SAE Aero Design

Mid-point Review

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1) Introduction

The SAE Aero Design Competition is an event that is held annually for college students. Teams from all over the country gather and compete in three unique classes: Regular, Micro, and Advanced. The capstone team is tasked with the design and construction of an airplane that adheres to the requirements of the Regular class competition. There are many constraints that the competition has to make the task complex and difficult. The competition provides a chance for engineering students to learn something about designing and building a product and having fun while doing it. Most learning has been done in the classroom, so this project gives engineering students the chance to get hands on experience which will help in the future for the engineering profession. This report includes the problem definition, details on fabrication of the airplane, a final design, a bill of materials, and a project plan.

2) Problem Definition

Need Statement

Northern Arizona University does not have an airplane design to compete in the SAE Aero design competition, so the team is tasked with the design and construction of the airplane.

Project Goals

The goal of this project is to design and build an airplane that satisfies all SAE Aero design competition requirements and bring it to competition. It is important to aim high when setting goals, so the team will aim to win the SAE Aero Regular class competition. This project will be very educational in the manufacturing process, as well as the design aspects that will be needed to complete the airplane. Writing a report and orally presenting the final product is required, so the team will compile an exceptional report and presentation detailing the design and manufacturing processes.

Objectives

Table 01. Objectives

Objective	**Measurement**	**Unit of Measurement**
Carry max payload	Weight	Force pounds (lb)
Carry a payload from point A to B	Distance	Feet (ft)
Small turning radius	Distance	Feet (ft)

Table 1 contains the objectives that the team has decided are critical for the project. Carrying a max payload is important as the competition adheres to teams that can lift the most weight. To complete a circuit and get a score in the competition, the payload must be moved from one point to another. A small turning radius for the aircraft allows for faster circuit completion resulting in a higher score in the competition.

Constraints

1. Aircraft Dimension Requirement

The dimension must not exceed 175 inches [1].

2. Material and Equipment Restrictions for Regular Class

The use of Fiber – Reinforced plastic (FRP) is not allowed, except in the motor mount, propeller, landing gear and control linkage component. Also, not allowed is the use of rubber bands to make the wing retain to fuselage. Furthermore, any types of gyroscopic or other stability assistance are not allowed [1].

3. Aircraft System Requirements

The airplane requires the use of a electric single motor, gearboxes, belt drive systems, and propeller shaft extensions are allowed in tow condition (one-to-one propeller to motor RPM should be maintained) and the prop(s) must rotate at motor RPM [1]. The battery should have: 6

cell (22.2 volt) Lithium Polymer (Li-Poly/Li-Po) battery pack. The minimum requirements for Li-Po battery are: 3000 mAh, 25c) and homemade batteries are prohibited [1]. A 2015 version 1000 watt power limiter from the SAE supplier is required and supplied by Neumoters.com [1]. For the radio system the battery should have a minimum capacity of 1000 mAh [1].

4. Payload Requirements

For the payload, the team will focus on the interior dimension and we must follow the requirements in Table 2 [1].

Table 02. Length Width Height Tolerance For Payload Bay

Length	Width	Height	Tolerance
10.00	4.00”	4.00”	+ 0.125”, - 0.000”

The airplane should have one or more removable access for the payload bay. The payload interior surfaces have to be unbroken and smooth. The payload must also be secured to the airframe, as well as contain payload plates. The only penetrations are allowed in the payload bay surfaces is □payload support assembly. The support assembly for the payload must be removable and the bay will never considered as payload [1].

5. Other Requirements

The airplane must take off within a maximum distance of 200 ft. Likewise, the airplane must land within a maximum distance of 200 ft. Also, the time to complete all aerial tasks must be no more than 180 seconds [1].

6. Quality Function Deployment and House of Quality

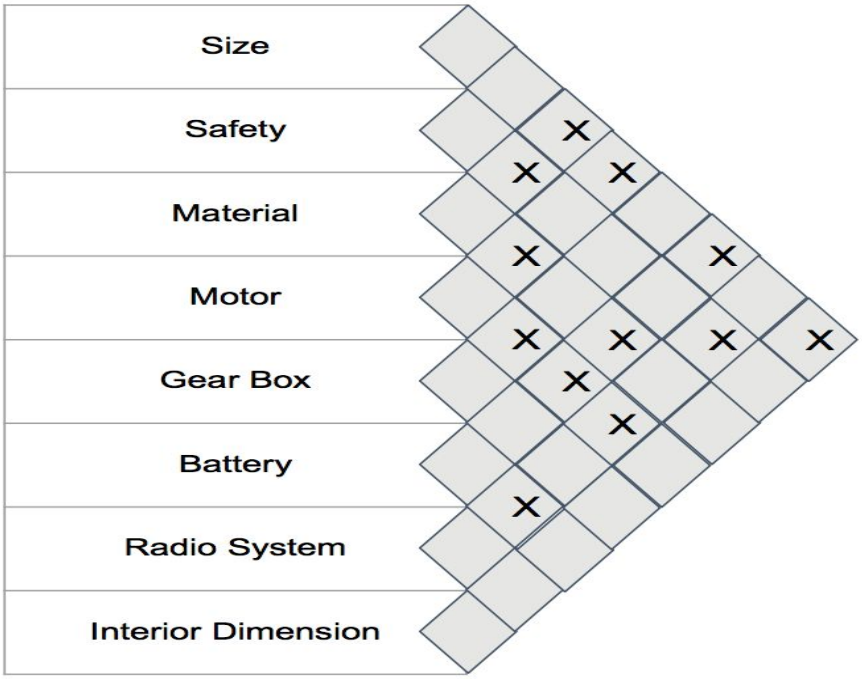
In Table 3 below, compared are the regular class design requirements with engineering requirements. These comparisons are given a score, then the engineering requirements are ranked by importance. Safety, material and motor were found to be the most important.

Table 03. Quality Function Deployment

Regular Class Design Requirements	**Weights**	Size	Safety	Material	Motor	Gear Box	Battery	Radio System	Interior Dimension
AIRCRAFT DIMENSION REQUIREMENT	5	9	1	0	0	1	0	0	9
MATERIAL AND EQUIPMENT RESTRICTIONS FOR REGULAR CLASS	5	3	9	9	9	1	3	3	1
AIRCRAFT SYSTEM REQUIREMENTS	5	3	9	3	9	1	9	9	0
PAYLOAD REQUIREMENTS	5	3	3	9	3	1	3	0	9
	Raw score	90	110	105	105	20	75	60	95
	Scaled	1	1	1	1	1	1	1	1
	Relative Weight	14%	17%	16%	16%	3%	11%	9%	14%
	Rank	5	1	2	2	8	6	7	4

In the house of quality, Table 4 below, the team took the engineering requirements from the Quality Function Deployment, Table 3, above to compare them with each other. The comparison will help the team know which requirements are related with the others.

Table 04. House of Quality



3) Fabrication

Wing

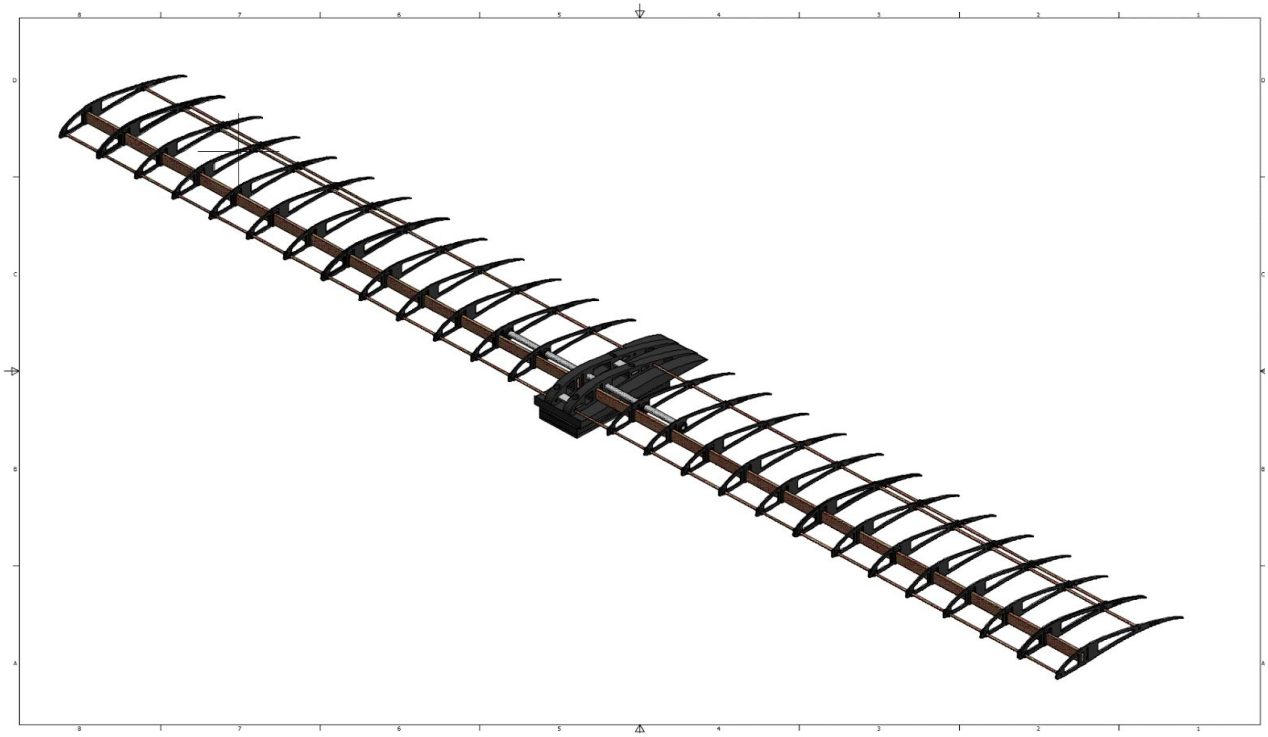


Figure 01. Final Wing Design

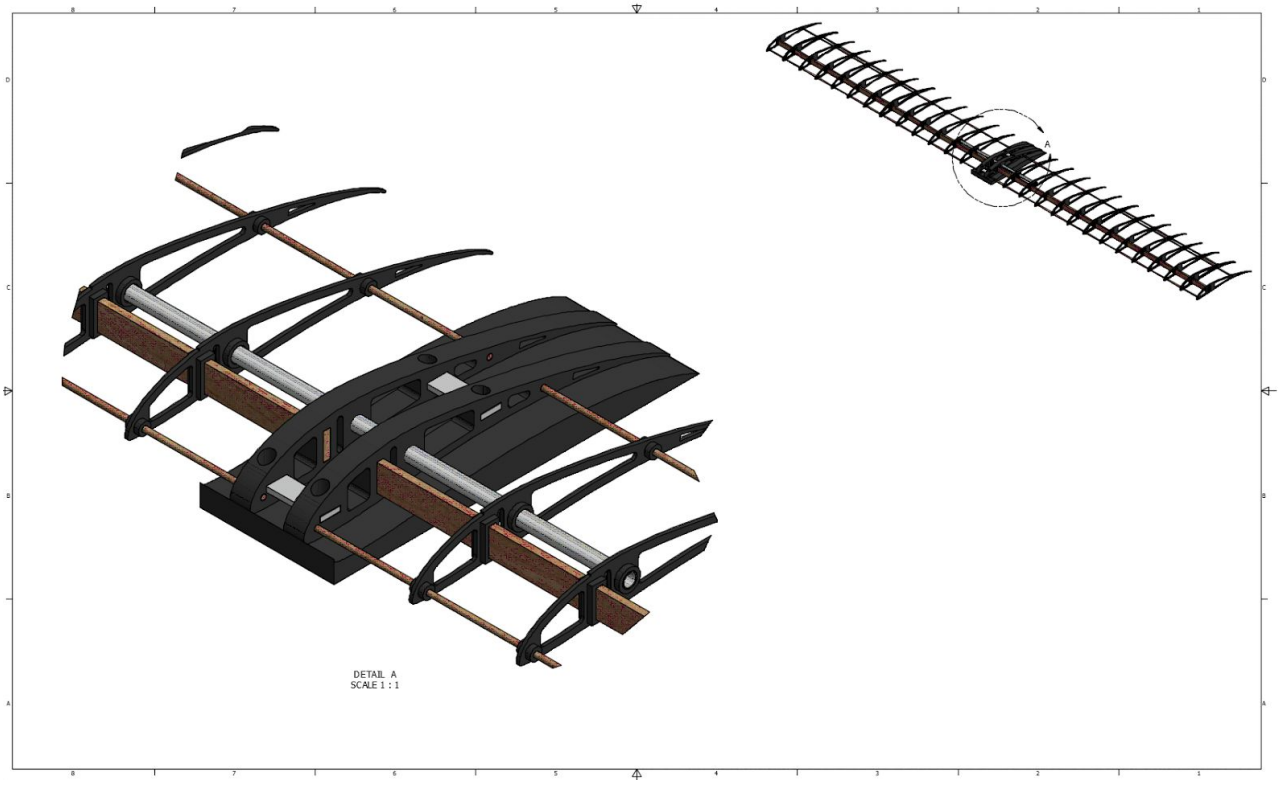


Figure 02. Center Piece of Wing

The wing has a specific rib shape to create the most lift with minimal speeds, which are the conditions our plane will be flying with in the competition. The design that we decided to go with is the S1223 airfoil. This design is specific to the SAE competition for lifting a lot of weight without moving at high speeds. The team decided to max out the length of the wing to try and carry a payload of twenty pounds. Our final product for the wing comes out to be 99 inches. The wing will carry all of the payload weight which gives us the ability to make the fuselage lighter than normal. The center structure is 3D printed with ABS plastic to ensure the strength that will be needed to hold the weight of the payload. The final wing design gets the most lift that can be obtained with the speeds that plane will be flying at.

Fuselage

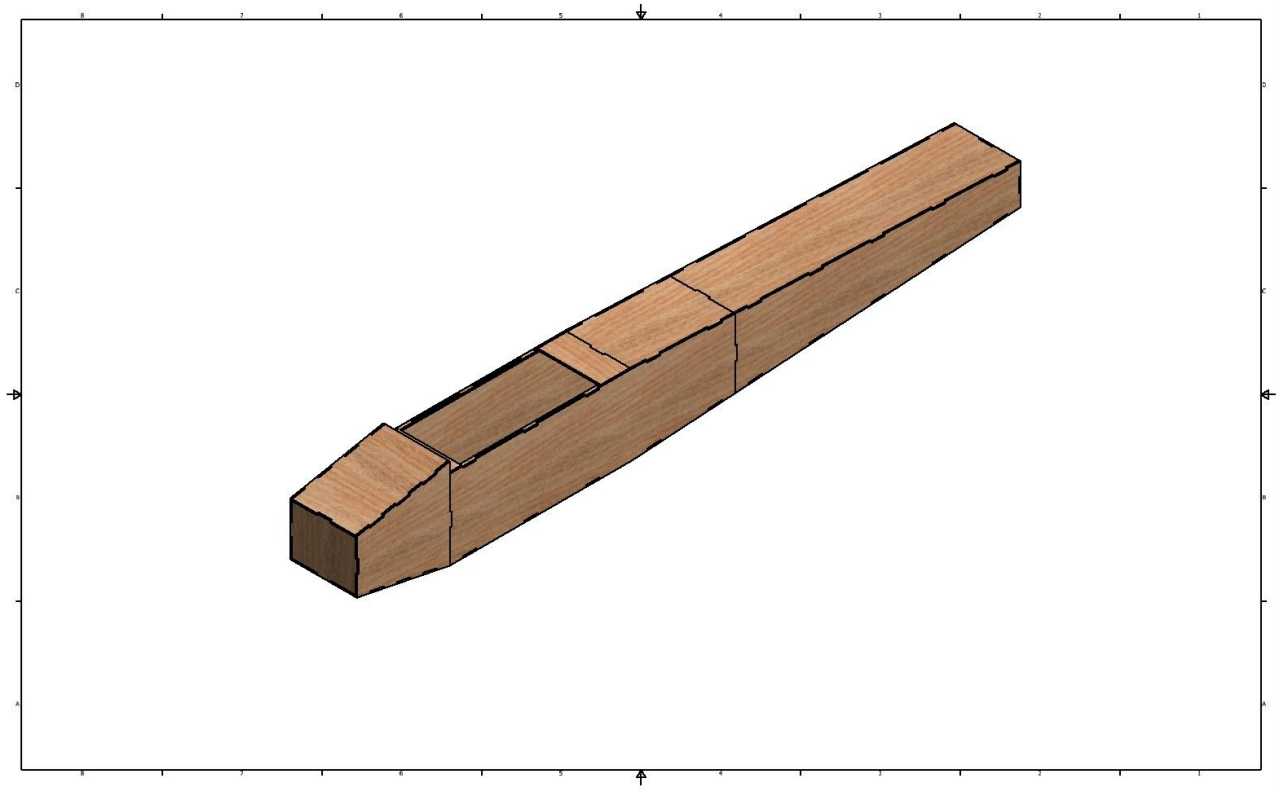


Figure 03. Final Fuselage Design

The team decided to go with a rectangular prism design instead of using a bar tail or a cylindrical shaped fuselage. The team decided to use birch sheets of wood to build the fuselage with. The team laser cut the pieces and implemented a notched design to help make the

construction more efficient. The notch design made each piece line up with each other perfectly just like a puzzle piece. These notches also allowed for better contact surfaces for the glue to adhere to. This fuselage is hollow which makes the plane a lot less lighter than alternate designs for a fuselage. The final design is lighter than alternate fuselage designs, which allows the plane to handle carrying more weight for the competition which will result in the team's success in competition.

Tail

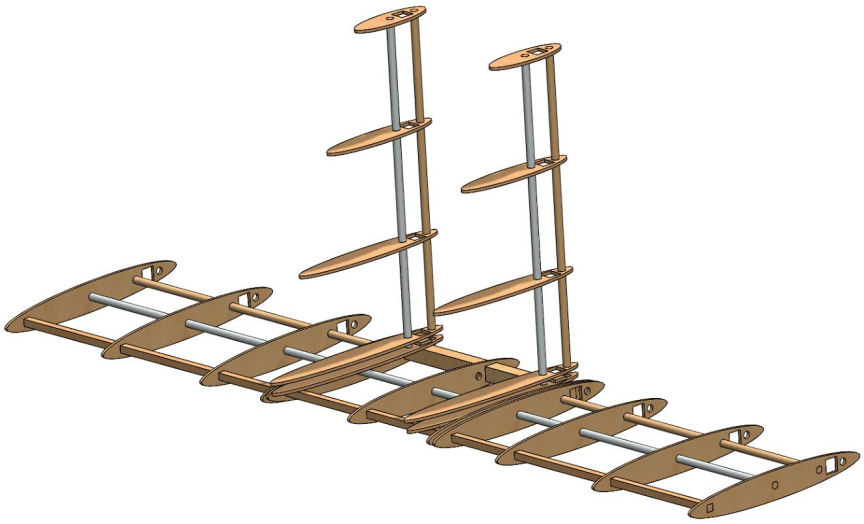


Figure 04. Tail Design

Above is the tail design for our airplane on solid works. This twin tail design will be attached by super gluing the wooden parts, while attaching the aluminum pipe by washers in each side and put a screw through it.

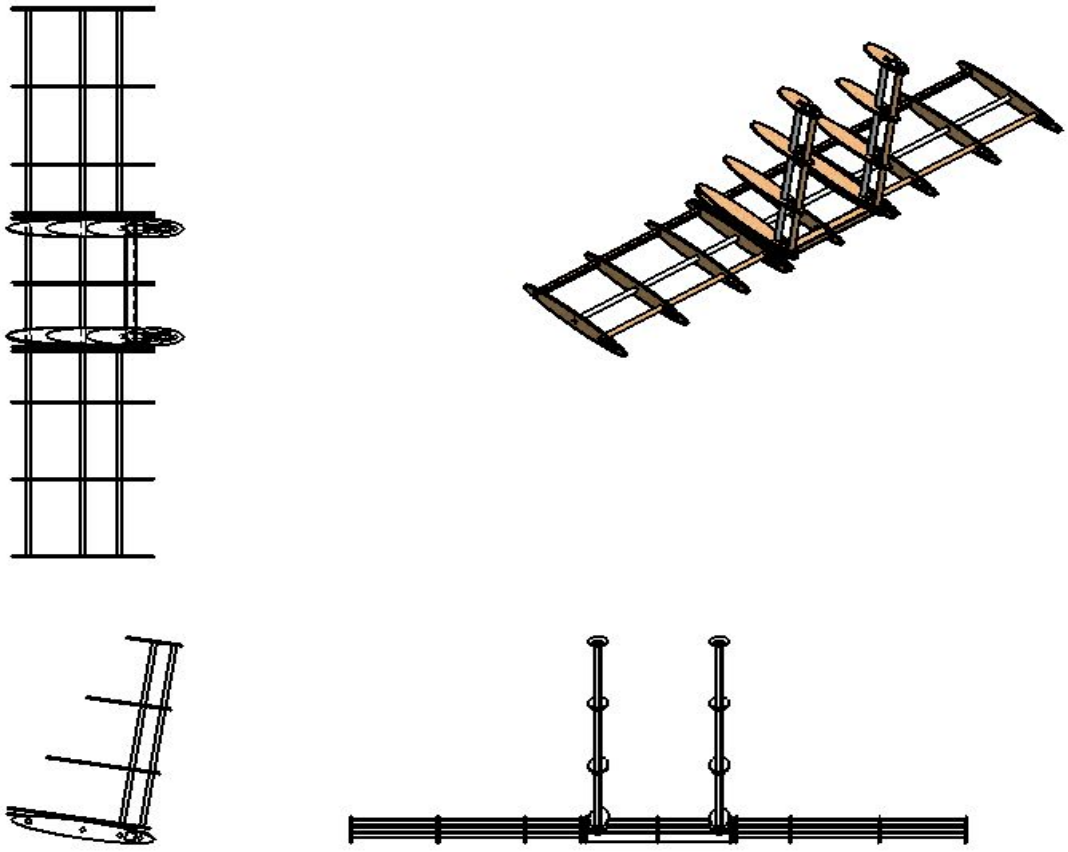


Figure 05. Tail design views

The figure above shows the front, top, and right view for our tail design.

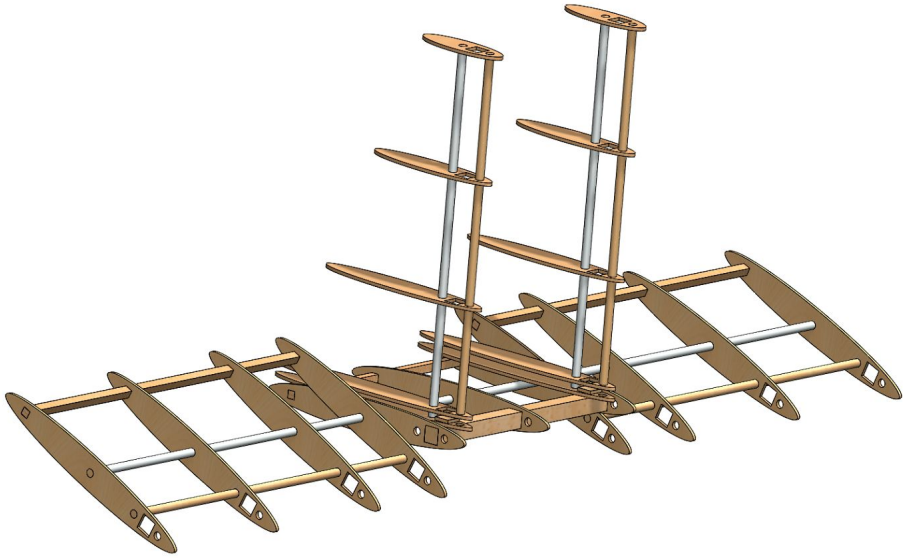


Figure 06. Tail design

The figure above shows that each part of the vertical and horizontal stabilizer moves each way, up, and down, and right and left.

Figure 07. Tail Construction

The figure above shows the construction of the tail. The right two pieces are the horizontal stabilizer, and the two left pieces are the vertical stabilizer. As shown six rips are used for the horizontal stabilizer and four for the vertical.

Figure 08. Tail Monokote

The figure above shows the processing of applying monokote the stabilizers.

Figure 09. Finalized Tail Construction

The figure above shows the finalized construction of the stabilizers. The stabilizers will be attached to the fuselage.

Electronics

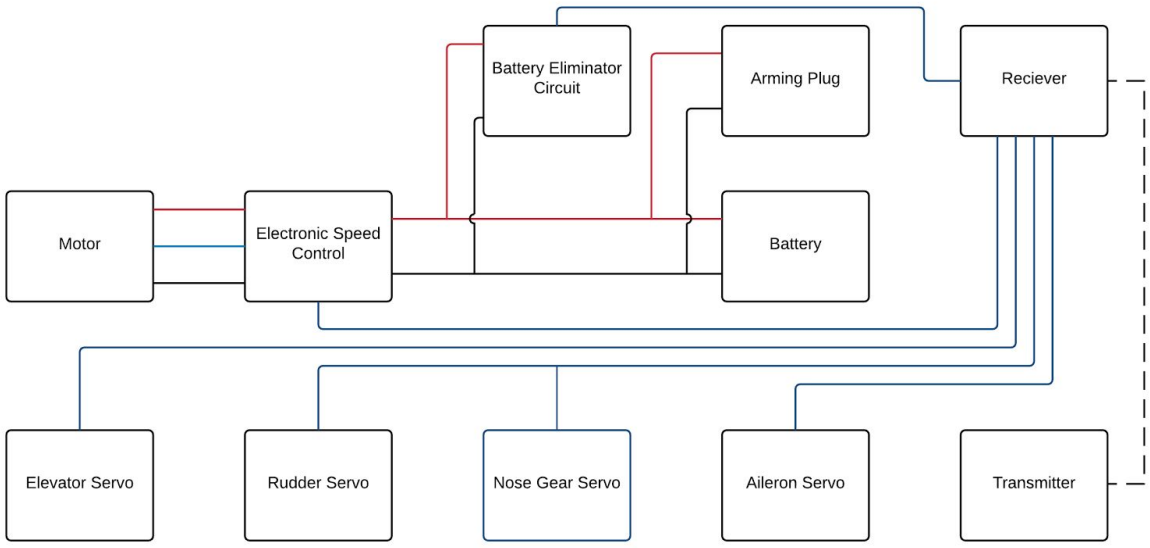


Figure 10. Functional Diagram

Shown above is the functional diagram for the electrical components of the aircraft. Red wires are positive, and black wires are negative. Blue wires denote servo wires. The battery is connected to the electronic speed control (ESC), which is then connected to the motor with a variable controller allowing for different power settings. The arming plug is connected to the

battery as well, providing a killswitch. This is required by competition rules. Also wired to the battery is the battery eliminator circuit (BEC). Connected to the BEC is the receiver via a servo wire. This eliminates the need for a separate battery for the receiver. Configured to the receiver are the servos connected to the different control surfaces. The rudder servo and nose gear servo are connected via a y-harness, and one will be reversed giving the proper control to the user. There will be one elevator servo and two aileron servos connected to the receiver as well via a y-harness. Finally, the receiver is configured to the transmitter wirelessly via a 2.4 Ghz signal.

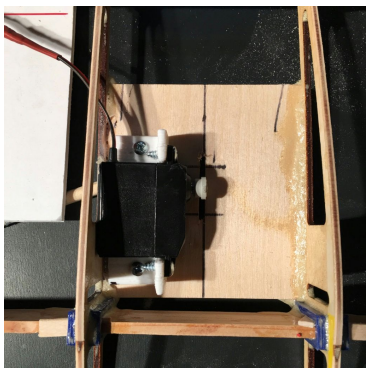


Figure 11

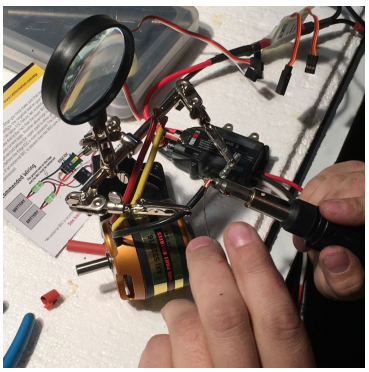


Figure 12

Figure 13

Shown above are a few examples of the electronics implemented in the final design. Illustrated in Figure 8 is a servo mounted to the wing. Connecting the electronics required a lot of soldering, shown in Figure 9. Figure 10 shows the propeller attached to the motor mounted to the nose of the fuselage.

Difficulties

The team ran into many obstacles throughout the fabrication of the plane. Most of the obstacles that we came across were simply buying things like nuts, washers, bolts, glue, sticks and balsa sheeting to complete the components in the best manner possible. One of the biggest difficulties that the team ran into was the monokote that needed to be put on every external surface of the plane. The monokote process takes very delicate work. The sheets need to be ironed on to each of the contact points of the exterior surfaces on the plane. This process is tedious and needs to be done with delicacy in order for the monokote to be able to shrink to a tight fit. The monokote must be a tight fit in order for the air to flow as smooth as possible

preventing turbulence. While heating the monokote with a heat gun to make it shrink, it is very easy to put a hole in the surface. The monokote also needed more surface area to stick to than the team had anticipated. To move past this obstacle with a good final product on the wing, horizontal stabilizer and vertical stabilizer the team glued on balsa sheeting along the edges of each of the components. This resulted in much tighter fit monokote which will in the end make the plane flights go much smoother.

4) Final Design

The final design and fabrication of the aircraft has the dimensions of 99” wingspan by 55” fuselage length by 19” tall to the tip of the vertical stabilator. The total combined linear dimensions of the aircraft is 173”. This is just 2” short of the 175” dimension constraint. The aircraft features heavy duty aluminum tricycle landing gear able to absorb the high stress of landing with a payload. Attached to the landing gear are 4” tubeless rubber tires on high strength plastic wheels. The aircraft features unique control surfaces utilizing a stabilator design approach which provides more control than traditional control surface designs. Mounted on the front of the aircraft is a 22.2 volt dc motor with a 18” diameter propeller attached to it. The figures below show the aircraft after the fabrication phase.

Figure 14. Final Design North West Isometric

Figure 15. Final Design North Isometric

Figure 16. Final Design North East Isometric

5) Future Modifications

Although a final design has been presented, multiple minor modifications need to be addressed before testing. Currently, the team's motor has its coil exposed to the air. During flight, this exposure could lead to moisture or debris interfering with the motor causing a malfunction. To prevent this from happening, a cowling will be added to cover the motor. The cowling will be designed and manufactured using rapid prototyping. Secondly, the vertical stabilizers in the current design are subject to a small amount of deflection. To fix this, a small bar will be added to the vertical stabilizers to achieve more stability and control. Thirdly, the nose gear servo needs adjustment, as a reverse servo is required for the current design. Finally, in the current design, the aircraft's center of gravity lies at about a half chord. To achieve balance,

an aircraft's center of gravity needs to lie at a quarter chord from the leading edge of the wing. The team will accomplish this by moving internal electrical components towards the front of the airplane's fuselage. Also, the insertion of payload plates will help the team obtain a more desirable center of gravity.

6) Bill of Materials

Table 05. Bill of Materials

Items	Quantity	Description	Cost	Website
Motor	1	AXI 5325/16 GOLD LINE	$ 299.99	http://www.hobbyexpress.com/axi_gold_5325_16_outrunner_motor_522473_prd1.htm
Motor mount	1	N/A		
Propeller	1	APC 18x12WE	$ 11.72	http://www.apcprop.com/product_p/lp18012we.htm
Nose gear	1	Nose Gear with Nose Gear Mount Block (HAN1306)	$ 4.99	http://www.horizonhobby.com/nose-gear-with-nose-gear-mount-block-han1306
Landing gear	1	Constructing at machine shop		
ESC/BEC	1	CASTLE CREATIONS Phoenix Edge 75	$ 101.96	http://www.castlecreations.com/products/phoenix-edge.html
Battery	1	Eflight 3200mAh 6S 22.2V 30C LiPo, 12AWG EC3	$ 99.99	http://www.horizonhobby.com/helicopters/batteries/3200mah-6s-222v-30c-lipo--12awg-ec3-eflb32006s30
Arming plug	1	SAE 2016 Arming Safety Harness	$ 30.00	http://neumotors.cartloom.com/shop/item/111799
Power limiter	1	SAE Limiter V2 2016	$ 50.00	http://neumotors.cartloom.com/shop/item/24377
Receiver	1	AR610 6-Channel DSMX Aircraft Receiver (SPMAR610)	$ 49.99	http://www.horizonhobby.com/ar610-6-channel-dsmx-aircraft-receiver-spmar610
Servos	5	Extra High Torque Servo (SPMS601H)	$ 44.99	http://www.horizonhobby.com/extra-high-torque-hybrid-servo-spms601h
Y-harness	2	Y-Harness: Telemetry (SPM1516)	$ 5.99	http://www.horizonhobby.com/y-harness%3A-telemetry-spm1516
Wheels (2 orders)	4	Big Wheels, 4" (DUB400RV)	$ 15.49	http://www.horizonhobby.com/big-wheels--4-dub400rv
Balsa dowels	10	3/16" x 3' balsa dowels	$57.80	http://www.specializedbalsa.com/cart.php
Balsa sheeting	6	Balsa Sheet 3/16 x 12 x 36	$112.59	http://www.specializedbalsa.com/cart.php
Pine spar	2	2in.x4in.x10ft Kiln-Dried Heat Treated Spruce-Pine-Fir Lumber (161659)	$ 4.05	http://www.homedepot.com/p/Unbranded-2-in-x-4-in-x-10-ft-Standard-Better-Kiln-Dried-Heat-Treated-Spruce-Pine-Fir-Lumber-161659/100077951
Aluminum tubing	1	36 in. x 1/2 in. x 1/16 in. Aluminum Round Tube	$ 10.67	http://www.homedepot.com/p/Crown-Bolt-36-in-x-1-2-in-x-1-16-in-Aluminum-Round-Tube-35190/202183508
Aluminum sheeting	n/a	3/16" Aluminum Scraps	Donated	
1/32-in nylon-coated cable	1	Loos Galvanized Steel Wire Rope, Nylon Coated, 7x7 Strand Core	$ 12.16	http://www.amazon.com/Loos-Galvanized-Coated-Breaking-Strength/dp/B0050K3476/ref=sr_1_1?s=industrial&ie=UTF8&qid=1449792941&sr=1-1&keywords=1%2F32+nylon+coated+cable
ABS	29.58in^3	$250/52in^3	$ 142.22	
TOTAL			$ 1,054.6	

Table 5 above shows the bill of materials for the team's aircraft. The motor, battery, ESC/BEC (Electronic Speed Control/Battery Eliminator Circuit), balsa, and ABS plastic take up the bulk of the airplane costs. The receiver and servos also add a significant amount of cost. Funds will be received from NAU SAE, specifically for the ABS. The ABS three-dimensional print is needed for the center of our wing because it must be one solid piece to have the amount of strength that needed to support the weight of the aircraft. The landing gear, motor mount, and aluminum sheeting will all be machined. The arming plug and power limiter are specified SAE competition requirements.

7) Project Plan

Table 06. Project Plan

Task	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15	W 16
Fuselage design																
Wing construction																
Tail design																
Parts for Fuselage and Tail																
Fuselage construction																
Tail construction																
Landing gear design																
Fabricate airplane parts																
Airplane construction																
Finalize airplane construction																
Test/modify airplane																
Hardware review 1			◆													
Hardware review 2					◆											
Hardware review 3							◆									
Hardware review 4										◆						
Midpoint presentation								◆								
Hardware review 5												◆				
Walkthrough Presentation														◆		
UGRADS Presentations																◆

Table 6 above details the project plan for the second semester of mechanical engineering capstone design. Tasks have been assigned on a biweekly basis in the form of hardware reviews. Weeks one and two consist of fuselage design, tail design, and wing construction. Weeks four and five include fuselage and tail construction, and landing gear design. Weeks six through nine involve the fabrication of the airplane. Weeks ten through twelve consist of testing and modifying the airplane. Progress will be presented halfway through the semester, while a final report will be compiled and presented at the end of the semester. The plan which we are progressing after the spring break is testing our team aero design and get data feedback and then doing research and calculation for this project.

8) Conclusions

In conclusion, the Northern Arizona University SAE Aero senior capstone team will design and build an aircraft to compete, as representatives of Northern Arizona University, in the SAE Aero design competition. The capstone team has finished the design and build phases of an aircraft that adheres to the SAE Aero competition requirements and constraints. The wing design has been implemented and has been constructed. The tail design has been implemented and has

finished fabrication. Final electrical components of the aircraft, such as the motor, propeller, battery, and electronic speed control have been installed. The team has finished the major design and construction of the aircraft, with testing and minor modifications to be accomplished by the next hardware review. The team has begun detailing the final design and manufacturing processes in preparation for the final presentation. Basically our team is trying to do as much effort as we can to fixing the error and calibration to reach the significant fit based on SAE AERO design requirement.

9) References

[1] What-When-How, "Tail design", Conventional Tail, T-tail, Dual Tail, Triple Tail and Twin Tail. Available: what-when-how.com.

[2] National Aeronautics and Space Administration, "structures and materials", aircraft background, P3-4.

[3] P. J. Pritchard, Introduction to Fluid Mechanics 8th Edition. Fox and McDonald. Wiley, 2011.

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[5] "Airfoil Tools," Airfoil Tools. [Online]. Available at: http://airfoiltools.com/. [Accessed: 2015].

[6] Flight calculations. Ecalc Calc for Airplanes. [Online]. Available at: http://www.ecalc.ch/