2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33135

The Concept of Technological Literacy Examined through the Lens of a Case Study Concerning the Boeing 737 Max Accidents

Dr. John Heywood, Trinity College Dublin

John Heywood is professorial Fellow Emeritus of Trinity College Dublin- The University of Dublin. He is a Fellow of ASEE and Life Fellow of IEEE. he is an Honorary Fellow of the Institution of Engineers Ireland. He has special interest in education for the professions and the role of professions in society, and the work of ASEE's TELPhE division from whom he has received a best paper and meritorious service awards. He has also received awards from the junior Institution of Engineers for coordinating the observations of the British Astronomical Association and Radio Society of Great Britain of Sputniks 1 and 2. He is author of Engineering Education. Research and Development in Curriculum and Instruction which received an outstanding research publication award from the Division for the Professions of the American Educational Research Association. He is also author of The Assessment of Learning in Engineering Education: Practice and Policy; The Human Side of Engineering, and Empowering Professional Teaching in Engineering

The Concepts of Technological Literacy and Technological Competence Examined through the Lens of a Case Study concerning the Boeing 737 Max Accidents

Abstract

Every citizen has to contend with the technologies that impinge on their lives in order to avoid being controlled by them, but by no means every citizen is aware that this is the case, or that they are being substantially controlled in what they do by these technologies. To provide awareness of and skill in contending with technology might be considered the *raison d'être* of programmes in technological literacy yet TELPhE has paid little attention to technological literacy as a form of public discourse. The intention of this text is to rectify that position, not to end such debate, but to begin it.

The rationale derives from a common view of literacy which is "information taken for granted in public discourse". While curriculum designers would begin by establishing the knowledge that a technologically literate person should take for granted, they would want a citizen to be able to contextualize that knowledge, that is, to be technologically competent. It requires judgement and therefore the capability to react to and act on contingent events.

The first purpose of this paper is to demonstrate that while technological literacy is not a discipline it may be considered as an umbrella that brings together various "knowledges" from traditional disciplines for the purpose of developing technological judgement or competence. Technological Competence is the skill that provides us with a technological way of viewing the world in which we live that enables us to respond to and control the contingencies caused by the technologies that accost us in daily life. Since technological literacy embraces engineering literacy the provision of engineering courses for non-engineers will not of themselves develop technological competence even though instruction in qualitative engineering evidently contributes to a liberal education as traditionally conceived.

It is argued that the solution to technological problems, in particular those in which the citizenship has an investment, mostly involve "knowledges" other than those that are technical. It is not to argue that they do not require a qualitative understanding of engineering. It is to argue that because they are by their nature contingent, an information giving curriculum based on a collection of traditional disciplines is unlikely to develop technological competency. The most likely curriculum to develop technological competency will be problem/project based, accompanied by a study of qualitative engineering. Because it is likely to require students to obtain knowledge independently, and because individuals and organizations learn, its base should be an active understanding of the nature of learning. Some examples of transdisciplinary programmes are mentioned together with some transdisciplinary texts, but they err on the side of information giving rather than problem solving and critical thinking which lie at the heart of technological competence.

The second objective is to use a case study to demonstrate this argument and at the same time illustrate another role for case studies, namely in curriculum development.

1. Introduction

Last year in pursuit of the continuing debate about technological literacy among members of the Technological and Engineering Literacy and Philosophy division (TELPhE) of the American Society for Engineering Education (ASEE) it was suggested that TELPhE had significantly failed to consider the needs of the general public, or to consider the different audiences that had to be served within that conglomerate in answer to the question, - “Why technological literacy and for whom?” Previously it had been shown that it was difficult to get an agreed definition of technological literacy. It was suggested that one reason for this state of affairs was that technological literacy did not have an adequate philosophical justification: this in turn led to the suggestion that it might be viewed as an umbrella concept which allowed for content and method to be developed for the numerous audiences it was required to serve. This is not a surprising proposition since on the one hand technology is a product that impacts on society, and on the other hand is the result of a process (engineering) that meets a specified need [1]. It is a “knowledge”-“information giving” view based on traditional approaches to the curriculum and the disciplines of which it is composed.

The extraordinary range of disciplinary knowledge involved in the development of an idea, its design, manufacture, and impact on the market is partially illustrated by the model of engineering and technology shown in exhibit 1 [2]. The model was not intended to embrace computer literacy.

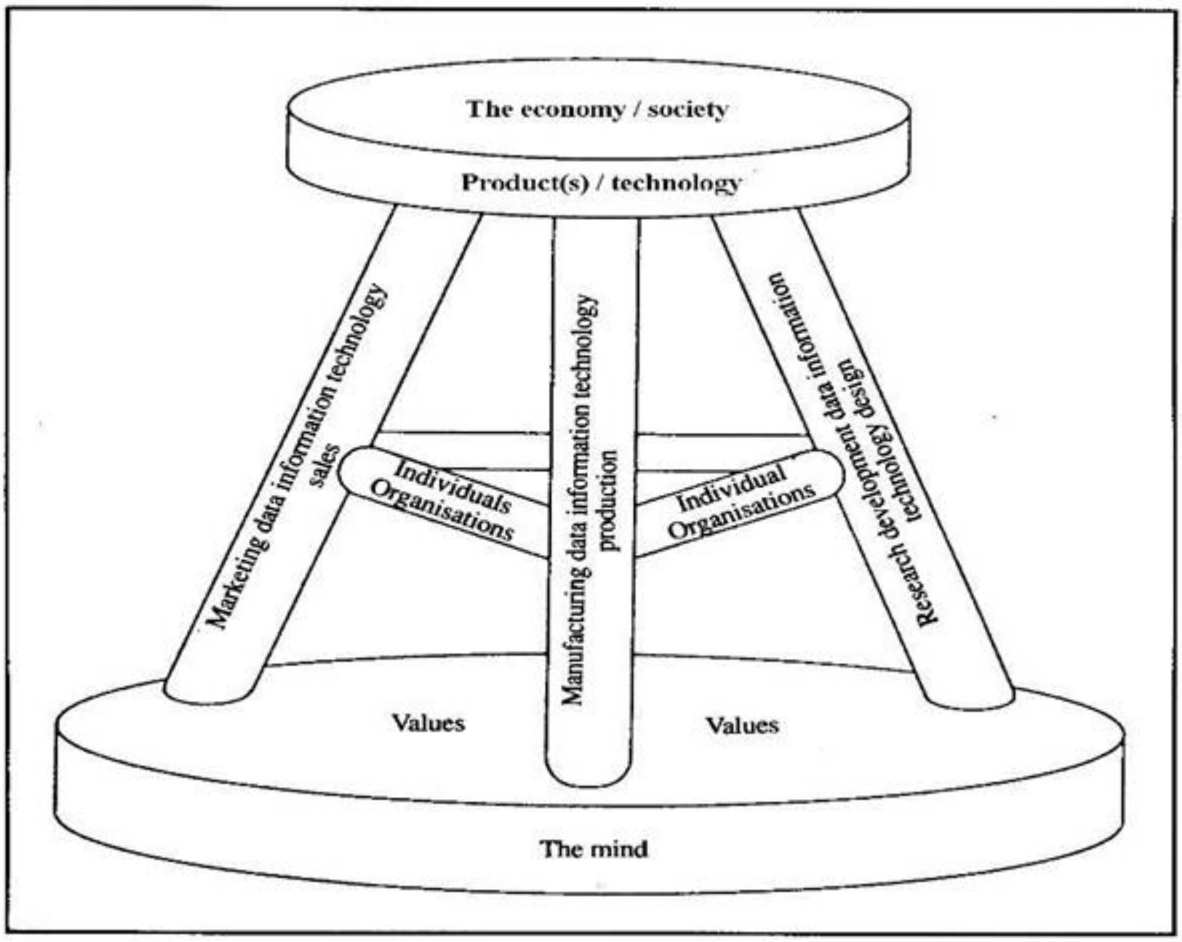

Exhibit 1

The seat and the base belong to technological literacy whereas engineering literacy is described by the seat's supporting framework. Krupczak and Blake analysed American documentation and came up with the astonishing conclusion that "technological literacy and engineering literacy each claim the same set of topics" [3], a finding that appears to give concurrent validity to the proposition that technological literacy while being different from necessarily embraces engineering literacy.

Acceptance of this proposition explains Dr Mani Mina's contention that engineering students are technologically illiterate because they focus on the technical without reference to its environmental and social context. This view has surfaced from time to time since the end of the second world-war but within the conceptual framework of the time. For example, in the nineteen-sixties the UK Council of Engineering Institutions recognized this need by requiring aspirants to the Chartered Engineer designation to have passed an examination in "The Engineer in Society" [4]. UK universities responded in a variety of ways to accommodate this demand, and at least one implemented a transdisciplinary component for this purpose within its industrial administration programme for engineers [5]. A partial attempt to implement a modification of that course within the Irish k - 12 curriculum was made in the late nineteen-eighties [6]. A completely revised programme was provided on-line on an experimental basis with volunteer academic and post-graduate participants at Iowa State University [7]. While transdisciplinary these programmes were primarily information giving rather than contingent, and problem oriented.

No diagram, however, can show the dynamic nature of the activity or the mish-mash of knowledges and inter-connections that bring an idea to fulfilment. One variant of the diagram, for example, shows arrows in both directions between the base and the seat because not only is it evident that technology influences values, but values do and should influence technology. At the same time values also inform organizational behaviour and structure; thus, in understanding any failure, these have to be taken into account since they might be the ultimate cause of failure.

Another variant of the diagram shows a two tiered base with the bottom tier being labelled conscience. Employees may be faced with adapting to a culture that leads to poor design, a few may speak their mind, others may be afraid to speak out. Such problems easily become matters of conscience and personal (mental) conflict. Issues of this kind have been largely ignored by contributors to TELPhE.

Krupczak et als view of engineering as process requires some amplification. In essence it is a socio-technical process constructed from small sub-systems or networks of role players (not necessarily human) whose interactions drive the system forward. Such structures are open to conflict both within and between them. For example, as Larry Bucciarelli has shown designers work in a social system and the resultant designs are as much a result of the culture created by the system as they are of anything else [8]. Elsewhere it has been suggested that underpinning all these knowledges is the desire of an organization to learn [9].

Therefore to be technology literate an individual requires an integrated knowledge from a number of disciplines including engineering. This in turn means that a curriculum composed of engineering plus a variety of subjects in the social sciences and the humanities neither serves the goals of technological literacy or the goals of liberal education because it is but a collection of bits and pieces of knowledge. This has been a problem for those who have designed and implemented transdisciplinary courses related to the engineer and society such as those mentioned above. However, a different picture of curriculum emerges if it is considered from the perspective of learning; given that learning is that process by which experience develops new and reorganizes old concepts, the curriculum may be understood as a particular grouping of *key concepts* [10]. In this context they will be common to some or all of the "knowledges" providing scaffolds for future learning. Together, as they are grouped, they form and re-form the frames of reference on which the skill of integrated thinking depends. This they do by virtue of the questions posed by a technological incident, the answers given, and the testing of their veracity. They are fundamental to the development of what Drew calls "technological judgement", and this writer terms "technological competence".

David Drew argued that while the ability to understand information suggests a person is literate, it is a minimum competence. "A person must go beyond understanding how a device works to considering the implications of its use for society" [11]. That, he argued, required a person to be able to contextualize knowledge, and to think critically.

Given that without contextualisation information does not lead to judgement or action, the purpose of acquiring information must be to construct conceptual frame-works that enable the exercise of the competence of conceptualization. "Technological competence" as it is called in this text, leads to judgement, and action. It functions at many levels: for example, it will vary from the competency expected of the general population (the citizen) to that of the specialism of the design engineer – the expert- who, because of learning in the organization, will have knowledge and skills that extend beyond that which can be learned from books and the curriculum.

The conduct of official inquiries is made difficult because citizens will want to contextualize the information available to them for a variety of different reasons. At one end of the spectrum will be issues for the taxpayer and investors: at the other end will be those immediately affected by the failure such as the injured or bereaved. In the case of B737 Max disasters there will be millions who through no fault of their own will have to fly on B 737 Max aircraft, and some will be afraid. Since the primary purpose of an inquiry, unless otherwise stated, is to make recommendations that ensure that such accidents do not occur again, there is an obligation on society to ensure that its citizens are in a position to verify the veracity of what is recommended. Here, that skill is called "technological competence" the successful exercise of which is to be technologically literate. In this sense technological literacy is not a "knowledge(s)" but a "competence" as the term is commonly used. It follows that technological literacy is not a discipline but a way of understanding the technological world in which we live in order for us to control it.

A technologically competent public requires of any serious failure, to know if its cause can be contributed to any person or persons. If a public enquiry is held into an event, the public needs to know that the person in charge of the enquiry can be trusted: but, they also need to accept that the specification, that is the question asked of that person, will provide the answers they need, that attempts will be made apportion blame, and that where rectification is required that it will be expedited and done properly. Given that investors were quick to suggest, as was the company, that pilot error was the cause of the B737 Max accidents the public will need to know whether it was simply human error or some other cause, as for example, the training they received to fly this type of aircraft (CS 6.6: CS 13.2).

These issues have been contentious in other public inquiries, as for example, in the Grenfell Fire Inquiry in London which continues [12]. The residents of the tall residential block that caught fire in 2018 killing 72 people not only want closure for themselves, but they want action on the many hundreds of similarly constructed buildings in the UK, so as to avoid similar disasters. In this case they are clearly acting in the "common good", a term which came to be much used during the COVID 19 pandemic. They did not want an official government inquiry which was prevented from examining the ultimate cause as opposed to the immediate (apparent) cause; they wanted the original design and its authorisation to be examined, not the refrigeration unit that started the fire. But, they did not trust the Judge appointed to chair the inquiry to determine who had authorised the building to be constructed in such a way that it was a fire hazard. In the future they will have to judge the reliability and validity of the report when it is published, and that will require technological judgement.

Shortly after the fire, it was argued at TELPhE that "a major purpose of a curriculum in engineering and technological literacy is to better enable the public to ask and better understand the answers to the questions that such disasters cause" [13]. Put in another way, it is to provide educational frameworks that will develop a level of "technological competence" among the public.

Common to both inquiries is the speed with which judgements are sometimes made on the basis of evidence that is not necessarily reliable. First impressions might be wrong, but they may persist. For example, newspapers led some residents and members of the public to believe that a baby was thrown from the Grenfell Tower and caught by someone in the street. These beliefs persisted among some members of the public even when they were shown to be untrue. The baby, for instance, was never found. In such circumstances it can be argued that a prerequisite for the development of technological competence is an understanding of how we learn, how our perceptions influence that learning, how easily we are deceived, how to ask the right questions, and how to judge the veracity of the answers [14].

In sum technological competence enables us to function in a technological world from which there is no escape.

The purposes of this text are (1) to support these arguments by reference to (i) a study of the Boeing 737 MAX air disasters completed early in 2020 which is given in the appendix, and referenced as CS in this text, and (ii) to validate the case study by cross-referencing it with the Official report of the US House Committee that was published later in the same year: it is referenced as OR in this text [15]. In the event criterion validity was established with the Official report. (2) To briefly consider the implications for the development of technological competence, and higher education more generally. (3) By inference, to demonstrate the potential of case studies to contribute to curriculum design and development.

The study begins with an illustration of the importance of the key questions that determine the pathway an inquiry will take: throughout the discussion questions that the citizenship will want answers to are considered. The idea of contextualization is illustrated by reference to the cockpit of the aircraft which also demonstrates the importance of the key concept of "socio-technical system". The case study is used to derive key concepts that may be used in the design of a curriculum.

The culture and sub-cultures in the organization are shown to have contributed to poor decision making. They are also shown to have originated with the change in business objectives that occurred when Boeing was merged with McDonnell Douglas. Considered as a learning system the organization was not structured as impediment to learning. These created a relatively closed and hierarchical system with a one way system of communication. Finally it is argued that the development of technological competence which enables judgements to be made about the many issues involved is more likely to be achieved by a problem/project based approach than it is by and information giving approach.

2. The remits for the case study (CS) and Official Report (OR).

Different questions were put to the author of the private report and the members of the Congress Committee of Inquiry. The private report has been used with permission as the case study (CS) in this text: it is reproduced in its original form in the appendix**.** The remit from the economists inquiring into financial aspects of the Boeing organization was to consider if the accidents could be linked to the financialization of the company, which it was argued, resulted from the merger of Boeing with McDonnell Douglas [16].

From the perspective of the curriculum it is immediately apparent that a knowledge of finance is required which might be obtained from studies of the 2008 financial crash. It is not readily apparent that a substantial knowledge of engineering is necessary.

The House Committee clearly believed that it had a wide ranging remit although it is not specified as such. Its Official Report (OR) begins with a short introduction which describes the circumstances of the investigation, namely the crashes that killed all the persons on board of each of the aircraft, 354 in all. The report states that the second crash took place "just two years and two days after the Federal Aviation Administration (FAA) had certified the new 737 derivative aircraft as safe to fly. Clearly it was not" (OR, p 2). This indicated that the investigation would take into account the regulatory procedures; matters of great concern to the public. Given that they are procedural and legal they are not about the technical except in so far as a citizen will want to be assured by independent reviewers that all aspects of the design have been taken into account in any re-certification of the aircraft.

> 1st para p 3.
> "This report concludes the US House Committee on Transportation and Infrastructure 18-month long investigation of the design, development, and certification of the 737MAX aircraft and related matters. The Committee's investigation has revealed multiple missed opportunities that could have turned the trajectory of the MAX's design and development toward a safer course due to flawed technical design criteria, faulty assumptions about pilot response times, and production pressures. The FAA also missed its own opportunities to change the direction that the 737 MAX based on its aviation safety mission. Boeing failed in its design and development of the MAX and the FAA failed in its oversight of Boeing and its certification of the aircraft"
>
> Last sentence of 2nd para p 3.
> "The fact that a compliant airplane suffered from two deadly crashes in less than five months is clear evidence that the current regulatory system is fundamentally flawed and needs to be repaired"

Exhibit 2. Extracts from the Introduction of the US House Committee on Transportation and Infrastructure Report of its investigation into the design, development, and certification of the 737MAX aircraft and related matters.

Exhibit 2 is a summary of the Committee's findings given on page 3 (OR, p 3). The first sentence is a statement of the Committee's brief.

In compiling the Official Report (OR) its authors made use of some of the articles that were also used in the case study and in particular those of Gates, Glazer (CS 8), and Kitroeff. These, together with the conclusions, give criterion validity to the case study. Since then Gates and Kitreoff have published several articles on the topic. The Official Report also makes references to articles published by Bloomberg. It is accompanied by 1374 notes and references.

3. A frame-of-reference for contextualization -pilot error and training.

It was suggested above that contexture in complex situations may be aided by the construction of a frame-of-reference that provides an anchor against which emergent frames can be related. In this case, given a citizen's motivation to fly, one such framework that may help a citizen understand the complexity of the problem, from which ever perspective (manufacturer/customer) it is viewed, is that of pilot training. This is because (1) from the beginning of the investigation pilot error became a central issue, and (2) it was a failure of the engineering system. Both investors and the company were quick to blame the accident on pilot error [CS 6.6; 13.2]. Therefore the key questions are, would pilot training have greatly reduced the probability of an accident, or was it a design fault? Answering them will cause other frames of reference to emerge, especially if the question of financialization is introduced into the mix. But, in understanding what might have happened in the cockpit, it is essential to understand that the cockpit is a socio-technical system, the technical design of which impacts on the behaviour of pilots [19].

Flight simulator training is very expensive: but, Boeing made the assumption that it would be unnecessary because the aircraft was a development of the 737 series for which the pilots to be used on the 737Max were already trained [CS 5]. Substantial training might also have indicated to the FAA and others that the changes in design which necessitated such training would not be considered as a natural development of the 737 and, therefore, require costly and time consuming new certification. The company's actions were directed at making sure that such training was not required.

Given that this understanding became part of the belief structure (creed) it is not surprising that the company took no action when a test pilot reported that it took him 10 seconds to respond to an uncommanded MCAS (Manoeuvring Characteristic Augmentation System) activation which he said was "catastrophic". The House Committee wrote, "Boeing repeatedly referred to that test data in internal documents but never relayed that information to the FAA or to MAX pilots because there was no specific requirement to share it" (OR 100,; 113).

The Official Report (OR) also stated that "Boeing assumed that pilots would respond to an unexpected MCAS activation as if it were a runaway stabilizer trim event, within four seconds" (OR 111). The National Transportation found that this assumption led Boeing **not** to "evaluate all the potential alerts and indications that could accompany a failure that also resulted in uncommanded MCAS operation". Moreover, it was not clear on what basis the advice given by the FAA concerning pilot reaction time of 3 seconds was made. The Joint Authorities Technical Review who made this point noted that analysis of aviation accidents demonstrates that pilots may take "a significantly longer time to recognize a malfunction and respond to it than the test flight guidance suggests" (OR 112). Multiple alerts and indications can increase a pilot's work load (CS 6.7 item 9). They are also likely to increase the level of 'noise'. The test pilots experience dated to November 2012.

According to the Official Report, a Boeing Engineer asked his colleague the following question "Do you think that with pilot training/knowledge of the [MCAS] system there will be sufficiently quick response to the stab runaway during the windup turn/recovery and that it is appropriate to deem it hazardous and have the MCAS system designed to meet this? Or should we step up to catastrophic with the assumption that not all pilots will recognize it quickly enough?" (OR 114). The Committee found that "as in several other cases Boeing engineers asked the right questions concerning key details, but they were inadequately resolved or dismissed by some of their colleagues. If these questions had been more thoroughly addressed at the time they could have helped, in some cases potentially dramatically, to improve, the safety of the 737 MAX" (OR 114).

Irrespective of the answers this fundamental assumption led Boeing to insist that simulator training was not required. Moreover, the pilots manuals need have no information about the MCAS. The Official Report dismisses Boeing's statement that it was awaiting FAA directions on the matter of training and substantiates its argument (OR144/145). The issue of pilot training occupied a whole chapter of the Official Report (Ch 7).

It will be seen, for example, that a mind map or frame of reference could be structured around the key concepts of "decision making" "finance" and "safety". Or, another map could be constructed around the "fundamental assumption". Who made it? Why was it not open to question? Etc., or around the key concept of the cockpit as a socio-technical system.

Aids such as these help the citizen decide whether or not this is sloppy management, and or cognitive dissonance, and/or derived from financialization, and/or a mix of these. They lead citizens into other areas of knowledge where they will have to acquire a descriptive (qualitative) understanding of principle(s) of engineering, in particular flight [20].

4. The merger of Boeing with McDonnell Douglas (CS 3)

G. Mukunda linked the merger of Boeing and McDonnell Douglas in 1997 to financialization on the one hand, and on the other hand to the troubles that the 787 Dream liner had had in production [CS 3.1, 3.4; 3.5]. According to Foroohah, outsourcing and the problems associated with an extremely complex supply chain ultimately cost Boeing $28 billion more than it should have [21].

Mukunda argued that the culture of McDonnell Douglas came to dominate that of Boeing, and the cost cutting that ensued, because it valued balance sheets and high returns on investment [OR 36], ensured that the high quality engineering culture that an aircraft required could not be maintained. "The prowess of the engineers' technical designs and innovative diagrams were replaced by accounting acumen and financial decisions of business executives. Production schedules and monetary costs, not technical specifications and safety considerations" (OR 37) came to dominate the organization. It was inevitable that organizational structure and the behaviour of individuals in the organization would be affected (see section 6 below).

Tension between the manufacturer and the market

But there was also a significant tension between the manufacturer and the market which was primarily for short and medium haul aircraft. Boeing was in a race to collar as much of this market as possible from Airbus, its competitor [CS 4].They were in fierce competition with each other, and had, and have a major place in the economies in which they are located. It follows that the market is a major determinant of design decisions, and these decisions may be of more significance than financialization. However, the market depends on what is offered as the basis for negotiations, and what is offered may be directly connected to financialization. It is evidently easy to link fiancialization to general decisions relating to the development of a new aircraft, its overall design specifications, and the method of manufacturing [CS 4.1].

An aircraft is a set of integrated sub-systems that functioning together meet the overall design specification. It is important to appreciate that in development this specification and the specifications of the sub-systems can be modified as difficulties emerge, or market requirements change; but, such modifications will affect costs [CS 4.2].

The design, development and manufacture of an aircraft is a massive complex venture undertaken within the framework of constraints imposed by the stakeholders and regulatory authorities. These constraints also impose limits on financialization in so far as the costs of meeting these requirements are concerned. Of these constraints two are in conflict; they are, the market and safety. In this case flight simulator training would have added significantly to the safety costs. In such cases the regulatory authority is the umpire, it is therefore, important that the regulatory authority should be independent of all the other stakeholders [CS 4.3].

More generally it seems that the market reinforced the dominant culture which provides another conceptual frame for establishing the ultimate cause behind the MCAS failure.

5. Culture in the merged organization

By culture we mean here the values, beliefs and attitudes around which a group or network of individuals cohere. Such cultures can demand the monopoly of our loyalties particularly if we wish to avoid role conflict. Like Mukunda the House Committee came to the view that the culture of the organization created sub-cultures which were detrimental to the design process [OR 238] [22]. It is assumed that in any large group there will be sub-cultures. It is also assumed that some of these groups may be formal and others informal, and that the way they interact will either be in or against the direction required for the achievement of the organizations goals. The primary task of management at all levels is to motivate everyone in the direction of the organizations goals, and success or failure will depend on the views that managers have of what it is that motivates people.

In the 1960's Edgar Schein described three models of beliefs about what motivated persons that had come into the management literature: he called them rational economic, self-actualising, and complex [23]. The first two came from much discussed theories of human behaviour by Douglas McGregor and Abraham Maslow. The third, the complex person, was his own development.

The first, which is the interest here, was Douglas McGregor's so called theory X and Y. Theory X was based on the economist's dictum that a rational person will do what is in his best interests [24]. The shock administered to economists in recent years is that humans do not necessarily behave rationally. Financialization treats people as cogs irrespective of whether it is in their best interests or not. It depends on the same axioms as theory X (following Schein):

1. The individual is primarily motivated by economic incentives and will do that which gets him or her the greatest economic gain.

2. Since economic incentives are under the control of the organization, an individual is essentially a passive agent to be manipulated, motivated and controlled by the organization.

3. The individual's feelings are essentially irrational and must be prevented from interfering with his or her calculation of self-interest.

4. Organization can and must be designed in such a way as to neutralize and control the individual's feelings, and therefore his or her unpredictable traits.

Barry Turner a senior engineering manager said theory X derived from the view that work was "part of the punishment for original sin" (p 323, [25]). Control is obtained by authority: it is evident that hierarchical organizations are suited to such control. McGregor contrasted theory X with theory Y in which people were enabled to achieve their own goals "by self-steering towards the success of the enterprise as a whole" (p 324).

It is evident that the organizational climates created by these different approaches to management will be very different For example, in the same year that McGregor published his theory, a study of open and closed systems in the American electronics industry suggested that people in open systems were better motivated and more effective than those in closed systems[26]. Open systems would have many similarities with theory Y.

Similarly a Scottish study that distinguished between firms in the electronics industry that were run more like bureaucracies (mechanistic) with those that were rather like open systems (organic) and found that the latter were more likely to be innovative [27]. Organic organizations were characterized by:

"1. An emphasis on continual adjustment and redefinition of individual tasks and the contributive nature of specialist knowledge".

"2. Interaction and communication consisting of information and advice rather than orders, may occur at any level as required by the process and a high degree of commitment to the goals of the organization exists" (pp 121-122).

It is contended here that the three sub-cultures identified by the US House Committee are of an organization that was in theory X mode and was a relatively closed system. In the latter attitudes and values are passed down from the top to the bottom, no response is wanted. To achieve its financial goals the system tends to become tightly hierarchical and closed. One of the pioneers of socio-technical systems theory, Fred Emery of the Tavistock Institute noted that "the problems on one level are more frequently (but not always) found to be dependent upon solutions being found at a higher level, than vice-versa; and those problems that occur on adjacent levels are usually more independent than those on levels more than once removed from each other" [28].

It seems from the reports that the organization was able to mold some, if not many, workers to its way of thinking; which is to be expected in strong sub-cultures. For example, senior engineers embraced the goal that the aircraft should *be seen* to be a development of the 737

NG and not a new airplane because a new aircraft would require a completely new certification entailing substantial additional costs [CS 8.3: 8.4: 9.6]. Among those costs would be simulator based training which would not be necessary for pilots transitioning to the 737 MAX from the 737NG. As previously indicated the costs of simulator training are huge.

Senior engineers embraced these goals as did some employees. For example a group of them assisted Boeing develop its plan to downplay the role of the Maneuvering Characteristics Augmentation System (MCAS). The system in which it functioned was later found to be a major cause of the two accidents (OR 135). At this meeting (documented in Boeing's compliance data base (OR 96)), a strategy was devised to treat MCAS as an "addition to speed trim" to help prevent increased "cost" due to changed manuals" […] "If we emphasise MCAS is a new function there may be greater certification and training impact" (OR 100). "Externally we would communicate it as an addition to the speed trim. Internally continue using the acronym MCAS […] (OR 94). Put in another way this would avoid the cost of simulator training which was "a design objective of the MAX program" (OR 25).

The Official Report (OR) stated that this goal "undermined appropriate pilot training requirements, hampered the development of safety features that conflicted with that goal and created management incentives to downplay risks of technologies that jeopardized that goal" (OR 25).

These attitudes relate to what the US House Committee called a "culture of concealment".

A culture of concealment

The Official Report describes a "culture of omission". "Boeing made a decision to simply omit the fact that the AOA (angle of attack) Disagree alert on the majority of its 737 MAX fleet were inoperative not only from airlines, but from MAX pilots and the FAA as well. [….] Boeing's actions may not have directly jeopardized the safety of any aircraft, but the way Boeing handled this issue endangered the reputation of the company" (OR 128, 137). In the executive summary it is called a "culture of concealment" which seems to be a more accurate description (OR 13).

Trust

The missing sentence in the above quotation read, "This paints a troubling picture of the corporate and cultural challenges Boeing must squarely face to regain the trust of Federal regulators, its customers, and the flying public". It raises, as in the Grenfell Tower inquiry, the important issue of trust. How can the public know whom to trust among institutions (as for example, banks and regulators such as FAA) experts, and politicians? These are issues that are currently "live" in the public discussions of COVID 19 (December 2020).

A culture of fear

The Official Report (OR) comments on a report from an engineer that was cited in both the *Seattle Times* and *New York Times*. The complaint was about one of eight proposed design changes that were rejected by Boeing. The proposal was to fit a synthetic airspeed system in order to solve the problem of loss of conventional airspeed data by providing pilots with a "stop gap" estimate of airspeed on which they could rely to maintain control of the aircraft through landing (OR 170). This action was suggested on three occasions and was rejected each time on grounds of cost and training. The *Seattle Times* when reporting on this complaint, said that the, “employee expressed concerns about retaliation for even raising these issues, internal at Boeing”. The Official Report (OR) continued “The Boeing employee apparently wrote, that given “the nature of this complaint, the fear of retaliation is high, despite all official assurances that should not be the case. There is a suppressive cultural attitude toward criticism of corporate policy-especially if that criticism comes as a result of fatal accidents” (OR 172).

By filing the complaint the engineer was exercising his/her ethical responsibility. While it is known that some senior managers were engineers, questions about their exercise of ethical leadership were not asked in the report.

The House Committee wrote “The AOA Disagree Alert issue may not rise to what Boeing and the FAA believe are critical safety issues. However, the Committee’s investigation has found that it sheds light on a broader cultural issue within Boeing regarding business decisions the company makes when it is forced to confront ethical issues impacting on its customers” (OR 126).

Negative reactions to feedback

In addition to the feedback of the test pilots described in section 3 above there are other examples in the Official Report (OR) that are of concern.

For example, fifteen months prior to FAA certification in March 2017 a Boeing engineer asked a question about the dependence of MCAS on one AOA sensor. He asked, are we vulnerable to single AOA sensor failures with MCAS implementation or is there some checking that occurs? “On June 13th 2016, a few months before Boeing re-designed MCAS to give it more authority a Boeing test pilot observed that the MCAS countered his attempts to trim the plane while flying at a low speed maneuver. This situation raised concern with the same engineer who had previously asked about the vulnerability of aircraft with only a single AOA sensor. In reviewing a plot of the test data, this engineer noted that the “ratchiness” of MCAS was causing the airplane to oscillate and recommended that the issue be further examined by Boeing’s “squawk” process” (OR 109- see OR 100- 111).

“Unfortunately, like the engineer’s previous question about MCAS relying on a single AOA sensor, the new concerns were ultimately dismissed” (OR 109).

Much of chapter 8 “Production Pressures” of the Official Report (OR) is devoted to retelling the experience of Mr Ed Pierson a supervisor at the final assembly plant (OR 177 – 188). Mr Pierson was an ex US Navy Captain, Pilot, and Squadron Commanding Officer. He complained to Boeing’s 737 General Manager Mr Scott Campbell that the integrity of the 737 Max was being undermined because of worker fatigue and extreme production pressures. (These pressures arose from the fact that successful marketing had brought Boeing an order book for around 5000 aircraft at peak in 2018. At peak the Renton final assembly plant was building, of the order, 52 planes per month).

There was a five week interval between Mr Pierson’s request for and the actual interview. Then Mr Pierson told Mr Campbell that there were 38 unfinished airplanes outside the factory, that workers were fatigued and that “fatigued workers make mistakes” [..]. “My second concern is schedule pressure (combined with fatigue) is creating a culture where employees are either deliberately or unconsciously circumventing established processes". He recommended temporarily shutting down the production line "to allow our team to regroup so we can safely finish the planes outside and then shift our attention to the planes inside" (OR 176). He said that he did not make this recommendation lightly.

In his conversation with Mr Campbell he pointed out that in similar circumstances the military would have stopped the activity. He said that Mr Campbell had replied that "*the military is not a profit making organization*".

Boeing did not evaluate Mr Pierson's concerns but ramped up production of the 737 MAX.

Mr Pierson retired in September 2018 out of frustration that Boeing was not considering his safety concerns. The US House Committee on the basis of reports in an Australian magazine *Traveller* and the *Seattle Times* came to the conclusion that things had got worse after Mr Pierson's retirement. Their stories seemed to validate what Mr Pierson had reported. The *Seattle Times* reported that some work groups had "asked their managers about perhaps stopping the production lines in order to catch up" on all of the half-finished airplanes that were accumulating at the Boeing factory. Managers responded categorically that a pause cannot happen because of "the severe impact it would have on supplies, on airline customers, and on the company's stock price" (OR 179).

After the Lion Air Crash on 29th October 2018 Mr Pierson, on numerous occasions, tried to communicate with the Boeing lead investigator on the crash to inform him of his observations, but without success. In December he wrote to the CEO of Boeing. This led to an exchange of correspondence with Boeing's Assistant General Counsel. From the perspective of this study the final sentence of Mr Pierson's letter is of more than passing significance "I'm confident that Boeing has the resources to fix these problems. The question is whether or not there is the ethical leadership and will to set aside pride and potential liabilities to get to the truth" (OR 181). Given the statements in the Official Report (OR) it seems the Housel Committee thought not.

Safety Culture Survey

The FAA's Aviation Safety Organization (AVS) employed the MITRE Corporation to conduct a mixed methods investigation into the safety culture (surveys, interviews, focus groups) of its 7,147 members. While only 25% of the members responded to the survey the House Committee believed that the combination of methods gave a comprehensive view. They were pleased with the finding that 71% believed their front line manager supports safety, and that 69 per cent agreed that they were comfortable reporting safety issues/concerns. However, they were disappointed to find that 56 percent of the respondents from the Air Certification Service believed "external pressure (eg industry) is perceived to get in the way of safety decisions". Worse "49 percent believed that safety concerns/incidents will not be addressed so they don't report them, and 43 percent do not believe the FAA appropriately delegate certification activities to organizational and industrial designees" (OR 69).

Exhibit 3 is a reproduction of a list of responses to the survey questions that the House Committee thought "mimicked what it had heard from numerous whistle blowers over the past eighteen months" (OR 69). It should assist citizens in coming to a conclusion about the type of organizational culture that functions in the industry. They will want to know that the organization is capable of learning from its mistakes.

6. Management and engineering

The picture that comes across of the relationships between engineers and managers is of "direction and control". It so happens that this is the definition of management in the *Little Oxford Dictionary*. It implies that all of us exercise direction and control to some extent over ourselves, and to a greater or lesser extent over others. There is, therefore nothing unique about management. Moreover this was a finding of a task analysis of everyone in engineering functions in a highly innovative firm in the British aircraft components industry. Put in terms of a taxonomy of training objectives for engineers and technicians it was a general category that applied across the board of tasks [29]. Yet during the years of financialization management came to be seen more as a specialist activity. In Britain this could be dated back to decisions in the 1950's to set up separate schools of management thus separating managers from engineers and scientists. That there are conflicts between them is illustrated by the responses in exhibit 3.

- "It feels like we are showing up to a knife fight with Nerf weapons. It is a challenge to be an equal match with Boeing in the meetings/conversations".
- "They [industry] just keep going up the chain until they get the answers they want".
- "There is no respect for an expert culture that has existed through years of experience. There is no acknowledgement of recommendations made by experts or an explanation about why a different decision was made".
- There is a fallout of us not being able to do our job. Accidents happen and people get killed".
- "It is common for people to be selected based on managerial skills only regardless of their technical expertise…they don't understand the true risks of the decisions they are making; they are making decisions that they don't have a clue about".
- There is a perception that technical skills don't matter for managers and they are selected on their ability to be molded and compliant with upper management's direction".

Exhibit 3. Selection of responses from the FAA Culture Survey conducted by the Mitre Corporation selected by the Committee (OR 69).
https://www.mitre.org/sites/default/files/publications/caasd-03-2015.pdf

This difference in values between engineering and management is no better demonstrated than in Michael Davis's comments on the Challenger disaster (CS 3.1). Unfortunately the Official Report (OR) does not give information on the qualifications of the managers or the engineers although it is clear that some very senior managers were also engineers. Therefore, it is not possible to draw any parallels with the Challenger disaster except perhaps in the case of Mr Pierson where it seems evident that Boeing wished him to behave like a manager since he was in a managerial position. He was instead, it seems, acting like an engineer who was also a manager within the framework of an engineering code of ethics.

It seems clear from the official report that management and engineering values were often at odds with each other in the behaviour of some engineers.

7. Organizations as learning systems: motivation and relationships

Two studies of organizations as learning systems suggest that the new Boeing organization found it difficult to learn. Indeed the House Committee left open the question of Boeing's willingness to admit and learn from the company's mistakes" [OR 238] Arising from the UK study referenced above, one of its authors suggested that the sub-systems in an organization were rather like classrooms. The factors that impeded or enhanced learning in the classroom were similar to those that impeded or enhanced learning in the organization, and that the most important condition for learning is motivation [30]. It is not surprising that workers should have hated Boeing at a time when it had laid off 50,000 workers or that they should have been cheered up by the announcement of the plan to build the Dreamliner. Dominic Gates wrote "over the years, there's been a constant sway of opinion within the workforce as to how they view the company, sometimes positive, sometimes negative" (CS 3.5).

These studies were sufficient reason to progress the argument although they test the proposition not against the technology, but against the organization, and the way organizational structures interact with individuals. This view is also supported by a much more recent study of learning in college by Daniel Chamblis and Christopher Takacs who found that the most important thing in the quality of a student's education was to do with the way a college is organized to help students with their relationships; and that went for the classroom experience as well [31].

Substitute manager for teacher, or go so far as to view the investor as the principal teacher, and the same principles apply. Professional engineers cannot avoid relationships since according to Trevelyan between 25% and 30% of their time is spent liaising and coordinating [32]. Good relationships are at the heart of the much mentioned but poorly executed skill of communication. Failure to inform the authorities, in particular the FAA, fragmented communications, and deliberate decisions not to communicate contributed to the failure of the Boeing organization (OR 71; 75 and Ch 6).

"Four incidents illustrate an ODA (Organization Designation Authorisation) system that failed to inform the FAA of important information the Agency should have been made aware of, and in most cases, exposed the flying public to potential dangers" (OR 71). And again, "Most notably, the certification of MCAS illustrates how fragmented communications resulted in information gaps within FAA concerning the critical system. These information gaps precluded key FAA employees from developing a full understanding of MCAS, its operational characteristics, and safety risks. Furthermore Boeing failed to communicate fundamental information to all of the FAA offices that should have been aware of key data related to the certification of the 737 MX" (OR 73).

Clearly some problems arose from lack of clarity about what should and should not be communicated, and other problems arose because of organizational design.

A problem for the citizen is to determine whether in some cases what appears to be a communication failure was in fact deliberate. This is a particular problem in understanding the relationship between Boeing and Collins Aerospace Systems whom Boeing had blamed for its software problems (see OR chapter 6).

Learning becomes sloppy when a workforce is poorly motivated. Indeed Dhieren Bechai an aeronautical engineer took the view that a major contributory cause was "*extremely sloppy management*". As an example he cited a problem with the cockpit display, the AoA sensor and sales. Like cars aircraft are sold with optional extras. The instrument panel contains an AoA Disagree light which lights up when there is a difference of more than 5.5^{o} between the left and right sensors. According Bechpai it "was believed to be optional and made standard as part of the MCAS redesign. It now turns out that Boeing intended it to be standard for the Boeing 737 MAX, but it was linked to the optional item, and therefore not properly activated" [CS 11.1: OR Ch 6].

A person who is learning effectively is acquiring considerable tacit knowledge about, for example, which communication systems work and which don't (CS 12.4). Informal lines of communication may not only be necessary but more efficient than formal. This point is illustrated by Travis who wrote the "lines of code were no doubt created by people at the direction of managers. Neither such coders nor their managers are as in touch with the particular culture and mores of the aviation world as much as the people who are down on the shop floor […] Those people have decades of institutional memory about what has worked in the past and what has not" […] He might have added and *how* things work (CS 12.4)..

It is well established that to be an effective learner it is necessary to be able to reflect on and take action if that reflection suggests that action should be taken: similarly, a major quality is the ability to judge the merits of and respond to criticism. Bechpai points out that the sloppiness was not helped by Boeing's ability to put pressure on FAA people (paid for by itself) and inhibit the level of criticism required during the certification process (CS 12.4).

The case study suggested that the inability of Boeing to learn might be due to cognitive dissonance [CS 13.2]. That is, a tendency in human behaviour when faced with conflict to favour our own view, in the belief that it has greater advantages than an opposing view which to most other people would seem to be more advantageous. If organizations are learning systems then they are as much open to cognitive dissonance as the individual. Simple observation suggests that it is often very difficult to change such opinions, and that it is a significant factor in trying to change an organization. It is one reason why investors may hang on to the belief that these accidents were due to pilot error.

As was shown above there is a quite different dimension of learning to the executive skills required in decision making, problem solving and dealing with people. It relates to skills where rote responses are required at speed, as in flying an aircraft: although, that is not relevant in this particular context, it is relevant in the context of learning as a key concept in the development of technological competence.

8. Summary and conclusions

The first purpose of this paper has been to demonstrate that while technological literacy is not a discipline it may be considered as an umbrella that brings together various "knowledges" from traditional disciplines for the purpose of developing technological judgement or competence. This is demonstrated by the foregoing analysis.

Technological Competence is the skill that provides us with a technological way of viewing the world in which we live that enables us to respond to, and control the technological contingencies we accost in everyday life. Since technological literacy embraces engineering literacy the provision of engineering courses for non-engineers will not of themselves provide for the development of technological competence even though instruction in qualitative engineering evidently contributes to a liberal education as traditionally conceived.

The second objective was to use a case study to demonstrate this argument and at the same time illustrate another role for case studies, namely in curriculum development. It was not proposed that this could be done by single case study and reference was made to a paper previously presented at TELPhE on the Grenfell Tower Fire. Its significance was that it focused on the importance of the first order questions that determine the parameters of an inquiry, and the second order questions that the citizen not only needs to be able to ask, but to determine the veracity of the answers given.

While this questioning activity describes in no small measure technological competence it omits the importance of trust that is inevitably involved when citizens are dealing with "knowledges" beyond their experience. Covid 19 exemplifies this situation, but it also illustrates the importance of key competencies when functioning in a contingent situation. If citizens' understand *key concepts* such as chance, probability, and risk, they will be able to bring to bear an element of objectivity into what they are told, and more particularly how it is told by the media, as for example, the level of risk associated with the Astra-Zeneca and Johnson and Johnson vaccines.

It is argued here that *key concepts* are as much curriculum objectives as the kind of objective associated with *The Taxonomy of Educational Objectives*. Moreover, as several authors have shown they may be used to construct curriculum schema. A particularly good example of such a framework is provided by the Liverpool integrated for middle schools which has been shown to be generalizable at all levels of the curriculum [33]. A number of key concepts are revealed by the case study. Some of them could be the core or nucleus key concepts for the mind (concept) maps from which a curriculum may be constructed. For example "cause", "learning", and "socio-technical system".

Citizens use terms like "cause" and "learning" somewhat casually. "Correlation" and "Cause" are often confused. Understanding events that are related to technologies requires that we are precise. Both the Grenfell and Boeing studies show that the "apparent cause" of the fire could be attributed to a faulty refrigerator, and in the case of the crashes a piece of software. But the residents of Grenfell were quick to point out that had safe materials been used in the cladding a different story might have been told. Questions then arose about who approved the materials, who approved the redevelopment designs: questions that were asked in order to find someone to blame for the faulty authorisation of these designs. In the case of the Boeing crashes the company and investors were quick to blame the pilots but unravelling why the pilots could not control the aircraft led to the view that on the one hand the pilots should have been trained, and on the other hand to limitations in the design of the system both of which were due to company decisions relating to beliefs about the behaviour of investors. Thus, the beginning cause of the accidents would appear to be financialisation. The company had promoted a culture that focused on keeping costs down at the expense of quality. It failed to understand that the organization was a socio-technical system, or that units of the design such as the cockpit were also socio-technical systems.

The primary focus of this paper has been on technological literacy which embraces engineering literacy. It has been to show that the solution to technological problems, in particular those in which the citizenship has an investment, mostly involve "knowledges" other than those that are technical. It is not to argue that they do not require a qualitative understanding of engineering. It is to argue that because they are by their nature contingent an information giving curriculum based on a collection of traditional disciplines is unlikely to develop technological competency. The most likely curriculum to develop technological competency will be problem/project based, accompanied by a study of qualitative engineering. Because it is likely to require students to obtain knowledge independently, and because individuals and organizations learn, its base should be an active understanding of the nature of learning. Some examples of transdisciplinary programmes were mentioned together with some transdisciplinary texts but they erred on the side of information giving rather than problem solving and critical thinking which lie at the heart of technological competence.

TELPhE has never considered technological literacy as a competence and in consequence has never considered curriculum design from that perspective, the same is equally true of qualitative engineering which leaves wide gap in its understanding of technological and engineering literacy particularly as it applies to the citizenship.

Acknowledgements

I am grateful to Charles Larkin and his associates for allowing me to reproduce the draft report which I prepared for them that makes up the appendix.

My thanks to the unknown reviewers for their helpful suggestions and to Sarah Heywood, Alan Cheville, John Krupczak and Mani Mina for their varied and critical comments.

Notes and references

[1] (a) J. Krupczak et al. Defining technological literacy. *Proceedings Annual Conference of the American Society for Engineering Education.* Paper AC 2012-5100. 2012.

(b) J. Krupczak and J. W. Blake. Distinguishing engineering and technological literacy in Heywood, J and A. Cheville (eds) *Philosophical Perspectives on Engineering and Technological Literacy*. No 4. TELPhE Division American Society for Engineering Education. Washington DC. American Society for Engineering Education. 2014.

[2] J. Heywood. Toward technological literacy in Ireland: an opportunity for an inclusive approach in Heywood J and P. Matthews (eds). *Technology, Society and the School Curriculum. Practice and Theory in Europe.* Manchester. Roundthorn Press. P 234. 1986.

[3] loc.*cit* reference 1(b)

[4] Author. *Education and Training 1966. Statement No 2. The Council's Examination. Part 2 Syllabuses.* London Council of Engineering Institutions pp 8-9, 1966.

[5] (a) J. Heywood. American and English influences on the development of a transdisciplinary course on the Technologist and Society. Collected Papers of the Educational research and methods division of the American Society for Engineering Education. Annual Conference, Iowa State University. June 1973 pp 12 – 29.

(b) N. Carpenter and J. Heywood Undergraduate preparation for industry. A design for learning. Design Activity International Conference. London. Design Research Society August 1973.

[6] *loc.cit* ref 2. See also S. Owen and J. Heywood. Transition technology in Ireland. An experimental course. *International Journal of Design and Technology Education* 1, (2), 21 – 32 1990.

[7] J. Heywood and M. Mina The role of the transdisciplinary course in the reform of the Engineering Curriculum. *Proceedings Annual conference of the American Society for Engineering Education*, Paper 11678, June 2015.

[8] L. L. Bucciarelli. *Designing Engineers*. Cambridge MA. MIT Press. 1994.

[9] J. Heywood. The Idea of a firm as a learning organization and its implications for learning-how-to-learn. *Philosophical and Educational Perspectives in Engineering and Technological Literacy*. Issue 3. Division for Technological and Engineering Literacy and philosophy. TELPhE. Washington.DC. American society for Engineering Education. 2016.

[10] See chapter 4 on Concept learning J. Heywood. *Engineering Education. Research and Development in Curriculum and Instruction*. Hoboken NJ Wiley/IEEE Press.

[11] D. Drew. Moving the needle from Literacy to Knowledge. A. Cheville (ed). *Philosophical Perspectives on Engineering and Technological Literacy*. No 4. TELPhE Division American Society for Engineering Education. Washington DC. American Society for Engineering Education. 2017.

[12] J. Heywood, J and M. Lyons. Technological Literacy, Engineering Literacy, Engineers, Public Officials and the Public. *Proceedings Annual Conference American Society for Engineering Education.* Salt Lake City. 2018.

[13] *ibid.*

[14] J. Heywood. *The Human Side of Engineering*. San Raphael. CA. Morgan and Claypool. Chapters 1 – 3. 2017.

[15] Final Committee Report. The Design, Development and Certification of the Boeing 737Max. Prepared by the majority staff of the Committee on the Transportation and Infrastructure. September 2020. US Congress.

[16] In the three decades before the financial crash of 2008 the financial system changed from one that invested in the future of firms to one that maximised profits for shareholders who responded to the economist Milton Friedman's dictum that the purpose of the firm is to maximise returns to the shareholders. It is this process that is termed financialization. It is a process that completely changed the financial value system, not only the beliefs of those who ran it but, in particular, of those on the right of the political spectrum; a belief in the supremacy of the market.

Rana Foroohar [17] calls on the British economist and bank regulator Adair Turner to explain financialization [18]. She writes that according to him it is the securitization "*of existing assets (like homes, stocks, bonds, and such) and turning them into tradeable products that* *can be spliced and diced and sold as many times as possible-that is until things blow up as they did in 2008*." (p7, CS 2.2).

Foroohar continued "*the rest simply stays inside the financial system, enriching financiers, corporate titans and the wealthier fraction of the population which hold the majority of financial assets in the United States, and, indeed, the world*". In those circumstances one of the measures of financial success is the number of mergers completed because businesses could be paired back and assets sold as a means of making profit. Globalisation becomes important because firms go to where labour is cheapest. It was a process that was encouraged by governments.

Simple you might think; not so. Turner wrote "*The sheer complexity of the securitized credit and shadow banking system on the eve of the crisis is mind boggling*" (p 26). We can, however, understand that if only 15% of all financial flows go into investment in projects in the real world that that is not good for the economy, and, therefore for us. We can also appreciate that if the system depends on debt and the encouragement of the plebs to borrow that that, also, is not good for the economy. Yet, that is what happened and it was supported by policy makers and regulators who believed that more financial innovation was the key to economic success (p 29). But in 2008 it crashed, and many poor people were caught in debt, often with mortgages they could not afford. Worse, thirteen years on some are still in trouble; but, no one seems to care.

[17] R. Foroohah. (2016). *Makers and Takers. The Rise and fall of American Business*. New York. Crown Business. 2016.

[18] A.Turner. *Between Debt and the Devil. Money Credit, and Fixing Global Finance.* Princeton, NJ. Princeton University Press. 2016.

[19] The key concepts of socio-technical systems analysis are 'system' and 'central task'. Our understanding of behaviour in organizations depends on our appreciation that systems tend either to be open or closed. It was, for example, the purpose of Barnes analysis to determine the relative effectiveness of open and closed organizations in the electronics industry. As Jahoda said (in *The Education of Technologists,* 1963), "*Whether we think of the human organism or of an industrial enterprise as a system some interaction must take place between such systems and the environment*". It is this that the Tavistock Institute established empirically thus giving birth to socio-technical systems theory. F. E. Emery, F. E. *Characteristics of Socio-Technical Systems*. Doc 527. London. Tavistock Institute for Human Relations. 1959. See also F. E. Emery, (ed). *Systems Thinking.* Harmondsworth, Penguin. 1969,

[20] For a discussion of qualitative thinking in engineering and generally see J. Cowan. *On Becoming and Innovative University teacher. Reflection in Action*. Buckingham. SRHE and Open University Press. 1998.

[21] At a general level moving production half-way round the world, a long way from R and D may be harmful of innovation (CS 3.3). Pisano and Shih write, "When R & D and manufacturing are highly modular, the major characteristics of the product (features, functionality, aesthetics, and so on) aren't determined by the production processes, and the two activities can be located apart without any consequences. When modularity is low, the product design can't be fully codified in written specifications, and design choices influence

manufacturing choices (and vice-versa) in subtle and difficult-to-predict ways. In these cases keeping manufacturing near R & D is valuable”. One might add, since the culture created enhances the possibility of effective communication.

G. P.Pisano and W. C. Shih. Does America really need manufacturing? *Harvard Business Review.* March issue. 2012.

[22] *loc.cit* reference 8.

[23] E. Schein *Organizational Theory*. Englewood Cliffs, NJ. Prentice Hall. 1965.

[24] D. M. McGregor. *The Human Side of Enterprise*. New York. McGraw Hill. 1960

[25] B. T. Turner, *Management Training for Engineers*. London. Business Books. 1969

[26] L. B. Barnes. *Organizational Systems and Engineering Groups. A Comparative Study of Two Technical Groups in Industry*. Boston, MA. Harvard Graduate School of Business Administration. 1960.

[27] T. Burns and G. Stalker. *The Management of Innovation*. London. Tavistock. 1961.

[28] *loc.cit* reference 19.

[29] M. B. Youngman, R. Oxtoby, J. D. Monk and J. Heywood. *Analysing Jobs*. Aldershot. Gower Press. 1978.

[30] J. Heywood. *Learning, Adaptability and Change. The Challenge for Education and Industry.* London. Paul Chapman (Sage). 1989.

[31] D. F. Chambliss and C. G. Takacs. *How College Works*. Cambridge MA. Harvard University Press.2014.

They wrote “relationships are the necessary precondition, the daily motivator and the most valuable outcome. A student must have friends, needs good teachers, and benefits from mentors. A student must have friends, or she will drop out physically or withdraw mentally. When good teachers are encountered early, they legitimize academic involvement, while poor teachers destroy the reputation of departments and even entire institutions. Mentors we found, can be valuable and ever life changing…relationships are important because they raise or suppress the motivation to learn, a good college fosters the relationships that lead to motivation”.

[32] J. Trevelyan. *The Making of the Expert Engineer*. London CRC Press (Taylor and Francis). 2014.

[33] Described briefly in J. Heywood. *Assessment in Higher Education. Student learning, Teaching, Programmes and Institutions.* London. Jessica Kingsley, 2000.

APPENDIX

DRAFT

Boeing, Financialization (and) the Boeing 737Max Crashes (and the case for technological literacy)

1. Introduction

1.1. Within a period of 6 months Boeing's latest aircraft in the 737 series, the 737 MAX 8 was involved in two fatal accidents in which all the passengers and crews in the two aircraft lost their lives. Both the public and investors need to know and understand the causes of the accident. Given the suggestion that troubles experienced by the 787-Dreamliner while in service were due to financialization, it is not unreasonable to ask whether or not financialization had a role in the two 738 MAX accidents. But in asking this question, questions are necessarily asked about the knowledge and understanding (sometimes called technological literacy) that the public and investors should have to judge culpability on the one hand, and on the other hand the effectiveness (not efficiency) with which the organization achieves its goals. In trying to answer the question of the relationship with financialization the scope of that knowledge and understanding is displayed.

1.2. The study is presented in two parts. The first part, describes the long term drift toward financialization in the stock markets'. The effects of the merger of Boeing with McDonnell Douglas, and its impact on the development of the 787 Dreamliner are considered. Attention is drawn to the fact that conditions in the commercial market also impact on development and cost. While there are only two major manufacturers of airliners in the western world they compete for sales among multiple airlines, each with their own requirements. As with an automobile variants are developed. This part ends with a brief history of the variants of the 737 and Airbus 320 with whom it competes.

1.3. The second part is devoted to considerations of the two accidents which caused the grounding of the 737 MAX. Since the focus of the paper is on the public understanding of the issues, and because there is a vast popular literature on these events the prime sources used are well referenced commentaries in Wikipedia which include summaries of the accident reports, and selected articles including some written by the Pulitzer award winning aerospace journalist Dominic Gates.

1.4. In any discussion of Boeing its role in the United States economy should be understood. As of 2018, in terms of revenue, it is the second largest defence contractor in the world. It sells airplanes, rotocraft, rockets, satellites, telecommunications equipment, and missiles. It is the largest exporter in the US by dollar value. Seen in this light the mind-boggling sums that appear in this text are not as large relative to the organization as they may seem.

1.5, Its only competitor in large airline manufacture in the western world is Airbus; the story that unfolds is much about the competition between the two.

Part I

2. Financialization.

2.1. Financialization has its origins within the Chicago School of economists and, in particular, Milton Friedman. They held that the purpose of the corporation was to maximise financial value. It led to a particular view that the social responsibility of business is to increase profits. The person in the street would expect those profits to be re-invested in the Corporation. But this did not happen.

2.2. Rana Foroohar who has explained what happened in the world of finance during the last five decades [1] draws on a British financial expert Adair Turner [2] for an explanation. She writes "In simple terms what Turner is saying is that rather than funding the new ideas and projects that create jobs and raise wages, finance has shifted its attention to securitizing existing assets (like homes, stocks, bonds, and such) and turning them into tradeable products that can be spliced and diced and sold as many times as possible-that is until things blow up, as they did in 2008" (p7). A key weapon in this form of financing is the merger.

2.3. "Turner estimates that a mere 15 per cent of all financial flows now go into projects in the real economy. The rest simply stays inside the financial system, enriching financiers, corporate titans, and the wealthiest fraction of the population, which hold the vast majority of financial assets in the United States and, indeed, the world" (p7). So it is the rich get richer and the poor get poorer.

2.4. This move toward financialization happened in the three decades before the financial crash of 2008. The philosophy of the "Free Market" dominated thinking. For some politicians and economists the free market was superior to government. Government should, therefore, not attempt to regulate the market [3]. Adair Turner wrote, "When I became chairman of the UK Financial Services Authority in autumn 2008, I was soon aware that the presumption in favour of market completion and market liquidity-as many financial contracts as possible as widely traded as possible -was an accepted article of faith. As a result most policy makers far from seeking to constrain finance's remarkable growth, favoured deregulation, which could unleash yet more financial innovation" [p 29, 2]. The idea of deregulation became contagious and spread well beyond the world of finance. It was coupled with the view that companies, and individuals were not only capable but morally capable of carrying out their own self-assessments. It is clear, as will be shown, that this culture had infected those involved in the certification of aircraft.

3. The merger of Boeing with McDonnell Douglas and the 787 Dreamliner [4].

3.1. One instrument for releasing assets is the merger. Financiers are not concerned with what the companies do but with what assets can be released into the financial system. The aircraft industry has had its fair share of mergers. Mukunda links the merger of Boeing and McDonnell Douglas in 1997 to financialization on the one hand, and on the other hand to the troubles that the 787 Dream liner had [5]. He argues that the culture of McDonnell Douglas came to dominate that of Boeing, and that the cost cutting that ensued ensured that the high quality engineering culture that an aircraft requires could not be maintained. Michael Davis in his examination of the Challenger disaster shows clearly the tension between the management and engineering cultures in Morton Thiokol which built the rocket, and the role conflict that this caused for the vice president of engineering when his boss asked him to think like a manager rather than an engineer [p 43; 6]

3.2. Foroohah also draws attention to the Dreamliner as an example of the "close links between financialization and outsourcing to cheap labour countries, since the key goal of finance is to move liabilities (like labor costs and factories) off the balance sheet. The last few decades of outsourcing saved American business lots of money and helped push profit margins to record highs, but they also introduced a level of supply chain complexity and risk that companies are only just beginning to grapple with" [p 166, 7]. It is a situation that the COVID 19 pandemic is causing us to begin to understand; it was the undoing of the Dreamliner.

3.3. But, it also seems that moving production half way around the world, far away from R and D may be harmful of innovation in the long run [8]. Pisano and Shih write, "When R & D and manufacturing are highly modular, the major characteristics of the product (features, functionality, aesthetics, and so on) aren't determined by the production processes, and the two activities can be located apart without any consequences. When modularity is low, the product design can't be fully codified in written specifications, and design choices influence manufacturing choices (and vice-versa) in subtle and difficult-to-predict ways. In these cases keeping manufacturing near R & D is valuable"[9]. One might add, since the culture created enhances the possibility of effective communication.

3.4. Both Foroohah and Mukunda point to differences in the managerial approaches of Boeing and McDonnell Douglas. The former's approach was that of "engineering" whereas McDonnell Douglas was "risk averse and focused on cost-cutting and financial performance, and its culture came to dominate the merged company. It is well understood that organizational culture and motivation are closely related. Learning ceases or becomes sloppy when a work force is poorly motivated [10].

3.5. In 2019 the Pulitzer award winning aerospace journalist Dominic Gates said. "One of the great things about this beat is that I get to talk to blue-collar workers. I talk to white-collar engineers. I talk to executives. But when I first joined the company (*The Seattle Times*) in 2003 and started covering Boeing, it seemed like everybody who worked at Boeing hated the company. It was a really bad time 50,000 people had been laid off in the previous six years" which was the first six years of the Boeing McDonnell merger [11]. While his perspective supports Mukunda's thesis, it is qualified by the view that motivation "began to change at the end of my first year, when they announced that they were going to make a new airplane, the 787. Gradually over the next few years people regained their faith, they started hiring again and morale picked up. Over the years, there's been a constant sway of opinion within the workforce as to how they view the company, sometimes positive, sometimes negative" [12].

3.6. Nevertheless Foroohah reports that over the objections of the career-long Boeing engineers, the 787 was developed with an unprecedented level of outsourcing, in part, the engineers believed, to maximise Boeing's return on net assets. "Out sourcing removed assets from Boeing's balance sheet but also made the 787's supply chain so complex that the company couldn't maintain the high quality the airline requires. Just as the engineers had predicted, the result was huge delays and runaway costs"[13]. Foroohah noted that "consumers began to cancel their orders as the inability of suppliers to communicate with one another, deliver to specs (including safety), and bring designs in on time resulted in massive development delays. More than 25,000 employees went on strike in the middle of the project. And there were so many technical problems with one supplier that Boeing had to pay $80 million to buy the firm and integrate it into their existing operations. Ultimately the Dreamliner became an embarrassing money pit that has so far cost Boeing $28 billion more than it should have" [p 168, 14]. "By doing exactly what Wall Street wanted, they actually increased the risk" [15]. The question put by Larkin and Corbet is clearly triggered by this experience. But this leaves out the possibility that the market is equally influential in development, design and manufacturing decisions.

4. The market for airliners

4.1. Apart from Russia there are two firms that service the international market for passenger aircraft. These are Boeing based in the US, and Airbus based in France. They are in fierce competition with each other, and have a major place in the economies in which they are located. The largest part of that market is for short and medium haul aircraft. It follows that the market is a major determinant of design decisions, and these decisions may be of more significance than financialization. However, the market depends on what is offered as the basis for its negotiations, and what is offered may be directly connected to financialization. It is evidently easy to link fiancialization to general decisions relating to the development of a new aircraft, its overall design specifications, and the method of manufacturing [16].

4.2. An aircraft is a set of integrated sub-systems that functioning together meet the overall design specification. It is important to appreciate that in development this specification and the specifications of the sub-systems can be modified as difficulties emerge, or market requirements change. It is rather like the variations in a particular automobile as exhibits 1 and 2 show.

4.3. The design, development and manufacture of an aircraft is a massive complex venture undertaken within the framework of constraints imposed by the stakeholders and regulatory authorities. These constraints also impose limits on financialization in so far as the costs of meeting these requirements are concerned. Of these constraints two are in conflict, they are the market and safety. In such cases the regulatory authority is the umpire, it is therefore, important that the regulatory authority should be independent of all the other stakeholders.

5. The Boeing 737 series [17; 18] and Airbus 320 family of aircraft [19; 20; 21].

5.1. The Boeing Airplane Company was founded in 1916 in Seattle by William Boeing and has therefore a long history in the design, development and manufacture of aircraft [22]. The Boeing 737 was envisioned in 1964 as a supplement for the Boeing 727 on flights between 50 to 1000 miles [18]. It was to seat between 50 and 60 passengers. Up to the 737 MAX there had been 6 main variations. There were 7 other variants (e.g. Business jet; converted freighter program). The main variants are listed in exhibit 1.

5.2. Airbus resulted from a consolidation of the European aerospace industry in 1970 [19]. Thus while a new entity it had considerable experience of aircraft design and manufacture that resided in the companies it brought together. Its first product in 1972 was the A 300 which was the world's first twin aisled, twin engine aircraft. The A 310 was a shorter, re-engined and re-winged variant. The A 320 family (exhibit 2) was built on the success of these aircraft [20]. The variants of the A320 are shown in exhibit 2.

5.3. Aircraft are built in response to perceived and actual needs of the market. These are generally related to seat numbers, fuel and operational efficiencies. On offer will also be a range of engines from different manufacturers.

5.4. Variants of existing rather than new aircraft make it easier to gain certifications to fly from the regulatory authorities. The relationship between the plane maker and the regulatory authority is key for without a certificate an aircraft cannot fly. It will be observed that seating capacity is a key feature, and that this is adjusted by shortening or lengthening the aircraft. In general it is assumed that changes of length do not alter the essence of the aircraft. A key issue in the 737 MAX debate is whether or not it was in "essence" a new aircraft. Shortening or lengthening an aircraft may require the provision of different engines and wings. Sometimes outside events put pressure on both the airline companies and makers to change designs. In this respect the 2008 increase in the price of fuel had an impact on on-going developments.

5.5. At the same time the aircraft makers will be trying to maximise shareholder value and will want to avoid anything that rocks the boat: thus, there is always a tension between the market a safety, At the same time the makers do not go out looking for a crash, for a crash can damage a firm both commercially and financially, the latter by a change in rating in the finance market. This is what happened when the Boeing 737 MAX was grounded after two fatal crashes. At the same time Larkin's question is not unreasonable for the demands of Wall Street, which may mean cost cutting, might compromise design (of a system, sub-system) in respect of safety. The complexity of a modern aircraft makes such a proposition difficult to evaluate.

5.6. In the immediate aftermath of a tragedy, myth and counter myth are likely to be generated in the media as was the case with the Grenfell Tower fire in London [23]. This makes it more difficult to get at the truth. But as in the Grenfell fire accident that is often found when science and technology are applied to the issue.

Type	**Capacity and other**	**Market and competition**
737 Original (first generation)	Intended to supplement Boeing 727 on short hauls for 50 to 60 passengers. 60% of structure and systems of the 727 used in the 737 design.	Competition with BAC 111 and DC9. Structure gave the 737 – six abreast seating compared with the five seat structures of the BAC 11 and DC 9. In consultation with Lufthansa.
737-100	100 seat capacity. The 727 thrust reverser had to be redesigned including changes to the nacelle.	
737-200		United Airlines required the fuselage to be stretched by 1.93 m.
737 200 Advance	Increased range, more powerful engines, greater fuel capacity.	
Production ended 1988.		
737 Classic. (second generation) **Introduced in 1984.** **737-300**	149 seat capacity.	

	Engine had to be redesigned because of the size of the original, and the low ground clearance of the 737.	Fuselage stretched by 2.87m around the wing.
737-400	188 seat capacity.	Fuselage stretched by 3.0m
737-500	Direct replacement of the 737-200. 140 seat capacity.	Fuselage is 48 cm longer than the 737 200. In 2008 jet fuel reached a peak. 40% of the retail price of the ticket was for fuel compared with 15% in 2000. United Airlines Replaced all its 737 classic fleet with Airbus 320 aircraft to reduce fuel consumption.
737 NG (third generation) Variants -660, -700, -800 and -900. Introduced 1997	Seat capacity between 108 and 215. Longer range and larger variants than its predecessor. Reduced fuel consumption compared with classic range,	Competitor Airbus 320 family. Increased engine size necessitated ovoid shape to enable ground clearance
737 MAX (fourth generation)	Seat capacity 138 – 204 two class configuration. Variants Max 7, Max 8, and Max 9 replace 737- 700, -800 and 900. Aim to match A320neo.s 15% fuel burn advantage	Competitor proposed new Airbus 320 Engine size is increased giving a range of 5,954km to 7,084km. Fuel consumption reduced by 14% from the 737NG. A split tip winglet is used.

Exhibit 1. Derived from Wikipedia entries- Boeing 737 [8; 9].

Aircraft type	First comm flight	Variants of A 320	Capacity	Competition/other
A 320 (ceo)	Feb, 1987		Seats 150 - 186	B 737 DC9
A 321 (ceo)	March 1993	Stretched A320 by 6.94 m	Seats 185 -230	
A319 (ceo) [15]	August 1995	A 320 Shrunk by 3.73 m (7 fuselage frames)	Seats 124 - 156	B 737 – 300/-700
A 318	January 2002	2nd shrinking by 2.39 m	Seats 107 - 132	No longer in production
A320 (neo)	January 2015	3 – based on A319/A320/A321		Expected increase in fuel efficiency 15%

Exhibit 2. A320 Family of Airbus. (ceo – current engine option, original family; neo – new engine option). Based on Wikipedia.

Part II

6. The Context. -Lion Air flight 610 – 29th October 2018 [24].

6.1. The 737 MAX 8 was scheduled to fly from Jakarta (Indonesia) to Pangkai Pinang (Indonesia) with 189 people including 6 cabin crew, 1 child and 2 infants. As described in Wikipedia the flight "took off in a westward direction before circling around to the northeast heading, which it held until crashing offshore northeast of Jakarta in waters estimated to be up to 35m deep. The flight crew had requested clearance to return to the Jakarta airport 35 km into the flight. The accident was located 34 km off the coast of the island of Java"[25].

6.2. […] A preliminary report was issued by the Indonesian National transportation Safety Committee on the 28th November. "After airspeed and altitude problems an AoA (angle of attack) sensor was replaced and tested two days earlier on the accident aircraft. Erroneus airspeed indications were still present on the subsequent flight on 28th October which experienced automatic nose down trim. The runaway stabilizer non-normal checklist was run, the electric stabilizer trim was turned off, and the flight continued with manual trim; the issues were reported after landing" [26].

6.3. "Shortly after takeoff on 29 October, issues involving altitude and airspeed continued due to erroneous AoA data and commanded automatic nose-down trim via the Maneuvering Characteristics Augmentation System (MCAS). The flight crew repeatedly commanded nose-up trim over the final ten minutes of the flight". [27] As Gates reported, data from the Black box showed that the vane (sensor) "triggered MCAS multiple times during the deadly flight, initiating a tug of war as the system repeatedly pushed the nose of the plane down and the pilots wrestled with the controls to pull it back up before the final crash" [28].

6.4. "The preliminary report did not state whether the runaway stabilizer trim procedure was run or whether the electric stabilizer trim switches were cut out on the accident flight" [29].

6.5. It should be noted that on the 28th October flight a third pilot was travelling in the cockpit who was able to assist the pilots in overcoming the difficulty. Different pilots flew the accident flight.

6.6. Wikipedia noted that "Boeing pointed to the successful troubleshooting conducted on October 28th as evidence that MCAS did not change runaway stabilizer procedures and emphasised the longstanding existence of procedures to cancel MCAS nose-down commands" [30]. It should be noted that some immediate press reports and some investors put the accident down to pilot error.

6.7. The Indonesian authorities issued a final report one year later on the 25th October 2019. The first five and the ninth of nine factors reported as contributing to the accident were [31]:

"1. During the design and certification of the Boeing 737 MAX 8 assumptions were made about flight crew response to malfunctions which, even though consistent with current industry guidelines turned out to be incorrect".

"2. Based on the incorrect assumptions about flight crew response and an incomplete review of associated multiple flight deck effects, MCAS's reliance on a single sensor was deemed appropriate and met all the certification requirements".

"3. MCAS was designed to rely on a single AoA sensor, making it vulnerable to erroneous input from that sensor".

"4. The absence of guidance on MCAS or more detailed use of the trim in the flight manuals and in flight crew training, made it more difficult for flight crews to properly respond to uncommanded MCAS".

"5.The AoA DISAGREE alert was not properly enabled during Boeing 737 MAX 8 development. As a result, it did not appear during flight with the mis-calibrated AoA sensor, could not be documented by the flight crew and was therefore not available to help maintenance identify the mis-calibrated AoA sensor".

"9. The multiple alerts, repetitive MCAS activations, and distractions related to numerous ATC communications were not able to be effectively managed. This was caused by the difficulty of the situation and performance in manual handling. NNC execution, and flight crew communication, leading ineffective CRM application and workload management. These performances had previously been identified during training and reappeared during the accident flight".

6.8. During the year between the interim findings and the final report of the Indonesian authorities there appeared a report of an investigation by *New York Times* journalists in February 2019, several reports by Dominic Gates in *The Seattle Times,* and numerous other newspaper and magazine articles. A similar accident with the 737 MAX 8 in Ethiopia occurred on March 10th near Addis Ababa. (See exhibit 3). Gates reported that investigators at the crash site found the "plane's jackscrew, a part that moves the horizontal tail of the aircraft, and it indicated that the jet's horizontal tail was in an unusual position – with MCAS as one possible reason for that [32].

7. A *New York Times* Investigation of the Lion Air Crash reported February 3rd 2019 [36].

7.1. James Glanz and his colleagues, note that the development of the 737Max was in response to the announcement by Airbus late in 2010 that it would make a more efficient A320, This, as they put it, "amounted to a frontal assault on Boeing's workhorse 737" [37].

Flight 302 departed from Addis Ababa to Nairobi on March 10th at 0838 local time and six minutes later crashed. The Wikipedia report reads, "One minute into the flight, the first officer acting on the instructions of the captain reported a "flight control" problem to the control tower. Two minutes into the flight, the plane's MCAS system activated, pitching the plane into a dive toward the ground. The pilots struggled to control it and managed to prevent the nose from diving further, but the plane continued to lose altitude. The MCAS then activated again, dropping the nose even further down. The pilots flipped a pair of switches to disable the electrical trim system, they also shut off their ability to trim the stabilizer into a neutral position with the electrical switch located on their yokes. The only other possible way to move the stabilizer would be by cranking the wheel by hand, but because the stabilizer was located opposite to the elevator, strong aerodynamic forces were pushing on it. As the pilots had inadvertently left the engines on full take-off power, which caused the plane to accelerate at high speed, there was further pressure on the stabilizer. The pilots' attempts to manually crank the stabiliser back into position failed. Three minutes into the flight with the aircraft continuing to lose altitude and accelerating beyond its safety limits, the captain instructed the first officer to request permission from air traffic control to return to the airport. Permission was granted and the air traffic controllers diverted other approaching flights. Following instructions from air traffic control, they turned the aircraft to the east, and it rolled to the right. The right wing cane to point down as the turn steepened. At 8:43, having struggled to keep the plane's nose from diving further by manually pulling the yoke, the captain asked the first officer to help him to put the stabilizer back into neutral trim and turned the electrical trim tab system back in the hope that it would allow him to put the stabilizer back into neutral trim. However, in turning the trim system back on, he also reactivated the MCAS system, which pushed the nose further down. The captain and first officer attempted to raise the nose by manually pulling their yokes, but the aircraft continued to plunge toward the ground" [34].

All 149 passengers and 8 crew were killed in the crash.

A preliminary report was published on the 4th April: The interim report was published a year later on the 9th March 2020. Wikipedia summarise the findings of both reports, gives statements from the parties, and includes expert analysis. In the report it is stated that "the left and right angle of attack (AoA) values deviated by 59º. The AoA disagree message did not appear. The left minimum operating speed and left stick shaker speed was computed to be greater than the maximum operating without any invalidity detection. The pitch flight detector bars disappeared then reappeared with left and right displaying different guidance. The left sticker activated. The nose down trim (MCAS) triggered four times. The right over-speed clacker activated. On the third MCAS trigger there was no corresponding motion of the stabilizer, which is consistent with the stabilizer trim cutout switches being in the "cutout" position at that moment. The MCS design relied on single AoA sensor inputs making it vulnerable to undesired activation. The difference training from B737NG to B737 MAX was inadequate" [35].

Exhibit 3. Ethiopean Airlines Flight 302 crash 10th March 2019 [33].

Boeing proposed to upgrade the 737 with engines that would have the same fuel efficiency. Boeing then went on set about persuading its "customers and crucially, the Federal Aviation Administration that the new model would fly safely and handle enough like the existing model so that 737 pilots would not have to undergo costly retraining" [38]. The idea that training, even for experienced pilots, is costly may come as a surprise. But it does, so to eliminate it, is to reduce the overall cost to the customer. As Glanz and his colleagues pointed out, strategic decisions at this point set in trail decision making series in relation to engineering, business and regulation that might be related to the first accident.

7.2. At this time the accident was still under investigation and they noted that Lion Air had a long history of maintenance problems so, if the crash had been caused by poor maintenance that would have ruled out financialization as a prime cause. But the journalists recorded another factor that became a matter "intense debate" namely, the "determination of Boeing and the FAA that pilots did not need to be informed about a change introduced into the 737's flight control system for the MAX, some software coding intended to automatically offset the risk that the size and location of the new engines could lead the aircraft to stall under certain conditions" [39].

7.3. The journalists concluded that "the judgement by Boeing and its regulator was at least in part a result of the company's drive to minimize the costs of pilot retraining" [40]. This presupposes that a pilot cannot be told about the change and expect to cognitively accommodate it without retraining. Boeing evidently believed in the transfer of skill for it must have believed that the long established emergency procedures for the 737 wold enable the pilots to cope with a malfunction of the system (technical term –Maneuvering Characteristics Augmentation System (MCAS)) irrespective of their knowledge of its existence. If the airlines were convinced that there was not much difference between the new model and the old model, and that they would not have to pay for hours of training on a simulator they might be more easily persuaded to make the change. "So even though it is a different airplane design, the control laws that fly the airplane are designed to make the airplane behave the same way in the hands of the pilot" [41] said Boeings CEO. A view, in which, as indicated above, the FAA acquiesced.

7.4. This has to be seen against the factor that led to the inclusion of MCAS in the system which was to prevent the nose lifting up at low airspeeds to the angle at which it would stall because the larger engines, now mounted, might cause a de-stabilizing effect. But MCAS was written to use the aircraft's stabilizers in a different way to the way they were used on the previous versions of the 737.

7.5. In sum the journalists argued that the Lion Air Crash raises "questions about whether Boeing played down or overlooked largely for cost and competitive reasons, the potential dangers of keeping pilots uninformed about changes to a critical element in the plane's software" [42].

8. How the Boeing 737 MAX disaster looks to a software developer (*IEEE Spectrum*, April 18th 2019 [43])

8.1. In his article Gregory Travis argues that at the heart of the 737 MAX tragedies is a fundamental problem that goes back to the initial design which attempted to develop the 737 series faced with a specification that meant it had designed a new plane. In the article, in a box in Bold, *IEEE Spectrum's* Editor includes feedback to an earlier draft of the article from a 737 pilot for a major airline which reads, "Everything about the design and manufacture of the MAX was done to preserve the myth that 'it's just a 737. Recertifying it as a new aircraft would have taken years and millions of dollars. In fact, the pilot licensed to fly the 737 in 1967 is still licensed to fly all subsequent versions of the 737" [44]. Travis who apart from being a software developer owned and flew his own Cessna which had been updated in the previous year with a new autopilot the effect of which had been to require him to obtain a "Supplemental Type Certificate" because the autopilot manufacturer and the FAA agreed that the plane was so changed that is was no longer the same Cessna as it was when it was rolled off the production line.

8.2. One thing the 737 MAX was not was the 737 that "first appeared in 1967 […] a smallish aircraft with smallish engines and relatively simple systems" [45]. But as exhibit 1 shows the market demanded larger machines of ever increasing electronic, electrical, and mechanical complexity, to accommodate the increasing numbers of persons wishing to fly, or from its point of view to make flying cheap in order to attract much larger number of the populace to fly.

8.3. Travis begins with the reminder that the Carnot Efficiency principle that the hotter and larger a heat engine the more efficient it becomes. The larger the engine the less fuel per unit of power is used. When Boeing began to increase the size of the engines they found that there was little or no clearance with the ground so they had to ovalise the engine making that particular model of 737 very distinctive. This was not possible with the much larger fan size that was chosen of diameter 176 cms [46], and in order to facilitate an engine of this size it had to be mounted in front of the wing. Because this altered the centreline of the engines thrust, when power is applied to the engine, the aircraft has a "significant propensity to "pitch up" or raise its nose" [47]. "This propensity to pitch up with power application thereby increased the risk that the airplane could stall when the pilots "punched it" (as my son likes to say. It's particularly likely to happen if the airplane is flying slowly. Worse still, because the engine nacelles [48] were so far in front of the wing and so large, a power increase will cause them to actually produce lift, particularly at high angles of attack. So the nacelles make a bad problem worse" [49]. Travis considers this to be aerodynamic practice of the worst kind because at high angles of attack (AoA) the nacelles function as a wing and produce lift. "The lift they produce is well ahead of the wing's center of lift, meaning the nacelles will cause the 737 MAX at a high angle of attack to go to a higher angle of attack" [50].

8.4. Rectification of this defect would involve extensive and very costly modifications to the airframe. "What's worse, those changes could be extensive enough to require not only that the FAA recertify the 737 but that Boeing build an entirely new aircraft" [51] which would defeat the objective of producing an aircraft that was just another 737. However, a relatively cheap solution was available which was to introduce software that pushes the plane's nose down when it thinks that the plane might go beyond the limits of the angle of attack. It is this this software that is called MCAS in the text above. It means Maneuvring Characteristics Augmentation System which, if the AoA is too high, commands the trim system which makes the plane go up or down, to lower its nose. Thus, to function effectively, it has to have absolutely reliable information about the angle of attack.

8.5. For this purpose each side of the aircraft is fitted with two sets of AoA sensors (which are like wind vanes). “Normal usage is to have the set on the pilot’s side feed the instruments on the pilot’s side and the set on the copilot’s side feed the instruments on the copilot’s side. That gives a state of natural redundancy in instrumentation which can be easily cross-checked by either pilot. If the co-pilot thinks his airspeed indicator is acting up, he can look over to the pilot’s airspeed indicator and see if it agrees. If not, both pilot and co-pilot engage in a bit of triage to determine which instrument is profane and which is sacred” [52].

8.6. Travis writes, “When the flight computer trims the airplane to descend, because the MCAS system thinks it’s about to stall, a set of motors and jacks push the pilot’s control column forward. It turns out that the Elevator Feel Computer can put a lot of force into that column-indeed, so much force that a human pilot can quickly become exhausted trying to pull the column back, trying to tell the computer that it should not be happening”[53].

8.7. Certainly the reports of the accidents suggest that the pilots were engaged in a wrestling match. But, Travis continues, “Not letting the pilot regain control by pulling back on the column was an explicit design decision. Because if the pilots could pull up the nose when MCAS said it should go down, why have MCAS at all?” [54]. […] MCAS “denies the pilots the ability to respond to what’s before their own eyes”. And finally, “the software (on the 737 MAX) relied on systems known for their propensity to fail (AoA indicators) and did not appear to include even rudimentary provisions to cross-check the outputs of the AoA sensor against other sensors, or even of the other AoA sensor”.

8.8. Travis concludes, “It is likely that MCAS, originally added in the spirit of increasing safety, has now killed more people than it could ever have saved. It doesn’t need to be “fixed” with more complexity, more software. It needs to be removed altogether” [55]. It is a view that is not shared by Dhierin Bechai, an Aeronautical engineer.

9. The Boeing 737 MX Misconceptions: An Engineers View, Aug 21st 2019 [56].

9.1. Dhierin Bechai the author of this paper took a contrary position that while there was a lot wrong with the development and certification of the Boeing 737 MAX, and while the design of the MCAS system was weak, the aircraft needs the MCAS to achieve required feel forces, therefore, the MCAS should be improved.

9.2. Bechai was concerned that several damaging myths about the aircraft were portrayed in the media. In sum many people have been led to believe that the aircraft is aerodynamically unstable, and second that the MCAS was installed to prevent stalling, neither of which is true. Dhiern Bechai considers that the *New York Times* report is one of the best of its kind and should be read with an open mind. In exhibit 3 that part of the report dealing with the MCAS is shown. Mr Ludtke who is cited was a flight crew operations engineering analyst who was involved in the design of some of the other safety features of the aircraft. It will be noticed that while the principle was not new, having been used in the 737 NG, in the 737 MAX it was designed to use the stabilizers in a different way. At issue here is whether or not the text implies that the MCAS was included to prevent stalling?

9.3. My judgement is that many readers would take this to be the case. Similarly with the article by Travis (see exhibit 5 which repeats the key sentence in the text above). Also when explaining how the AoA sensors work Travis asks the reader to imagine what happens to your hand when you put it outside the window of your automobile and rotating it while travelling on the highway. “As you rotate your hand, your arm wants to move up like a wing, more and more until you stall your hand, at which point your arm wants to flop down on the car door”[57].

9.4. The truth of the matter is that while the MCAS system might help prevent a stall that was a secondary function, intended or not. Its purpose was made clear by Boeing’s CEO who is quoted by Bechai as saying “When you take a look at the original design of the MCAS system. I think in some cases, in the media, it has been reported or described as an anti-stall system, which it is not. It’s a system that’s designed to provide handling qualities for the pilot that meet pilot preferences. We want the aeroplane to behave in the air similar to the previous generations of 737s. That’s the preferred pilot feel for the airplane and MCAS is designed to provide those kinds of handling qualities at a high angle of attack” [58]. That feel is transmitted through the yoke.

9.5. Bechai offers the following argument which starts with regulations concerning stall characteristics shown in exhibit 6. He points out that the regulations do not allow abnormal nose pitching. He argues against the view that the aircraft is prone to stalling because of the lift and thrust of the engines, or the view that nacelle design was at fault because by far the largest destabilizing element of the aircraft is the fuselage. “The 3-4 meters nacelles with the 69.4 inch turbofan embedded are not providing moments sufficiently high to make the aircraft go from a stable to an unstable aircraft”[59].

9.6. He concludes, “So the MCAS is not about stall prevention nor about making an aerodynamically unstable aircraft stable. In the regulatory frame of stall characteristics (exhibit 6), the Boeing 737 MAX has a pitch up tendency at higher angle of attacks. This behaviour isn’t permissible but doesn’t mean the aircraft is aerodynamically unstable or controllable. It’s simply undesired behaviour because changing characteristics change the handling qualities of the aircraft” [60]. “I think”, he writes, “MCAS simply was a certification requirement to achieve required handling qualities. If the aircraft at tiny spots in the flight envelope develops undesired handling characteristics, this can be fixed by a robust augmentation system”. So why bother with MCAS when as Bechai demonstrates the plane is aerodynamically stable? The answer is as Travis asserts that it is a different plane and would, therefore, require a much more costly process of certification. At the heart of the matter is the desire to provide the airline industry with a plane that is begotten from the 737 NG which has the benefit that 737 pilots will easily adapt to the aircraft and require little training. So what did the pilots find out after the event that caused the furore about training?

10. The Speed Trim System and training

10.1. Dhierin Bechai explains that in certain circumstances because of the positioning of the engines on 737’s a high thrust setting can move the aircraft away from trim. In such circumstances a Speed Trim System returns the plane to trim. It functions so as to increase the stick forces so that it will be harder to move the plane away from its trimmed speed. Boeing’s description of the system is given in exhibit 7. In the 737 MAX the MACS was a module within this system. In contrast to the STS which is about speed stability the MACS is about speed stability. The effect on the control stick of STS is to make it difficult for crews to move the aircraft aware from trimmed speed, whereas the effect of MACS is to make the control stick feel lighter requiring the pilots to give more precise control of the stick. The complete system was meant to give the pilots the feel of the 737 too which they were used.

For this reason they would not require expensive training. However, the pilots of the 737 MAX were unaware of the inclusion of MACS and how it functioned. That they needed training is clear from the Indonesian authority's summary of the nine factors contributing to the crash listed above.

10.2. There is another reason for training which arises from the fact that Boeing were changing a fundamental philosophy, Gates use the term 'tradition' but philosophy is to be preferred since it conditions the beliefs and attitudes of the pilots, and any radical change in that philosophy has to be negotiated. The change was from the pilot having complete control of the aircraft to the aircraft being controlled the MCAS automatic control system without pilot input. It is well understood that in any system involving such change the individuals involved have to be prepared for such change if it is to be successful. This is an example of what Bechpai calls "sloppy" management.

11. Sloppy management

11.1. Management is used in the broadest sense of decision making: making sure that the right people are employed and the right things are done. Bechai gives two examples of "extremely sloppy" management that contributed to the crash. The first relates to the cockpit display, the AoA sensor and sales. Like cars aircraft are sold with optional extras. The instrument panel contains and AoA Disagree light which lights up when there is a difference of more than 5.5^{o} between the left and right sensors. According Bechpai it "was believed to be optional and made standard as part of the MCAS redesign. It now turns out that Boeing intended it to be standard for the Boeing 737 MAX, but it was linked to the optional item, and therefore not properly activated" [61].

11.2. More serious however was not going with two AoA sensors. Travis wrote, "It is astounding that no one who wrote the MCAS software for the 737 MAX seems even to have raised the possibility of using multiple inputs, including the opposite angle-of-attack sensor, in the computer's determination of an impending stall. As a lifetime member of the software development fraternity, I don't know what toxic combination of inexperience, hubris, or lack of cultural understanding led to this mistake"[62]. Bechpai is in no doubt that it is likely that this mistake was made because of a faulty risk assessment on the consequences of systems failures. The results of this assessment led Boeing to believe that linking MCAS to one AoA sensor was acceptable.

11.3. Details of that risk assessment had already been confirmed by *The Seattle Times*. Gates in an earlier article (March 17th/21st) had reported on Boeings "System Safety Analysis" of MCAS [63]. *The Seattle Times* confirmed that the safety analysis-

"Understated the power of the new flight control system, which was designed to swivel the horizontal tail to push the nose of the plane down to avert stall. When the planes later entered service, MCAS was capable of moving the tail four times farther than was stated in the initial safety analysis document".

"Failed to account for how the system could reset itself each time a pilot responded, thereby missing the potential impact of the system repeatedly pushing the airplane's nose downward".

"Assessed a failure of the system as one level below "catastrophic". But even that "hazardous" danger level should have precluded activation of the system based on input from a single sensor-and yet that's how it was designed" [64]

11.4. The more serious charge by both Bechpai and Gates is that the significant changes made to the MCAS authority did not initiate any further discussions with the FAA which brings the system of certification under the spotlight.

12. Certification [65]

12.1. The function of the Federal Aviation Authority (FAA) is to certify that a plane is safe to fly within certain conditions. Up to 2004 the FAA and Boeing collaborated in this process through Designated Engineering Representatives (DER). They were technical employees of Boeing who were appointed by and reported to their technical opposites in the FAA. After 2004 these safety engineers were appointed by and reported to Boeing managers and called Authorized Representatives (AR). As Gates puts it "Boeing now has an entire organization within the company so authorized. The individual FAA authorized reps-Boeing engineers – report up the chain to their Boeing managers, not the FAA" [66].

12.2. This move was very much part of the political culture of the times which favoured limited regulation, and delegation to the point of self-regulation. This seemed to be the direction in which the FAA was travelling. It was part of the prevailing culture of the "free-market".

12.3. Dominic Gates and Mike Baker concluded from reviews of documents and interviews with former and current engineers that "Many engineers, employed by Boeing while officially designated to be the FAA's eyes and ears, faced heavy pressure from Boeing managers to limit safety analysis and testing so the company would meet its schedule and keep down costs" […] "While fewer employees involved in certifications said they handled the pressure as a regular part of the job, others describe the work environment as hostile, focused on achieving FAA approval within the schedule and cost targets. Some of those workers spoke on condition of anonymity to protect professional relationships or for fear of retribution" [67]. Gates and Baker give two examples which have many similarities with the Challenger episode described above that highlight the differences between the requirements of management and those of engineering. The one in which the engineer concerned is named is given in exhibit 8. In the other case where Boeing had to give in to the demands a senior company engineer for more stringent testing on a system related to the new engines for the MAX he was "abruptly (removed) from the program even before conducting the testing he had advocated" [68].

12.4. If this lengthy news story is correct, and it seems to tally with the *New York Times* piece, then it is very difficult not to conclude that Boeing was more interested getting the finances right than in safety. But, and it is a very big 'but' no manufacturer is going to design an aircraft to crash. So while it may be argued that the examples given induce an organizational culture which serves fiancialization, it may equally be argued as Bechai does, that what happened, was more the result of sloppiness than anything else which was not helped by that Boeing's ability to put pressure on FAA people (paid for by itself) and inhibit the level of criticism required during the certification process. Either way, it suggests poor management and misunderstanding which might have been brought about by financialization.

For example, what was the effect on the loss of many thousands of worker after the 1997 merger on the institutional memory, the tacit knowledge that is built up about what things work and what things don't, which systems of communication work and which don't and so on. This problem is illustrated by Travis who wrote the "lines of code were no doubt created by people at the direction of managers. Neither such coders nor their managers are as in touch with the particular culture and mores of the aviation world as much as the people who are down on the shop floor […] Those people have decades of institutional memory about what has worked in the past and what has not " […] He might have added and how things work.

13. Takeaway for the public and investors

13.1. Bechai draws attention to the fact that "there's a big difference between the science and what is actually written and understood by the general public" [69]. That is his takeaway. The general public are seldom brought into contact with articles of the kind written by Bechai or Travis. In this case *The Seattle Times* gave a very creditable performance; its diagrammatic explanations were excellent. Not one of these articles is complete, each looked at the problem from a different perspective. They raise issues about the technological understanding that is required to understand the issues raised. How do relatives judge what is correct and what is incorrect? How much science/technology do they need to know to be able to judge the truth or falsity of a particular claim? As was shown in the Grenfell Fire tragedy the media can easily deceive the public.

13.2. But it is not only the public it is the investors who are ready to accept the argument that best seems to serve their interests. Like Boeing they were quick to blame the pilots. Bechai suggested that "many investors "talk in the direction of their investment and they are blinded by reality and when reality is presented to them in the form of thorough knowledgeable analysis, they see it as a direct attack on investment" [70]. (A circumstance commonly called cognitive dissonance). "That's not the case, aircraft are extremely complex products and when these products are put under the magnifying glass it might and likely has a connection with the investment". Those who purchase into such an industry should at the very least ensure that those they elect to represent them, know something about that complexity, ensure they have detailed technical reports especially about reliability and certification, and are able to ask pertinent questions about the detail of products, production and organization and their management. These qualities have on occasion been called technological literacy but they go well beyond the technical. In this sense it would seem that the vast majority of the public and investors are technologically illiterate.

"Early analysis revealed that the bigger engines, mounted differently than on the previous version of the 737 would have a destabilizing effect on the airplane, especially at lower speeds during high banked, tight-turn maneuvers, Mr Ludtke said. The concern was that an increased risk of the nose being pushed up at low airspeeds could cause the plane to get closer to angle at which it stalls, or loses lift, Mr Ludtke said".

"After weighing many possibilities, Mr Ludtke said, Boeing decided to add a new program – what engineers described as essentially some lines of code – to the aircrafts existing flight control system to counter the destabilizing pitching forces from the new engines".

"That program was the MCAS"

"MCAS according to an engineer familiar with the matter was written into the so-called control law, the umbrella operating system that, among other things, keeps the plane in "trim" or ensures the nose is at the proper angle for the plane's speed and trajectory. In effect the system would automatically push the nose down if it seemed that the plane's angle was creating the risk of a stall".

"Both MCAS and the so-called speed trim system- the automatic stabilizer controls used on the 737 NG and earlier versions- operate primarily via the horizontal section of the 737's tail fin, which consists of a relatively narrow "elevator" in the back and a larger surface called a stabilizer in the front. In manual flight, pilots move the nose up and down by pulling or pushing on the control-column, also called a yoke, to pivot the elevator one way or the other".

"Ordinarily, the stabilizers accomplish a more subtle task, making sure that the up and down forces on the tail keep the plane balanced around its center of gravity. Either pilot can control the stabilizers electrically using switches at the top of the yoke".

"MCAS was designed to use the stabilizers in a different way".

"The modified system's first task was to automatically off set the stall risk created by the change in the size of the location of the engines".

"MCAS was necessary for the airplane to be certified by the FAA to have met all the regulatory design requirements for stability and control", Mr Ludtke said".

"In addition to addressing safety MCAS also let the plane handle much like its predecessors from a pilot's perspective. In assessing whether existing 737 pilots would need to spend hours training on simulators to fly the MAX, the FAA would take into account how similarly the two versions handled".

Exhibit 4 Extract from Glanz, J. Cresswell, T.Kaplan and Z. Wichter (2019). Behind the Lion Air Crash, a trail of decisions kept pilots in the dark. *The New York Times*. February 3rd.

1. "This propensity to pitch up with power application thereby increased the risk that the airplane could stall when the pilots "punched it" (as my son like to say. It's particularly likely to happen if the airplane is flying slowly […]

2. "When the flight computer trims the airplane to descend, because the MCAS system thinks it's about to stall, a set of motors and jacks push the pilot's control column forward. It turns out that the Elevator Feel Computer can put a lot of force into that column-indeed, so much force that a human pilot can quickly become exhausted trying to pull the column back, trying to tell the computer that is really, really should not be happening"[…]

Exhibit 5. Two extracts from George Travis as cited in this text

25.203 Stall characteristics

"[a] It must be possible to produce and to correct roll and yaw by unreversed use of the aileron and rudder controls, up to the time the aircraft is stalled. No abnormal nose-up pitching may occur. The longitudinal control force must be positive up to and throughout the stall. In addition, it must be possible to promptly prevent stalling and to recover from a stall by normal use of controls".

Exhibit 6. Extract from documents published by the Government Publishing Office cited by Bechai (6/20- ??)

"The speed trim system (STS) is a speed stability augmentation system designed to improve flight characteristics during operations with low gross weight, aft center of gravity and high thrust when the autopilot is not engaged. The purpose of the STS is to return the aircraft to trimmed speed by commanding the stabilizer in a direction opposite the speed change. The STS monitors inputs of stabilizer position, thrust lever position, airspeed and vertical speed and then trims the stabilizer using the autopilot stabilizer trim. As the airplane speed increases or decreases from the trimmed speed, the stabilizer is commanded in the direction to return the airplane to trimmed speed. This increases control column forces to force airplane to return to the timed speed. As the airplane returns to the trimmed speed, the STS commanded stabilizer movement is removed"

Exhibit 7. Boeing's description of the speed trim system as cited by Dhierin Bechai.

"It's a Boeing manager who determines if an individual representative's performance is sufficiently cooperative, as evidenced by the experience of Mike Levenson, who has worked as an FAA representative at several companies and served at Boeing in an AR role at Boeing for five years until 2013"

"He said that while there's always pressure on FAA representatives in an aviation world full of deadlines and cost considerations, most industry managers are able to find a balance to ensure the ARs have independence. He said he didn't find that to be the case at Boeing".

Levenson worked on certifying aircraft repairs at Boeing and said her certified more than 500 in his time there, though he did not work on the MAX. On three occasions, he declined to certify repairs. The first two times, Levenson said he got called into a supervisor's office. On the third occasion, in June 2013, a proposed repair clearly did not meet all of FAA requirements, he said. After he declined to approve it, Levenson said, his manager "told me to go back and find compliance or my contracted would not be extended". Levenson agreed to do additional work and consulted with other college but still couldn't verify the repairs compliance. "When I reported this to my manager, I was told this was unacceptable, and was summarily dismissed the following day" […]

"The FAA said it had no record of Levenson filing a complaint. Levenson said he talked to the agency but didn't file anything formally"

Exhibit 8. Reported by Gates and Baker [Gates 28].

Notes and references

1. Foroohah, R (2016). *Makers and Takers. The Rise and fall of American Business*. New York. Crown Business.

2. Turner, A (2016). *Between Debt and the Devil. Money Credit, and fixing Global Finance.* Princeton, NJ. Princeton University Press.

3. Reich, R. B (2016). *Saving Capitalism. For the Many not the Few*. New York. Alfred Aknof

4. Wikipedia. Boeing 787 Dreamliner. https://en.wikipedia.org/wiki/Boeing_787_Dreamliner. Accessed July 3rd 2010 (last updated 29th June 2020).

5. G. Mukanda. (2014). The Price of Wall Street's Power. How the financial sector's outsize influence is undermining business. *Harvard Business Review* pp 70 -78 (June).

6. Davis, M (1998). *Thinking like an Engineer*. New York. Oxford University Press.

I have generalized the specific context on the basis that all organizations are made of work systems or sub-systems. Each of these develops its own ways of working, its own language. In effect it creates its own sub-culture. In this case it appears that the vice president, an engineer was the link between the executive and the engineers. As an engineer he had been opposed to the launch but he changed his mind under what seemed to be pressure from above. Michael Davis writes (p44) "One explanation of the difference (between engineering and management) would stress technical knowledge. Managers are trained to handle people. Engineers are trained to handle things. To think like a manager rather than an engineer is to focus on people rather than things. According to this explanation Lund was asked to concern himself primarily with the best way to handle his boss, the Space Center and his own engineers. He was to draw on his knowledge of engineering only as he might draw on his knowledge of a foreign language, for example, to help him understand what his engineers were saying. He was to act much as he would if he had never earned a degree in engineering"

"That explanation of what Mason was asking of Lund seems implausible. But if it seems implausible, what is the alternative? If Mason did not want Lund to treat his knowledge of engineering as peripheral (as it seems mason, also an engineer, did not do when he earlier re-examined the evidence) what was he asking Lund to do? What is it to think like an engineer, if not simply to use ones knowledge of engineering?" Michael Davis then seeks an answer to the question by first examining the codes of ethics that engineers have.

In this case the stakes for Morton Thiokol were extremely high not only because of the costs involved in not launching the rocket but its reputation. This created its own system which brought it into conflict with the engineering system via the human link thereby creating role conflict for that person. This position seems to be vindicated by Davis findings. He talks about environment rather than culture. "How might we change the environment? One way is simply to talk openly and often about what we want people to notice. For example, Lund would probably have refuse to do as Mason suggested if the people back at Morton Thiokol's headquarters in Chicago regularly reminded him that he was no ordinary manager: "we are counting on you to stand up for engineering considerations whatever anyone else does". Indeed had Mason heard headquarters say that to Lund a few times, he could hardly have said what he did say. He might well have deferred to Lund's judgement even though NASA was pressuring him. "Sorry", he could have said, "My hands are tied"."

7. *loc.cit* 4. " In 1990, Boeing was producing 80% of key components in house, including wings, fuselage and tail assemblies before the company contracted out such production to other suppliers. In 2005, Boeing sold its commercial aircraft plants in Kansas and Oklahoma, which together was the largest in-house aircraft-component maker within Boeing. The plants at the time produced parts for every Boeing commercial jet except the 717, supplied the fuselage sections and wing elements for four Boeing jets in addition to the 787, employing 7, 200 and 1, 300 respectively. By outsourcing Boeing achieved better financial returns and redistributed financial risk. By 2012, suppliers, particularly for 737NG series, were responsible for producing the bulk of the airframe, while in-house production accounted for less than 40% of a plane's parts".

8. Pisano, G. P and W. C. Shih (2012). Does America really need manufacturing? *Harvard Business Review.* March issue.

9. *ibid.*

10. *loc.cit* ref 1.

11. Blatchford, T (2019). Behind the byline: Meet aerospace reporter Dominic Gates. *The Seattle Times.* June 13 2019.

12. *ibid.*

13. *loc,cit* ref 5.

14. *loc.cit* ref 1

15. *ibid.*

16. *loc.cit* ref 5.

17. Wikipedia. Boeing. https://en.wiki[pedia.org/wiki/Boeing. (last edited July 3rd. 2020)

18 Wikipedia. Boeing 737. https://en.wikipedia.org/wiki/Boeing_737. (last updated July 1st 2020)'

19. Wikipedia. AirBus. https://en.wikipedia.org/wiki/Airbus (last edited 3rd July 2020)

20. Wikipedia. Airbus A320 family. https://en.wikipedia.org/wiki/Airbus_A320_family. (last updated June 21st 2020).

21. Wikipedia Airbus 319. https://en.wikipedia.org/wiki/Airbus_319. (last edited July).

22. *loc.cit* ref 4.

23. Heywood, J and M. Lyons (2018) Technological literacy, engineering literacy, engineers, public officials, and the public. *Proceedings Annual Conference American Society for Engineering Education*. Paper 23287.

24. Wikipedia. Lion Air Flight 610. https://en.wikipedia.orgwiki/Lion_Air-Flight-610. (last edited 30th June 2020. Accessed July 6th 2020).

25. *ibid*

26. *ibid.*

27. *ibid*

28. Gates, D (2019). Flawed analysis, failed oversight: How Boeing, FAA certified the suspect 737MAX flight control system. *The Seattle Times* 17th March 2019.

29. *loc.cit* Ref 24.

30. *ibid*

31. *ibid.*

32. *loc.cit* Ref 28.

33. Wikipedia, Ethiopian Airlines Flight 302. https://en.wikipedia.org/wiki/Ethiopian_Airlines_Flight_302. (last edited 22nd June 2020. Accessed July 6th 2020).

34. *ibid.*

35. *ibid*

36. Glanz, J. Cresswell, T.Kaplan and Z. Wichter (2019). Behind the Lion Air Crash, a trail of decisions kept pilots in the dark. *The New York Times*. February 3rd.

37. *ibid.*

38. *ibid.*

39. *ibid.*

40. *ibid.*

41. *ibid.*

42. *ibid*

43. G. Travis (2019). How the Boeing 737 MAX disaster looks to a software developer. *Design* Shortcuts to make a new plane look like an old familiar one are to blame. *IEEE Spectrum.* April 18th. https://sectrum.ieee.org/aerospace/aviation/how-the-boeing-737-max-distaer-looks-to-a-software -developer?utm_source=techalert&utm_medi

44. *ibid*.

45. *ibid*.

46. Wikipedia. Boeing 737 MAX. https://en.wikipedia.org/wiki/Boeing_737_MAX. Accessed July 3rd (last edited July 2nd 2020). Includes a description of engine development.

47. *loc.cit* ref 43.

48. Wikipedia. Nacelle. https:// en.wikepedia.org/wiki/Nacelle. Accessed July 3rd 2020. Housing separate to the fuselage which holds the engine

49. *loc cit* ref 34.

50. *ibid*.

51. *ibid*.

52. *ibid.*

53. *ibid.*

54. *ibid*.

55. *ibid.*

56. Bechai, D (2019). The Boeing 737MAX Misconceptions. An engineer's view. August 21st, Seeking Alpha. https://seeking alpha.com/article/4286602-boeing-737-max-misconceptions-engineers-view?lift_email_rec=false.

57. *loc.cit* Ref 43.

58. *loc.cit*. Ref 56.

59. *ibid.*

60. *ibid*.

61. *ibid*.

62. *loc.cit* 43.

63. *loc.cit* Ref 28.

64. *ibid.*

65. Gates, D and M. Baker (2019). Engineers say Boeing pushed to limit safety testing in race to certify planes, including 737 MAX. *The Seattle Times*, 5th May 2019.

66. *ibid.*

67. *ibid.*

68. *ibid.*

69. *loc.cit* Ref 56.

70. *ibid*.