

The first four steps are handled within the DB. The DB has been put to use to provide in an intermediate step (step four) suitably selected, structured, and condensed flight vehicle conceptual design data and information. The research goal, to develop an *evolutionary* and *revolutionary* N+3 generation commercial subsonic large long haul transport, requires to account for as many design-related interactions as necessary, since the rationale for the evolution of aircraft is diverse as a quick browse through aviation history reveals. The aircraft design disciplines identified relevant and the representative case studies of design ingenuity selected both elements need to be appreciated mutually, to efficiently serve the design understanding where innovation provided answers to otherwise troublesome problems. The updated DB embodies a technology-baseline attained, which is considered state-of-the-art for the current research undertaking.

Flight Vehicle Knowledge-Base

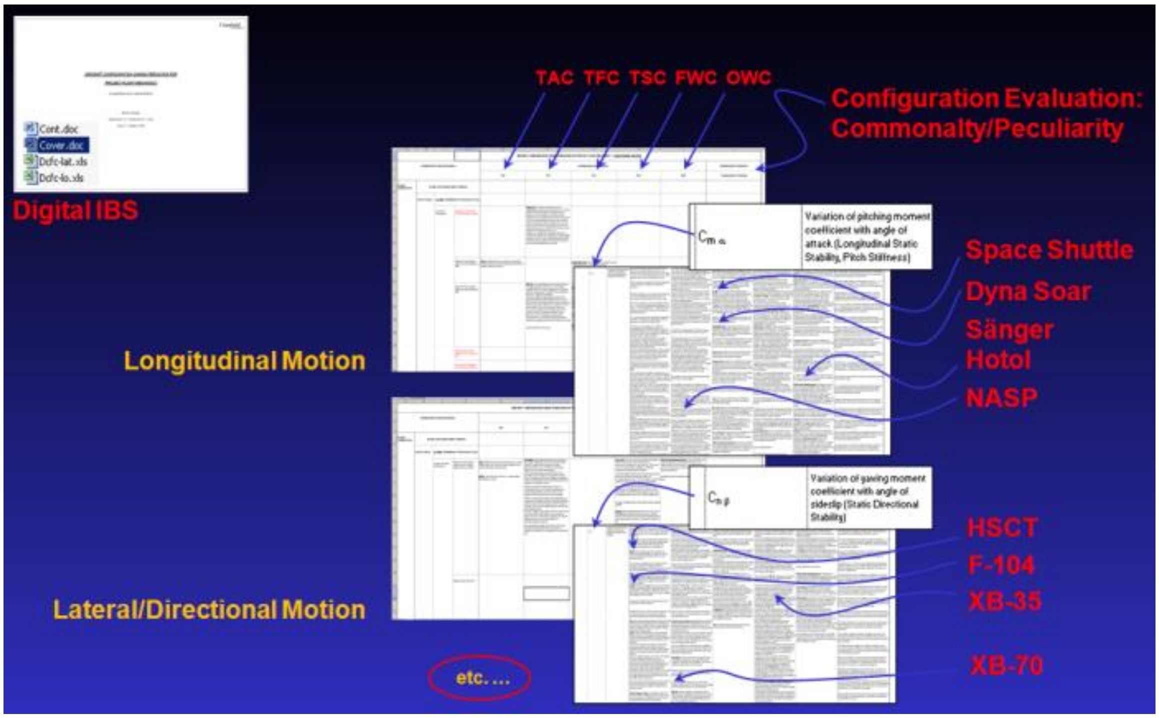

Figure 2. Design lessons-learned of selected design case-studies. (Reference 4)

The aircraft conceptual design knowledge-base (KB), as advanced and utilized for the present research undertaking, has to be considered an early development-version of a fully operational design knowledge-based system (KBS). Without reiterating the capability of exemplary KBSs, the KB system utilized here is a 'manual' system in contrast to the ideally automated KBS. However, independent on the degree of automation, both systems have in common that knowledge itself is the focus and that the knowledge acquisition activity is recognized as being one of the most problematic areas of KBS development. Clearly, it is the knowledge collecting, knowledge management and knowledge utilization activity, where the priorities for the present flight vehicle conceptual design KB have been laid due to time constraints imposed.

The primary objective of developing the dedicated aircraft conceptual design KB has been, to make relevant normal and radical design knowledge effortlessly available. The particular strength of the system manifests, in that it enables the user to advance his/her understanding with respect to the variety of legacy aircraft configurations by identifying aircraft configuration commonalties and peculiarities. This feature has been empowered by placing particular emphasis on consistently grouped flight vehicle configuration-specific design knowledge. As a result, design detail, for example longitudinal stability, can be compared between the range of aircraft configurations. This approach finally enables a reliable and trust-worthy generic aircraft configuration parameter identification process.

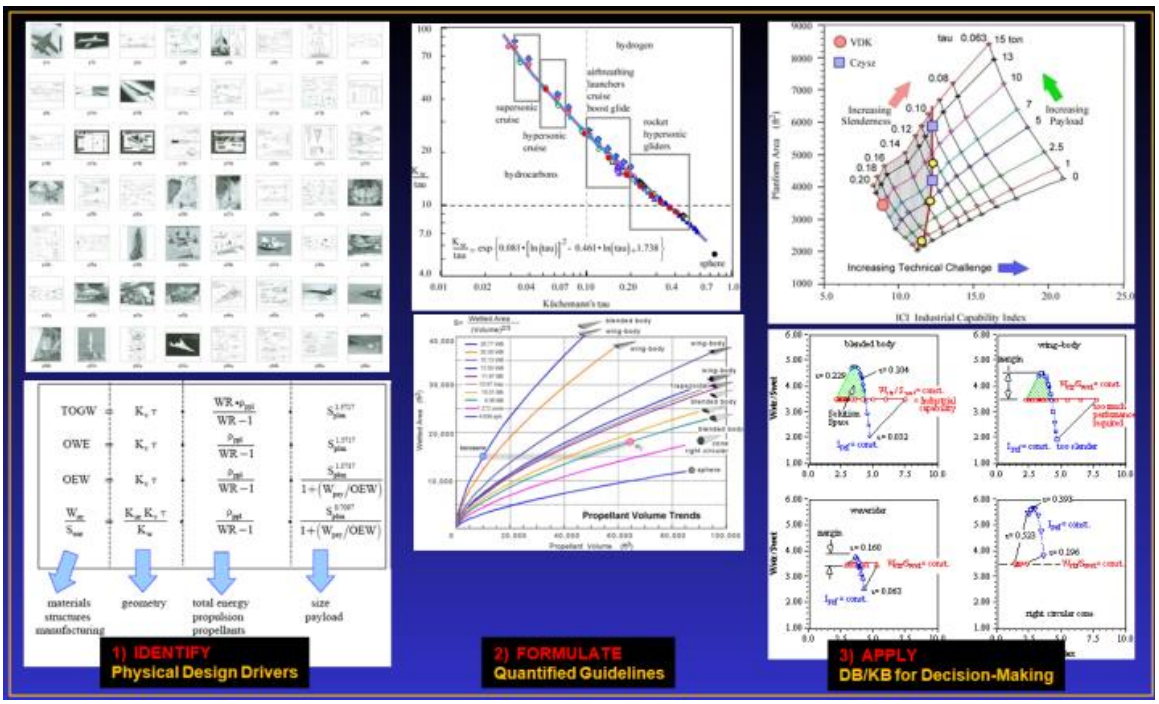

Figure 3. KB development steps resulting in numerical design guidelines. (Reference 4)

Figure 2 overviews the lessons-learned section as described above. This section clearly emphasizes on physical understanding and design related decision-making of relevant aircraft case studies.

Figure 3 introduces the steps required to arrive at knowledge-derived numerical design guidelines. At first, intimate technical understanding of pertinent design case studies enables the identification of gross design-drivers and variables with significant impact on the overall design. Those gross design drivers then form the basis for the underlying sizing relations in the sizing methodology. The resulting numerical design guidelines represent a true continuum of the pertinent design characteristic in contrast to the narrow exposure of typical point-design characteristics.

The ‘living-character’ of the DB and KB is ensured by permitting unconstrained data & knowledge entries as gained during the iterative design life-cycle.

In summary, the dedicated aircraft DB and KB have both matured towards fully integrated design support domains. The AVD Laboratory is routinely utilizing the project-specific DB and KB in concert with the process domain (sizing methodology), see Figure 4.

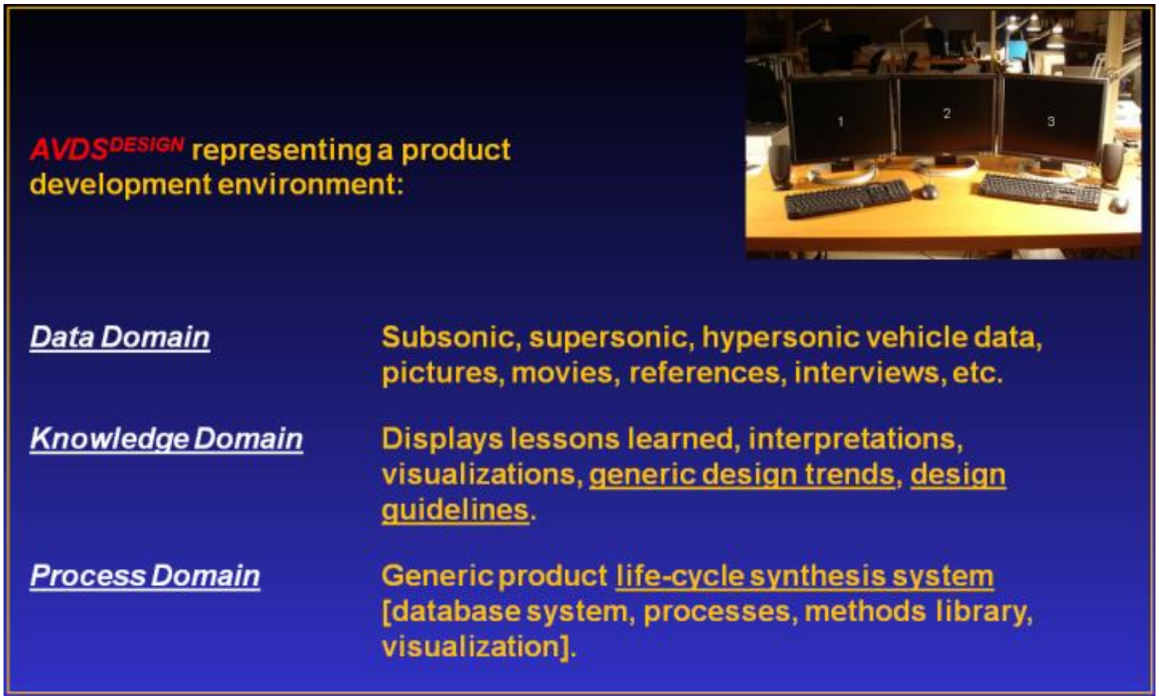

Figure 4. Integration scheme of data domain, knowledge domain, and process domain. (Reference 1)

AVD Sizing Process

AVD^{sizing} is a constant mission sizing process capable of first-order solution space screening of a wide variety of conventional and unconventional vehicle configurations. Solution space screening implies an overall focus on visualizing multi-disciplinary design interactions and trends. AVD^{sizing} is based on the *Hypersonic Convergence* sizing approach for transonic to hypersonic vehicle applications as developed at formerly McDonnell Aircraft Company between 1970 and 1990, see Reference 5. The modular process implemented with AVD^{sizing} relies upon a robust disciplinary methods library for analysis and a unique multi-disciplinary analysis (MDA) sizing logic and software kernel enabling data storage, design iterations, and process convergence. The integration of the disciplinary methods library and the generic multi-disciplinary sizing logic enables the consistent evaluation and comparison of radically different flight vehicles, see References 6, 7. The flight vehicle configuration independent implementation of AVD^{sizing} allows for rapid parametric exploration of the complete flight vehicle system via a convergence check to mission. Figure 5 visualizes the top level sizing process implemented.

At the heart of the process is the weight and balance budget. The results from the geometry, performance constraint and trajectory modules (weight ratio, required T/W ratio, and vehicle geometry) are provided to a weight & volume available and required logic. For a given vehicle slenderness parameter$\left(\tau = V_{total}/S_{pln}^{1.5}\right)$, the planform area is iterated through the total design process until weight & volume available equal weight & volume required.

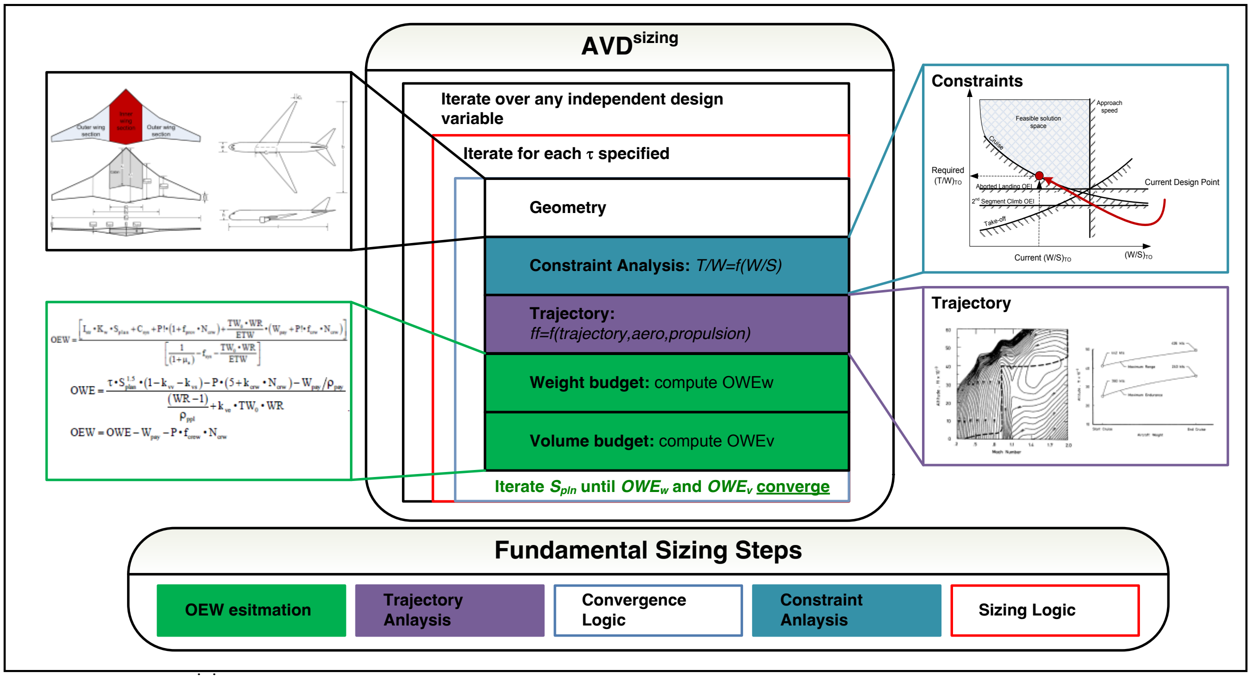

Figure 5. AVD^{sizing} methodology visualized via Nassi-Schneidermann structogram. (Reference 8)

N+n Technology Matrix and Design Mission

This study investigated in total 6 case studies for 6 unique technology portfolios (Table 1), 1 market segments (Boeing B777-300ER, 335 PAX), and 2 design scenarios (variable altitude, fixed altitude [27 kft]). Primary technology packages included, Reference 7:

N+0 (Baseline for comparison)
Tail-aft configuration
Aluminum structure, high bypass turbofan, partial laminar aerodynamics.

N+1
Tail-aft configuration

Composite structure, next generation high bypass turbofan, increased laminar aerodynamics.

N+2
Thrust vector control
Composite structure, next generation high bypass turbofan with thrust vectoring capability, increased laminar aerodynamics.

Blended wing body
Composite structure, next generation high bypass turbofan, increased laminar aerodynamics.

N+3
Tail-aft configuration + strut-braced wing
Composite structure, next generation high bypass turbofan, natural laminar aerodynamics.

Tail-aft configuration + truss-braced wing
Composite structure, next generation high bypass turbofan, natural laminar aerodynamics.

Table 1. N+n Technology Level Assumption Summary (Reference 1)

	N+0	N+1	N+2	N+3
Structures and Material	Aluminum primary structure with some composite secondary structure	Primarily Composite primary and secondary structure - 15% reduction in structural weight	Same as N+1	Mainly composite primary and secondary structure -Externally braced wings for thin natural laminar flow airfoils -Empirical correction factors based on VT studies
Propulsion	Available high-bypass turbofans EX: GE90, SFC_{cruise}=0.56	Next Generation high-bypass turbofans EX: B787, Genx SFC_{cruise}=0.502	Same as N+1	Same as N+1

Aerodynamics	Conventional wing design techniques	Improved laminar flow airfoils with - $Re_x = 4.95x10^6$	Integrated winglet (BWB) - Effective aspect ratio = 1.1	Thin Natural laminar flow wing and fuselage combinations -Laminar flow Rex from F-14 wing glove experiment -Hoerner method for interference drag
Passenger Comfort	Standard cabin pressure (8,000 ft equivalent pressure) and passenger volume (approx 2.0 m3 / PAX for a 3 class cabin)	Increase passenger comfort cabin pressure (6,000 ft equivalent pressure) and passenger volume (approx 2.4 m^3 / PAX)	Same as N+1	Same as N+1
Configuration(s)	Tail Aft	Tail Aft	Thrust Vector Control Blended Wing Body	Strut-Braced Wing Truss-Braced Wing

Design Mission

The N+0 Boeing B777-300ER baseline is evaluated using the published formal design mission; Table 2. AVD^{sizing} is utilized to derive the required (1) geometry, (2) weight, (3) thrust and wing location to satisfy (a) the mission, (b) minimum direct operating cost and (c) statically stability with a static margin of, $0.05 < SM < 0.10$. This mission definition has been used for each vehicle configuration.

There are two design scenarios which have been considered; (1) Variable cruise altitude, and (2) Fixed cruise altitude. The first case solves for the altitude corresponding to cruise at max L/D for each step through the cruise phase. This is analogous to a cruise-climb trajectory for commercial aircraft. The second case has a fixed cruise altitude of 27 kft. The lower cruise altitude is an environmental benefit, due to reduced cirrus cloud formation from aircraft contrails.

Table 2. Design Mission - Boeing B777-300 ER (Reference 1)

Mission requirements	
Crew weight	
Crew (1-Captin, 1-1st officer, 14 cabin attendents)	1472 kg (3,250 lbs)
Payload weight	
Maximum (175 lbs passenger + 40 lbs cargo)	69853 kg (154,000 lbs)

370 pax (3-cabin), 33,770 kg cargo	
Design Passengers (325 pax, 6,474 kg cargo)	38168 kg (84,150 lbs)
Range	
Design	14075 km (8,000 nm)
Velocity	
Design Cruise Speed	0.85 M
Take-off field length (TOGW)	< 3,048 m (1,000 ft)
Landing field length (max landing weight)	< 1,767 m (5,780 ft)
Fuel reserves	926 km (500 nm)

Design Study Results

Variable Cruise Altitude (Figure 6)

N+1 Results

- The composite aircraft provides reduced DOC and fuel burn while increasing passenger comfort.
- This passenger comfort level will be used in N+2 and N+3
- Due to this, composite materials will be utilized in N+2 and N+3 configurations

N+2 Results

- While both the BWB and TVC provide an aerodynamic benefit the BWB gains greater performance through a structural weight reduction
- The BWB has the capability for ~15% improvement in DOC over N+1 and could meet the fuel burn reduction requirements of the N+2 initiative (~50 % relative to current technology, N+0)
- TVC demonstrates ~10% improvement in DOC over N+1 while requiring extensive R&D and certification challenges
- BWB approaches the N+2 fuel burn objective of 50%

N+3 Results

- Comparison of N+3, N+2, N+1 relative to N+0 baseline; the laminar flow TBW shows the greatest potential of performance & cost improvements
- TBW currently provides marginal improvement of SBW
- TBW and SBW approach the N+3 fuel burn objective of 75%

Fixed Cruise Altitude - 27 kft (Figure 7)

Mission changes from baseline B777 mission

- Cruise Altitude - 27 kft (8.2 km) maximum cruise altitude
- Cruise velocity - Constant 480 kts. Resulting in a cruise mach number of ~ 0.81 M

General disciplinary design impacts

- Geometry - Slight reduction in wing sweep due to the lower design mach number
- Propulsion - increased in SFC
- Aerodynamics - the $(W/S)_{TO}$ required for cruise at 27 kft at or near L/D_{max} is typically lower than the $(W/S)_{TO}$ required for approach. Therefore, the aircraft will cruise at a C_L lower then $C_{L(L/Dmax)}$

N+n Results

- The TBW and SBW performance is reduced due the significant reduction in cruise L/D
- The TBW/SBW cruise altitude reduces from ~55 kft to 27 kft
- TAC,TVC,BWB cruise altitude reduces from ~33 kft to 27 kft
- Results: TBW and SBW suffer the most from reduction in cruise altitude
- TBW and SBW still out perform TAC, TVC, and BWB

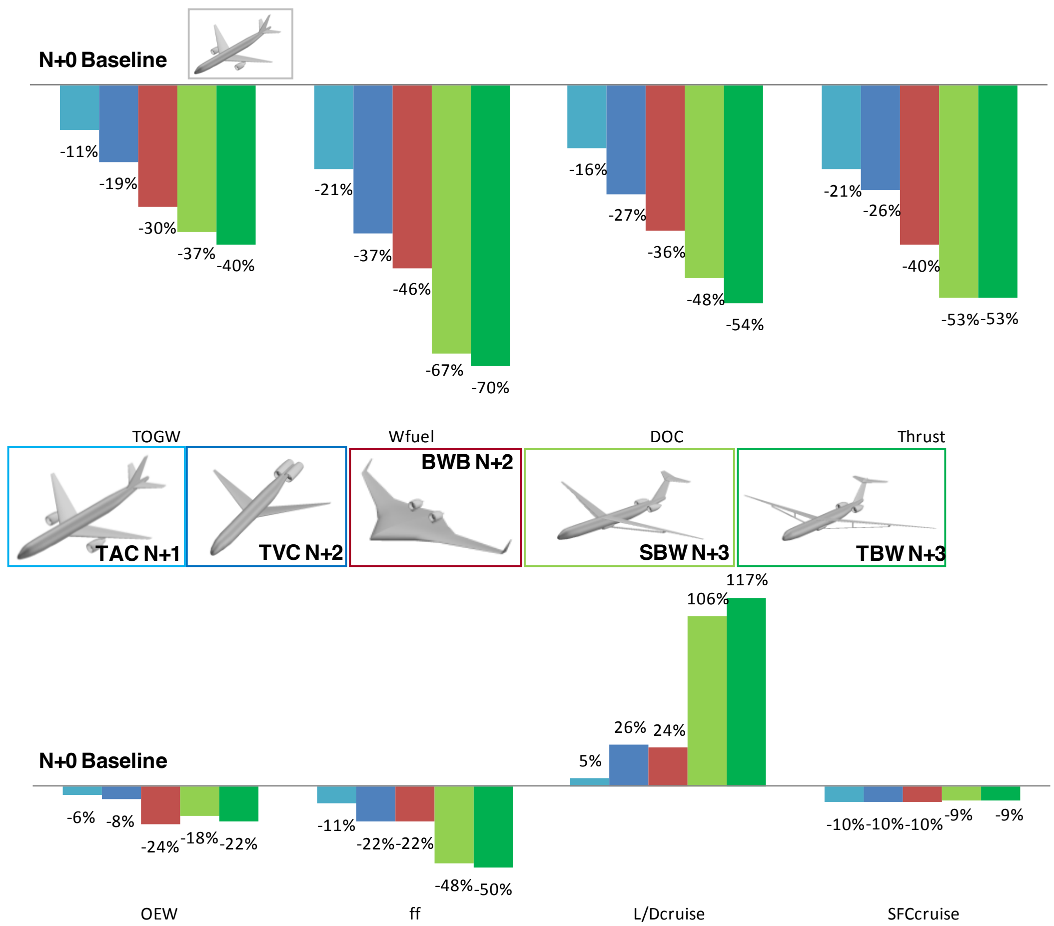

Figure 6. N+n Design Study Results - Variable Cruise Altitude (Reference 1)

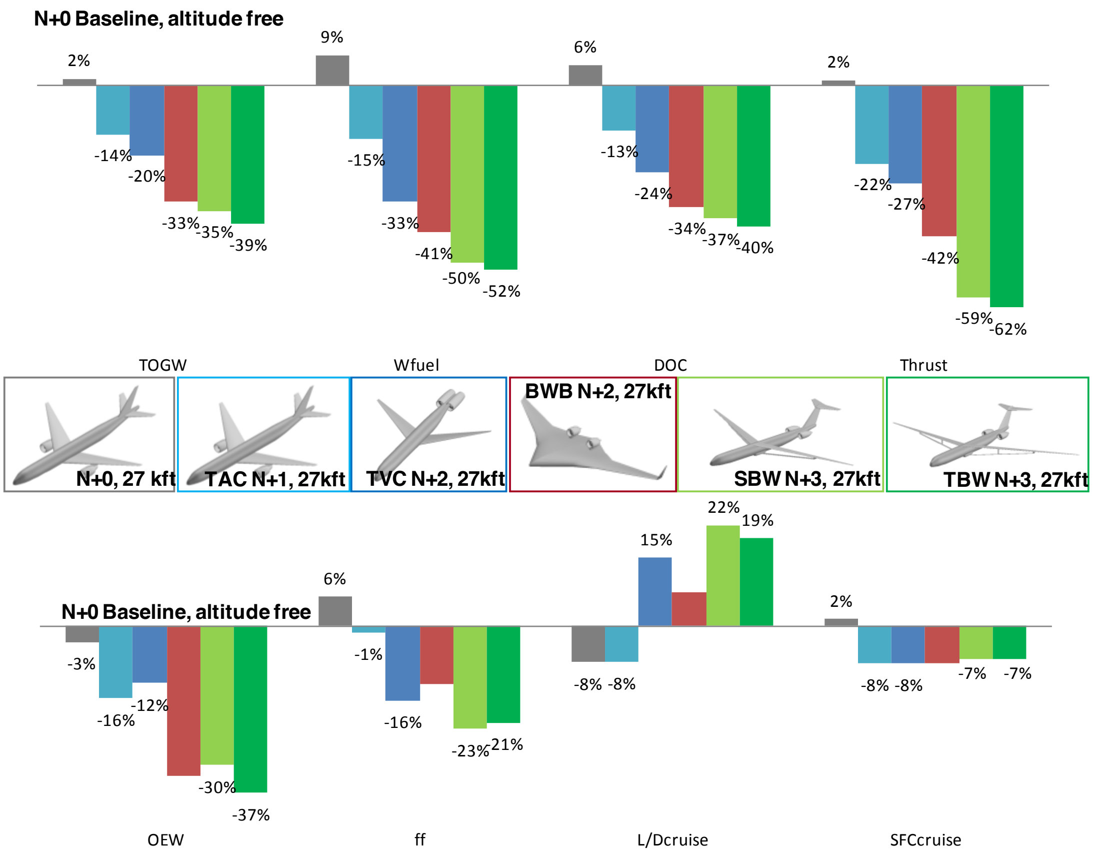

Figure 7. N+n Design Study Results - 27 kft Cruise Altitude (Reference 1)

Comparison of Design Results

When the vehicles are resized for a fixed cruise altitude at 27,000 ft

- TBW and SBW - 20% increase in fuel burn relative to the variable altitude case
- TAC, TVC, BWB - 5% percent reduction in fuel burn relative to the variable altitude case
- TBW and SBW suffer the most from cruise altitude reduction, however, still promise performance benefits over the configurations investigated
- Environmental study comparing 70% fuel burn reduction vs. 50% reduction plus cirrus cloud reduction is required before fixing the maximum cruise altitude to 27 kft
- This study demonstrates the need to explore the design mission early in the project.

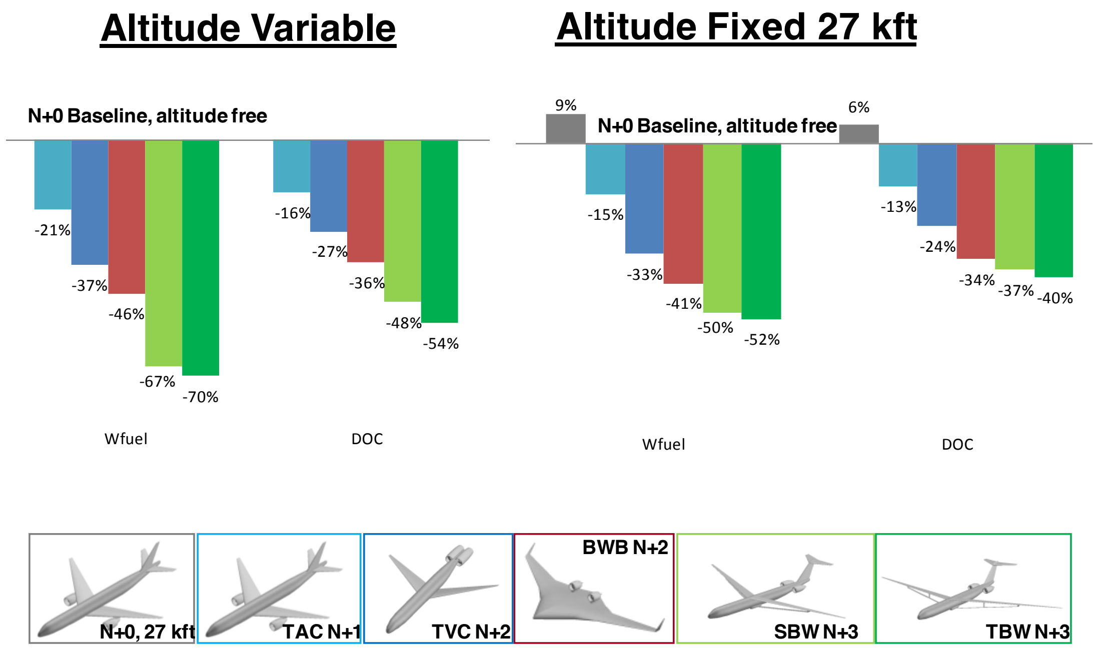

Figure 8. Comparison of Variable Altitude and 27 kft Design Study Results (Reference 1)

Summary and Conclusions

Overall, AVD^{sizing} in combination with the Methods Library has proven to be a robust and accurate tool set for transonic aircraft parametric sizing. The approach demonstrates that a single process with variable methods can be applied to conventional and unconventional transonic aircraft of extreme mission. In summary, the follow conclusions can be drawn from the case studies.

Methodology Conclusions

1. The total sizing methodology has proven flexibility and validity for a variety of transonic transport applications.
2. The methodology can be used to determine primary design drivers for a new engineering problem.
3. The selection of appropriate disciplinary analysis methods is critical. Incorrect methods tend to distort the conclusions, not only total accuracy but overall correctness of the solution space throughout the design process.

Lessons Learned – Aircraft Conceptual Design

1. TAC transports are highly sensitive to the mission due to the coupling of conflicting

disciplines and requirements despite their disintegrated appearance (distinct wing, fuselage, empennage, etc.).
2. Composite structure provides a larger benefit for long-haul wide-body aircraft s (B777) then narrow body aircraft (B737/A320) due to the effects of scale, and time spent during cruise. Long haul aircraft are more sensitive to technology improvements because of the larger fuel requirement from the mission. As such developing a next generation narrow body aircraft (B737/A320) represents a more difficult technical challenge.
3. The thrust vectored transport shows significant performance improvement over the classical TAC, if the aircraft can be proven controllable in nominal and failure conditions (ex: OEI). The current design has proven to posses significant control problems. Further design iteration is required determine if these problems can be remedied.
4. The Blended Wing Body (BWB) demonstrates a strong sensitivity to cabin aspect ratio in terms of wave-drag and structural efficiency. It is imperative to correctly perform the cabin layout within the context of the total vehicle. The classical paradigm of disintegrated fuselage and wing design no longer hold.
5. The SBW shows modest improvements in fuel savings if (1) laminar flow can be maintained as determined by the F-14 wing glove experiment, if (2) transonic interference is manageable between the strut and the wing, and if (3) the strut can reduce the total wing group weight by 20%.
6. Slowing the SBW down would allow for reducing wing sweep without a reduction of wing thickness, thus allowing increased laminar flow without a wing weight penalty due to aeroelastic constraints.

Acknowledgments

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AVD^{KBS} - Standing on the Shoulders of Giants

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Abstract

George Santayana is known for saying "*Those who cannot remember the past are condemned to repeat it*". Throughout the development history of aerospace engineering conceptual design, much knowledge has been generated although, to the best of our knowledge, no efficient system has been developed to help aerospace communities keep and use such valuable inheritance. In this context, we do routinely witness events such: (i) the failure of aerospace projects, like Titan IV, whose explosion has been deemed the responsibility of a design defect; (ii) the losing of valuable aerospace specialists and their expertise, like at Boeing, "…*more than half of the Boeing work force will be eligible for retirement within the next decade. That's roughly 80,000 employees' cumulative corporate wisdom walking out the door*."; (iii) the ostensibly well-kept but not easily accessible knowledge has seldom shown its value and contributed to activities, like the books and journals covered by dust in library.

In order to efficiently use energy, time and money, and apply previous precious design knowledge to current aerospace design problems, the key requirements on which a modern knowledge-based system (KBS) have to be based reads as follows: (i) accumulate and maintain aggregate knowledge; (ii) supply information relevant to any particular design effort; (iii) predict unavailable information based on trends from available knowledge.

To this end, a first of its kind aerospace conceptual design knowledge based system, AVD^{KBS}, is introduced in this paper. It provides researchers with a convenient way of storing, applying and predicting knowledge in a total systems approach. The categories of the system are differentiated by knowledge collection, exhibition, application, innovation and update. The structure of AVD^{KBS} is constructed according to the requirements of the AVD parametric sizing method - AVD^{SIZING}, providing an integrated iterative conceptual design capability. All those concepts are demonstrated by a novel proof of concept case study, such like the re-engineering of *Project Mercury*. This case study seeks to showcase AVD^{KBS} as a standalone system in addition to its integration into a multi-disciplinary parametric design environment.

Background

In the history of human society, the value of knowledge can never be over emphasized. Current human achievements, like exploring the Mars and moving at the hypersonic speed, are all based on massive findings and subsequent applications. Moreover, current age is often referred as an *Exponential Knowledge Explosion* age, and it is estimated "*a week's worth of New York Time's contains more information than a person was likely to come across in a lifetime in the 18th century*". Consequently, facing the already overwhelming and still exponentially growing amount of knowledge, a question comes into existence: how should we efficiently manage those valuable legacies and assets for future activities?

Besides the traditional ways of knowledge retention, like textbooks, journals and encyclopedias, benefiting from the development of computer science, researchers all over the world propose various Knowledge-Based Systems (KBS) to proficiently capture, store and apply knowledge. The following table is a succinct summarization of the KBSs developed during the past decades:

Table 1 Knowledge-Based Systems (KBS) Development

Researchers	**Year**	**Discipline**	**Contribution**
John F Gilmore[1]	1984	Computer Science	Discussion on system requirements of a KBS
Kunio Murakami[2]	1984	Computer Science	Preliminary research on inference engine and knowledge base
Fu Tong[3]	1985	Computer Science	Investigate environment for building KBS supporting various knowledge functions
Anton Bigelmaier[4]	1986	Computer Science	Discuss representation problems in CAD-system KBS building
Haruo Yokota[5]	1986	Computer Science	Propose a model and architecture of a KBS with unification applications
L. Marinos[6]	1989	Computer Science	Propose an architectural framework for integrating database and knowledge base
M.A. El-Kady[7]	1990	Electrical Engineering	Build a knowledge-based system for power cable design
O. Felix Offodile[8]	1991	Mechanical Engineering	Build a KBS for choosing assembly robot for mechanical assembly.
Stipe Fustar[9]	1992	Electrical Engineering	Develop a knowledge-based system for weekly power system operation scheduling
N. Sirilertworakul[10]	1993	Mechanical Engineering	Establish a knowledge-based system for selecting casting alloys and process

Bojan Dolsak[11]	1994	Mechanical Engineering	Build a KBS on deciding the appropriate mesh resolution
A.M. Buis[12]	1996	Geodetic Engineering	Develop a KBS to be combined with GIS to support parceling design task
Stewart Long[13]	2003	Computer Science	Build a knowledge-based system to automatically assess IT skills
Nobuhide Nishiyama[14]	2006	Computer Science	Develop a KBS for QoS service
Kihyeon Kim[15]	2007	Information Technology	Build a knowledge-based system for diagnosing ECG and heart disease
Ali Malkawi[16]	2007	Civil Engineering	Integrate KBS with a thermal simulation engine for replacement building features
S. Guo[17]	2009	Power Engineering	Build a KBS for Fault Diagnosis in Solar Power Tower plant
Shaobin Chen[18]	2010	Mechanical Engineering	KBS working with remote sensing module for target recognition tasks
Tomasz Kowalewski[19]	2010	Naval Engineering	Build KBS with hazard zone identification system for the ship power plants design
Yannick Naudet[20]	2011	Illuminating Engineering	Develop a knowledge-based system on daylighting performance in facade design

In 1980s, based on the evolution of artificial intelligence technologies, researchers from Computer Science field try to apply those technologies into a new application area – the knowledge-based systems. Those systems are supposed to manage certain domain knowledge using reasoning techniques, so that they can provide advice aiding human activities.

To build such systems, researchers first propose frameworks and models to clarify the problems like: what components the systems should possess in terms of both hardware and software and how they should work in order to perform the supposed functions. The aim of this effort is to point out a path to the functional knowledge-based systems, but no actual system is developed at this stage. In this era, John F. Gilmore[1] discusses the system requirements of KBSs, their relevance with computer-aided technology and points out a potential application. Kunio Murakami et al[2] do preliminary research on inference engine and the related knowledge base. Anton Bigelmaier[4] investigates the representation problems for geometrical knowledge in CAD-system knowledge base building, including rule knowledge and method knowledge, and he suggests they can be represented by operations and structures of operations.

After the initial theoretical preparations, researchers begin to build knowledge-based systems. Based on the development of operation systems and programming languages, like Prolog and Python, and more affordable and powerful computing hardware, many systems in a variety of fields are developed. Those systems are usually combined with the artificial intelligence techniques, such as Rule Based Reasoning and neural networks, so that they can perform the basic system functions, including interpretation, reasoning and retrieval. However, those systems can only provide advice to human users based on simple input and reasoning procedure, and the application and selection of those advices are performed by users, so the overall analysis process is still manual. That's why those systems are often referred as Expert Systems. The selected examples in this kind of knowledge-based systems are: a power cable design knowledge-based system from M.A. El-Kady et al[7] , it can both assist designers in design and educate fresh engineers; an assembly aiding knowledge-based system developed by O. Felix Offodile et al[8] , which can receive user demand and layout specifications to choose the mechanical assembly robotic systems based on the information in the assembly robots knowledge base; a work scheduling knowledge-based system from Stipe Fustar et al[9] , it can provide assistance for weekly power system operation scheduling including "load prediction, inflow prediction, possible run-of-river hydro production, storage hydro production, unit commitment, generator maintenance and power interchange between interconnected power systems".

Around the beginning of 1990s, researchers find the great potential of combining the newly developed knowledge-based systems with the existing systems, like databases or processing modules, so that they can work together to perform more complex tasks. L. Marinos et al[6] start proposing a framework for integrating the knowledge base and database, focusing on the knowledge and data representation problems. However, the real functional systems of this kind come into existence around 2000s. A.M. Buis et al[12] develop a knowledge-based system, which can work with the Geographical Information System to help finish more and more difficult parceling design work. Besides this, more systems in this kind are developed later on. Ali Malkawi et al[16] combine their knowledge-based systems with a thermal simulation engine and a database to assist the decision making for choosing replacement building features. Shaobin Chen et al[18] incorporate the knowledge-based system with a remote sensing module to conduct target recognition tasks. Because this kind of knowledge-based system are linked with either database or other functional modules, they can either use the collected data to enrich their knowledge source, or take advantage of past project experiences to make it as starting points for the new analysis, like Case-Based Reasoning (CBR). In this way, it saves human energy and time, but most of those systems are not totally automatic and they need human help to accomplish the analysis.

In current age, based on the mature of the knowledge-based systems, its application area has greatly expanded. Besides their traditional applications in Engineering and Computer Science fields, they quickly show their excellence in other industry and academic fields, like medical care, agriculture, business management, textile and so on. Kihyeon Kim et al[15] build a knowledge-based system for ECG and heart disease diagnosis. Yannick Naudet et al[20] develop a knowledge-based system to take both visual performance and visual comfort of the daylighting performance into the façade design. In some application field, the knowledge-based system can even automatically accomplish an analysis task. Stewart Long et al[13] use a knowledge-based system to automatically assess candidates' IT skills to check their qualification. To keep up with the internet developments, researchers also develop web-based knowledge-based systems, so that the application can serve remote customers. Nobuhide Nishiyama et al[14] use semantic web language to build an online knowledge-based system for QoS services.

However, until now, no effort has been spent on theoretically summarizing the development of the knowledge-based systems to offer a big picture of them, and few of the existing systems provides a knowledge update mechanism for updating purposes. Consequently, those systems easily become obsolete after a short amount of time.

Motivation

Due to the complexity and multi-disciplinary constraints in aerospace engineering conceptual design, the knowledge management methods are still traditional, consisting of textbooks, journals, engineering drawings, archives, report servers, lessons learned documents, etc. According to our literature search, there are only a few KBSs efforts proposed, none of them has produced a practical KBS for aerospace design application; see Table 2.

Table 2 Knowledge-Based Systems Development in Aerospace Engineering Design

Researchers	**Year**	**Discipline**	**Contribution**
Christian Freksa[21]	1986	Aerospace Engineering	Framework proposal of knowledge engineering for design expert systems.
Stewart Baily[22]	1987	Aerospace Engineering	Proposal of knowledge-based aeronautical conceptual design system.
W. A. Dos Santos[23]	2009	Aerospace Engineering	KBS for satellite conceptual design.
C. Gong[24]	2010	Aerospace Engineering	Knowledge-based tactical missile intelligent conceptual design environment.

For any KBS in engineering design, the first task is to collect the design knowledge, and then document and archive it. After that, some mechanism needs to be developed to utilize it. During the application process, if the current information available to the user is sparse, new knowledge needs to be generated to solve the unknown. Based on this, any successful KBS must be capable of (a) knowledge collection, (b) knowledge categorization, (c) knowledge application, (d) knowledge innovation and (e) knowledge update. This first-order KBS specification will be used as criteria to evaluate the KBS development in aerospace engineering design and decision-making.

Besides the latest work from W.A. Dos Santos and C. Gong (WDCG) in Table 2, three other widely used aerospace engineering resources are also selected for comparison: *Jane's All the World's Aircraft* (JAWA), *AIAA Electronic Library* (AIAA) and *CATIA V5* knowledge ware tools (CATIA).

Table 3. Current Aerospace Engineering Design KBSs Comparison

Item	JAWA	AIAA	CATIA	WDCG
Knowledge Collection	√	√	√	√
Knowledge Categorization	×	√	√	√
Knowledge Application	×	×	√	√
Knowledge Innovation	×	×	×	×
Knowledge Update	×	×	×	×

From the comparison in Table 3, it is obvious to conclude that none of the listed KBS is capable of storing, categorizing, applying, inventing and updating knowledge. A truly practical aerospace KBS implementation is still absent in the current aerospace engineering design community. The *AVD Laboratory* at UTA makes the very first effort in developing an industry-relevant thus practical aerospace KBS dedicated to the strategic conceptual design phase.

Methodology and Implementation

Introduction

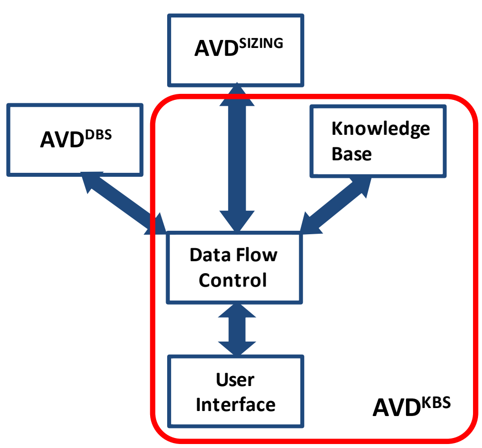

Figure 1. AVD^{KBS} Components and Logic Relationship to AVD^{DBS} and AVD^{SIZING}

AVD^{KBS} is developed to function in two primary modes: (a) a standalone system for knowledge storage, education and reference, and (b) as an interactive system with other AVD methodology modules to complement the parametric aerospace sizing process. The general relationship of AVD^{KBS} within the existing AVD design environment is:

AVD^{KBS} mainly contains three primary components: the (a) knowledge base, (b) data flow control unit, and (c) the user interface. The *knowledge base* resembles the actual knowledge pool. The *data flow control unit* consists of mechanisms which are designed to manipulate the data transfer between the knowledge base and the other logical modules, see Figure 1. This module is responsible for providing the system-logic to AVD^{KBS}; it performs all the system functions to connect previously independent systems in order to make them work as an integrated unit. The *user interface* provides a software connection between the user and the system to perform system functions (knowledge entry, knowledge manipulation) without getting into details of MS Access and Matlab coding.

System Level

In order to implement the capabilities of knowledge storage, classification, application, creation and update, we propose a five-level KBS classification and organization scheme:

1) *Knowledge Collection*: gather knowledge from various resources, which mainly contains the lessons learnt, design guidelines and past project experiences.
2) *Knowledge Categorization*: sort collected knowledge according to certain criteria, and express them in a variety of forms for further applications (tabular, numerical, graphical, text, etc.).
3) *Knowledge Application*: employ the categorized information in multiple tasks, including young engineer education, research reference and automatic parametric sizing process.
4) *Knowledge Innovation*: generate new knowledge through reasoning mechanisms (AVD^{SIZING} reasoning technique) to solve the unknowns.
5) *Knowledge Update*: manual/automated knowledge updating (dynamic KBS).

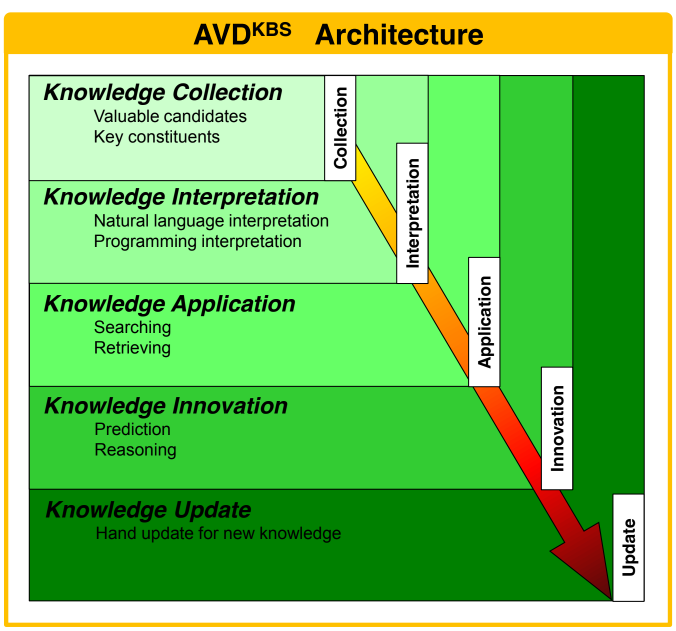

Figure 2. AVD^{KBS} Architecture and Hierarchy.

The prototype KBS implements the proposed concept by using the data and knowledge rich case study *Project Mercury*. The building process is introduced with the following sections.

Knowledge Collection

Knowledge collection is the first primary and non-trivial step in every KBS building process, and its aim is to identify and obtain all the required information. Its completeness and correctness directly influence the KBS quality and functions. This process lasts throughout the whole KBS life cycle, thus it resembles the notion of 'life-long learning'. Any newly collected or generated knowledge has to update the system manually or automated.

The knowledge base assembled for the *Project Mercury* launcher consists of conceptual design level methods, experiences and lessons learnt, all spanning *Project Mercury* from launch until completion. This information is valuable, because it contains the key points of how the problems have been solved during the conceptual design phase. It directly does mirror what mistakes can be avoided.

The knowledge sources are mainly formally published project report. *Project Mercury* is an especially rich data, information and knowledge case study. The general *Project Mercury* information resources available can be divided into the following categories:

1) NASA reports: such as NASA SP-4001, NASA SP-4201, contract report NAS 1-430, etc.
2) NASA project conferences: such as *Project Mercury* presented at the Fourth Annual Meeting of the Human Factors Society and Press Conference at Washington D.C. on 9 April 1959.
3) NASA news releases: such as Fact Sheet MA-8.
4) Reports, papers and presentations from other institutions: such as the AIAA space flight testing conference.

The knowledge needed for the parametric sizing process is first identified. Then it is searched and located in the resource. And after that, detailed information, like author, application field, descriptions and so on are extracted and documented in the our own format for following applications.

Knowledge Categorization

After gathering the main part of information available from all resources, the knowledge is classified according to the primary engineering disciplines of relevance. For each discipline,

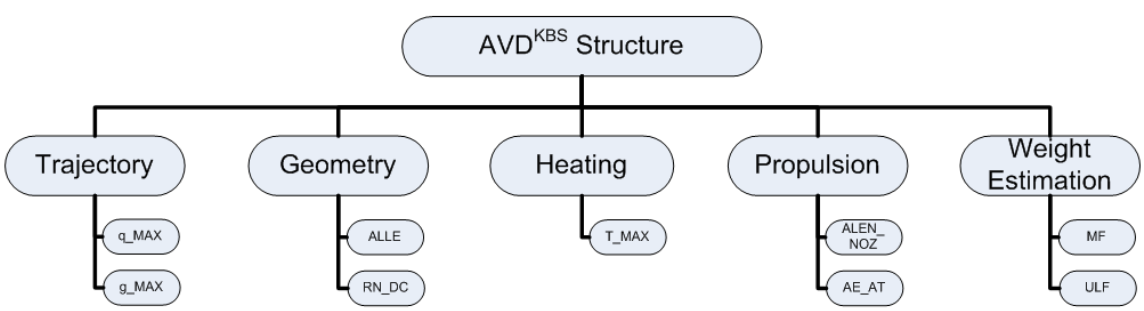

Figure 3. Project Mercury AVD^{KBS} Disciplinary Sub-structure.

gross design variables are identified for numerical knowledge harvesting purposes, see Figure 3. The five knowledge-rich disciplines of relevance for early design of *Project Mercury* are: trajectory, geometry, aero-thermo-dynamics-heating, propulsion and weight estimation, see Figure 3.

This early categorization of knowledge is providing a pragmatic structure to search, retrieve, document and utilize the knowledge available. Furthermore, the five disciplinary categories are directly interfacing with the needs of the 'reasoning technique' employed, the AVD sizing method and software AVD^{SIZING}. Considering the system's generic potential for any other project of interest, the AVD^{KBS} storage structure facilitates both, the required disciplinary categories and the knowledge itself, overall providing a platform with growth potential for future expansion.

Each knowledge entry is classified to consist of two parts:

1) General Information: author, source and application area
2) Detailed Information: application assumptions, input & output, and complete knowledge contents.

For the knowledge *general information*, it summarizes who proposes the knowledge and in which publication. It also specifies its application area by differentiating the design phase, discipline, categories and applicability.

For the knowledge *detailed information*, since the original expression can be mathematical equations, engineering drawings, or only experience descriptions, then the original description will be expanded into either of the following three expression forms:

1) *Verbal Expression*: Engineering language employed to describe the details of the knowledge targeting the three primary user categories (a) decision-maker, (b) systems integrator, and (c) technologist.
2) *Mathematical Expressions*: Mathematical formulas in the form of numerical guidelines are used to illustrate trend-patterns in the knowledge available, targeting the reasoning technique AVD^{SIZING} by aiding the automatic parametric sizing process. Again, the knowledge contents is prepared for targeting the three primary user categories (a) decision-maker, (b) systems integrator, and (c) technologist
3) *Visual Expressions*: Meaningful engineering drawings, figures and tables are used to express the knowledge contents at hand, targeting the three primary user categories (a) decision-maker, (b) systems integrator, and (c) technologist.

The above specification has been translated into a MS Access knowledge overview card and template, see Figure 4.

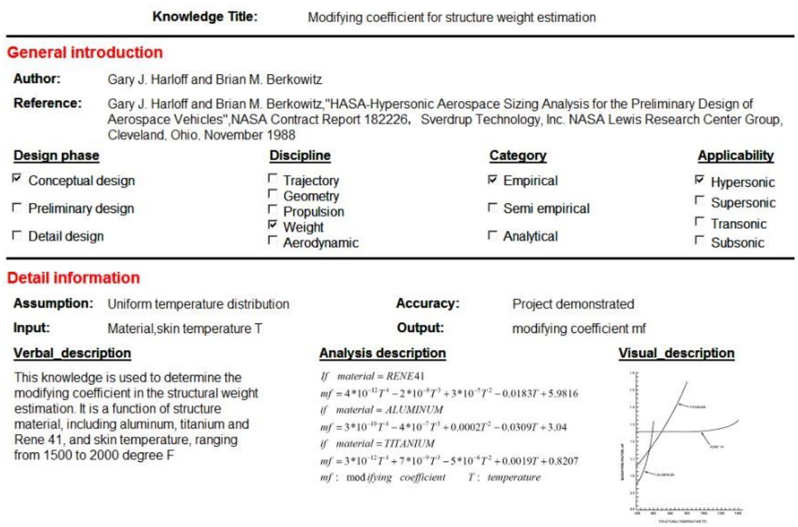

Figure 4. Knowledge Overview Card and Template for *Project Mercury*.

Knowledge Application

Having prepared the available knowledge entries as described in the sections above, the knowledge application section builds mechanisms to pragmatically utilize the knowledge. This section provides two primary functions aimed at knowledge management: (a) knowledge searching and (b) knowledge retrieving.

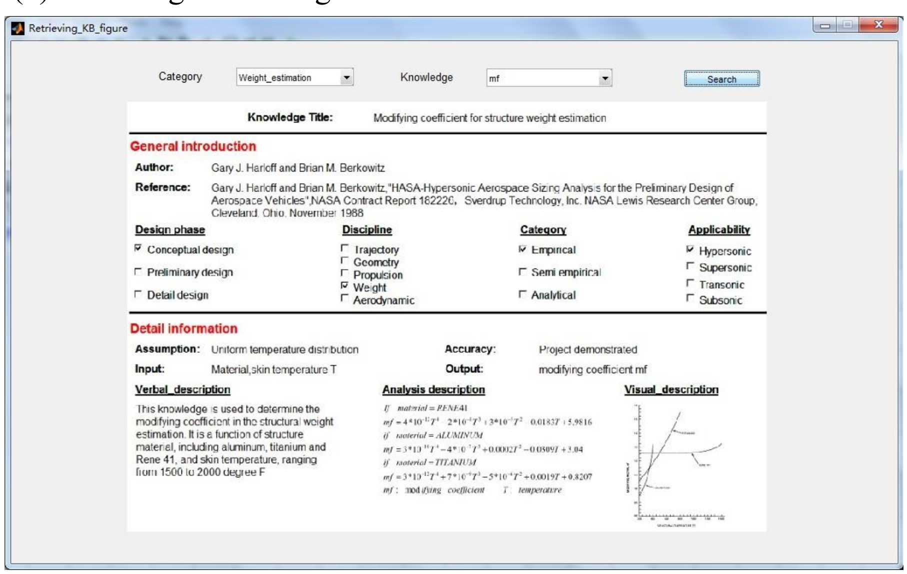

Figure 5. Knowledge Searching Screen.

The knowledge searching function fulfills the research reference and education objectives. It facilitates the three primary user categories (a) decision-maker, (b) systems integrator, and (c) technologist to quickly find useful information and apply them to the problem at hand. Thus, it provides the learner relevant knowledge entries 'at the fingertips' in a filtered and clean format. A graphic searching window is created to identify relevant knowledge entries stored in the system. Figure 5 shows an example of knowledge entries related to a weight estimation method.

The retrieving function serves the automatic parametric sizing process AVD^{SIZING}. It automatically retrieves relevant knowledge entries from AVD^{KBS} and directly feeds the parametric formulation into the parametric sizing process. During the analysis, if a necessary variable is missing, a search mechanism will first go through a lookup table. If the variable is found, the name of the sub-function able to solve for the missing variable will be retrieved. The function will be executed and feeds its result directly into the parametric sizing process.

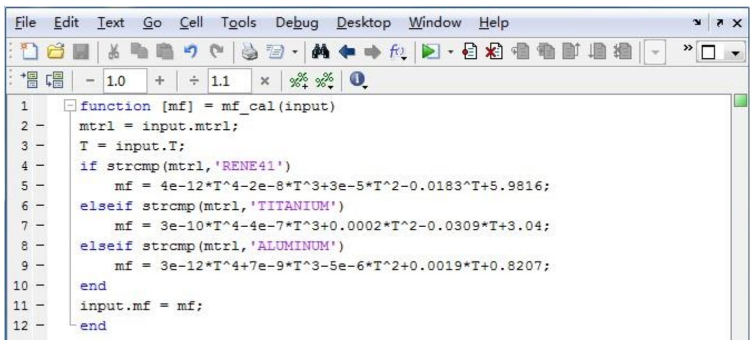

Figure 6. Retrieving Sub-function Programming.

Knowledge Innovation

The knowledge retrieving functions can solve most of the missing information in the automatic parametric sizing process. However, if some necessary variable cannot be found in the lookup table thus AVD^{KBS}, the knowledge innovation mechanism has to be applied. It mainly conducts a Case Based Reasoning (CBR) process. The CBR will search the AVD^{DBS}; if the variable is found as applied for a past project, data related with the variable will be retrieved. Then, a regression

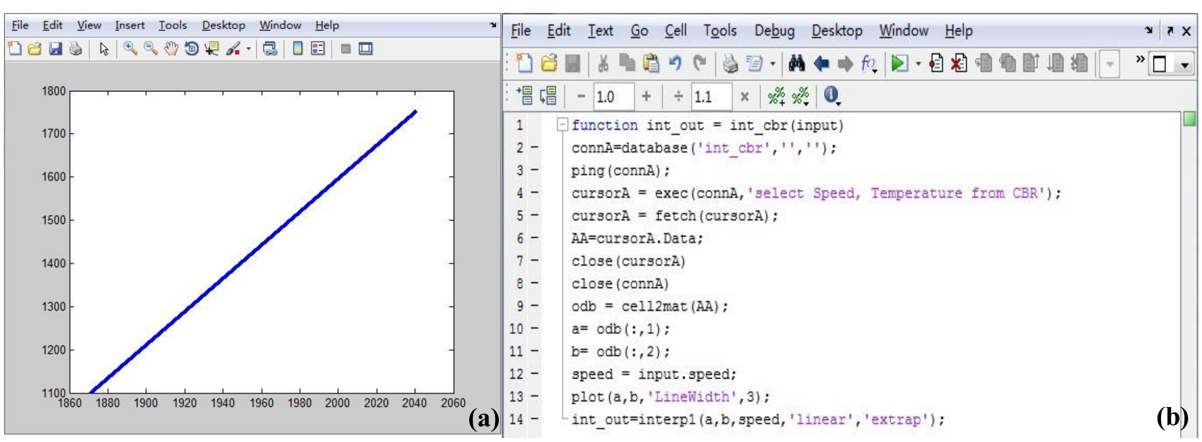

Figure 7. Knowledge Innovation using CBR (a) Regression Line, and (b) Sub-function.

line will be drawn and an interpolation method will be used to identify a value for the unknown variable. Obviously, the user is tasked to determine if the starting point identified serves the problem at hand.

Within the *Project Mercury* case study, the team identified a lack of understanding related to the capsule maximum (peak) temperature during re-entry. Consequently, past projects' maximum temperatures and speeds have been retrieved from AVD^{DBS}, a regression line has been constructed for review. The trend information provided educated the team on the subject. The relationship has been judged to adequately represent the physical phenomena as a starting point for the analysis of the capsule maximum (peak) temperature during re-entry. Consequently, the interaction between AVD^{KBS} and AVD^{DBS} resulted in a parametric approach delivering the input requested by AVD^{SIZING}. A sub-function is written to perform this process.

Knowledge Update

For the *Project Mercury* case study, AVD^{KBS} can be considered sufficiently proficient due to its rich legacy knowledge contents embedded for the parametric sizing analysis. However, even the execution of an independent reverse-engineering study results in the generation of never-before-seen understanding. This new knowledge can be due to flawed knowledge identified in the past,

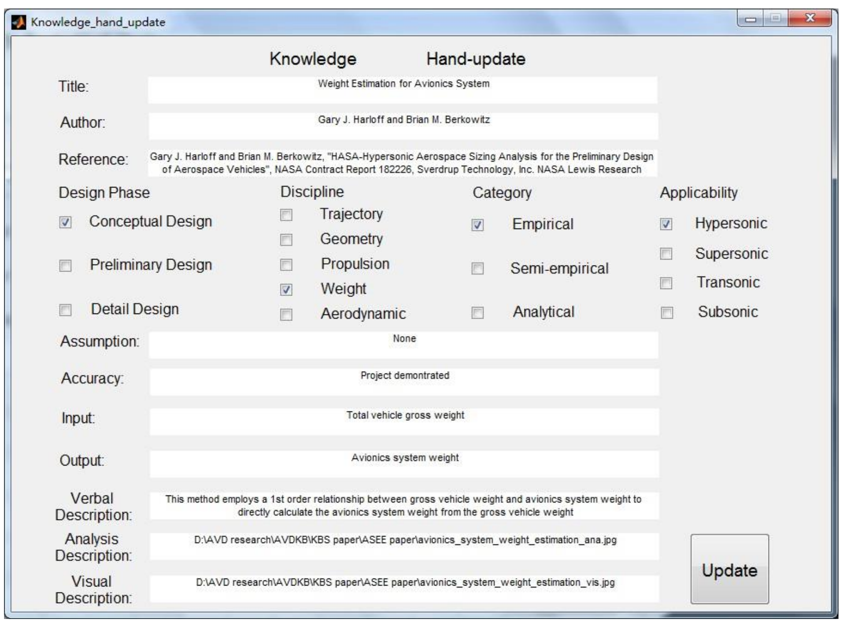

Figure 8. AVD^{KBS} Manual or Hand-update Screen.

different technology assumptions, difference in the integration approach, etc. Clearly, AVD^{KBS} has to be a dynamic system capable of internalizing new entries while the project is in progress. An efficient knowledge update mechanism or learning function has been devised. In other words, AVD^{KBS} is integrated in the iterative development cycle during the entire project forecasting life-cycle.

A graphic knowledge update window has been developed to enable the operator to manually update new knowledge into the AVD^{KBS}; this sequence simply resembles ‘learning’. Detailed information related to the new knowledge entry can be directly entered via the GUI shown with Figure 8. The ‘Update’ button formally accepts the knowledge entry into AVD^{KBS}.

Other Interfaces and Mechanisms

An important function of AVD^{KBS} is to aid AVD^{SIZING} to perform the automatic parametric sizing task. Thus, an interface is developed for the operator to specify the sizing mission requirements, see Figure 9.

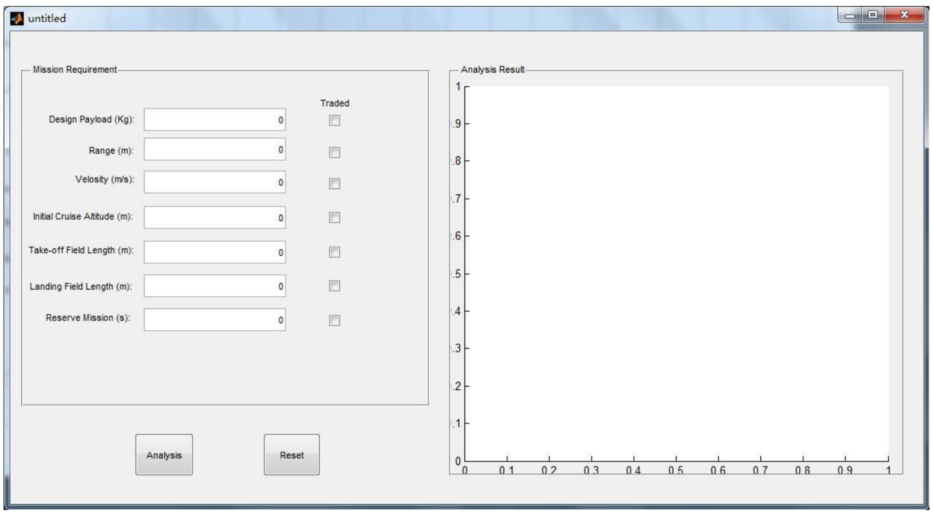

Figure 9. Mission Input Screen.

According to previous AVD Laboratory parametric sizing projects, the mission requirement inputs consist of seven key parameters: design payload (kg), range (m), velocity (m/s), initial cruise altitude (m), take-off field length (m), landing field length (m), and reserve mission duration (s). It is not required to completely fill in all of these parameters; the user is free to define the mission statement as practical. AVD^{KBS} provides a ‘Traded’ option, see Figure 9. If

$$\text{Vehicle Points} = \sum \left(\overset{1^{st}\text{ Step}}{\begin{cases} \text{Match} & 1 \\ \text{not} & 0 \end{cases}} \times \overset{2^{nd}\text{ Step}}{\begin{cases} \text{Not traded} & 7 \\ \text{Traded} & 1 \end{cases}} \right)$$

Figure 10. Two-step Grading Mechanism

specific mission parameters are not checked, the system will consider the parameter as a hard requirement, or it will be considered as a traded requirement in the vehicle selection process. This function is of significance since it enables the design team to explore the mission solution space resulting in the correct mission definition.

Having defined the either ‘rigid or flexible’ mission requirement trade space, the system will go through a ranking or ‘Grading’ process with the aim to identify the baseline vehicle and mission combo. During the process, each vehicle documented in AVD^{DBS} will be ranked (graded); the vehicle with superior ranking is going to be selected as the baseline vehicle for a given mission statement.

The 'Grading' mechanism is a two-step process. For the first step, the parameter from documented vehicle will be compared with the users' input value chosen; if they match within a tolerance, the vehicle receives one point for this parameter; if they don't match, the vehicle will get zero points. For the second step, the point will be multiplied by a coefficient whose value is determined by the 'Traded' option. If it is untraded, the point will be multiplied by seven, which makes sure the vehicle satisfying the hard requirement always gets the most points. For the parameters with the 'Traded' option checked, any point will only be multiplied by one. The same process is repeated for the other six input parameters. The sum of those points is the vehicle's total points. After all the vehicles are graded, the vehicle with the most points is selected as the baseline vehicle.

After the baseline vehicle is selected, its technical representation will be drawn from AVD^{DBS}; this input-deck then starts the sizing code AVD^{SIZING}.

Project Mercury Launcher Case Study

The *Project Mercury* launcher case study serves to evaluate the performance of AVD^{KBS} in cooperation with the other AVD system modules. Objective is to achieve an automatic parametric sizing process. Having already introduced the interplay between the individual modules AVD^{DBS}, AVD^{KBS} and AVD^{SIZING} with preceding sections, we focus with the following on the automatic sizing process and the results. The process is automatic, thus the user is only required to input the mission requirements; the analysis result will be directly displayed in the analysis result window. The mission requirements of the *Project Mercury* launcher are defined as follows:

Table 3. *Project Mercury* Launcher Mission Requirement

Item	Value
Design Payload (Kg)	1995.8
Range (m)	0
Velocity (m/s)	2251.86
Initial Cruise Altitude (m)	
Take-off Field Length (m)	0
Landing Field Length (m)	
Reserve Mission (s)	

The payload is defined by the gross weight of the *Project Mercury* capsule, which is 1,995.8 kg. Since we are concerned with only the launcher, the range is defined as zero; the velocity is chosen as the separation speed, which is 2,251.86 m/s; it is a vertical take-off launcher, the take-off field length is chosen as zero. The rest of the mission requirement parameters are left blank, and none of the 'Traded' options is checked, see Figure 11.

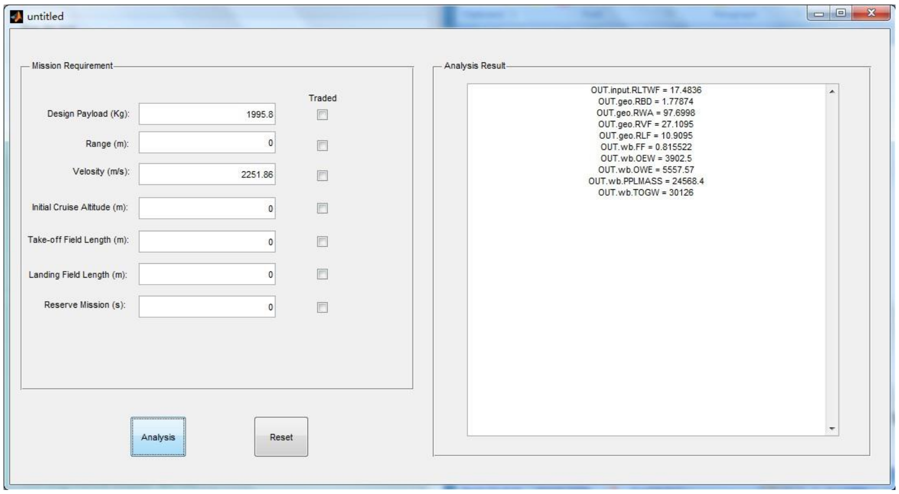

Figure 11. Parametric Sizing Result for *Project Mercury* Launcher.

Having finished the input formulation, the analysis button is clicked and the sizing process begins. After the grading process is executed, the *Project Mercury* launcher will be selected as the baseline vehicle and its technical details are stored at AVD^{DBS}, serving as the input deck for the execution of the sizing process. The unknown variables will be solved by the methods described in either Section 3.5 *Knowledge Application* or 3.6 *Knowledge Innovation*. Finally, the sizing result will be displayed in the analysis result window.

Although much more design results can be retrieved from the analysis, the results selected in Table 4 aim to show the important AVD parametric sizing characteristic of concurrently converging both launcher volume and weight. The results presented in Table 4 show agreement with published *Project Mercury* launcher data and the chosen design point. This case study demonstrates the overall functioning of AVD^{KBS} in concert with AVD^{DBS}, both aiding the AVD^{SIZING} code to complete an automatic parametric sizing analysis.

Table 4. *Project Mercury* Launcher Design Study Results

Sizing Code Output	Design Variable	Unit	Design Point	Project Mercury	Error (%)
Geometry					
RLTWF	$L_{booster}$	m	17.48	17.48	0
RBD	$D_{booster}$	m	1.78	1.78	0

RWA	S_{wet}	m^2	97.70	97.66	0.04
RVF	V_{tank}	m^3	27.11	26.96	0.005
RLF	L_{tank}	m	10.91	10.86	0.005
Performance					
FF	FF		0.815	0.815	0
OEW	OEW	Kg	3902.5	3875.49	0.007
OWE	OWE	Kg	5557.57	5530.65	0.005
PPLMASS	W_{fuel}	Kg	24568.4	24436.38	0.005
TOGW	TOGW	Kg	30126	29967.03	0.005

Summary and Future Work

This paper introduces the motivation for the development of a dedicated aerospace knowledge-based system. AVD^{KBS} can work as both, a standalone system for knowledge storage, education and reference, and alternatively as an interactive system with other AVD system modules to complete an automatic parametric sizing process. Its main functions can be summarized by knowledge collection, categorization, application, innovation and update. Graphic interfaces are developed to aid the user to conveniently retrieve knowledge and conduct parametric sizing analysis without getting into the details of MS Access and Matlab coding. A case study is conducted to demonstrate the primary system functions and functionality. Consequently, AVD^{KBS} provides us with an efficient tool to employ previous legacy knowledge such to making us stand on the shoulders of giants.

Due to the characteristics of the sizing method employed at the AVD Lab, both new knowledge and new vehicles thus knowledge are generated during the analysis process. Consequently, a mechanism has been developed to document not just legacy *but* new knowledge with the system for future references. It is a requirement that this knowledge-updating mechanism should be ideally automatic since the generation of new knowledge and vehicles is fast when employing an automatic sizing process when compared to the interruptions caused due to hand manipulations. Since not all knowledge is of relevance nor appropriate for the problem at hand, a mechanism needs to be developed to appropriately select the correct knowledge-entry.

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Critical Uses of Language in the Globalized Engineering Workplace and in Engineering Education

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Abstract

Given the changing demographics within the United States, as well as the internationalization of colleges of Engineering, the globalization of the workplace, and the presence of the multicultural workforce, the profession is well aware of the need for cross-cultural competence. The hidden, culture-specific meanings and intentions behind words themselves, however, are less represented in the engineering education literature. It is critical, therefore, that engineering educators, students, and professionals become consciously aware of the ways in which people from dissimilar cultural and language backgrounds tend to use language for different meanings, whether speaking their native language or a foreign language. Language use is such that speakers in these circumstances often do not know that they are misunderstanding the intentions behind the words that the other is using. Instead, they attribute negative personality characteristics to the person, or to the group to which the person belongs. This misunderstanding often leads to harmful emotional reactions, which can ruin collaboration and cost millions of dollars. Yet, professionals can counteract any such problems by drawing on recent findings in specialized subfields of linguistics, which address the culture-specific use of language to create intention, meaning, and ultimately communication.

Thus, this article offers information about the ways in which language use differs across cultures and threatens successful communication. It provides specific examples, culled from contemporary research, to illustrate this phenomenon in Arabic, Chinese, French, German, Japanese, Korean, Portuguese, and Spanish. Strategies for successful interaction with people from differing backgrounds are presented as well.

Introduction: Cross-cultural Competence, Demographics, and Engineering

Sometimes, even if they are speaking the same language, participants in a spoken or written interaction will “mis-communicate.” The more different their backgrounds, experiences, and the cultures from which they come, the more likely it is that misunderstanding and miscommunication will occur. If their native language is not the same, the potential for misunderstanding is markedly increased.

What is most insidious is the fact that often the participants will not even know they are failing to communicate. Instead, they will ascribe negative personality traits and behavior to each other. That is because different cultures tend to assign differing interpretations to specific words, phrases, texts, and situations. Thus, what may be polite interaction in one culture may be an insult in another. Furthermore, although Participant A may have learned Participant B's language and speak it well with him or her, nevertheless, speaking the same language does not mean assigning the same *meanings* to spoken or written words. As Blum-Kulka and Oshtain say, "[S]econd language speakers might fail to communicate effectively, *even when they have an excellent grammatical and lexical command of the target language*"[1] (my italics). In other words, mastery of grammar and vocabulary do not ensure successful communication.

It is no secret that cross-cultural competence is critical for the profession. Engineering professionals realize that, in the engineering workplace and in engineering education, professionals, students, and faculty come into frequent contact with others who come from different backgrounds, both abroad and at home, and they know that cross-cultural competence is necessary for successful educational and business transactions[2,3,4].

First, engineering endeavors are increasingly international and collaborative in nature. Indeed, according to ENR.com, the top 200 international engineering design firms are located in twenty-four countries: Australia, The Netherlands, U.S.A., U.K., Egypt, Canada, Spain, Singapore, France, Finland, Denmark, Japan, China, Sweden, Italy, Australia, Taiwan, Lebanon, S. Korea, Belgium, Germany, Austria, Ireland, and Kuwait [5]. According to Devex, "[r]ecent decades have seen a growing involvement of major engineering firms in international development projects. The world's developing communities have become clients under a corporate portfolio that includes both mega-infrastructure undertakings and small projects that provide basic services to impoverished villages"[6].

Second, paradoxically, the international nature of the workplace may be found in one's own "cultural backyard." There is a better understanding that multicultural diversity occurs both within societies, as well as between them[7,8]. For example, California (including the Los Angeles and San Francisco metropolitan areas) has quite possibly the largest population of Vietnamese heritage citizens outside of Vietnam: 380,000, while Houston and Dallas-Fort Worth combined boast a population of over 110,000 inhabitants of Vietnamese ancestry[9].

Countries and cities alike show this trend. According to the U.S. Government Census, "more than one in five people in the U.S. are first or second generation"[10.] Similarly, the U.S. workforce is also becoming more diverse. For example, between 1980 and 2010 the percentage of "Whites" declined from 82% to 72%, with a projected decline to 63% by 2020, while, conversely, minorities, defined as African-Americans, Hispanics/Latinos, Asian-Americans, and Native Americans rose from 18% to 28% and are projected to increase to 37% of the population by 2020”[11]. At the same time, the least educated are among the fastest growing segments of the population.

Similar situations exist in the United Kingdom. For example, “it is estimated that over 300 languages are spoken in London”[12], and by the 2001 census “30% of London residents had been born outside England”[13]. As for the U.K. itself, in 2011 the five most common countries of birth of inhabitants of the United Kingdom were Germany, the Republic of Ireland, Pakistan, India, and Poland[14]. In addition, “there were an estimated 988,000 EU8 (Czech Republic, Estonia, Poland, Hungary, Latvia, Lithuania, Slovakia and Slovenia) born residents in the UK,” as well as “an estimated 141,000 Romanian and Bulgarian born residents in the U.K.”[14].

Therefore, DeGraaff and Ravesteijn argue for “more ‘complete engineers’, i.e. engineers with sophisticated and practical knowledge, not of technology alone, but of ‘technology and society’”[15].

Third, engineering education programs are also aware of this reality. Because of the increasingly international and collaborative nature of some engineering endeavors, educators are ever more insistent that engineers need excellent cross-cultural social skills. “Globalization presents engineering educators with new challenges as they face the need for graduates who can function comfortably in an increasingly distributed team context which crosses country and cultural boundaries”[16].

Furthermore, both students and professors themselves comprise a diversity that is widely acknowledged. If, for example, one “googles” the keywords “engineering school diversity professor student,” one will easily find a number of universities addressing the diversity of their student populations. When students work together, “it remains a big challenge for students with different educational backgrounds, practical experience and ethnic backgrounds, to coordinate their knowledge, thinking and activities”[17]. In addition, “googling” “diverse faculty engineering schools” calls up a number of universities affirming the diversity of the faculty.

Thus, it is clear that on a number of levels engineering education is facing and attempting to address the need for effective cross-cultural competence: because of demographics in one’s home country, because of student-professor diversity, and because of the internationalization of engineering and the global workplace[16,17]. There are many aspects to the complex issue of cross-cultural competence that engineers ideally should possess, ranging from language proficiency, to an understanding of nonverbal behavior, to knowledge of various culture-specific attitudes and behaviors with regard to time, etc.[8].

This article builds on and expands this understanding of cross-cultural competence needs in the engineering profession by addressing specific language and linguistic problems that may surface during spoken and written interactions. Examples culled from a variety of languages are described and explained in order to demonstrate how engineering students, faculty, and professionals can begin judging whether or not miscommunication may be occurring in meetings, collaborations, or the classroom. It describes ways one can anticipate and approach situations in which "people talk differently, when speaking the same language." Resources and tools for further reading are proposed, should one need to expand one's knowledge of a specific culture, with whose members one is interacting.

Language Use and Miscommunication across Cultures

Every human being tends to think his or her meanings are the "right" meanings and the "only" meanings. The problem is "the hazard of *assuming similarity instead of difference*"[18]. Through the words, phrases, and conversations from different languages that are discussed below, it will become clear how important it is to assume difference instead of similarity, while still exhibiting good will toward the other.

Words

Words display culture-specific meaning, and people can easily misunderstand another's use of a word. In this section words denoting appropriate human behavior and interaction ('politeness,' 'little brother,' 'precious,' 'respectable,' 'worthless,' 'friend,' 'clique'), physical objects and spaces ('watch' and 'garage'), and attitudes toward reality ('fate,' 'early,' 'late') will be presented.

'Politeness' in the Chinese and Japanese Cultures, 'Little Brother,' 'Precious,' 'Respectable,' and 'Worthless' in the Chinese Culture

In the Chinese culture "denigrating self and respecting other remain at the core of the modern conception of *lǐmào*, or politeness"[19]. It would never occur to a U.S. American to define politeness in this way; denigrating oneself while respecting the other is not a foundational definition of most if not all forms of politeness in the English and U.S. American cultures. Furthermore, it would also not occur to a U.S. American to use the words "little brother," "precious," "respectable," and "worthless" when introducing him- or herself. In many parts of the country, "casual friendliness" is the modus operandi in our interactions, with nods towards interest in the other ("Nice to meet you," for example).

Therefore, polite Chinese introductions come across as strange in the North American setting. In the example below two men are meeting and introducing themselves. The first calls himself little brother to show that he is respecting the other, because in his culture a little brother has less status than a big brother. (Again, one is to self-denigrate by showing modesty about one's own self.) He also provides his last name, and not his first, the latter of which would be highly inappropriate. Furthermore, he does not introduce himself first, but rather asks for the other's name first. When asking for the other's name, the words "precious" and "respectable" are used, in order to "elevate" the other's position. The other denigrates himself by calling his last name "worthless."

M: Your precious surname?
S: Little brother's surname is Li. Your respectable surname?
M: My worthless surname is Zhang[19].

One can only imagine the effrontery when a U.S. American businessman, not knowing these conventions, offers his own name first and then calls a Chinese colleague, whom he has just met, by his first name. From the American's point of view, the relationship seems to get off to a good start, while from the perspective of the Chinese man, that is not the case. In fact, just the opposite impression is made on the Chinese speaker[20].

Finally, *lǐmào* or politeness includes "attitudinal warmth," "demonstration of kindness, consideration, and hospitality to other," "refinement," and "self's behaviour to other which meets certain standards"[19]. Without these particular senses of relationship, politeness is not accomplished in Chinese.

Politeness is very similar in the Japanese culture, where successful politeness occurs when the person the speaker is talking to, the addressee, "thinks a speaker is showing he/she thinks well of the addressee or not too highly of him/herself"[21]:

> For example, a secretary will often use so-called 'humble forms' (*kenjoo-go*) when referring to his boss if someone from outside the company calls to speak to the boss. Politeness arises from the use of 'humble forms' by the secretary in this case, not because it shows the addressee is outside the secretary's group (exclusion), but because the secretary shows he thinks his group (including his boss) occupies a different position to that of the addressee (that is, distinction). In other words, the secretary, as a representative of the people in that company (including the boss), shows they do not think too highly of themselves[21].

'Friend' in the French Culture

Another important word is 'friend.' Most human beings have relationships with people to whom they are not related by bloodline or marriage. Yet the meaning of the word 'friend' varies considerably from culture to culture. In France a true French friend is expected to intervene in one's life, while a true friend in the United States is expected to allow one one's autonomy. According to Carroll, a French person will tell a friend about a problem he or she is having, for example feeling exhaustion from work, and the friend will insist on getting involved and helping, saying for example: “I’ll pick you up at eight and we’ll go to the movies. You’re beat, you need to relax. I’m not going to stay here doing nothing while you work yourself to death right before my eyes”[22]. After several protests, the person with the problem will give in.

But what that same behavior evokes in a U.S. American is complete annoyance. As Carroll notes, “an American would undoubtedly shy away from such authority. It would represent an unbearable invasion of the other person’s private life…”[22]. In fact, she cites an American who thought just that and said the following: “I like L. very much, and we’re good friends, but she has one fault that drives me crazy. Yesterday, for example, I was heading for a meeting and I ran into her. … She offered to take care of Jackie at her house whenever I want, so that I can catch my breath a bit … as if I were incapable of taking care of my daughter and my work at the same time”[22].

‘Clique’ in the German Culture

When Germans and American speak with each other, they also often “mis-speak.” The word ‘clique’ is a case in point, where the German equivalent indicates a group of lifelong friends, and the U.S. American use is more negatively weighted in connotation, as a group of friends who wish to exclude others. A German *Clique* is a group with whom you feel safe and secure, and it refers to the people whom an American might call “my friends.” A German speaker could very well say, for example, “I go out with my clique.” This is how one young German described a *Clique*:

> For years I've been a part of a pretty large group of about twenty people [in Germany] who enjoy each other and continue to meet with each other, former classmates in school or my band, and the people meet each other all the time, and everyone knows everything about the other-up to a certain point that everyone knows how to respect, and you can talk about almost everything. You feel safe and secure…[23].

‘Watch,’ ‘Early,’ ‘Late’ in the Portuguese-Speaking Brazilian Culture

Words denoting objects and time can have various connotations in their definitions, too. It is known to many U.S. Americans that many Spanish-speaking cultures have a different relationship to time from more Anglo-type cultures. The word *mañana,* meaning ‘tomorrow,’ for example, also exists in Portuguese as *manha,* and the relationship to time in Brazil is also different from that in the Anglo areas of the United States.

Studies have found that in Portuguese the word ‘watch’ (as in ‘wristwatch’) denotes approximate time instead of exact time[24]. They have found that Brazilians consult their watches less than

United States inhabitants do. They have also found that Brazilians' watches are less accurate, so a watch does not have to be as accurate in the Brazilian definition of the object as it does in the North American. In addition, with regard to the attitude toward the time that the watches tell, "Brazilians were more flexible in their definitions of the words 'early' and 'late,' … [and] Brazilians expressed less regret over being late"[24]. Another of the important findings was that U.S. citizens "had more negative overall impressions of a person who is frequently late"[24].

Naturally, this could lead to cross-cultural miscommunication, the U.S. citizens perceiving their southern counterparts negatively as not prompt, punctual, or on time, while Brazilians could perceive those in North America as fixated on punctuality over, for example, relationships[24]. Of course, now that the digital world has taken over, Portuguese cell phones are as exact in their telling of time as are those in the United States.

'Garage' in the Columbian Culture

Another interesting word has to do with physical space, a *garaje*. In some houses in Bogota, Columbia the garage seems to be a part of the living room, with no wall at all between the spaces, or at most a short divider. While it is true that people in both the U.S. and Columbia can be proud of their cars and keep them spotless in very clean garages, nevertheless upon seeing the cars seemingly "on display"[25], American exchange students thought of their Bogotan hosts as ostentatious and showy. However, what they did not realize is that the garage had "the additional function of providing party space for dances and play space for younger children. Therefore, by blending the garage into the living room a greater expanse is possible inside the house"[25]. Especially if space is at a premium, this would make sense.

'Fate' in the Russian Culture

Finally, there are key words that have similar and yet very different meanings in different languages. The Russian word for 'fate' is one such word that some would say even defines the Russian character. Wierzbicka provides a lengthy, nuanced discussion of the Russian meaning and interpretation inherent in the Russian word *sud'ba.* Part of her description is the following:

> *Sud'ba* implies neither a "good" or meaningful outcome, like 'destiny*,*' nor a "bad" or meaningless outcome, like 'fate*;'* nor is it totally neutral between good and bad;… it hints that one can expect more bad things than good things to happen to one, but it presents human life as incomprehensible (as well as uncontrollable) rather than as meaningless and necessarily tragic. … It presents life as not subject to the individual's control, while evoking the idea of an external controller, but it leaves the possibility open that the external control may come from other people – for example, from social tyranny or political oppression – rather than from other-worldly sources[26].

Thus, it would be incongruous to think of one as "master of his or her fate," yet that is exactly what the North American value system assumes: we are in control of what happens to us.

It is thus easy to see that speaking the language of the other is not simply memorizing a list of words with their equivalents in one's native language. In fact, the implication is that vocabulary lists are a kind of pitfall, since there are very few words that have a one-to-one correspondence across languages, and vocabulary lists specify no culture-specific connotations. Similar issues exist with phrases.

Phrases

If words provide potential pitfalls for communicating across cultures, phrases and strings of words are equally dangerous territory, maybe even more so. 'Speech acts' is a term given to phrases, sentences, or utterances that comprise a verbal behavior. According to Austin[27], by our words we are actually "doing something." In other words, what we say can be an action: a warning, a promise, or thanks. Additional examples include comforting, allowing, disputing, greeting, advising, among others.

Speech acts are particularly helpful in understanding cross-cultural communication, because if one extrapolates the basic ideas from Austin, one comes to see that a sentence or utterance has at least three levels of interpretation: a literal meaning, the speaker's interpretation, and the listener's interpretation, also called 'locution' (the literal meaning), the 'illocution' (the speaker's interpretation), and the 'perlocution' (effect on the listener, or listener's interpretation)[27]. These three levels work fine, unless of course, the speaker's interpretation differs from the listener's, a problem that often occurs in cross-cultural communication. Thus, one may understand the words "How are you?" But a cashier uttering them at a supermarket in Texas, U.S.A. will use them as a greeting and conversation opener, while a German will not understand the meaning, because one opens conversations at grocery stores with the German equivalent of 'hello' or 'good day' (more on that topic below).

In this section, examples of speech acts are provided, including the acts of welcoming, understating an opinion, inviting someone to dinner, opening a conversation, hedging, overstating a threat, or making a request. All can lead to gross misinterpretations.

Welcoming in Arabic

In the United States, when we welcome someone into our home, we might say something like the following: "I am delighted to see you. Please make yourself at home." These words are the speech act of welcoming. However, when an Arabic speaker welcomes one into his home, he might mean exactly these words, but instead say something like the following: *"*You have extremely honoured me by coming into my abode. … I am not worthy of it. This house is yours; you can burn it if you wish. My children are also at your disposal; I would sacrifice them all for your pleasure. What a blessed day this is, now that the light of your countenance has shone upon us"[28].

The Arabic speaker does not, of course, mean what he is saying. Nevertheless, the North American is taken somewhat aback, and it is quite possible that misunderstanding occurs. The North American thinks that the Arabic speaker exaggerates too much and is, perhaps, volatile. In some situations, the North American might take the Arabic speaker at his word.

Understanding in English

On the other hand, Arabic speakers misunderstand the use of understatement in English and the fact that the English speaker does not say all that he or she means. Thus, when a speaker of British or Australian English wishes to say that something would be very silly, she or he might use the word 'rather:' "His appearance at the Baronet's must have been rather a silly one"[28]. Similarly, a U.S. American who says "That's a bit much" could mean "That is too much."

Thus, the problems arise on both sides: the overstatement of the Arabic speaker seems too effusive, dishonest, or too emotional to the North American, while the understatement of the English speaker is very frustrating to the Arabic speaker, for whom it seems that English speakers never say what they mean, and, from his point of view, have no artistry in their speech.

Chinese Invitation to Dinner

If the Chinese must elevate the other and denigrate the self in their talk, then in situations of invitations to dinner, the person who is being invited must at first refuse, saying it will be too much trouble for the host, while the host must insist several times, saying that it will be no trouble at all. Only then can the invitee accept.

In the following example, several talk exchanges are required in order for a prospective mother-in-law to make, and a prospective son-in-law to accept, an invitation to come to dinner. There must be several offers by the mother-in-law and several refusals by the son-in-law before it is considered polite for him to accept. The mother-in-law will say things like: "Come by for dinner tomorrow," while the prospective son-in-law will say things like: "I can't come. It's too much trouble for you.[21]" The mother-in-law will retort with the following arguments: "Trouble? Nothing! The food is already made! Whether you come or not, it's the same meal! You have to come. If you do not, I will feel offended"[19]. The son-in-law will eventually accept the invitation. Accepting too soon is not acceptable. However, the interpretation a North American might have is that the prospective mother-in-law is imposing her will on the prospective son-in-law, and he is acting hypocritically, because he wants to accept the invitation and does not until prodded. Yet neither is the case. The American interpretation would never occur to a Chinese speaker.

Conversely, a Chinese speaker would misinterpret a simpler invitation and acceptance by a North American as impolite, maybe even impudent. Yet North American politeness definitions allow, even require, one to accept a similar invitation more readily.

‘Hi, how are you?’ in American English

‘Hi, how are you?’ is a phrase that never ceases to stump German speakers who come to the Midwestern or Southern United States. When they hear a cashier say it in a grocery store, they think the cashier is exceptionally interested in them[29].

In all reality, however, when one steps up to the cashier after having waited in line at the grocery store to pay for one’s groceries, the cashier is actually greeting the customer and indicating the opening of the interaction with this phrase. Essentially, she is saying, “I am greeting you. It is now your turn. You may speak to me.” If the customer were to speak to her before that point, that talk would be considered an interruption of the ongoing interaction between the cashier and the customer who is in line ahead.

A German cashier, however, does not greet with such a speech act and instead will say *Hallo* (‘hello’) or *Guten Tag/Morgen* (‘good day/morning’) and will reserve ‘Hi, how are you?’ for people she or he already knows. Thus, the young German man who came to his turn at the supermarket in Texas heard the young woman cashier ask him how he was. He did not know what to think, and so interpreted her greeting as an overture to getting to know him better. He thought that since he and she were both young, of similar age, and therefore both probably single, she might be indicating interest in him. He then promptly began telling her about his life, specifically his recent root canal problem. Of course, the cashier had such a confused look on her face that he knew something had gone wrong.

His take-away interpretation was that Americans are superficial and don’t mean what they say. Conversely, Americans perceive Germans as rude, because they do not make use of the same conversational routine formulas that Americans do[29].

Hedging in Korean

Koreans, like the Chinese and the Japanese, are not supposed to self-aggrandize. So when they are asked whether they can do something well, if they can, they will not come right out and say it. Instead, they will hedge, demonstrating modesty about their acquired knowledge and their abilities. Thus, when asked whether he knew how to keep score in bowling, a Korean speaker answered with “Yeah, approximately.” In this case it was a Korean tutor in computer programming who was helping a North American student work on creating a computer program to keep bowling scores. The tutor was very familiar with bowling, but responded as stated above. The student thought that the tutor did not know much about bowling, and this misunderstanding led to further miscommunication as the tutor tried to talk the student through computer strokes when attempting to program scores for spares and strikes[30].

Overstating a Threat in Russian

Sometimes misunderstanding speech acts can cause wars, or if not wars, at least cold wars. In Russian there is the story of Soviet Premier Nikita Khrushchev talking about the advantages of communism over capitalism in 1956, stating, in Russian, that “Мы вас похороним,” i.e. “We will bury you!”[31]. It was not, however, a threat to bomb with a nuclear attack, as the Americans thought, but rather, “We’ll be here even when you’re gone.”

Requesting in Spanish

Anyone who has watched caricatures of Mexican Spanish speakers speaking English might recall the speakers saying something about “my leetle dog” or “my leetle burro,” meaning “my little dog” and “my little burro.” However, they will not realize that what is actually going on is the use of the diminutive in Spanish. Thus, Lola becomes Lolita in the diminutive form. In requests, too, the diminutive is often “used to mitigate the request by softening its force”[32]. Thus, one will not say, “Will you do me a favor?” (“¿Me haces un favor?”). Instead, one will ask, “Will you do me a little favor?” “¿Me haces un favorcito?” This is considered nicer, more polite, more appropriate. It has nothing at all to do with the magnitude (or lack thereof) of the favor. It may be a big favor, but be called a little one out of politeness, in order to soften the “blow” of the request. So when a Spanish speaker asks for a big request by asking, “Will you do me a little favor?” he or she is not lying, but rather softening the harsh tone of a request.

If words and phrases can cause problems in communication, whole texts – conversations, for example – can cause negative stereotypes as well.

Conversations

When human beings speak, they have an idea of what is to be said first, second, third, and so on. When one goes into a restaurant in North America, one may be greeted by a host or hostess and be asked, “How many?” and then, “What’s the name, please?” and finally, “It’ll be about fifteen minutes.” After that, if the event happens in a predictable way, certain other things will be said as the diners are being seated, and as the waitperson comes to the table. All through the meal and up until the diners leave, certain predictable expressions will be uttered. It is almost as if the speakers follow a “restaurant script” for getting through the meal with their customer/host/waitperson interactions. This kind of background knowledge is indeed called a script, and a whole theory has evolved around it called script, or schema, theory (Schank and Abelson)[33]. It is as if we know what we are going to say and hear before we begin a routine interaction. The words may not be exactly the same every time, and sometimes the interaction does not follow the script, but native speakers know the script anyway.

So, too, in conversation, there are ways to structure the conversation and determine what comes first, what kinds of topics can be addressed and how, and how one must interact with the others in the conversations. The following section presents three cases in point: the structure of conversations in Asian cultures, heated debates in German and Swiss conversations, and the enthusiastic overlapping that occurs when the French speak in casual conversations.

Asian Conversational Structure

One could say that the Chinese need to self-denigrate carries over into conversational structure, because of the fact that in a conversation a Chinese speaker will provide reasons for his or her thesis before providing the thesis. In a business conversation, for example, the Chinese speaker will begin with the particulars, including background or reasons, and conclude with the main point, comment, or action suggested. This is because the "Asian speaker feels uncomfortable putting his suggestion first before he has given his reasoning"[20]. The speaker wants to provide a reason for his impositions on the other, to mitigate the (negative) impact of the suggestion or comment.

The North American, on the other hand, will first state the suggestion, comment, or main point, then the reasons and particulars. When this happens, each side cannot follow each other, and the Asians think the North Americans are rude, while the North Americans reinforce their stereotype of the "inscrutable" Asian[20].

Heated Debate in Germany and Switzerland

The scripts that one uses determine, to a great extent, not only the sequence of verbal and non-verbal behavior in a speech event, but also the content and the ways of speaking that are considered appropriate.

Even between North Americans and Northern Europeans, great differences exist. German and Swiss speakers of German exhibit conversational traits that North Americans find repugnant, and vice versa. In many German environments it is considered polite and in good form, as well as a good way to get to know people, to argue politics and controversial issues. These heated debates are considered good fun, and all are expected to take part[34,35]. In the U.S. middle-class culture, one gets to know another by stressing commonalities. Thus North Americans are often dismayed and call the German speakers rude for confronting them, while the German speakers think of the North Americans as shallow, because all they want to discuss in those same situations is what they have in common, sports or cars or family background, rather than "topics of substance"[29].

French Overlapping

The interpretation of the North Americans in French culture is not that they are shallow (how the Germans interpret them), but that they are rather dull and uninterested. In French culture it is considered appropriate and right to overlap (interrupt) when engaged in a lively discussion with friends. One must figuratively "jump into" the conversation. In fact, what U.S. Americans consider rude is, in France, "proof of spontaneity, enthusiasm, and warmth, a source of unpredictability, interest and stimulation, a call for participation and pleasure"[22]. However, "for an unsuspecting American, … the rapidity of the exchange may be interpreted as a series of interruptions (and therefore an indication of aggression) and the tone of the voice as an expression of anger"[22]. It is for this reason that U.S. Americans often do think of the French as rude, while the French think of Americans as uninterested dullards.

Bridging the Gaps

Awareness of the ways in which language can cause problems when working with engineering students, educators, or professionals is important, but not sufficient, to successful communication. Although the path to intercultural communication is fraught with obstacles, nevertheless the obstacles can be overcome, and as people get to know each other, they also give each other the benefit of the doubt, especially if they realize the person is from a different background, and they make clear they are trying to meet common goals.

Some overarching suggestions should help readers apply, with a form of meta-awareness, the above understanding to cross-cultural situations in which they find themselves. Here are a few helpful hints:

1. One should remember that proper, acceptable, appropriate use of language is not rooted in some natural law of science or the universe, but rather in variable human culture.

2. Not all speakers of a language will exhibit the same linguistic behaviors all the time, nor will their interpretations of those words always be the same in similar situations. There may be regional differences, or outside influences. Some may live not in their heritage country, but in the United States, for instance.

3. Above all, one should not "assume" she or he knows the other's intended meaning. It is critical that one always also not assume that the behavior or language of the other is fraught with ill intention or ill will. One must "check and clarify the meaning of words and phrases, and test [his/her] own understanding"[30].

4. If possible, it helps immensely to get to know the "other" – the person who is different from one. Specifically, it helps to build shared knowledge by disclosing and eliciting key information, "including the intentions and broader context as to why something is said or

requested, in order to help build trust and mutual understanding and to reduce uncertainty"[30].

5. Finally, easily accessible, readily comprehensible resources are critical. In addition to the sources in the references below, one can take advantage of key search terms in google scholar, using the name of a language or cultural group coupled with one or more of these words or phrases: 'intercultural communication,' 'pragmatics,' 'conversation analysis,' 'intercultural misunderstanding,' 'discourse,' 'discourse analysis,' 'speech acts,' 'communication patterns,' and 'cultural anthropology.'

Once rapport and a certain level of trust have been established, one can actually ask another how he or she interprets various words, phrases, objects, spaces, and behaviors. The following strategies have been gleaned from a number of sources, but especially from Carl Rogers[36], to elicit a speaker's true feelings, beliefs, values, and attitudes.

1. In order to signify understanding and encourage further talk, one can acknowledge comprehension by providing back-channel behavior ("m-hm," "I see," nodding one's head as appropriate) and by repeating what the other has said.

2. To seek clarification, interpret, check understanding, and test perceptions, one can do several speech acts: ask what the other means ("What does X mean?"), ask if the other can say more about the situation ("Can you tell me more about it?"), and request an example or experience ("Can you tell me about something that happened to make you think that?" or "Can you give me an example?").

3. To confirm understanding, one should clarify the interpretations of the other by again paraphrasing ("When you say X, you also mean Y, don't you?") and summarizing ("Let me see if I've understood you correctly. You said that…").

Conclusion

Learning about another cultural group and their ways of talking, acting, and interpreting the world doesn't have to take all of one's time. An engineer is busy as it is. Instead, it can be a well chosen article that helps one understand and, for a moment, "walk in the shoes of the other," so that the goal one wishes to accomplish with the other will come to successful fruition, whether it be to teach, to learn, or to collaborate. Avoiding the pitfalls of uninformed cross-cultural language use makes communication effective and successful. It can, literally, help people build bridges.

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A Student's Perspective on Impediments to Retention and Graduation in Mechanical Engineering

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Abstract

This paper provides a student's perspective on factors that cause students to drop out before graduation or take more than four years to earn a Bachelor of Science degree in Mechanical Engineering. On a larger scale, this paper aims to contribute to the ongoing effort to improve the graduation rate of the students of any state University without compromising the quality of the education or the value of the engineering degree.

In this paper, several categories of impediments to students' academic success are presented and analyzed. The impediments were hypotheses by current students at the end of the engineering program at the University of Texas at San Antonio (UTSA). The impediments are: (1) cost of attending, (2) dissatisfaction with the faculty members, (3) strict course prerequisite chains, (4) availability of courses, (5) high school preparation, and (6) difficulty of courses.

The analysis of the problems a student faces during their academic journey aims to consolidate the research in the form of a unified data, and present a statistical correlation of this data to the student's level of general interest in mechanical engineering, socio-economic background, and history of previous scholastic performance. The information obtained from the statistical data was collected in the Fall semester of 2012 at UTSA, and from the interviews of the current and former mechanical engineering students during the same semester. The analysis stage of the paper is followed by solutions for the problems identified. The proposed solutions include the changes to the curriculum structure, more classes offered in a semester to accommodate all the students trying to register for a class, and better core preparation of the student in the areas of mathematics and physics.

The results can be generalized to a model that fits other colleges offering degrees in science and technology. One of the implications of this work is that programs should create road maps for the beginning engineering students highlighting the potential impediments identified on their path with the accumulated shared experience and success stories of those who completed the curriculum themselves.

Introduction

The life of a college student studying engineering is difficult and has many challenges and road blocks, some foreseen by an incoming freshmen student and others not. Along the way, many students leave engineering for a variety of reasons.[1] The average engineering degree calls for four years of studying assuming the student is able to attend and complete a minimum of sixteen hours per semester. This is improbable because the tuition cost alone of an average university is high enough to put any family in a situation where they are requiring their son or daughter to work during the semesters. When taking engineering courses, the average class calls for at least three to four hours of studying a week, and when taking five to six classes a semester that turns out to be fifteen to twenty-four hours of studying. A student's time will quickly burn up and that is still without adding the time to work or do other important activities necessary in everyday life.

These impediments weigh heavily on the fact of graduation succession rates and that of the attendance rates of incoming freshman that are willing to take on the journey as an upcoming engineering major. Engineering is known to be a prestigious degree in that it is very difficult to pass classes, understand the various topics of engineering, etc. But what should not make students deter from the road of engineering is the degree plan set forth by the college of engineering. In a four year degree, the average semester calls for five to six classes and that is without remedial courses such as College Algebra or Pre-Calculus for Engineering students. The problem is that even for the brightest students, completing five or six engineering courses per semester with good grades is challenging, due to the fact of the vast amount of material covered in each and every class. In the end, the average engineer will graduate in five to six years with a bachelor's degree where other majors will have had their bachelor's and possibly a master's degree in the same amount of time.

Program Impediments

There are many impediments that a student faces when attending college. The first impediment is the cost of attending college, as college can be a financial burden on the student. As rigorous as an engineering degree may be, some students can take up to seven years to finish an engineering program. As one can imagine, seven years of college just for a bachelor's degree can be very costly. Once a student recognizes the steep price, on an already intellectually demanding degree, dropping out and working immediately does not seem like a bad idea.

The second impediment is the dissatisfaction with professors. A student may become highly discouraged from getting through an engineering program if the program has a professor that has the inability to reach the students in terms of teaching the course. Often times, if the student does not like a particular professor, the student may have a difficult time in more than just one class as they could be required to take the same professor for multiple classes. As a below average professor can come in many different forms, typically a professor that is hard to understand during lecture, disorganized, or is not helpful, this may lead the student into dropping the class or dropping the entire program.

The third impediment is the amount of prerequisites assigned to a significant number of classes and the string of required classes in an engineering degree. With such a strict sequence of courses every engineering student must follow each semester, failing, withdrawing, or dropping a course can set the student back a semester or more, or force them to take summer classes. This can be a major problem for a student due to the fact that it can affect them financially, as the student will have to pay for the class again, and remain in the program for another semester or two.

The fourth impediment is the availability of courses in a semester. With such rigid course prerequisites, students are forced to take certain classes each semester at the time it is offered. This means the student has little choice in the class meeting time and must take the class regardless of the instructor. This introduces time conflicts for many students. The student that may be working can be taking another class only offered at that specific time during their work hours. This often is the result of a lack of professors at a university, but the students are the ones who have to pay for it. With such little scheduling flexibility, students are often forced to delay taking a class they to graduate promptly. As a result, a lack of course availability pushes their graduation back, and increases the amount of tuition they have paid at the end of their college career.

The fifth impediment is the poor course preparation students have coming into the engineering program. Being placed into various math or science classes can have a lingering affect later on in a student's academic career because of the knowledge gaps the students may have. The gap in a student's knowledge may never be filled, and will be repeatedly exploited as the student progresses to harder classes. It may result in lower grades, and additional studying for certain classes as the gaps cause the student to not understand or recognize concepts to their fullest

The sixth impediment is that engineering courses are difficult. The courses require a grasp of mathematics and physics. Any weakness in academic preparation make it especially difficult for students since engineering classes are often fast paced. The amount of material covered in a typical class does not allow the instructor time to re-teach prerequisite material. Also, students can't fall behind in a face-paced class because the material often builds throughout the semester. Failing to understand material early in the semester is often devastating as the semester progresses.

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Survey

A survey was designed and given to one hundred mechanical engineering students at the University of Texas at San Antonio (UTSA). Over 90% of the respondents were upperclassman. The survey consisted of twenty-five questions, to illicit a student's perspective on the impediments. The types of questions that were asked were as follows, "on average how many hours a week do you study", "overall GPA", "what math did you start at in college", "have you ever dropped a course…", and "do you understand the applications of the material in the courses you study".

With a sizable pool of one hundred respondents, statistical analysis of different questions could be made. The processes of analyzing the data and reaching conclusions were as follows. Each survey was inputted into Excel, each of the twenty-five questions were assigned a letter from a to x. Then, each of the choices a student could have picked for each of the twenty-five questions was assigned a number one through five. For example, a question that only had two choices, were assigned one and two for simplicity. After all the data was in Excel, correlations were made by using various nested if and then statements. The if and then statements were used to see which student answered each of the various questions. If there was a great or lack of significance for the questions answered by all one hundred students, then there was a correlation between the two questions and the two answers a student had chosen. From those correlations, engineering programs can recognize what is really significant to get students through a rigorous engineering program based on students who are making it through the program and are almost finished. Ninety percent of the respondents of the survey were upperclassmen. With the impediments already presented from a student's perspective, changes could be made to engineering programs based on significant statistical correlations. There are two areas that should be revamped or implemented, (1) curriculum structure, and (2) additional class availability.

Analysis of Responses

Curriculum structure is an aspect of any program not to be overlooked. It can affect students on the topics of learning, and financial. Based on how well a curriculum is made, students can come out of engineering programs very knowledgeable or not. A key to being a good practicing engineer is what concepts, relationships, and information you retain and take away from college. To achieve a higher percentage of engineering students fully grasping and making connections between various engineering topics, the curriculum is the foundation at which that starts. A well thought out curriculum is also very useful due to the fact that if more students can successfully move through the program quicker, that is more appealing since the student is paying for college one way or another. The survey showed that 56% of the students take only four engineering classes a semester, and only 25% take five engineering classes a semester. As a result, the engineering program becomes more, and more expensive and lengthy.

Further, curriculum structure needs to be changed in a number of areas such as, (1) prerequisites, and (2) co-requisites, to help students benefit in how much they learn, and to reduce college costs. Having proper prerequisites is needed for most if not all the design engineering courses. But, many prerequisites are not needed for classes that revolve almost completely around theory. An exception is, for example, Statics, which should indeed be a prerequisite for Dynamics. The problem with unnecessary prerequisites is that it locks the student in for a semester on what they can and cannot take for courses. This possibly affects their graduation date, and in turn their financial situation. The issue with changing prerequisites is that whether or not the student can learn and pass the class without the prerequisite. The survey showed that 44% of the students have requested a prerequisite override, and of that 44%, 92% of the students were able to comprehend the material and pass the course they received the prerequisite override for. Thus, showing a lack of correlation of the pre-requisite class to the next class.

Co-requisites need to be better implemented throughout an engineering program. Often times, a student does not fully understand what exactly is being learned, as the real problem lies in why and how this concept is used in direct applications. Co-requisites can be very useful for understanding mathematical and engineering theory when shown more applications than just the ones introduced in a particular class, if they are even introduced in the same class. Having better co-requisites instead of some prerequisites for theory and application would result in higher retention when a student uses concepts from one class in three or four other classes they are taking that same semester. With a curriculum that incorporates better co-requisites, students can also reduce the amount of studying they do per week. Taking from the survey, 30% of students take 12 to 16 credits per semester and study from 10 to 30 hours a week. Also, 13% take 12 credits per semester and study 10-30 hours a week. Couple this with going to lecture and lab, studying outside of class for up to 30 hours a week plus the possibility of working a job can become taxing on a student. The survey shows that 46% of the students work on or off campus to help pay their tuition, so if proper co-requisites were in place and material in the majority of the students classes overlapped, studying time would be reduced[1].

Something interesting to take away from the surveys was that 50% of the students understand the applications of the material taught in engineering classes after they have finished the course. With half of the students not recognizing the real world engineering applications of some of these mathematical concepts, that is half of every class just memorizing, regurgitation, and forgetting while they are taking the class to attempt to pass it. An added benefit of showing students the direct applications of theory through another class that would otherwise be a prerequisite, make that class a co-requisite and students may perform better academically. Students will be taken out of the mindset of forgetting what they have learned to make room for new concepts, as what they are learning now is needed and used in all these other classes they are taking right now. Granted some courses involve material in lower level courses, but should not be taken as a co-requisite because of other required knowledge needed to understand the material, such as design courses.

The availability of classes is the next area of interest that must be considered. Availability of classes incorporate the impediments cost of attending and dissatisfaction with teachers. This area affects the student in (1) learning and (2) financially. The faculty at the UTSA is probably understaffed. Some upper division classes only have one professor teaching a particular course. This means a student is forced to take that class at that time, with no schedule/professor mobility. With no schedule mobility that could entail the student not being able to take all the classes they need to take that semester due to schedule conflicts. The following semester, they may run into the lack of available prerequisites, thus their graduation date falls behind and the student suffers financially by having to pay for another semester of tuition. With no professor mobility, the student can run into the issue of not being able to learn from that particular professor for a variety of reasons. The reasons may be the professor is hard to understand, was not helpful, or was not organized. Almost a third of the survey respondents have said they have dropped a course due to the professor being one of those reasons previously listed.

The lack of availability of classes being taught has a simple cookie cutter solution of just adding more sections of that particular class. The survey shows that typically the student body of the Department of Mechanical Engineering does not like the idea of weekend classes nor classes longer than 75 minutes. The results are as follows, 45% of student respondents would not be interested in weekend classes if made available and 50 minute lectures are the optimal duration for class. Twenty seven percent responded that they would not be interested in weekend classes if made available and 75 minute lectures are the optimal duration for class. Although the topic of adding more sections to more of the engineering classes offered is a very sensitive issue for a university due to availability of funds to hire more professors, actual physical classroom availability, and more macro-management needed to avoid the issue of a student "professor shopping". Professor shopping is where a student will take a specific section for a course due to the professor being very favorable in grading compared to another professor teaching another section during the same semester.

Conclusion

Through this paper, different impediments to retention and graduation rate were identified by senior-level engineering student's currently near the end of the engineering program. With six impediments stated, and a solution provided that incorporates four out of the six impediments, a University can easily recognize if they have not already the various problems that a student may face. The one impediment that will be more difficult for a University to address is the poor preparation of high school students. The issue of poor preparation could possibly be identified by the University through another solution, such as increased admission standards, but one could not be incorporated here in this paper. Universities should recognize the student as ultimately paying a great deal of money to attend college and get a full education. With a possibly popular program, coupled with prospective students that may be very inclined to start such an engineering program, the University should eliminate roadblocks which have little educational value or justification. The University benefits from having a large number of students interested in earning an engineering degree, and in large numbers of successful graduates starting careers in engineering.

Appendix

Table 1. Responses to Questionnaire. Total of 100 respondents.

Question	Choices	% Answered	Count
Major	ME	93%	93
	EE	3%	3
	CE	4%	4
Classification by Year	Freshman	1%	1
	Sophomore	7%	7
	Junior	37%	37
	Senior	55%	55
Overall GPA	2.0-2.5	7%	7
	2.6-3.0	44%	44
	3.1-3.5	32%	32
	3.6-4.0	17%	17
Years left till graduation	Less than 1 year	9%	9
	1 Year	53%	53
	2 Year	35%	35
	More than 3 Years	3%	3
How many hours do you take per semester	Less than 12	4%	4
	12	29%	29
	12 to 16	66%	66
	More than 16	1%	1
Have you ever dropped a course because the professor was hard to understand	Yes	33%	33
	No	67%	67
Have you ever dropped a course due to the professor being unhelpful	Yes	31%	31
	No	69%	69
Have you ever dropped a course due to the professor being unorganized	Yes	28%	28
	No	72%	72
Method of Payment (select all that apply)	Financial Aid	61%	62
	Parents	48%	47
	Work off campus	36%	36
	Work on campus	10%	10
	Other	19%	19
On average how many hours a week do you study	Less than 3 hours a week	7%	7
	3-10 hours a week	32%	32
	10-30 hours a week	45%	45
	More than 30 hours a week	16%	16

Did you transfer credits into UTSA from another college(select all that apply)	None	23%	23
	SAC	19%	19
	VISTA	14%	14
	UT Austin	6%	6
	Other	48%	48
Have you taken any science or math courses at another college	Yes	64%	64
	No	36%	36
What level of mathematics did you start at in college	Lower than College Algebra	9%	9
	College Algebra	34%	34
	Pre-calculus	16%	16
	Calculus I	27%	27
	Calculus II	14%	14
Are the courses always available when you need to register for them	Always Available	18%	18
	1-2 unavailable	65%	65
	More than 2 unavailable	17%	17
How many times did the prerequisites prevent you from taking the full load(12 hours) during a semester	Never	50%	50
	Once	21%	21
	Twice	14%	14
	More than twice	15%	15
Have prerequisites ever pushed your graduation date back	Yes	66%	66
	No	34%	34
Do you understand the applications of the material in the courses you study	During the course	60%	60
	After the course	38%	38
	Never	3%	3
Have you ever requested a prerequisite override	Yes	45%	45
	No	55%	55
If "yes" was your request approved	Yes	77%	34
	No	21%	10
If "yes" were you able to comprehend the material and pass the course you got the override for	Yes	89%	31
	No	11%	5
How many engineering courses do you feel you can complete successfully per semester	3	16%	16
	4	57%	57
	5	25%	25
	6+	1%	1
If there were weekend classes available would you be interested in them more than weekly classes	Yes	22%	22
	No	78%	78
What in your opinion is the optimal duration of a class	50 minutes	54%	54
	75 minutes	32%	32
	90 minutes	14%	14
	120 minutes	0%	0
	More than 120 minutes	0%	0
What in your opinion is the optimal distribution of the grade throughout the course	Equally distributed between midterms and final	66%	66
	More weight on midterms	20%	20
	More weight on the final	14%	14

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Hands-on Technology Education

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Abstract

The computer hardware basics are taught using traditional TTL logic gate units, such as, NOT, OR, AND, NAND, XOR, and XNOR gates. Circuits are created by placing these gates (chips) on breadboard and connected to 5V power supplies. Use of this set is unique particularly to jumpstart a digital logic circuits course as there is no alternative to this hardware setup for students to achieve fundamental knowledge on the logic gates, pin configuration of the chips and in building simple circuits on breadboard. However, too many connecting wires on the breadboard make the circuit cluttered and almost impossible to trace bugs in case the circuit fails to work. The problems could be anywhere from a faulty circuit design to the connections being loose and the board itself getting bad due to aging. Two major undesirable outcomes were observed in using this traditional way of learning, i) dissatisfactions of the learners and thereby reluctance to learn the subject and ii) difficult to complete a planned syllabus on time. It has been found that, as the circuits become more involved, it is a good idea to switch over to simulation tools, such as MultiSim. Use of Field Programmable Gate Arrays (FPGA) board is even a better choice. This helps students to create schematic circuits at ease and also in developing Hardware Descriptive Language (HDL) program. The schematic or the HDL code can simulate a circuit and help to fix any possible problems and finally to download the program on to FPGA board. The whole process is clean, neat, and encouraging to the users. As an added advantage, this hands-on process keeps the students engrossed in learning by keeping them away from side-talks, high-tech distracters, such as smart phones and iPads. On another front, we have introduced high-end technology in teaching assembly language using microcontrollers. There are newer versions of microcontrollers which are useful in adopting microcontrollers in a top-down approach. This approach keeps students interested in a new topic by focusing on what it can do rather than memorizing its syntax in the first place. Students learn the details of the course topics while working on the key outcomes of the course. This paper discusses the use of FPGA boards in teaching sophomore and junior level courses in digital logic and digital hardware design.

Introduction

The Digital Logic Circuit is a fascinating course for the beginners towards understanding the fundamentals of how a digital system works. The beauty of the course becomes obvious to the students in its counter-part lab course. Traditionally a lab course is taught using basic TTL logic gate units, such as, NOT, OR, AND, NAND, XOR, and XNOR gates. Students can easily visualize the functionalities of the basics gates which opens the door to the learning of the digital systems by hands-on experience. However, this excitement evaporates soon when the size of the circuits grows. Wirings of a circuit become overwhelming. Wiring the GND and Vcc pins are repetitive works for every chip. For example, a set of only five chips on a breadboard requires at least ten connecting wires leading to power and ground connections of the board. When inputs and outputs are connected together with the chips themselves being connected to implement a circuit, it becomes a nightmare to debug any single bug in the circuit. The bugs could be anywhere, from wrong circuit design, to wrong connections, loose pins or the board itself being a problem. It does not need to wait long to see students getting frustrated with the lab.

Considering all these practical problems faced in the laboratory, we decided to upgrade the lab with three objectives

1. Make the lab hour an enthusiastic period of learning by removing all unnecessary hurdles in completing each lab with satisfaction
2. Complete the lab syllabus on time.
3. Give a sense of satisfaction to the students that they have learnt a new course with high-end technology.

Strategy in Improving the Lab

In computer engineering program, the digital logic circuit is the first course to learn a digital system. Its counterpart is a lab which usually offers ten to twelve lab exercises. The first lab is usually to learn the pin and gate layouts of basic gates, like, NOT, OR, NOR, AND, NAND, XOR, and XNOR. Students grasp the functionalities of the gates by comparing the truth tables with corresponding observed outputs. The other labs are on combinational circuits based on Boolean simplifications, DeMorgan's Theorem, K-map solutions, Adder/subtractors, multiplexers and decoders, followed by simple flip-flop circuits.

Figure 1 shows the complete structure of a traditional lab on digital logic circuit. It is a power-connected box with a breadboard on it. Chips are added on it as per circuit; inputs are taken from 8 switches and outputs are seen in 8 LEDs as required. All chips are placed on the breadboard. A vertical bin box is seen close to the board that contains all TTL logic chips in individual drawers for the class. Each drawer is labeled with chip names and numbers for students to pick up the correct ones and return after completion of each lab.

Figure 1. Digital Logic Circuit lab with TTL chips on traditional breadboard

The lab on breadboard with logic gates (all hardware based labs) is an outstanding method to give the students very basic understanding of the digital logics. However, as the circuits grew, we noticed two problems every year, viz: a) students get bored with multiple wire connections and get frustrated when circuit did not work, and b) it was never possible to complete all the labs prescribed in the syllabus.

To alleviate these two potential problems, we adopted two new methods in the lab. The first method, introduced in Spring of 2011, maintained the traditional hardware system for the first few labs followed by the application of MultiSim simulation tools for the rest of the semester. The second method, introduced in Spring of 2012, was a mix of three things, i) traditional hardware, ii) MultiSim software, and iii) ~~the~~ use of XILINX FPGA on Digilent Nexys 2 board, the project being built using XILINX ISE software.

First Method

The equipment shown in Figure 1 was used to teach the truth tables of some basic logic gates and some simple digital circuits. Students appreciated this part as they could visualize how the digit systems work. They also identified the hassles of wire connections together with bugs generated from faulty and/or loose connections combined with often malfunctioning of the box itself that holds the board. As the complexity of circuit grew we switched the lab to the second level of using MultiSim software. It was a great relief from manual wiring of the circuits. Students could save the schematic on their flash drives. All the students appreciated it very much and we started teaching more labs than it was possible relying on just the traditional hardware system.

Second Method

During Spring 2012, the XILINX FPGA on Digilent Nexys 2 board with XILINX ISE was added to the first method as described above. Using the XILINX ISE, the students developed projects to implement circuits in two approaches, viz: i) schematics and ii) HDL programming. During Fall of 2012, a Special Topic course titled 'Digital Systems Design' was offered in which the students studied four-bit adder/subtractor, flip-flops, serial shifter and counter circuits using the Nexys 2 board with the XILINX FPGA platform. Figure 2 shows Nexys 2 board with XILINX FPGA platform as the heart of the system.

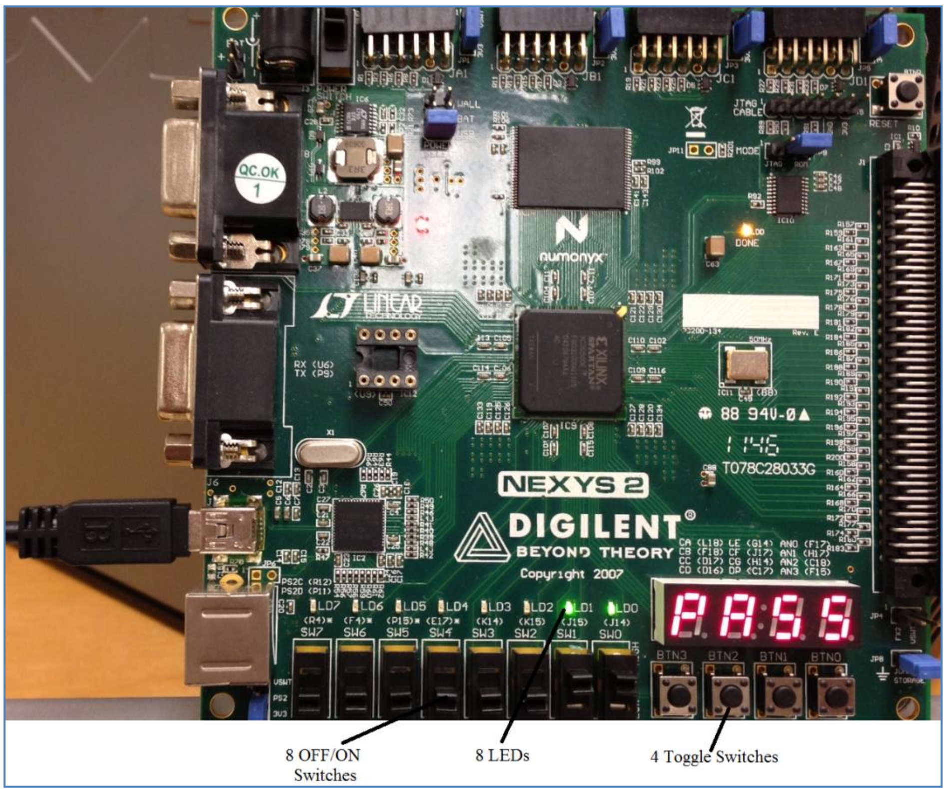

Figure 2. Nexys 2 board of Digilent, Inc, with XILINX FPGA on it.

Results and Discussions

Only Hardware Labs

In the beginning of semester, students used breadboard and TTL logic gates (actual hardware lab) to perform the first two labs. This short period gave students an opportunity to exercise with breadboard and real chips. This approach is tedious but essential for students to have a good grasp of the functionalities of the fundamental digital logic gates and their integration into useful digital circuits. This traditional method involved connecting each chip to the power source and to the ground for every chip in lab. This has a drawback of killing enthusiasm in the lab. The simulation technique, as an alternative, has a stimulating effect for students. They stay engrossed into the lab exercises.

MultiSim Labs

After couple of labs with the traditional hardware system, the students were exposed to simulations in the labs using the MultiSim software. To start a lab, students prepared logic circuits on a paper and then build circuit in the MultiSim editor by putting together the circuit elements, such as, logic gates, wires, LEDs as outputs, function generator, and oscilloscope, all from the editor and the library of parts. Students found the simulation lab more comfortable over the hardware labs. This increased the speed of lab activities and more labs were covered in the semester.

However, as the size of the circuit increases, the editor space becomes scarce, and as a result, the neatness of the circuits disappears.

FPGA Labs

The ISE WebPACK Design Software is free from XILINX[1]. It is fully featured front-to-back FPGA design solution for Linux and Windows operating systems. The driving force of the Nexys 2 and Nexy 3 boards is the XILINX FPGA chip. Use of this board together with the XILINX ISE WebPack offers two features for the students, viz: i) simulation using schematics and ii) HDL programming. In either of these cases, a '.bit' file is created which is downloaded onto the FPGA platform of the Nexys 2 or Nexys 3 board using a second software, ADEPT, of Digilent, Inc. Once downloaded, the students work on the hardware, the Nexys 2 or Nexys 3 board, to study the input and output relationships.

Schematic Labs

The ISE WebPACK Design Software requires a project to be created to start with. The major settings for the project are shown in Figure 3. The selection, "Schematic", highlighted with a red oval, indicates that this would be a schematic project. As an example of a circuit diagram, a positive-edge triggered D Flip-Flop as shown in Figure 4, would be created extracting circuit elements from the editor. This flip-flop circuit has one input, designated with name, "D" and another input, designated with name, "Clock". The single output is named as, "Q". This will be saved as a schematic (.sch) file associated with the project.

These two inputs and one output are mapped to the Nexys 2 board in a "User Constraint File" (.ucf) file as shown in Figure 5. The On/Off switches and the toggle switches in the Nexys 2 board are used as input and the LEDs are used to display the outputs.

Once all are in place, a '.bit' file is generated corresponding to the '.sch' and '.ucf' files. The '.bit' file is downloaded into the FPGA platform using a downloader, called ADEPT, which can be installed free from the Digilent Inc. web site.

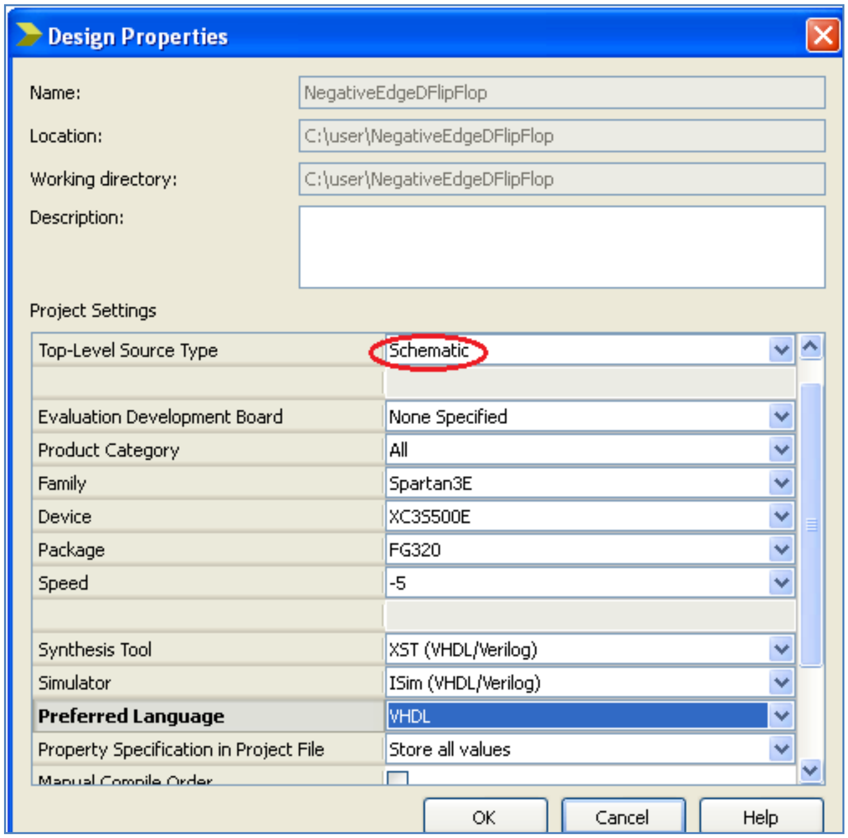

Figure 3. Creating project with ISE WebPACK Design Software

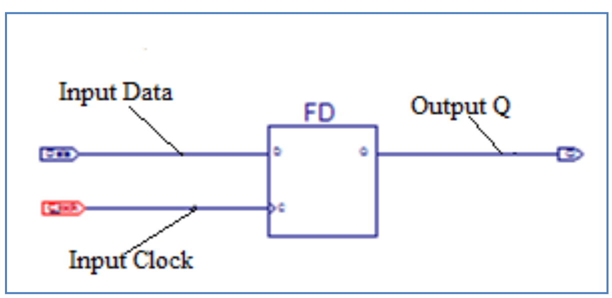

Figure 4. A schematic diagram of a circuit.

```
NET "Data" LOC = "G18";
NET "Clock" LOC = "H18";
NET "Q" LOC = "J14";
```

Figure 5. A User Constraint File. Two inputs are designated by On/Off Switches, G18 and H18 and the output is designated by LED J14.

Hardware Descriptive Language (HDL) Labs

Development of an HDL project is very much similar to the development of a schematic project. From the drop-down menu of "Top-Level Source Type" (Figure 3), this time, "HDL" should be selected instead of "Schematic". A '.vhd' file will be generated including the "Entity" and "Architecture" components. The Architecture component remains blank for the programmer to write code corresponding to the problem. The Entity component includes all inputs and output variable declarations as decided during project initiation.

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;



entity PositiveEdgeTriggerHDL is
    Port ( D : in  STD_LOGIC;
           Clk : in  STD_LOGIC;
           Q : out  STD_LOGIC);
end PositiveEdgeTriggerHDL;



architecture Behavioral of PositiveEdgeTriggerHDL is

   begin
      process (D, Clk)
         begin
         if Clk'event and clk= '1' then
            Q <= D;
         end if;
      end process;

end Behavioral;
```

Figure 6. The entity component is generated during project initiation. A programmer has completed the architecture for an edge-triggered D Flip-flop.

Figure 6 shows the HDL project file corresponding to the schematic project shown in Figure 4. The same '.ucf' file can be used. However, the input and output variable names should be edited as in the entity of the file.

When compiled, a '.bit' file is created. Then this '.bit' file is downloaded to FPGA in the Nexys 2 board. It is in this board, the students study the input/out relationship of the circuit just downloaded into the FPGA architecture.

As this new technology has been adopted to teach the digital logic circuits, students are seen very enthusiastic to learn and work with it. Even some students are seen working extra hours on extended projects. Figure 7 shows a group of students working with FPGA platform.

Figure 7. Students are checking results on the Nexys 2 board.

Conclusions

Introduction of FPGA technology into our digital logic course is a brand new addition of high-end technology. Students learn the digital technology via three different approaches in the same class. Since it includes a limited amount of the traditional hardware system in the lab, the students are not deprived of getting the fundamental knowledge on hardware. With MultiSim software, the students grasp the knowledge of circuit simulation. The FPGA platform allows the students work on the reconfigurable devices. They simulate a circuit with a schematic diagram alone and also by writing HDL codes. This was an extra-ordinary experience. Since the circuit is developed by schematics and HDL programming, the errors are easily identified and fixed. Students again work on the hardware platform of Nexys 2 board. This technology allows more lab materials to cover within a semester.

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Benefits of Service-Learning in Meeting Learning Objectives: Examples from Air Pollution/Environmental Engineering Courses

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Abstract

Service learning is "a teaching method which combines community service with academic instruction as it focuses on critical, reflective thinking and civic responsibility."[1] Dozens of studies have documented many benefits of service learning for students, including improved 1) ability to apply what they have learned in class to "real-world" problems (bridging the gap between theory and practice), 2) critical thinking skills and problem analysis, 3) communication skills, 4) teamwork skills, and 5) sense of civic responsibility and awareness of opportunities for community involvement. Many of these skills are important outcomes of engineering programs, and are evaluated as part of ABET. Service learning also promotes active involvement of students in their own learning, which has documented positive results.

This paper summarizes relevant research regarding the benefits of service learning in achieving the ABET outcomes mentioned above. It also describes examples of 4 service learning projects that the author's students have conducted:

- Operation SMART air quality presentations to elementary school girls for Girls, Inc.;
- Air Pollutant Sampling of Carbon Monoxide, Particulates, and Ozone for the American Lung Association;
- Analysis of Environmental and Economic Impacts of Energy and Water Efficiency Improvements for a Habitat for Humanity House;
- Analysis of Air Pollution Emissions for the Tema Oil Refinery, Ghana.

Effectiveness of the projects in improving student skills in application of knowledge, critical thinking, communication, and teamwork is evaluated, along with impact of the projects on students' sense of civic responsibility. Based on qualitative information from student project reflections, the projects were effective in helping students improve their skills in these areas.

Introduction

In an age when entire digital libraries are available to students at the click of a mouse button, the role of the college professor as transmitter of information is diminishing. With students proverbially awash in information via the Internet, the role of the faculty member in teaching students to think critically about this information becomes paramount. Faculty members also need to teach students how to apply this information effectively to real-world problems.

One pedagogy that allows faculty members to develop critical thinking skills in their students, including application skills, is service learning. Service learning is "a teaching method which combines community service with academic instruction as it focuses on critical, reflective thinking and civic responsibility."[1] Another well-known definition of service learning states:

> Service learning is a credit-bearing educational experience in which students participate in an organized service activity that meets community needs and reflect on the service activity in such a way as to gain further understanding of course content, a broader appreciation of the discipline, and an enhanced sense of civic responsibility.[2]

Unlike volunteer projects, which focus primarily on service, or internships, which focus primarily on learning, service learning project balance the goals of both service and learning. The relationship between service and learning becomes synergistic: "Service, combined with learning, adds value to each and transforms both. Those who serve and those who are served are thus able to develop the informed judgment, imagination, and skills that lead to a greater capacity to contribute to the greater good."[3]

This paper will first summarize relevant research regarding the benefits of service learning related to selected Accreditation Board for Engineering and Technology (ABET) outcomes. It will next describe examples of 4 service learning projects that the author's students have conducted in her own classes. Effectiveness of the projects in improving student skills in application of knowledge, critical thinking, communication, and teamwork will be evaluated, along with impact of the projects on students' sense of civic responsibility. The evaluation will be based on qualitative information from student reflections.

Research Regarding Service Learning Benefits

Dozens of studies have documented many benefits of service learning for students. Many of these skills are important outcomes of engineering programs, and are evaluated as part of the Accreditation Board for Engineering and Technology (ABET) reviews of undergraduate programs. Selected service learning benefits, their related ABET outcomes, and research studies documenting these benefits for engineering students are listed in Table 1. The studies listed used various methods of determining the effectiveness of service learning projects in meeting ABET learning objectives. Some studies relied on faculty observations/judgment [4-6]; other studies relied on student perception of effectiveness as reported in reflections [7,8] or surveys [9-13]. Only one study [14] employed a direct rather than indirect method of measuring gains in skills for service-learning vs. non-service learning students.

Table 1. Studies documenting service learning benefits for engineering students, and related ABET outcomes

Service Learning Benefit	**Studies Documenting Service Learning Benefit for Engineering Students**	**Related ABET Outcome**
1) Improved ability to apply classroom knowledge to "real-world" problems	Borg and Zitomer, 2008 [9]; Budny and Gradoville, 2011 [10]; Goggins, 2012 [5]; Ropers-Huilman et al., 2005 [11]; Sevier et al., 2012 [13]	**(a)** An ability to apply knowledge of mathematics, science, and engineering Also likely, depending on the project: **(c)** An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability **(h)** The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context **(j)** A knowledge of contemporary issues **(k)** An ability to use the techniques, skills and modern engineering tools necessary for engineering practice
2) Improved critical thinking skills	Borg and Zitomer, 2008 [9]; Chang et al., 2011 [4]; Lemons et al., 2011 [14]; Ropers-Huilman et al., 2005 [11]; Sevier et al., 2012 [13]; Talbert et al., 2003 [6]	**(e)** An ability to identify, formulate, and solve engineering problems
3) Improved communication skills	Borg and Zitomer, 2008 [9]; Chang et al., 2011 [4]; Goggins, 2012 [5]; Ropers-Huilman et al., 2005 [11]	**(g)** An ability to communicate effectively
4) Improved teamwork skills	Borg and Zitomer, 2008 [9]; Goggins, 2012 [5]; Ropers-Huilman et al., 2005 [11]; Schaffer et al., 2012 [12]	**(d)** An ability to function on multi-disciplinary teams
5) Increased sense of civic responsibility	Borg and Zitomer, 2008 [9]; Chang et al., 2011 [4]; Dukhan et al., 2008 [7]; Goggins, 2012 [5]; Ropers-Huilman et al., 2005 [11]; Wallen and Pandit, 2009 [8]	**(f)** An understanding of professional and ethical responsibility

Each of the service learning benefits is discussed in more detail below.

1) Improved ability to apply classroom knowledge to "real-world" problems

Since students apply knowledge learned in the classroom to a real-world situation, service learning projects obviously facilitate ABET Outcome (a), An ability to apply knowledge of mathematics, science, and engineering. Because the students address the real-world problems *in context*, they must address realistic constraints in their designs or analyses (Outcome (c)), and understand the impact of their solutions in societal context (Outcome (h)). The real-world projects expand student knowledge of contemporary issues (Outcome (j)), and in many cases will give students practice using the techniques, skills and modern engineering tools necessary for engineering practice (Outcome (k)).

2) Improved critical thinking skills

Service learning projects give students an opportunity to use higher order thinking skills, including application (discussed above), analysis, synthesis, and evaluation. The projects frequently require students to synthesize information learned in various sections of one course, or in multiple courses, in conducting an analysis or designing a solution. In choosing among multiple potential solutions, students may use an alternatives analysis to evaluate the potential solutions. These skills are necessary in solving engineering problems (Outcome (e)).

3) Improved communication skills

Students typically must communicate the results of their analysis or design to the client both orally and in writing, which provides an opportunity to improve communication skills (Outcome (g)). They often communicate with the client during the analysis/design process as well. The reflective component of service learning, which may be oral and/or written, also provides an opportunity to practice communication skills.

4) Improved teamwork skills

Service learning projects are often designed so that students work in teams; this at least partially facilitates Outcome (d), an ability to function on multi-disciplinary teams, although the teams may or may not be multi-disciplinary.

5) Increased sense of civic responsibility

Since students perform a service for a community client, they naturally learn about opportunities for community involvement as part of service learning; reflecting on their experience can lead to an increased sense of civic responsibility. These outcomes fall under ABET Outcome (f), understanding of professional and ethical responsibility.

Other Benefits

Many other benefits of service learning, such as improvement of student satisfaction with college, while worthy, do not relate directly to ABET outcomes and thus are not discussed at length here. A couple of benefits that merit a brief mention are the fact that service learning is a form of active learning pedagogy; it thus promotes active involvement of students in their own learning, which has documented positive results [15-18]. In addition using service learning projects (as opposed to "made-up" case studies, for example) can increase student motivation: the project has a community partner "client" interested in the result [4,5].

Service Learning Project Examples Related to Air Pollution and Environmental Impact Assessment

During the past 3 years, I have used service learning projects to help students learn how to apply the course content to solve real-world problems, as well as build critical thinking skills, communication skills, teamwork skills, and a willingness to contribute to the profession and community. So far, my students have conducted 4 service learning projects in 4 different environmental engineering courses, as summarized in Table 2.

Table 2. Service Learning Project Examples - Air Pollution and Environmental Engineering

Semester	Course	Project Title	Community Partner	Learning Objectives	Classroom Knowledge Applied
Fall 2010	CE 5324 Transportation & Air Quality	Operation SMART (presentations to elementary school girls)	Girls Inc. (Arlington)	1, 2, 3, 4, 5 (defined below table)	Various information about transportation & air quality
Spring 2011	CE 5322 Air Pollution Chemistry & Meteorology	Air Pollutant Sampling	American Lung Association (Ft. Worth)	1, 2, 3, 4, 5	Sampling of ozone, carbon monoxide, and particulates
Spring 2012	CE 5316 Current Topics in Environmental Engineering	Analysis of Environmental and Economic Impacts of Energy and Water Efficiency Improvements	Habitat for Humanity (Ft. Worth)	1, 2, 3, 5	Life cycle analysis software and methods
Fall 2012	CE 4350/5328	Analysis of Air Pollution Emissions	Tema Oil Refinery (Ghana)	1, 2, 3, 4, 5	Air pollutant emissions estimation, dispersion modeling, & control technology selection

1. Apply classroom knowledge to a real-world situation.
2. Apply critical thinking skills (application, synthesis, evaluation).
3. Improve oral and/or written communication skills.
4. Practice teamwork skills.
5. Increase sense of civic responsibility and awareness of opportunities for community involvement.

Students in the courses are primarily environmental engineering students, although a significant number are environmental science students. In the Transportation and Air Quality, typically about half of the students are specializing in Transportation Engineering. Although 3 of the courses were exclusively graduate courses, the service learning objectives and ABET-related outcomes are still relevant; just like undergraduates, graduate students need to be able to apply classroom knowledge to real-world problems, think critically, communicate effectively, and work well in teams. Each of the projects is discussed in more detail below.

1. Operation SMART Air Quality Presentations to Elementary School Girls for Girls, Inc.

In this project, teams consisting of 5 UTA students in my “Transportation and Air Quality” graduate course were responsible for developing and presenting 45-minute workshops to 20 girls grades 1-6 (ages 6-12) as part of Girls Inc. Operation SMART. The 3 teams each presented one workshop for Arlington, Texas, Girls Inc., for a total of 3 workshops on 3 successive weeks.

The workshops were supposed raise the girls’ curiosity about careers in science, math, and engineering, as well as teach the girls about transportation and/or air quality, primarily through hands-on activities. I provided a selection of hands-on activities, obtained primarily from government and non-profit organization web sites, from which the teams could choose. Students started the workshops with a brief overview of what transportation and/or environmental engineers do. Next, the UTA students facilitated the following hands-on activities (one activity per week):

- Air quality activity: “’Hole’-y Ozone! It’s the CFCs!”
- Transportation activity: “Balloon-Powered Car”
- Transportation and air quality activity: “When a Car Coughs: Taking a Close Look at Vehicle Exhaust”

Girls Incorporated of Tarrant County (www.girlsinctarrant.org/) is a nonprofit youth service organization dedicated to inspiring all girls to be “strong, smart, and bold” and increase the social competence of boys & girls. Girls Inc. sponsors Operation SMART (Science, Math, and Relevant Technology) to change girls' attitudes about science, math and relevant technology. The girls attend weekly Operation SMART meetings and participate in hands-on activities that are geared toward increasing their knowledge and confidence in each area.

2. Air Pollutant Sampling of Carbon Monoxide, Particulates, and Ozone for the American Lung Association (ALA)

Working together, the American Lung Association (ALA) and graduate students enrolled in my Air Pollution Chemistry and Meteorology course conducted a study of the air quality at four local area elementary schools during Spring 2011. The schools, identified by the ALA Dallas/Fort Worth office, fell in zip codes in the Dallas/Fort Worth area that had some of the most frequent pediatric emergency room visits for respiratory diseases.

4 teams of 3 graduate students each sampled ambient air at each designated elementary school in the morning when school began and afternoon when school ended on 3 different days. Concentrations of ozone, particulate matter, and carbon monoxide were measured using hand-held samplers, as well as wind speed, measured using a hand-held anemometer. Students were given instructions in class concerning proper use of the samplers and anemometer.

To help students improve their communication skills, they were given handouts with tips for effective presentations and writing. At the conclusion of the project, students gave oral presentations to the ALA representative summarizing their results. They also summarized their results in written reports, which were provided to the ALA. The ALA was interested in making the information available to appropriate representatives and senators in the state legislature, to underscore the importance of achieving good air quality for children in their district. The ALA also wanted to determine whether the sampling would support ordinances restricting school bus idling.

3. Analysis of Environmental and Economic Impacts of Energy and Water Efficiency Improvements for a Habitat for Humanity House

Graduate students in "Current Topics in Environmental Engineering" conducted a life cycle analysis of the environmental and economic impacts of efficiency improvements for a family home in the U.S., built by Habitat for Humanity. Habitat for Humanity is a non-profit that builds affordable houses with people in need.

The students first estimated environmental impacts for a typical Habitat home as a baseline, using EIO-LCA life cycle analysis software developed by Carnegie Mellon, and available free of charge via the Internet. We had discussed general principles of life cycle analysis in class, along with specifics of the EIO-LCA software, so students were able to apply this knowledge. Next, the students conducted a web search to find technologies for saving energy and water in houses. They chose $4000 of these improvements for the Habitat house, and used the software to estimate environmental impacts for the improved house. Finally, students conducted a cost analysis to determine the payback period for the efficiency improvements, and the cost savings over the lifetime of the home. We had discussed life cycle cost analysis in class, so students were able to apply this knowledge.

The results of the analyses were compiled and given to the local Habitat for Humanity chapter, Fort Worth's Trinity Habitat for Humanity. This provided Habitat information about the environmental and economic impact of installing efficiency improvements in their houses.

4. Analysis of Air Pollution Emissions for the Tema Oil Refinery, Ghana

Given the global nature of much engineering work now, I wanted to give my students experience working with an international project. I contacted one of my former Ph.D. students, Dr. Benjamin Afotey of Kwame University, Ghana, about potential projects in his country. He suggested Ghana's government-owned Tema Oil Refinery (TOR) as an interesting air pollution source.

Undergraduate and graduate students in "Fundamentals of Air Pollution" were thus charged with determining whether the Tema Oil Refinery in Ghana poses a threat to human health. In conducting the project, students applied information covered in various course units concerning emissions estimation, dispersion modeling, and particulate and gas control technology design. Students were first to estimate air pollutant emissions from various refinery processes using emission factors. Next, students were to estimate ambient concentrations of pollutants downwind from the plant under various meteorological conditions using dispersion modeling. Students then compared estimated ambient concentrations with health effect standards, to determine whether emission control technologies were needed. Finally, students were taught how to use a decision-making matrix, and told to construct a matrix to choose among pollution control alternatives. Students then estimated sizes of pollution control technologies. The results of the analyses were presented to Dr. Afotey to provide to oil refinery personnel.

Student Reflections on Project Effectiveness in Meeting Selected ABET-Related Objectives

As mentioned above, 3 methods are most often used for assessing the effectiveness of service learning projects in achieving student learning objectives: faculty observations/judgment, student perception of effectiveness as reported in reflections, and student perception of effectiveness as reported in surveys. This paper uses information from student reflections.

For all 4 projects, students answered written reflection questions about what they learned from the project. Reflection questions used for each project are listed in Table 3. Each project is identified by its client, as the most succinct way of identifying the project.

The Girls, Inc. project was the first one I conducted. In subsequent semesters, I shortened the list of reflection questions. The earlier question lists asked students to comment specifically on the project's impact on certain skills, such as communication and teamwork. The later question lists simply asked more generally what students learned from the assignment.

Table 3. Project Reflection Questions

Project Client	**Reflection Questions**
Girls, Inc.	1) WHAT? **Describe**: In 2-3 sentences, briefly, the service performed. 2) SO WHAT? **Examine** some of the following questions: • What was the significance of the service? • What did it mean to you personally? • What did you learn that could enhance your professional career? • Did the project help you develop communication skills? Why or why not? • Did the project enhance your understanding of course content? Why or why not? • What skills and knowledge learned in the classroom did you use/apply? • What skills or knowledge did you lack? 3) NOW WHAT? **Contemplate** some of the following questions: a. What insights did you gain that might assist you in your career? b. What is the connection of this experience to your future? c. What did this experience teach you about community involvement and professional responsibility? d. What is the relationship of your service experience to the big picture (societal changes)? e. How can you best use what you've learned?
American Lung Association	• How did this project enhance the course content? • What did you learn about oral and written communication skills? Teamwork? Professional development? Yourself? How will you use this knowledge in the future? • What will the project mean for the ALA? For the community? • What were the most difficult and satisfying parts of the project? • What changes should be made in the project to improve it for students in future semesters?
Habitat for Humanity and Government of Ghana	1. How will this assignment help address community needs? 2. What did you learn from this assignment? 3. How can you use what you learned in this assignment in the future (in your career or in community service)?

Tables 4-8 highlights student responses to the reflection questions that relate to the 5 service learning benefits/objectives discussed earlier. Student responses that the author judged to be representative are included in the tables, as well as those that the author found to be particularly meaningful/insightful or interesting. In Table 5, the thinking skill to which the comment relates has been added in parentheses.

The comments in Tables 4-8 are all positive, because in no cases did students state that the project negatively or neutrally impacted their skills. Students' failure to mention an impact, however, probably implicitly indicated that it was not significant. For example, in responding to the question "What did you learn from this assignment?", if a student did not mention "how to function in a team setting", then improved teamwork skills were likely not a significant project outcome for that student. In fact, the only project for which student reflections mentioned teamwork was the ALA project. The ALA project was the one that involved the most teamwork, and the only project in which the reflection questions specifically asked about teamwork.

No attempt was made to quantify how many students mentioned various benefits, given the different formats of the reflection questions for different projects. Tables 4-8 thus provide qualitative information only. Student surveys can provide quantitative data concerning perceived project impacts; although surveys were not used in the classes discussed in this paper, they will be used in future courses.

For some of the projects, students were provided information in class to help them develop oral and written communication skills (tips on effective public speaking and writing) and evaluation skills (construction of a decision-making matrix). Student comments in Tables 4-8 indicated that this information was helpful. Providing students guidance to facilitate their skill development likely does make service learning projects more successful. In the future, I hope to provide students with information about working effectively in teams as well.

The comments demonstrate that a portion, at least, of students in the courses believed that they learned skills from the service learning projects that would be valuable in their professional careers. In the area of critical thinking skills, student comments described development of analysis, synthesis, and evaluation skills that would be useful to them professionally. One student commented that the communication skills learned in the service learning project would help him/her in the public meetings aspect of his/her current job. The comments concerning civic responsibility were particularly encouraging. Although engineers (civil engineers in particular) deal with a variety of topics that impact the public, engineers often shy away from civic involvement, believing that they should focus their attention only on technical concerns. One student commented that he/she had learned that engineers <u>should</u> be engaged in the community, in this particularly articulate comment that bears repeating:

> This project taught me that our community is open to learning and that we as engineers have a duty to educate the general public about the adverse affects that their daily actions/choices can have on our current and future society. Often civil engineering projects/endeavors impact a vast portion of our society yet the many that we affect do not understand or know

> what or why we do what we do. It is up to us engineers to educate the public about our careers and related topics so that they, along with decision makers, can make educated decisions.

Along similar lines, another student wrote that he/she would now have the knowledge to intelligently contribute to city/town meetings. Another student even commented that the project led him/her to think more seriously about a job that would involve community service, such as a position with a non-profit. Finally, and likely most importantly, the comments concerning civic involvement indicate that the students learned personal efficacy - that their contributions can make a difference. As one student wrote: “I have contemplated joining Child Rights and You for long but I have not made the step till now. I was feeling too young to work in these programs but now I found out any contribution will help.”

Table 4. Student Reflections on Project Benefits Concerning ***Application of Knowledge to Real-World Problems***

Project Client	Student Comments
Girls, Inc.	This experience also made me to realize a better picture of the course because to simplify the concept of ozone I needed to summarize what I learned in the class in a way that delivers the concept without sounding complicated.
American Lung Association	The Service Learning Project provided an opportunity to apply classroom knowledge to a real world situation…. The project also gave me an understanding of how difficult it is to assess pollutant levels in ambient air, and revealed first hand the significant amount of variability in meteorological conditions and how they can affect pollutant transport. The project gave us the opportunity to apply the knowledge that we have learned in the class. Using the devices to measure the meteorological parameters in the field was very helpful to understand the material practically. Considering the meteorological parameters in the study also helps to understand the relationship between the pollutants' concentration and the parameters. Service learning is particularly important for engineering students because often fresh graduates are blamed that they do not have enough practical knowledge. Service learning could decrease the gap between the academic and practical knowledge. This is a new experience that I might work on when I go back to my country (Kuwait) and I will apply what I learned to evaluate air quality especially with oil sector around exploration and production areas.
Habitat for Humanity	I learned how to apply previously obtained knowledge (from economics to engineering classes) to real-world projects, especially with regard to applying that knowledge to the long-term environmental impacts of efficiency improvements made to systems.
Government of Ghana	This assignment was very helpful in fully understanding all of the concepts learned in the classroom and a good learning experience in the application of these concepts. One of the major things I learned was how to utilize the dispersion modeling calculations and apply it to a project. In this assignment I learned how to analyze a "real-world" case of air pollution emissions and suggest controls to reduce emissions to an acceptable level… Overall, the assignment helped me to understand how the various topics that we have studied this semester come together and can be used to solve a real-world problem.

Table 5. Student Reflections on Project Benefits Concerning ***Critical Thinking Skills***

Project Client	**Student Comments**
American Lung Association	The project required me to pull together a variety of concepts presented throughout the course, and to synthesize the information in order to analyze our data. (synthesis, analysis) Many factors effect air pollution such as wind speed, wind direction, atmospheric stability, and other local air factors like urban heat island. With this project, we were able to consider all of those factors while studying the air quality at our assigned schools. (synthesis)
Habitat for Humanity	This study helped us to figure out how to consider different parameters in making a decision through facing different options and evaluating their advantages and disadvantages. (evaluation) It will also aid in my decision making process as a professional.
Government of Ghana	…it was an excellent exercise in producing solutions to a problem that could very well be solved through various methods…. In order to … come up with a solution, a decision-making matrix had to be created to adequately explain why we chose the option that we did. (evaluation) I also learned how to use engineering judgment to create a decision-making matrix to compare different solutions, or in this case pollution control devices, in order to choose the best solution/design for a project. (evaluation) This case study was a practical application of what was learned in this course and it further familiarized the process of determining the needed air pollution control technologies. This process can also be implemented in all aspects of civil engineering: alternatives will always need to be analyzed and critical thinking used. (analysis, evaluation) …the detailed analysis and problem solving skills are and will continue to be used on a daily basis. (analysis)

Table 6. Student Reflections on Project Benefits Concerning ***Communication Skills***

Project Client	Student Comments
Girls, Inc.	I think that this experience helped develop my communication skills in new ways … having the ability to convert technical, scientific information into something that your audience can relate to and understand will be very helpful in the future. I think professionally it reminded me of the importance of connecting to audiences…. Being a professional engineer requires a lot of presentation skills, in company or out and having done this presentation was a great practice in my point of view. Most of my work consists of designing new roadways. These types of projects always involve the public which means lots of public meetings. Many of the issues that arise throughout the design process for roadways are technical in nature but the public often does not have the back ground education to fully understand the details of the problem/solution. This project has forced me to pay particular attention to my audience and their ability to understand the information I am presenting. This experience has helped me to be able to consider my audience's level of education and find effective ways to convey information that is technical in nature but yet interesting and understandable by someone without the background knowledge.
American Lung Association	…the writing assignments and writing tips helped me to evaluate my current skills and point to areas that need improvement…. The public speaking tips on how to clearly and effectively present information were also helpful and are something I can use to prepare for future presentations and meetings. By working with peers, professionals, and the community, this was an opportunity to improve my public speaking skills, management and organization, and writing techniques. Oral and written skills can be improved by practicing; it was a great chance to focus on these skills through our project and practice regularly…. For oral and written communication skills, I learned from my writing to be simple and clear in my ideas, know my audience and write on basis of how much they know, and write sentences that are related to the main point that I want to present. I learned about the importance of rehearsing before the actual presentation…. I learned that the audience wants me to succeed as much as I do. Thinking about this while preparing for the presentation will help me overcome the nervousness associated with it. As for report writing, I realized that figures and tables play an important part in preparing a good report. Having them in the report makes it easy to understand.
Habitat for Humanity	This assignment enabled me "to communicate effectively with clients, investors, and others within the construction industry, and be capable of articulating how decisions made from design conception through construction and occupation to building renovation and demolition affect the energy consumption and carbon footprint of the built environment."
Government of Ghana	If I go to work at a consulting firm, … I will have the experience of writing up a multi-page report describing results of a case study.

Table 7. Student Reflections on Project Benefits Concerning ***Teamwork Skills***

Project Client	Student Comments
American Lung Association	I mentioned before that I have the tendency to take over projects. It was always the thought that "if you want it done right, do it yourself." With my group, I knew I could rely on them and trust their decisions. We worked great as a team and used each other's knowledge and experience…. I think that this project has set me up to be better prepared for a career in my field. For teamwork, … I learned to respect my friends' opinions…. In the future … when I work with different people, I will follow the same procedures that we did such as working plan, sharing data, respect each other …. …it helped me to know the importance of communication among the team members for better performance…. I learned that my greatest strength was to work in a team. While this was not the first team project I've worked on, it was the first team project I've been involved with that occurred outside of school. In this case, effective teamwork was more important because we had to coordinate our schedules with the sampling and decide how the written portions would be divided, often all through e-mail. I think this will benefit me professionally because projects that occur in the workplace will be in this manner. There will be no teacher to coordinate for us….; we'll have to arrange everything ourselves and work together to get it all done.

Table 8. Student Reflections on Project Benefits Concerning ***Civic Responsibility***

Project Client	Student Comments
Girls, Inc.	I have contemplated joining Child Rights and You for long but I have not made the step till now. I was feeling too young to work in these programs but now I found out any contribution will help. I think that it is important to "step out of the comfort zone" and become involved in community service projects such as this. This workshop taught me that internal satisfaction lies when you actually work for the betterment of others…. Donating one's time to … community service (learning) projects is a win-win situation for all participants. This project taught me that our community is open to learning and that we as engineers have a duty to educate the general public about the adverse affects that their daily actions/choices can have on our current and future society. Often civil engineering projects/endeavors impact a vast portion of our society yet the many that we affect do not understand or know what or why we do what we do. It is up to us engineers to educate the public about our careers and related topics so that they, along with decision makers can make educated decision.

American Lung Association	As I continue to pursue my professional career goals, this project has given me new perspective on careers that could assist the community and the environment. In the past I have considered pursuing a job with more of a service component. Working on this project has re-enforced the idea of working for a non-governmental organization or in a governmental position. I believe the skills and knowledge that I have developed would be put to good use in a service-oriented job that would give me a greater sense of job satisfaction. As I am planning to be a professor in one of the universities in the future, I will make the service learning technique the main part of the curriculum that I will teach, so many services can be done for the communities from the students and it will be beneficial for both sides. The satisfying part about the project is the knowledge that the information collected by us is going to be used for the benefit of the community. Also the fact that we got the opportunity to take part and make a difference is very gratifying.
Habitat for Humanity	It is the duty of engineers to the customers to utilize energy efficiency scenarios in construction by choosing appropriate building materials…. Doing this assignment provided an opportunity to demonstrate different ways of reducing community needs such as energy and water and designing houses more sustainable….
Government of Ghana	I learned that no matter what place or country you live in the world, an environmental engineer will use the same processes or general methods to design pollution control devices with the health and safety of the human population at the top of their concerns. I would also have the knowledge to intelligently contribute to city/town meetings discussing ideas such as construction of new facilities that would serve as a point source for pollutant emissions and air quality in general. In the future I will be able to inform others on the harmful effects of air pollution, and strive to do my part in helping to reduce the emissions. This newfound knowledge of air pollution will improve my awareness of the problem in my daily life, and give me the opportunity to inform my colleagues about the issue. ….I will be more conscious about the global impact of some of my design work. By learning the basis of how some pollutants affect the atmosphere and the health of others, I will try to design ways to provide the necessary transportation while reducing emissions. This will be done by looking at intelligent transportation systems and cleaner transportation systems. Bangladesh is a developing country and it is clear that we have not only natural gas but also oil reserves and the population of the country suffers most from asthma, heart diseases, and cancers and so on. In future I can help my country to reduce these types of problems.

Conclusions and Recommendations

Based on qualitative information from student project reflections, service learning projects in air quality and environmental engineering at UT Arlington were effective in helping students improve their skills in application of knowledge, critical thinking, communication, and teamwork, as well as increase their sense of civic responsibility. In future courses, student surveys will be used, along with reflections, to provide a more quantitative assessment of the impact of service learning projects on student skills.

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GENERIC SPECIFICATION OF A WEIGHT ESTIMATION METHOD LIBRARY

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Abstract

The state of the art in estimating the volumetric size and mass of flight vehicles is held today by an elite group of engineers in the Aerospace Conceptual Design Industry. This is not a skill readily accessible or taught in academia. When faced with the challenge of estimating flight vehicle mass properties, many aerospace engineering students are encouraged to read the latest design textbooks, learn how to use a few basic statistical equations, plunge into the details of parametric mass properties analysis. To manage the growing and ever-changing body of weight estimation knowledge, and bridge the gap in Mass Properties education, a standardized engineering "tool-box" of conceptual & preliminary design weight estimation methods was developed for future projects in the UTA AVD Lab. It will also be used as a living body of work for use by future students in the AVD Lab. This "tool-box" consists of a weight estimation method bibliography containing unclassified, open-source literature for conceptual and preliminary flight vehicle design phases. To provide structure, a logic scheme based upon SAWE Recommend Practice 8 (RP8) is in place to direct users to the appropriate weight estimation methods for flight vehicle design problems. For each method library entry, specific data have been aggregated for organizational purposes such as applicable engineering design phase (conceptual, preliminary, and detail), mathematical techniques in use (empirical, semi-empirical, numerical, and analytical), applicable flight regimes (subsonic, transonic, supersonic, hypersonic), vehicle missions (altitude, speed, range, payload), customer (military, commercial, executive, etc), and flight vehicle configuration (Tail-Aft, Tail Forward, Fying Wing, Blended Wing-Body, Oblique Wing, etc). The weight method library's organization and functionality has been vetted by a survey of industrial professionals well-practiced in flight vehicle weight estimation – the results of which indicate the needs of a weight engineer revolve around thorough documentation of flight vehicle applicability, weight method processes and equations, and uncertainty. Transport aircraft validation cases have been applied to each entry in the AVD Weight Method Library in order to provide a sense of context and applicability to each method. This generic specification of a method library will be applicable for use by other disciplines within the AVD Lab, Post-Graduate design labs, or engineering design professionals.

Introduction

My job is to estimate how big flight vehicles are. That is to say formally that I am a Mass Properties engineer working in the conceptual design of aircraft. My work revolves around quick turn-around weight & balance estimation methods, usually of lower fidelity or granularity than is available in later design phases where more people and computational power is available, and airplanes are actually being built in factories. The UTA AVD Lab, through which I've learned much of what I know about conceptual design, is directly involved in Competitive Analysis, Conceptual Flight Vehicle Design & Development, Flight Test Simulation, Certification, System Risk Management, and Project Engineer Education. In supporting activities for each of these endeavors, knowledge is passed down through collaborative activity & "living documentation." In this way, knowledge & lessons-learned are preserved, all in the interest of invigorating the past of flight vehicle design such that we influence future generations of design.

One of the major problems I've experienced, along with other Mass Properties professionals, is a high turn-over rate of new hires to our engineering discipline stemming from:

1. a lack of understanding of the actual process of generation & usage of Mass Properties data,
2. a lack of stimulation in their analytical work, and
3. a lack of exposure to all Mass Properties tasks in ALL design phases.

So the aversion of engineering new hires to stay in the Mass Properties is – anecdotally – due to a lack of upfront exposure, and a lack of freedom to innovate their way into the field. Many of the new hires I've known in Mass Properties leave because they feel "stuck" in their work, feeling that they will be doing the same kind analysis with the same kind of tools for the rest of their careers. This is daunting when they've just left college with a highly under-utilized analytical skillset.

As my experience lies in weight engineering, I will focus my disciplinary knowledge on how the "weights group" of an engineering organization fits into the life cycle. The weights group takes up a portion of the design effort throughout the vehicle design life cycle. In certain phases, the weights group may boil down to the sole responsibility of one person, or may become one of a few responsibilities of an engineer. This applies to all parts of the "cradle to grave" flight vehicle life cycle, with varying levels of effort therein.

Disciplines currently covered in AVD lab:

- Design Synthesis
- Aerodynamics
- Flight Safety & Simulation
- Flight Controls
- Propulsion
- Structures
- Weight Estimation
- Certification

Just to give a brief overview of the weight engineering discipline, Figure 1 shows an outline of the flight vehicle weight estimation process within the each design phase [Note that "Class 2 aircraft" in commercial flight vehicle design refers to large transports, >20 passengers or equivalent payload].

Figure 1: A Process for Aircraft Weight Estimation in the Conceptual Design Phase

Market Analysis, Corporate/Competitive Intelligence

Mission Analysis, Commercial or Military?

Technology Matrix Evaluation, Unclassified or Classified

Configuration Trade Studies

Establish Vehicle Size Requirements

Structural Design Criteria Derivation, Weight Requirements Review

- Max Taxi Wt
- Take-off Gross Wt
- Payload Wt
- Wt Empty
- Max Landing Wt
- Fuel Wt
- Useful Load

Design Risk Evaluation

Y — Company has experience with design requirements — N

Y	N
Establish baseline Weight Empty	Find or Develop weight methods directly addressing high risk design attributes
Calculate weight empty growth factor for duration of program	Determine technical factors according to design assumptions and risk assessments

Refine initial Weight/ Balance Calculations

- Weight Empty
- Useful Load
- Mission Fuel
- CG per Wt State

Gross Weight Limit Exceeded

- Correct wing loading, lifting surface geometry
- Correct thrust/weight ratio, propulsion model
- Refine Requirements: Landing/T.O./Ground Handling
- Refine Requirements: Mission Profile/Flight Performance
- RESCHEDULE/ DELAY PROGRAM

Fuel Weight Performance Study

Take-Off	Accel/Climb	Cruise	Maneuver	Landing
• Distance	• AOA	• Cruise Time	• Loiter Time	• Glide Path
• MTOGW	• Climb Rate	• Cruise Alt	• # Turns	• Distance
	• Climb Time		• Load Factor	• Abrt'd Ldg
			• Altitude	• Fuel Margin
			• PL Jettison	• 3-σ

Method Reasonability Check

Empirical method	Semi-Empirical method	Numerical method
Statistical error, standard deviation	Weight reports, group weight checks	Method documentation

Minimize weight & balance calculation risk

Configuration Optimization Synthesis

Weight-Cost Analysis, Trade Studies

RFP Response: Design Configuration [Geometry, Dimensions, Layout]

RFP Response: Full Mass Properties Report [Weight, Balance, Inertia]

RFP Response: Mass Properties Estimation Method Documentation

RFP Response: Weight Control Plan, Value of a Pound

Flight vehicle weight estimation is physically critical as the lift of the wing or lifting surfaces must overcome the gross weight of the aircraft; the same goes for the balance and inertial properties. There is a high risk of control loss if the control surfaces are unable to maneuver the vehicle in flight due to high moments of inertia or an extremely forward or aft center of gravity. Aircraft weight estimations in the conceptual & preliminary design phases are essential in estimating both the parametric cost and performance of an aircraft.

Poor weight estimation results can also have programmatic impacts: the loss of a program contract as evidenced by circumstances surrounding the U.S. Navy A-12 Fighter, late deliveries and production delays as seen on the Airbus A400, and configurations that lead to severe performance risks or limitations like those seen in the F-104 Starfighter.

Introduction to engineering method libraries

For the purposes of this report, we shall define a method library as a grouping of source documentation pertaining to a set of methods that enable an engineer to calculate or obtain parameters relevant to an engineering design discipline. This includes but is not limited to the engineering fields of flight vehicle mass properties, stability & control, aerodynamics, propulsion, structures, and cost. Method libraries also take the form of design guides, handbooks, etc. These documents disseminate analysis methods from subject matter experts to engineers involved in the synthesis of design.

Practicing the State of the Art in Weight Engineering

Armed with flight vehicle design and analysis methods developed on their own, or handed-down by subject matter experts, conceptual designers are able to incorporate the most applicable equations and algorithms into a design synthesis code. The executed synthesis code generates design data that enables the conceptual designer to run trade-studies, explore the design space, or quickly screen the feasibility of new technologies or configurations.

Currently, a selective set of mass properties experts guard some of the best weight estimation methods for use in the conceptual and preliminary aircraft design industry. The design regime limitations are not usually well developed or documented for these methods. Typically, the reason why the designer or engineer is unable or unwilling to divulge or explore the limitations of these methods, or the logic he used in their development them, can stem from proprietary limitations, personal pride, lack of understanding, and short supplies of time and budget to produce adequate documentation. In cases where an engineer has applied a weight estimation method that has yielded satisfactory results, it is tempting not to challenge the method unless it fails to yield the desired results. This mindset may lend itself to the use of irrelevant methods.

Figure 2: Recommended deliverables of Aerospace Weight Engineering of the flight vehicle Life cycle, per SAWE-RP7

	Pre-concept	Concept Exploration	Dem/Val	E&MD	Production & Deployment	Operation & Support	Major Modification
Weight & Balance Substantiation Report	X	X					
Estimated Weight Report			X[1]	X[1]			X
Estimated Inertia Report			X[1]	X[1]			
Weight and Balance Status Report			X[1]	X[1]	X[1]		X
Calculated Weight Report			X[1]	X[1]			X
Sample Charts A & E			X	X	X[1]		X
Calculated Inertia Report			X[1]	X[1]			
Actual Weight Report			X[4]	X[5]	X[5]		X
Weight & Balance Handbook			X[4]	X[4]	X[4]		X
Balance Computer					X[6]		
Appendices to Actual Weight Reports			X	X	X		
Final Appendices to Actual Weight Report			X	X	X		
Post Design Weight Analysis Report					X[1]		
ECP Exhibit			X	X	X		X
Chart A / Form B / Chart C					X	X	X
Mass Properties Control & Mangement Plan			X	X	X[7]		X

[1] Based on audit aircraft

[2] Based on last aircraft

[3] For 1st aircraft

[4] For 1st, 2nd, 3rd, . . ., n th aircraft

[5] For 1st, 5th, 10th, 20th, 40th, 60th, . . ., nth aircraft

[6] If Class 2 aircraft

[7] Updated from E&MD

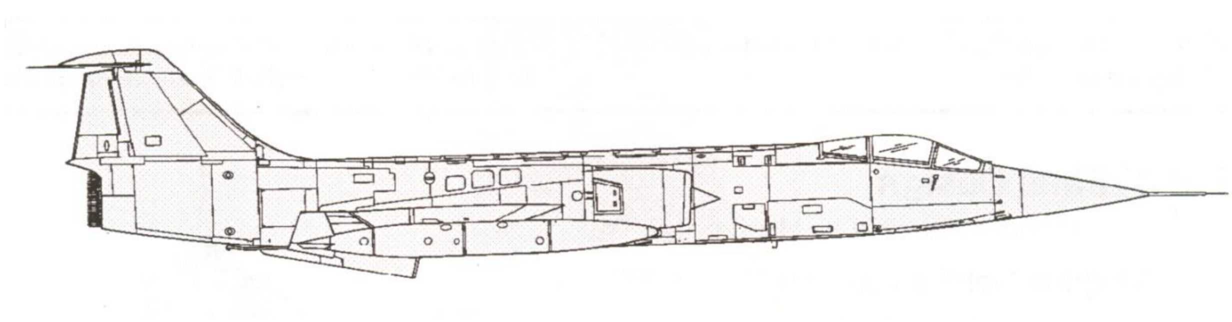


Figure 3: The pitch-up moment due to interaction of forebody and inlet wakes with the horizontal tail led to many horizontal tail design iterations on the F-104 Starfighter. Its CG was at 8% MAC. This precedes the aircraft design industry's understanding of wings with low aspect ratios, but is unprecedented in modern aircraft wing design.

Too many methods

In light of an abundance of available weight methods, the lack of an authorized or professionally endorsed baseline methods library forces the engineer to put together his or her own toolbox, thereby resulting in an unpredictable risk overhead. The commercial transport aircraft industry lacks an organized method library format, designating the aircraft design phase, design product, and the design flight regime limitations of each available method in a clear, standardized format.

Proprietary & Classification Issues

Attempts to unify the field can be accomplished by customer reviews of contractor methods, such as when the U.S. government solicits methods from their prime contractors [ref. Oole]; these usually result in "government-only" or classified content, preventing growth in the open-source world, and stifling education and potential innovations.

Design firms long flight vehicle legacies can lead to significant proprietary analysis resources. Weight engineering is also problematic because it has the capability to sell an aircraft on the grounds of meeting operational and/or cost-to-weight requirements. A program contract can be won based on whether or not a vehicle's configuration (structural & system design and operation) is affordable and meets or exceeds customer expectations.

Small Educational Investment

A third problem is a lack of educational investment in mass properties. This is often overshadowed by more exciting or fashionable technology development fields outside of mass properties analysis. Weight engineering has always been a small field of study. It now risks becoming a dying art as professional engineers struggle to overcome the above problems, per recent professional weight engineering society publications. Even members of SAWE* have requested better definition of available conceptual aircraft weight estimation methods. Industry has made a few attempts to bring open-source methods of the post-millennial era together to address method applicability and method generation. We see this in the publications of the SAWE (textbooks and papers). In the Society of Allied Weight Engineers journal Weight Engineering, Vol. 68, Spring 2009, the Hampton Roads Chapter of SAWE submitted that "…More reliable methods of predicting the mass properties need to be developed for the programs in the initial phases…[As] designs become more complex, the estimating techniques must become more sophisticated." I propose that weights engineering knowledge desperately needs to be preserved. That can happen through development & improvement of method libraries, such that method applicability is clearly known, and uncertainty & risk can be managed.

Research Objectives & Approach

The core objectives of this research involved supporting the AVD Lab in aircraft weight estimation activities, developing a standardized engineering "tool-box" for conceptual weight estimation methods, and documenting the results of my research in a master's thesis. The Combination of Industry Survey & Literature Search have lead to this specification for a Design

Weight Estimation Method Library . This specification and the incorporation of a Knowledge/Database (KB/DB) will lead to my Thesis & Final Method Library documentation. A standardized engineering “tool-box” of conceptual weight estimation methods is in development for future professional assignments; it will also be used as a legacy body of work for use by future students in the AVD Lab or elsewhere. This “tool-box” has unclassified, open-source bibliographic references for conceptual and preliminary design phases, clear designations of applicability & underlying assumptions for each weight estimation method, and the results of applicable validation case studies. The format of the method library is flexible enough to allow new methods or documentation to be added in the future as needed by future students or future AVD lab experiences. The data needed to build the weight estimation method library will require firm definitions of the aircraft design variables and parameters needed to solve each weight estimation method.

The weight method substantiation data (if it is available) will be found in engineering libraries such as the UTA AVD Lab Conceptual Design Library, the Lockheed Martin Corporate Research Library, the UTA Engineering Library, and aerospace industry research databases hosted by groups such as the Society of Allied Weight Engineers (SAWE), American Institute of Aeronautics & Astronautics (AIAA), International Society of Automotive Engineers (SAE), and the National Aeronautics and Space Administration (NASA).

For the sake of brevity and the availability of source material, the mission design regime for this study will be limited to commercial transport aircraft. Due to the closed, proprietary, and sometimes-classified nature of military aircraft methods, undisclosed military aircraft will not be validated for this body of research (e.g. military aircraft currently under production, with classified performance characteristics). However, methods that are applicable to military aircraft will simply be entered into the weights library for later study and potential future professional assignments.

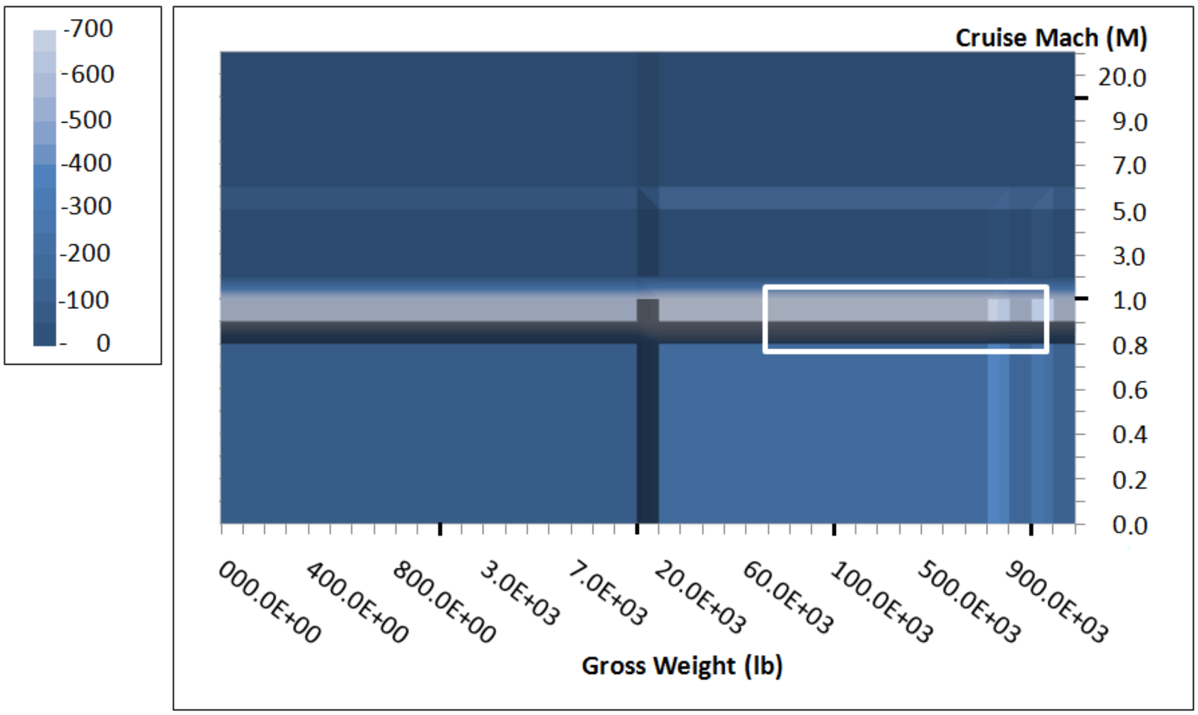
Aircraft design companies have released weight estimation methods, along with those developed by aircraft designers, through published design texts. The authors of these methods are included in the bibliography. These introductory texts and case studies will be the foundation for this body of research.

However, the purpose is to develop the logical process, as seen in the Introduction, that engineers & students can follow in order to successfully estimate the Mass Properties of an flight vehicle according to design & mission specifications. The purpose of this thesis is not to publish a new design weight-engineering textbook, nor is it to develop new weight estimation methods. Introductory weight engineering texts have been published by the Society for Allied Weight Engineers (SAWE). The decision-guides will be in place to lead the engineer toward the eventual decision to use an existing method, or create a new one.

As the weight estimation method database grows, the plan is to provide a series of “roadmaps” (preliminary figure as seen below) of the weight tools available based upon configuration & speed continuum. Each individual method will be consistently documented (derivation, constraints, limitations, applicability, etc.). This allows the engineer to visually zoom in to the desired aircraft design phase and performance characteristics (i.e. speed, wing-loading, landing

& take-off distance). By drilling down into the library, the designer can view the possible outputs (structural or systems weights, max gross take-off weight, max landing weight, and ramp weight), and required inputs & design variables used to decide upon a particular set of methods.

Figure 4: Number of Methods applicable to configurations under study, by flight-regime.



Industry professional survey

I administered a survey to a group of industry and government professionals involved in conceptual and preliminary design. The results reinforce the need for a consistent implementation of engineering method libraries. Out of 35 solicited surveys, six responses were submitted. The majority of respondents had over ten year of experience in both the Conceptual & Preliminary Design Phases. All respondents have been actively involved within the past 3 years in developing empirical regression weight estimation methods either from academic or company proprietary literature.

The preferred format for the Method Library is a paper copy or a website, mainly due to portability issues. The preferred content includes Flight Vehicle Mission, Speed, Method Equations or Algorithms, Design Area or section (wing, body, tail, subsystem, etc.), Actual data points/ substantiation, Design Phase, Previous Designer experience & sensitivities, and Technology factors. The methods should be documented by subject-matter experts and have their approval/ consent for use by designers or other weight engineers. One of the most important design decisions of putting together documentation is to make it easy to use – searchable, logical layout, and applicable data to the design process in question.

Method Library Specification

The specific data to be included in the method database will be divided into the following categories:

1) Engineering Design Phase: the literature search will cover the conceptual design (CD) and preliminary design (PD) phases while excluding the detail design phase.
2) Method Types: the weight engineering techniques available consist of the following analyses approaches: (a) empirical, (b) semi-empirical, (c) numerical, and (d) analytical. Empirical methods correlate aircraft weights (at the aircraft level and at the system or group level) with performance and configuration variables. Numerical methods combine models of an aircraft's fixed weights (e.g. weights & CG's of avionics & systems boxes) with a finite-element solver or similar technique to accomplish the structural and systems weight modeling. Semi-Empirical Methods employ a combination of the above. Analytical methods sum the detail design data of every component on an aircraft.
3) Aircraft Flight Regime: methods need to be categorized according to the design mission parameters for the type of aircraft (altitude, speed, range, payload, etc.).
4) Configuration Type: describes design features such as the blended-wing body, tail-aft, tail-first, joined-wings, high- or low-aspect ratio wings, etc.

Problem Statements

There are minimal indications of uncertainty or limitations associated with many weight methods found in open-source literature. When evaluating unmanned or novel concepts, extrapolating from existing "conventional" methods may be difficult or impossible. Development & maturation of technology, manufacturing methods, & customer requirements are NOT easily quantified within weight conventional weight methods without direct knowledge of the physical improvements themselves. There is NO authorized baseline library of weight methods. Design groups struggle to choose applicable methods because of this lack of direction. Validation & calibration practices for each method are required. Irrelevant methods get used OR time is wasted on developing new methods without the guidance of subject-matter experts. These problems consistently result in an unpredictable weight risk overhead. Here's what needs to be done in academia order to address the issues of open-source literature:

- Reduce risk for student design project by compiling clearly designated, current weight engineering methods and applicable knowledge into a usable format.
- Highlight applicability and uncertainty per each method in the library.
- Quantify how "tech-factors" for advances in technology, manufacturing, etc, will impact the weight method calculation.
- Gain industry endorsement to gain "authorization" of documentation.

Weight engineering helps flight vehicle designs meet or exceed performance and cost requirements. Professional weight estimation methods by nature are proprietary or classified. Time & budget for companies to investigate method Limits & Risk are scarce or unavailable. Method Limits & Risk and application are often left to the engineer's personal memory & experience. Design engineers are tempted to leave weight results unchallenged, unless their methods yield undesirable results. A design firm's ability to forecast risk is inhibited by a lack of substantiation. We fix these problems in industry by:

- Well-quantified risk levels (statistical bias errors, standard deviation, coefficients of correlation, validation results, etc.) for each method.
- Decreasing the time needed to decide to use existing or develop new weight methods.
- Enhancing the quality of risk-related decisions by developing understandable method substantiation and validation.
- Maintaining consistent documentation of methods in order to quicken the decision-making & documentation process.

Knowledge Discovery Techniques, and Method Data Structure

The current AVD method library format illustrates how, for any given disciplinary method library, there are similar developmental elements in design and analysis methods. Notice the mixture of quantitative and qualitative fields. All of these fields have been endorsed by a survey of industrial professionals.

- Bibliography (qualitative)
- Discipline (qualitative)
- Design Phase (qualitative)
- Title (Design section) (qualitative)
- Categorization (Method math) (qualitative*)
- Assumptions (qualitative*)
- Experience with method (qualitative*)
- Documented configuration applicability (quantitative)
- Accuracy of calculation (quantitative)
- Input Variables, Independent (quantitative)
- Equations, Algorithms (quantitative)
- Output Variables, Dependent (quantitative)
- Time to calculate (quantitative)
  * Indicates a field may be encoded as a real number.

There are, however, design elements that go undocumented in AVD method library layout. These become priorities for a few individuals; at the end of the day, it becomes a professional engineer's responsibility to know whether or not an analysis method work for them. For some of these "specialist" issues below, it would behoove the engineer to investigate these issues with the analysis method library data available.

- Robustness tests e.g. Monte Carlo and Response Surface Methods (RSM)
- Requirements specification, derivation, and verification,
- Trade study methods
- Engineering design strategy

For this Method Library Specification, the unique developmental elements in design and analysis methods for a synthesis environment shall be organized as follows:

Empirical regressions

- Built from an empirical data base of physical data from successful legacy designs and experimental prototypes.
- Documents the choice of statistical method of regression (i.e. method of least squares, polynomial regression, power-law), and regression statistics
- Generate "method" equations

Semi-Empirical methods

- Start with empirical design data (see above)
- Augment empirical data by a theoretical/numerical calculation method (i.e. structural design sizing) to improve confidence.
- Document choice of statistical method of regression (i.e. method of least squares, polynomial regression, power-law), and regression statistics
- Generate "method" equations

Numerical methods

- Use a higher-fidelity numerical configuration model to calculate an actual flight vehicle configuration
- Calculate interactions between nodes in vehicle configuration.
- Iterate to size the model properly such that flight vehicle model does not fail during design robustness tests (e.g., structure withstands physical load application, vehicle outperforms flight simulation, or a control system exceeds requirements of control law scenario trial)
- Document coarseness of model with the components modeled (wing sections, fuselage, engine pylons, etc), and the number of nodes for each model.

Analytical methods

- Use actual measurements from all aspects of the flight vehicle to model any aspect of the design (i.e. estimated/calculated/actual weights of detail parts, full-scale wind-tunnel model, virtual-reality aircraft maintainability model).
- Utilizes Estimated/Calculated/Actual models for every component interaction of the flight vehicle.
- Summation of component interactions to calculate gross vehicle interactions by discipline.

Thesis Proposal

The culmination of my research will be documented in a Graduate Thesis, "Development of a Conceptual Design Weight Estimation Library and Documentation." Flight vehicle weight estimation methods will be classified as applicable to conventional or unconventional aircraft configurations and their application in a modern flight vehicle synthesis environment. The research thesis will document everything that went into building the weight estimation method development process, including the following: 1) the fundamental structure and implementation of legacy weight estimation methods under study in a standardized format (including required inputs, outputs, and limitations on performance characteristics), 2) validation & calibration case studies for each method discussed, and 3) detailed recommendations for incorporating each method into a modern flight vehicle synthesis environment, and 4) any other decision criteria &

logical processes that can be used to chose decide upon or develop a weight estimation method for a design project.

As a means of practical application, this research undertaking will place emphasis on design configurations that lie within the AVD Lab's current research activities and contracts in progress. Weight estimation methods of three generations of design configurations will be covered. The first generation (N+1) consists of conventional "wing-tube" transport aircraft, designated as the "Tail-Aft-Configuration" (TAC). Examples include Very Light Jets (VLJ), Boeing B737, Boeing B777, Airbus A380. The second generation (N+2) consists of Flying Wing Configurations (FWC). Examples are Northrop Flying Wing Bombers (YB-49, XB-35, & B-2) [Note that these are the only operational flying wing configurations available], and Blended-Wing-To-Body Configuration (BWB). The third generation (N+3) consists of advanced design modifications to TAC: thrust vectoring in lieu of conventional turbofan and turbojet, and strut/truss wing structure in lieu of conventional cantilever wing. Advanced TAC case studies include B737 with Thrust Vectoring, and B777 with Strut/ Truss Wing and Thrust Vectoring.

The representative validation case data will be as follows below. Note that since the AVD lab is interested in all flight vehicle speed regimes, the speed ranges will vary from subsonic through hypersonic.

Performance Parameter	**B737-900ER**	**B777-300ER**	**A380-800**
Passengers by Class (1st Class/Business/Tourist)	215 (0/0/215)	378 (28/0/350)	555 (22/96/437)
Range (nm)	2,500	7,000	8,000
Speed (Mach)	0.82	0.84	0.82

Table 1: Tail Aft Configuration: Transonic Commercial Transport Missions using representative aircraft weight classes.

Performance Parameter	**YB-49**	**XB-35**	**B-2**
Power (hp)	10,500	12,000	?
Range (mi)	?	8,100	?

Table 2: Flying Wing Configurations

Summary and Conclusions

For many conceptual design analysis projects, the usual conceptual design practice is to create a database of actual design numbers from literature and legacy design documentation. As I've previously stated/hinted, the quality of this knowledge database is dependent upon the quality of the documentation. If the documentation is incomplete, the risk associated with correlating the data is increased. Weight data must be correlated with first principles in mind; the modern buzz-word to describe methods is "physics-based" methods. But all methods should be physics-based since the design of an aircraft must ultimately follow the laws of physics. How are the first principles of design analysis implemented within a method? Are they really "first principles", or are they just one engineer's design rules or assumptions? Examples of truly physics-based structural design methods can be found in textbooks by Shanley & Bruhn – experts in their fields, with clearly defined design examples in their respective texts that could be brought together to form the basis of a flight vehicle structure.

Many method authors have gone back to basic principles of aerospace engineering analysis and design to develop a unique set of methods for a specific configuration. Remember that the best methods will have a clear lineage from whence they came, and clearly delineate their engineering applicability. Parametric engineering analysis methods, which are what we've been talking about under the guise of empirical & semi-empirical methods, have been handed down generation to generation for the past one hundred years. It is now possible to continue passing on knowledge, but now future generations of engineers will be able to directly see their heritage, and how they can innovate their way into the future.

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