Weight Reduction Methods for the SAE Aero Design Competition

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Abstract

The Society of Automotive Engineers (SAE) has been hosting the Aero Design competition for 26 years. Kansas State University (KSU) has been a competitor at these events for the past 11 years and has enjoyed a history of success, including two overall victories. The format and rules of the SAE Aero Design competition encourage learning and innovation by requiring that only students make up the team and perform all of the design work and fabrication. This allows students to get a complete engineering experience encompassing the full design, build, and test engineering process before they step foot into the workforce.

For the 2011-2012 competition year, the KSU SAE Aero Design Team looked to improve upon an already proven, but heavy, design that finished 2nd in the 2011 Aero Design West competition. The team identified two main areas that could be redesigned to allow for a lower weight while retaining enough strength to handle the loads it would see in competition. These two areas were the fuselage and the landing gear. Complicating the redesign was the rules requirement that no fiber reinforced polymers could be used.

This paper and poster covers decisions the team made to design a new fuselage and landing gear structure, as well as fabrication issues and test results. The team utilized SolidWorks® and Finite Element Analysis (FEA) to design the new components, which allowed the parts to be "virtually" built and tested without spending any money on materials and fabrication until the final design was chosen. After many iterations, the design result was a cylindrical fuselage with rectangular cutouts with a significant weight reduction. Some of the difficulties that had to be overcome included how to fabricate such a shape and how to mount parts both internally and externally to a rounded surface. To reduce weight in the landing gear, the team came up with a unique idea to combine both the landing gear and the wing mount into one piece. This simplified what used to be many components into one component, allowing for efficiency in both the fabrication as well as in the assembly of the aircraft. Reducing down to a single component also resulted in significant weight savings. The new fuselage and landing gear designs were a huge accomplishment for the team. This process taught the team about looking at the big picture, meaning to not only look at the main goal (weight reduction) but also all of the secondary necessities (cost, ease of fabrication, assembly). The unique design was proven at the 2012 Aero Design West and East competitions. Not only did the fuselage and landing gear hold up to the rigors of competition, but the ability to replace components and reduce assembly time proved to be crucial parts of the team's ability to compete.

Introduction

Overall aircraft weight is an important factor in the SAE Aero Design competition due to engine and aircraft size being limited by the rules. In the past few years, teams have been able to take these limitations and create an aircraft with an overall gross lift of 40-45 pounds. Because flight score is determined almost solely by the amount of payload lifted by the aircraft, every ounce that can be moved from the empty weight of the aircraft into the payload bay results in a higher score. Most top teams have similar gross lift capabilities; therefore, the winner is usually the team with the lightest aircraft. This was the result of the 2011 Aero Design West competition, when KSU's team had the highest gross lift by several pounds, but finished second to a team with an aircraft so light it negated the advantages of KSU's high gross lift capabilities. This 2nd place finish motivated the team to focus on weight reduction for the 2012 competition aircraft.

With no changes being made to the competition rules and a reduction of experienced team members due to graduation, the team decided to start with the same basic design from 2011 and optimize the aircraft based on its performance during the previous year. To reduce the weight of the aircraft, the team identified three key areas where a weight reduction could be achieved without affecting the strength or reliability of the components: fuselage, landing gear, and wing. The rest of this paper will discuss the changes made to each component, results of these changes, technical accomplishments, and design lessons learned.

Fuselage

The 2011 design utilized a cylindrical fuselage. While this design provided a reduction in drag compared to fuselages with a non-circular frontal area, there were some issues with the design. A full-walled cylindrical tube made access to the various electronics in the front of the aircraft difficult. Attaching the wing and landing gear to the fuselage also became difficult due to the lack of flat surfaces. This issue will be discussed further in the landing gear section. The 2011 fuselage had a wall thickness of less than 1/8 inch, an outer diameter of four inches, a length of 20.25 inches, and weighed two pounds. While this is fairly light, the team set out to reduce this weight by half and fix the accessibility issues in the process.

To reduce weight, the team looked at using a "frame and stringer" structure similar to what is used to build commercial airliners. This structure proved too complex on such a small scale. However, the team theorized that the strength and light weight of this structure could be approximated by cutting pockets out of the wall of a cylindrical tube. Based on the given dimensional limits and team requirements for electronics and payload, it was decided that the fuselage would have a 4-inch inner diameter and a length of 17 inches. Using the FEA package of SolidWorks® allowed the team to optimize the design without spending money on the fabrication or testing of models. Multiple iterations of the design were analyzed and it was determined that cutting pockets out of a tube wall allowed the tube to maintain enough strength to handle landing loads and reduce weight in the process. The fuselage was tested to a 4G load to simulate a worst case scenario landing. The final design consisted of cutting a linear pattern of 3in x 2.25in pockets out of the tube and cutting that pattern about the axis four times for a total of 16 pockets. This essentially created a design with 1-inch frames and 7/8 inch stringers simplified into a one-piece structure. The wall thickness of the tube was increased from the previous design to a thickness of 1/8-inch. To handle stress concentrations that appeared in the corners of the pockets, a ¼-inch fillet was added to all corners. The final fuselage component weighed one pound; a 50% reduction of weight from the previous year. The new fuselage also retained enough strength to meet the requirements of the competition.

Landing Gear

To attach both the landing gear and wing mounts to the fuselage, the previous design used brackets to "box out" the fuselage and provide flat mounting surfaces. These increased drag and added weight. The team designed an integrated landing gear/wing mount component that reduced the number of parts from eleven down to only 3. This new landing gear was made of sheet aluminum that had to simply be laser cut and then bent to shape. This design simplified the manufacturing process, allowing multiple (spare) sets of landing gear to be produced both quickly and at low cost. The landing gear was designed to yield rather than fracture. This meant that upon experiencing either a 4G landing or 2G turn (worst case scenario forces that could be imposed by either the wheels or the wing), the component could survive well enough for the aircraft to complete its flight. Once back on the ground, the landing gear could quickly be replaced if structurally damaged.

Wing

The already proven wing design utilized a balsa sheeted foam core structure. A solid balsa leading edge or internal balsa spar could also be used for additional strength. The previous design used a one inch leading edge and a ½-inch spar placed at the quarter chord position. The team theorized that since the spar was closer to the center of mass of the wing, it could handle the bending moment of the wing more efficiently, allowing use of less material. After building and destructively testing multiple test sections, it was found that a ½-inch leading edge and ¾-inch spar provided an even stronger wing that would weigh up to two pounds less than the previous year's wing. Unfortunately, the as-built wing was 1 ½ pounds heavier. After investigation into why this happened, the team learned a very important lesson. The balsa wood used for the test sections had a very low density, while the balsa used in the production wing had density values that were all higher than the test section. This higher density balsa actually provided even more strength than the test section showed, but since the test section met the design requirements, this added strength was unnecessary especially considering the resulting weight penalty.

Biographical Information

Christopher James, Kansas State University
Christopher James is a senior in the Mechanical and Nuclear Engineering (MNE) Department at Kansas State University. He served as Team Leader for the SAE Aero Design Team for the 2011-2012 season and has been a member of the team for three years. Christopher is currently co-leading the team and plans to graduate with his B.S. in mechanical engineering in December.

B. Terry Beck, Kansas State University
Terry Beck is a Professor of Mechanical and Nuclear Engineering at Kansas State University (KSU) and teaches courses in the fluid and thermal sciences. He conducts research in the development and application of optical measurement techniques, including laser velocimetry and laser-based diagnostic testing for industrial applications. Dr. Beck received his B.S. (1971), M.S. (1974), and Ph.D. (1978) degrees in mechanical engineering from Oakland University.

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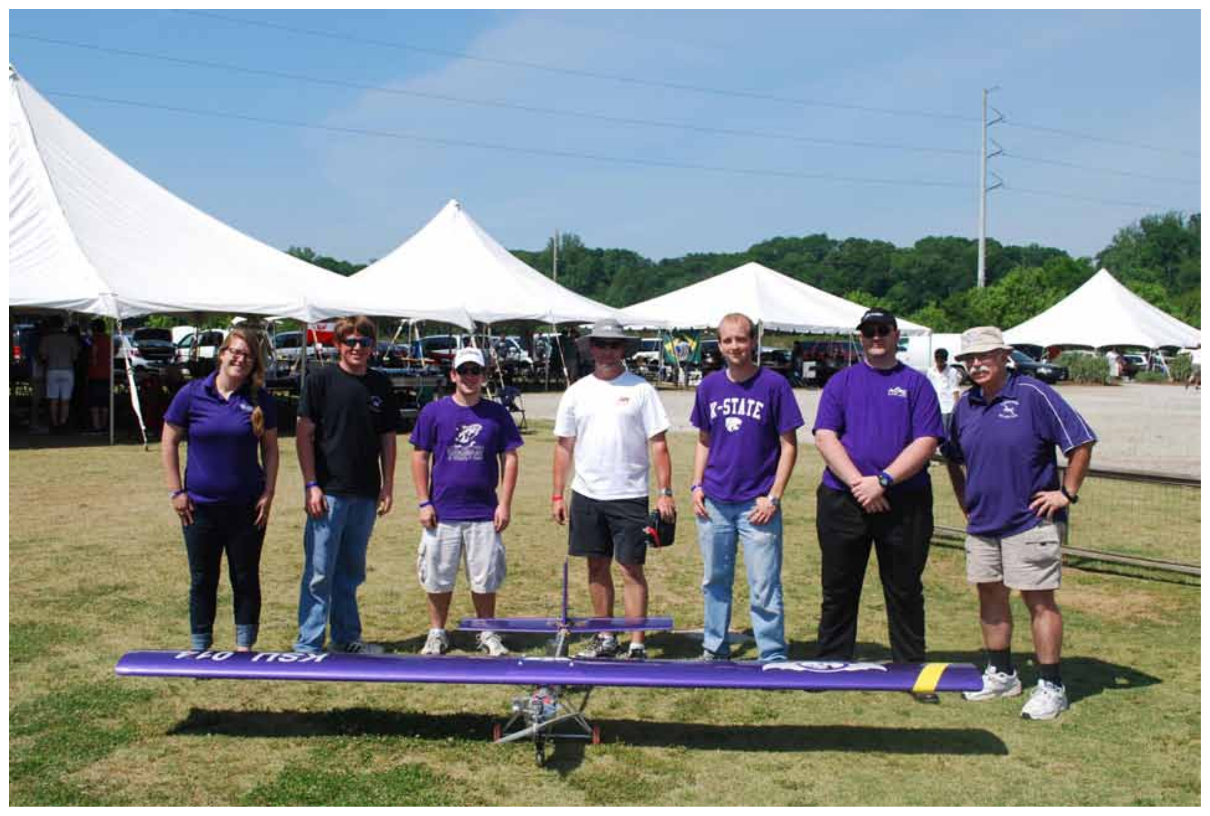
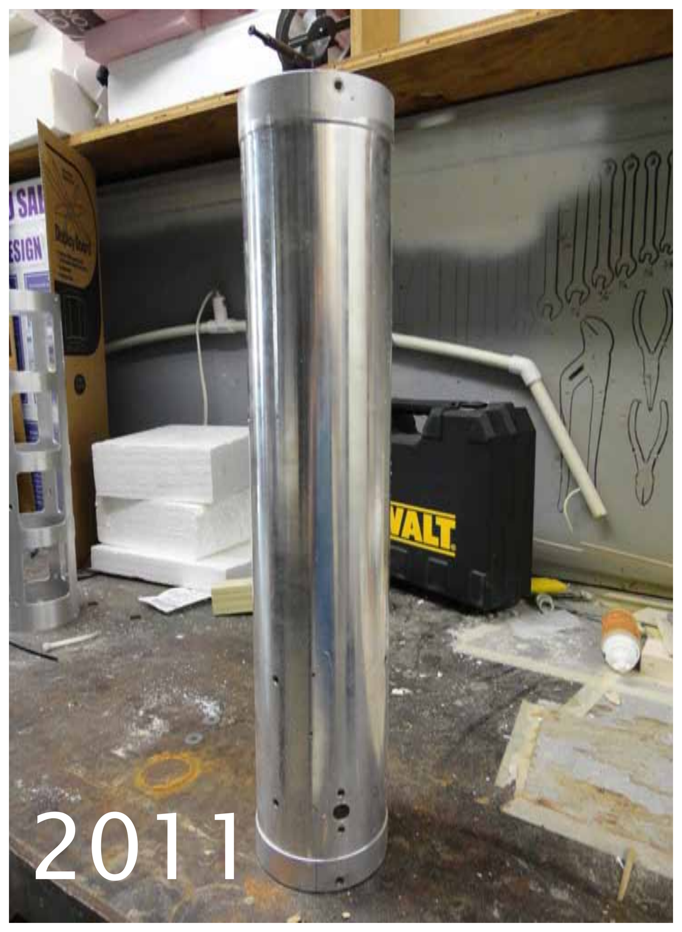
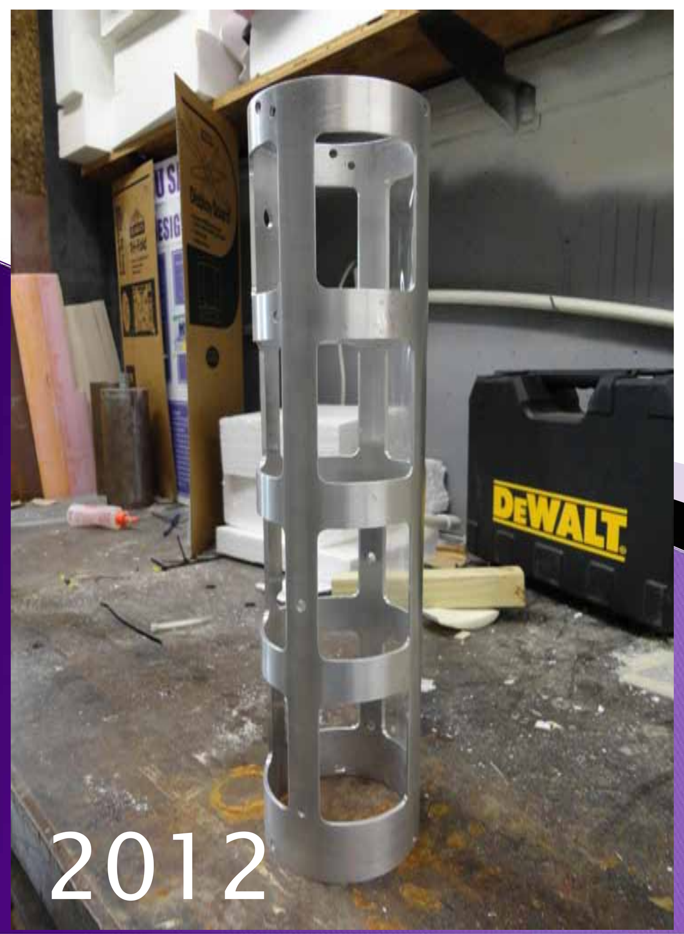
Introduction



Empty weight is an important aspect of aircraft design in the SAE Aero Design competition. A large portion of a team's score is based on the amount of payload that the team's aircraft can lift. Therefore, the more weight that a team can remove from its plane, the more payload they can lift. For the 2012 season, Kansas State University's Aero Design Team focused on reducing weight from a basic design that had proven successful in the past.

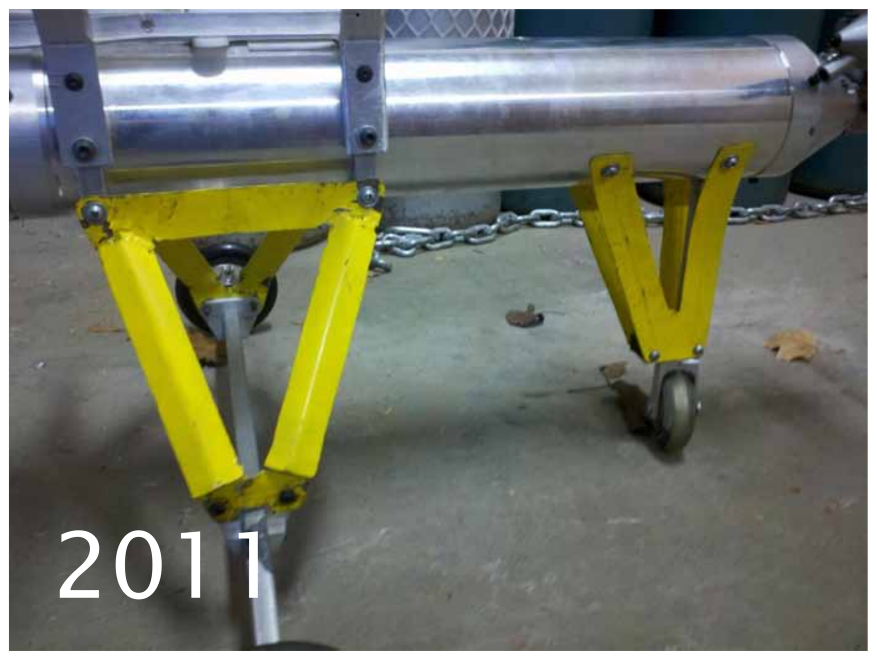
Fuselage

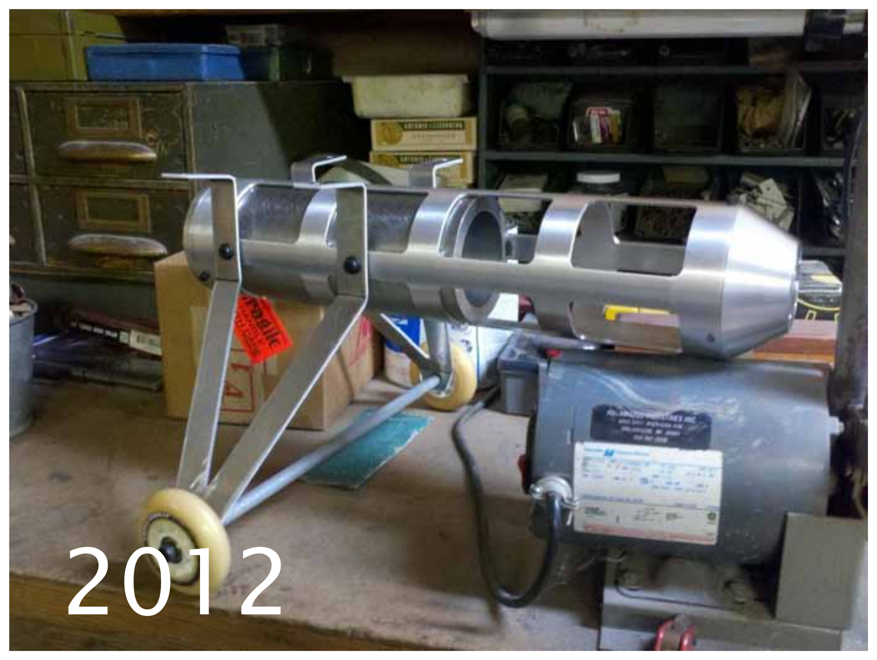




To reduce fuselage weight, a one-piece frame and stringer structure was used. This reduced weight while maintaining strength as compared to the previously used solid cylinder design. The one piece design was manufactured by cutting rectangular pockets out of a solid tube. This design allows fewer parts and a more simple construction as compared to a typical frame and stringer construction. The openings also allow for easier access to the electrical and structural components that are housed in the forward section of the fuselage. The 2011 design weighed 2 lbs while the 2012 design weighs only 1 lb. Both designs have similar strength and payload capabilities.

Landing Gear

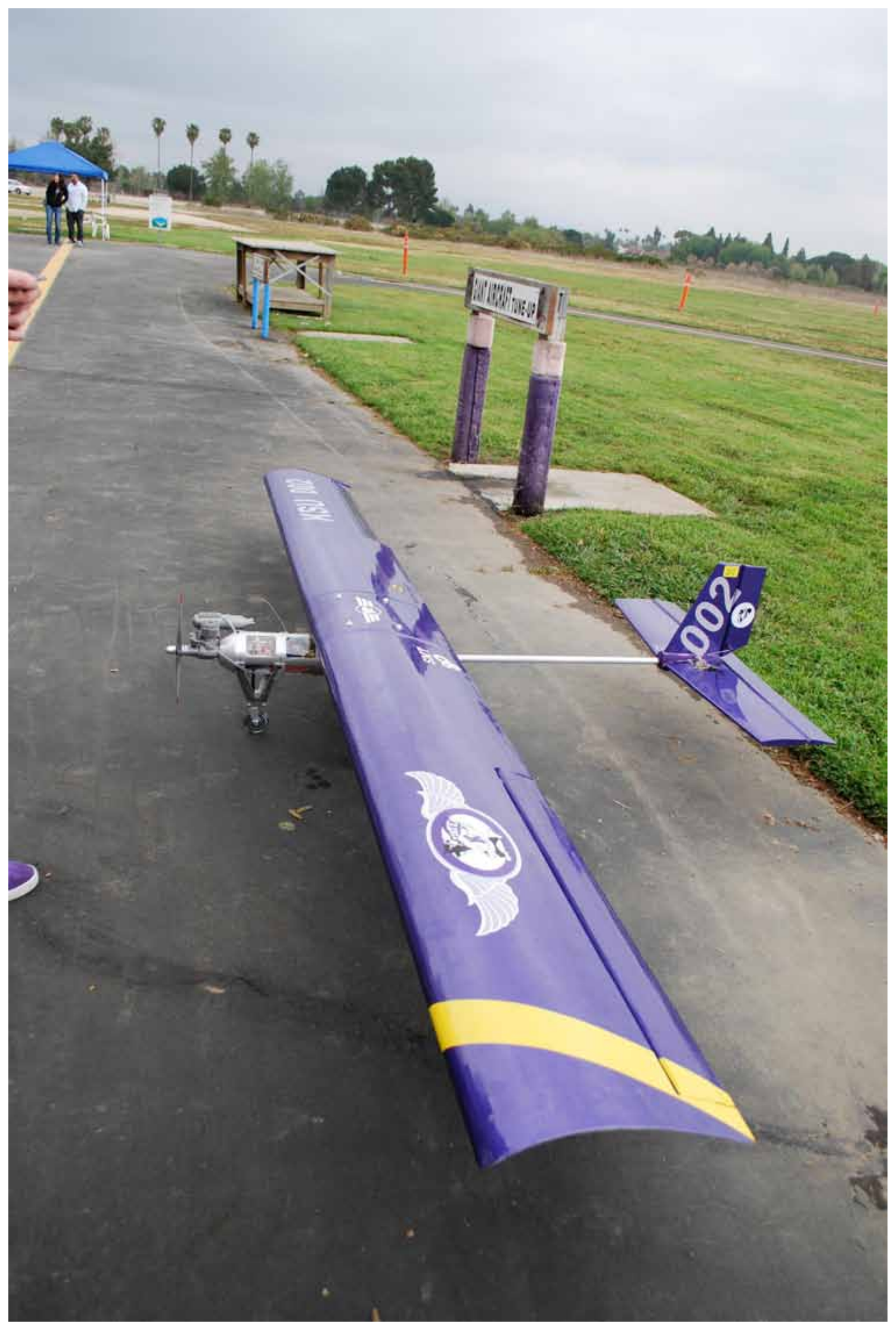




The landing gear design focused on reducing the number of components to reduce weight. By combining the wing mount and landing gear, the number of parts was reduced from thirteen to three. This reduced weight by 45%.

Wing

Weight reduction in the wing became a great learning experience. After experimenting with using various thicknesses of spar and leading edge balsa, an optimal design was found. However, due to the varying densities of balsa, the final product was two pounds heavier than expected. It was learned that attention to detail is necessary in every aspect of the aircraft design.



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