SAE Aero Design

Final Report

Ali Alqalaf, Jasem Alshammari, Dong Yang Cao,

Darren Frankenberger, Steven Goettl, and John Santoro

Team 16

Submitted towards partial fulfillment of the requirements for

Mechanical Engineering Design II – Spring 2016

Department of Mechanical Engineering

Northern Arizona University

Flagstaff, AZ 86011

Table of Contents

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 by Dr. John Tester, NAU SAE Club advisor, 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, concept generation, fabrication, and testing of the aircraft.

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. 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

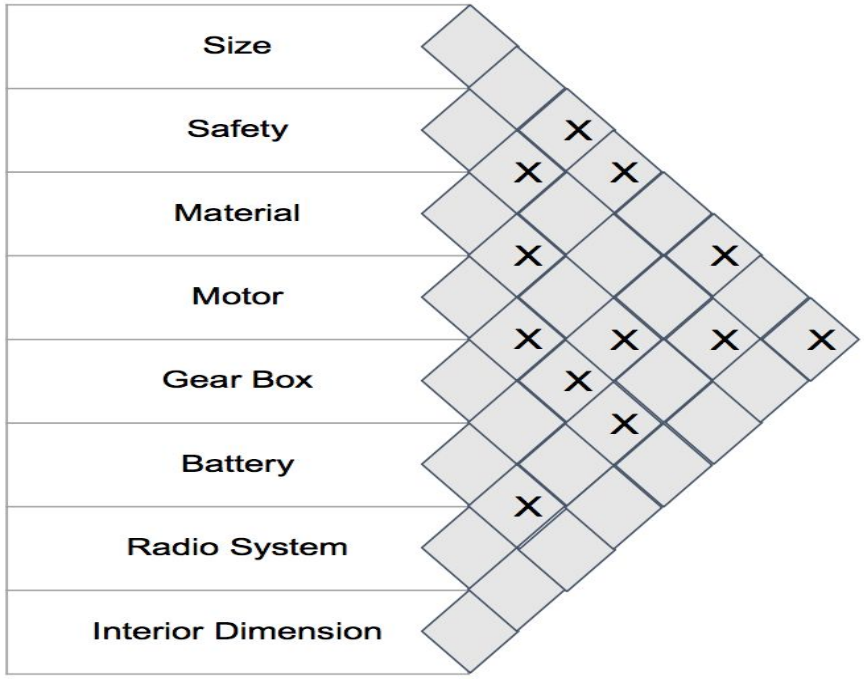
In Table 3 below, compared are the regular class design requirements with engineering requirements. These comparisons are given a score, then the engineering requirements are ranked by importance. Safety, material and motor were found to be the most important.

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



7) Concept Generation

a. Airfoil

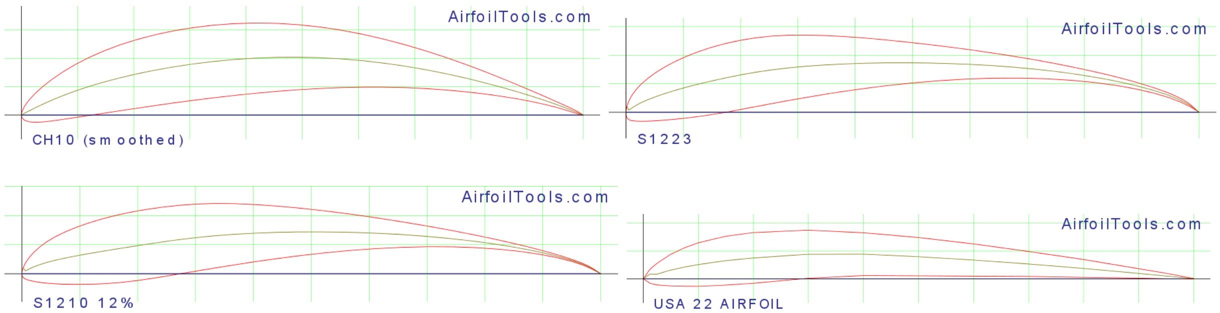


Table 05. Airfoil Weighted Decision Matrix

Decision Factors		**S1223**	**CH10**	**USA22**	**S1210**		
Criteria	**Wt.**	**1**	**2**	**4**	**5**	**Criteria**	**Definition**
Coefficient of Lift (max)	0.2	5	4	4	2	Coefficient of Lift (max)	The airfoil with the highest maximum lift coefficient
Design Lift Coefficient	0.1	4	3	2	2	Design Lift Coefficient	The airfoil with the proper ideal or design lift coefficient
Coefficient of Drag (min)	0.1	2	4	3	1	Coefficient of Drag (min)	The airfoil with the lowest minimum drag coefficient
Lift to Drag Ratio	0.3	5	2	5	5	Lift to Drag Ratio	The airfoil with the highest lift-to-drag ratio
Lift Curve Slope (max)	0.1	5	5	1	3	Lift Curve Slope (max)	How much flexibility of site layout is possible without CSS and PHP code
Pitching Moment Coefficient	0.1	4	2	2	2	Pitching Moment Coefficient	The airfoil with the lowest (closest to zero; negative or positive) pitching moment coefficient
Stall Quality	0.1	5	2	2	4	Stall Quality	The proper stall quality in the stall region (the variation must be gentle, not sharp).
Weighted Scores		4.5	3.0	3.3	3.1		

The decision matrix above compares airfoils.The team determined that the lift to drag ratio was most important with the maximum coefficient of lift coming in a close second. This was determined because the airfoil with best lift to drag ratio will be most effective for carrying a payload. The highest coefficient of lift combined with the highest lift to drag ratio will give us the best performing airfoil design. The airfoil the team chose based on the criteria was the S1223 airfoil.

b. Sweep and Taper Wing Configuration

Table 06. Sweep and Taper Wing Configuration Weighted Decision Matrix

Decision Factors		RECTANGLE	TAPER	DELTA	Which wing configuration do I use?	
Criteria	Wt.	1	2	3	Criteria	Definition
Weight	0.2	3	4	3	Weight	overall wing weight
loading	0.2	4	3	3	loading	Eases and facilitates the loading and unloading of loads and cargo into and out of cargo aircraft
Coefficient of Lift (max)	0.2	5	4	3	Coefficient of Lift (max)	The wing configuration with the highest maximum lift coefficient
Coefficient of Drag (min)	0.2	3	4	3	Coefficient of Drag (min)	The airfoil with the lowest minimum drag coefficient
Lift to Drag Ratio	0.2	5	4	4	Lift to Drag Ratio	The airfoil with the highest lift-to-drag ratio
Weighted Scores		4.0	3.8	3.2		

The criteria that were deemed most important for the sweep and taper of the wings were: weight, loading, maximum coefficient of lift, minimum coefficient of drag, and lift-to-drag ratio. The rectangle beats out the other two designs as it as a higher lift-to-drag ratio, higher maximum coefficient of drag, and easier in loading and unloading.

c. Landing Gear Configuration

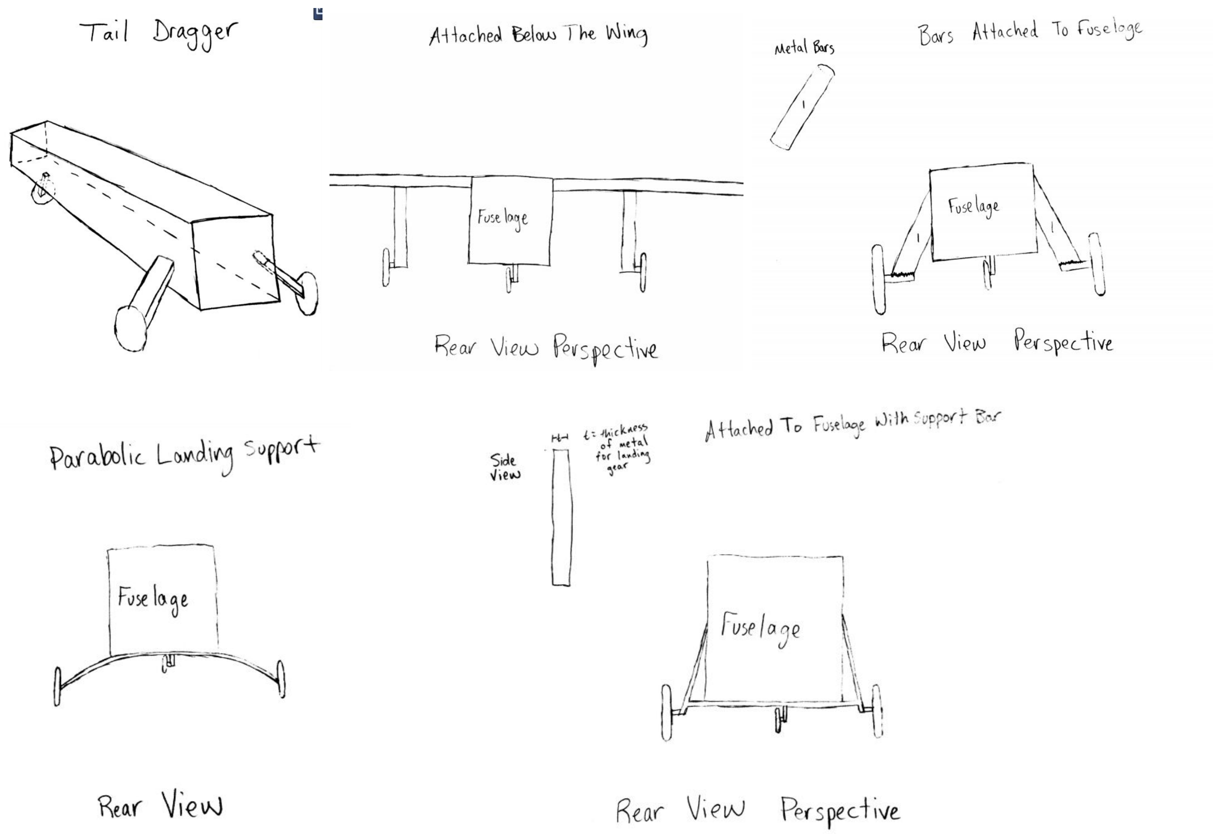
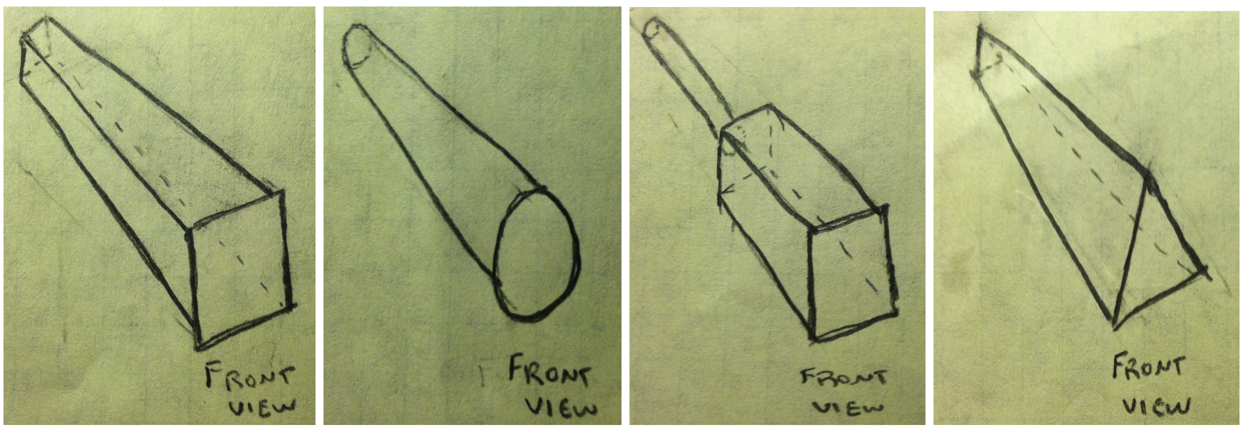


Table 07. Landing Gear Configuration Weighted Decision Matrix

Decision Factors		Tail Dragger	Attached Below The Wing	Bars Attached To Fuselage	Parabolic Landing Support	Attached to Fuselage With Support Bar
Criteria	**Wt.**	**1**	**2**	**3**	**4**	**5**
Weight	**0.16**	**5**	**1**	**1**	**4**	**3**
Strength	**0.16**	**3**	**4**	**3**	**3**	**5**
Coefficient of Drag	**0.16**	**5**	**1**	**2**	**4**	**2**
Control	**0.5**	**1**	**5**	**4**	**2**	**4**
Weighted Scores		**2.6**	**3.5**	**3.0**	**2.8**	**3.6**

The decision matrix above compares different landing gear configurations. The team decided that the control of the aircraft on the ground was the most critical criteria. This was decided because the team wants to make sure the landing and takeoff will not be an issue at the competition. The team's advisor and mentor both told the team that other teams' aircrafts had crash landings which was the most common way for aircrafts to get eliminated. The criteria that gave the attached to fuselage with a support bar the edge on the other designs, is the strength and weight. These criterias are also critical because the strength is needed so that the landing gear does not collapse while landing.

d. Fuselage Design



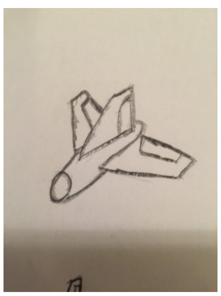
(From left to right - Rectangular Prism, Cylindrical, Bar Design and Triangular Prism)

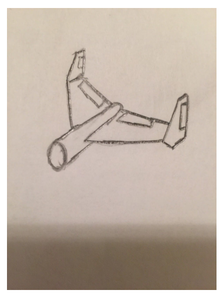
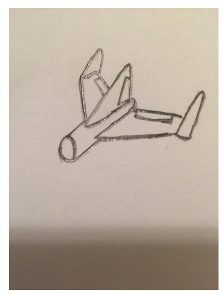
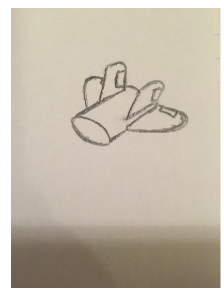
Table 08. Fuselage Design Weighted Decision Matrix

Decision Factors		Rectangular Prism	Cylindrical	Bar Design	Triangular Prism		
Criteria	**Wt.**	**1**	**2**	**3**	**4**	**Criteria**	**Definition**
Weight	0.3	5	5	2	5	Weight	Overall weight that the fuselage adds to the plane
Strength	0.3	4	2	3	5	Strength	How much force the fuselage design can have exerting on it before it breaks
Coefficient of Drag	0.3	4	5	2	3	Coefficient of Drag	The fuselage with the lowest minimum drag coefficient
Length	0.1	5	4	3	4	Length	The shortest fuselage the plane can have
Weighted Scores		4.4	4.0	2.4	4.3		

The fuselage is another critical design because it must keep drag to a minimum with also be strong with the least amount of weight and length. The less length the fuselage has, the more width we can give the wing which creates more lift. The strength, weight and coefficient of drag are weighted more because those criteria will affect the flight of the aircraft more than the length of the fuselage. The team decided that the length of the rectangular prism would be easier to minimize than the triangular prism design, while keeping the strength of the fuselage as well. The team also decided that the aircraft could get more volume with a rectangular prism which makes loading and unloading the payload bay much easier. The coefficient of drag was also less because the team believed the rectangular prism would have a more continuous airflow over the fuselage when it joins with the horizontal and vertical stabilizers.

e. Vertical and Horizontal Stabilizers



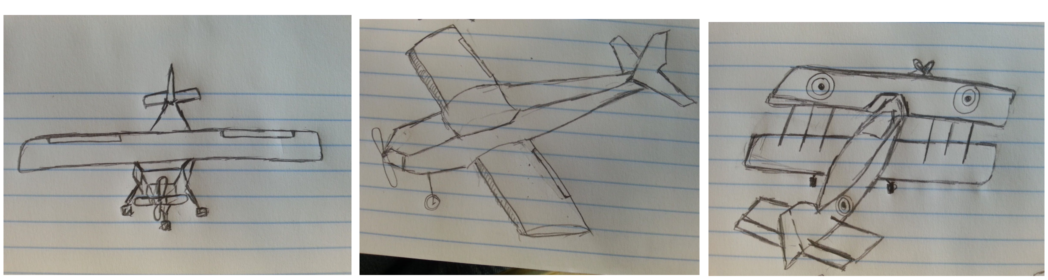




Conventional Tail **T-tail** **Dual Tail** **Triple Tail** **Twin Tail**

Table 09. Vertical and Horizontal Stabilizers Decision Matrix								
Decision Factors		**Conventional Tail**	**T-tail**	**Dual Tail**	**Triple Tail**	**Twin Tail**		
Criteria	**Wt.**	**1**	**2**	**3**	**4**	**5**	**Criteria**	**Definition**
Stability Coefficient	0.30	4	3	3	3	4	Stability Coefficient	The higher the stability coefficient, the straighter the airplane will move
pitching control (up and down)	0.25	4	4	3	2	4	pitching control (up and down)	The horizontal stabilizer prevent up and down motion of the nose of the airplane
yaw control (right and left)	0.25	4	4	3	3	5	yaw control (right and left)	The vertical stabilizer prevent the airplane from swinging side to side
Weight	0.20	4	4	3	2	3	Weight	The weight of the tail
Weight Scores		4.0	3.7	3.0	2.6	4.1		

The decision matrix above shows the design scores for vertical and horizontal stabilizers. The stabilizers job is to pitch (up and down) and yaw (right and left) the airplane. The twin tail design wins because it is more stable than most of the other tails. Furthermore, having two vertical stabilizers will help in being more effective upon other tails in yawing. Also, the height is cut in half if one was to use just one vertical stabilizer.

f. Wing Placement Configuration

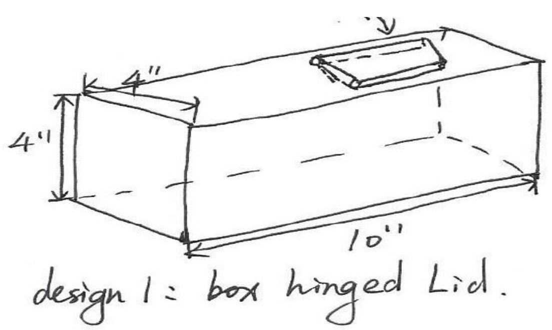


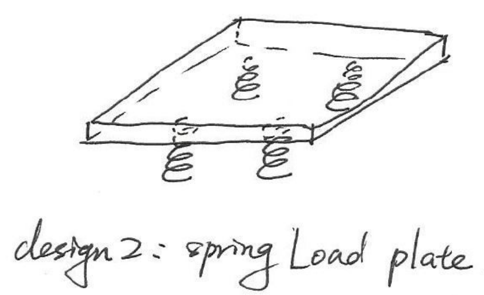
(From left to right- Monowing High Placement Monowing Low Placement Biplane)

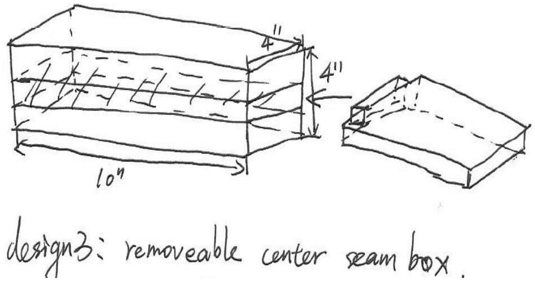
Table 10. Wing Placement Configuration Weighted Decision Matrix						
Decision Factors		**Monowing Low Placement**	**Monowing High Placement**	**Biplane**		
Criteria	**Wt.**	**1**	**2**	**3**	**Criteria**	**Definition**
Weight	0.1	5	4	2	Weight	overall wing weight
Loading	0.1	4	5	3	loading	Eases and facilitates the loading and unloading of loads and cargo into and out of cargo aircraft
Coefficient of Lift (max)	0.2	5	4	5	Coefficient of Lift (max)	The wing configuration with the highest maximum lift coefficient
Coefficient of Drag (min)	0.2	4	5	3	Coefficient of Drag (min)	The airfoil with the lowest minimum drag coefficient
Lift to Drag Ratio	0.4	4	5	2	Lift to Drag Ratio	The airfoil with the highest lift-to-drag ratio
Weighted Scores		4.3	4.7	2.9		

Based on the criteria, the top two designs were the monowing high and low placement. Low placement beats the high wing placement slightly in weight and maximum coefficient of lift. The high placement design beats out the low placement design, because it offers a smaller coefficient of drag, higher lift-to-drag ratio, and ease of loading.

g. Payload Configuration







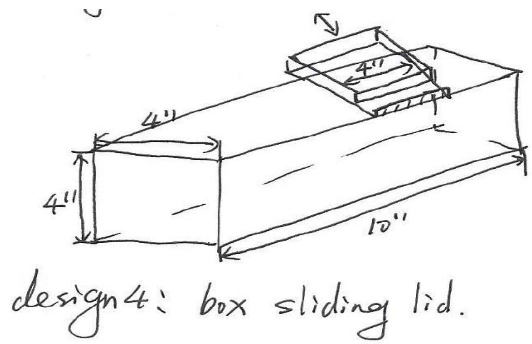
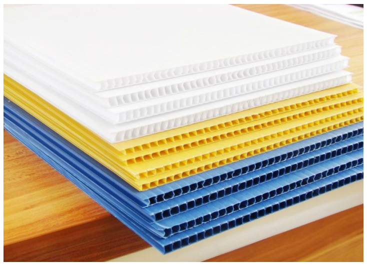


Table 11. Payload Configuration Weighted Decision Matrix

Decision Factors		Box w/ Hinged Lid	Spring Loaded Plates	Removable Center Seam Box	Box w/ Sliding Lid		
Criteria	Wt.	1	2	3	4	Criteria	Definition
Payload (max)	0.15	3	3	3	3	Payload (max)	Overall payload weight
Weight	0.40	3	2	1	4	Weight	Total weight of configuration
Cost	0.30	2	1	3	2	Cost	Cost of payload configuration material
Ease of Construction	0.15	4	1	3	4	Ease of Construction	Time required to construct
Weighted Scores		2.9	1.7	2.2	3.3		

Shown above are the payload configuration design concepts. Also above, is the decision matrix for the payload configuration. The payload configuration holds the payload in place in the fuselage. In terms of criteria, weight was deemed the most important, followed by cost, and payload and ease of construction. Design option 1 and design option 4 were the two highest ranking designs. Design option 4, the box with the sliding lid as it slightly edged option 1 in regards to weight and cost.

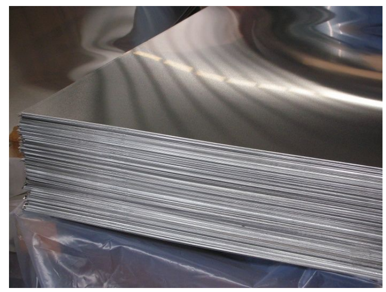
h. Material Comparison



Design 1: Plastic http://www.aliexpress.com

Design 2: Wood https://commons.wikimedia.org

Design 3: foam http://forums.sjgames.com



Design 4: Aluminum http://www.omnisteelsupply.com

Table 12. Material Comparison Weighted Decision Matrix

Decision Factors		Plastic	Woo d	Foam	Aluminiu m		
Criteria	Wt.	1	2	3	5	Criteria	Definition
Weight	0.20	5	4	5	4	Weight	Overall material weight
Strength	0.20	3	3	2	4	Strength	Strong or weak
Material formation	0.20	2	4	4	2	Material formation	The strength needed to format the material
Cost	0.40	3	5	4	4	Cost	Cost of the material
Weighted Scores		3.2	4.2	3.8	3.6		

The decision matrix above shows the criteria of the material the team is going to use for a majority of the airplane parts. In regards to material selection, strength, cost, weight, and formation are all important factors. The wood has the highest scoring material. It is easy to form, cheap, and has good strength.

i. Receiver



design 1, 2, 3: www.spektrumrc.com

Table 13. Receiver Weighted Decision Matrix

Decision Factors		4 Channel Aircraft Receiver	6 Channel Aircraft Receiver	7 Channel Aircraft Receiver		
Criteria	Wt.	1	2	3	Criteria	Definition
weight	0.3	5	5	0	weight	The receiver with the minimum weight
loading	0.2	3	3	2	loading	The receiver with minimum loading
time period recorded	0.2	5	5	5	time period recorded	The receiver with the suitable time period recorded
altitude recorded	0.2	4	5	4	altitude recorded	The receiver with the expected altitude recorded
Quality	0.1	5	4	5	Quality	The receiver should be with the best quality
Weighted Scores		4.2	4.3	2.5		

The decision matrix above compares different aircraft receivers. The team decided that the most important criteria is the weight of the receiver, with loading time period recorded, altitude recorded and quality following. Based on these criteria and the scorings, the team used a 6 channel aircraft receiver.

j. Transmitter



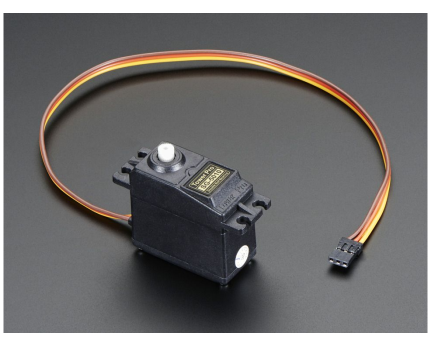
design 4, 5, 6: www.spektrumrc.com

Table 14. Transmitter Configuration Weighted Decision Matrix

Decision Factors		5 channel Transmitter	6 channel transmitter	7 channel transmitter	Which transmitter do I use?	
Criteria	Wt.	1	2	4	Criteria	Definition
Weight	0.2	4	1	5	Weight	overall transmitter weight
loading	0.3	2	0	0	loading	transmitter loading should be as small as possible
attenuate transmit signal	0.2	5	3	3	attenuate transmit signal	the transmitter should transmit suitable signal to the radio station
gains	0.1	5	5	5	gains	the ability of gaining signals
losses	0.2	3	4	1	losses	the ability of losses signals
Weighted Scores		3.5	2.1	2.3		

This decision matrix above compares transmitters. Weight, loading, signal, gains, and losses are all important criteria when choosing a transmitter. Based on the criteria, and their relative weights, the team used a 5 channel transmitter.

k. Servo



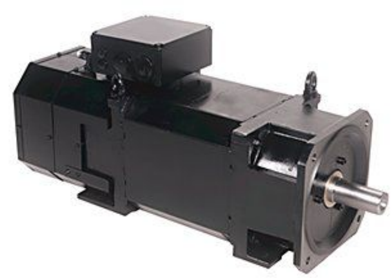



Table 15. Servo Decision Matrix						
Decision Factors		Standard servo	RC servo	high power servo		
Criteria	Wt.	1	2	3	Criteria	Definition
Torque coefficient	0.3	3	0	5	Torque coefficient	The higher the torque coefficient the better the servo is
Speed	0.2	3	3	5	Speed	The faster the speed is the butter servo
Size	0.2	0	0	4	Size	to fit the plane
Voltage	0.3	0	3	5	Voltage	higher the voltage leads to faster servo movement and more power
Weighted Scores		1.5	1.5	4.8		

In the decision matrix for the servo shown are the different criteria: torque coefficient, speed, size, and voltage. Also shown are the design concepts. From there, the team chose the torque coefficient and the size are the criteria that were to be focused on because the torque coefficient will decide how powerful the handling will be and for the size the team is committed to certain area specialty with the wing.

l. Speed Controller

Table 16. Speed Controller Decision Matrix						
Decision Factors		ESC:B50 0 3D/X	ESC,EC5 (V2)	12S MAX HEAVY DUTY BEC		
Criteria	Wt.	1	2	3	Criteria	Definition
voltage coefficient	0.3	0	3	5	voltage coefficient	coefficient of receiver battery
current coefficient	0.2	5	0	3	current coefficient	the larger the current coefficient the more power can handle
speed stability	0.3	0	3	5	speed stability	control force to hold the airplane in certain
speed option	0.2	5	5	5	speed option	to have the the variety of speed
Weighted Scores		2.0	2.8	4.6		

The criteria chosen for the speed controller are: voltage coefficient, current coefficient, speed stability, and speed option. The speed stability was deemed to be the most important criteria, as it assists in controlling the airplane. Based on the decided criteria and weights, the determined speed controller that the team will use is a 12S max heavy duty BEC.

m. Motor Size

Table 17. Motor Size Weighted Decision Matrix

Decision Factors		Brushed	Brushless	Which wing configuration do I use?	
Criteria	Wt.	1	2	Criteria	Definition
Weight	0.10	3	4	Weight	Overall weight that the motor adds to the plane
Thrust	0.30	3	5	Thrust	The amount of reaction force that the motor can create using the propeller
Thrust to Weight Ratio	0.40	4	4	Thrust to Weight Ratio	The ratio between how much weight the motor adds to how much thrust it creates
Control	0.20	3	4	Control	How easy the pilot can control the plane's speed
Weighted Scores		3.4	4.3		

The brushless motor is necessary because the control and thrust to weight ratio are better than the brushed motor. The brushed motor just does not produce enough control or thrust which makes the brushless motor much better for the aircraft. The brushless motor is significantly more efficient than the brushed motor and that is why is performed better in the decision matrix.

4) Fabrication

Wing

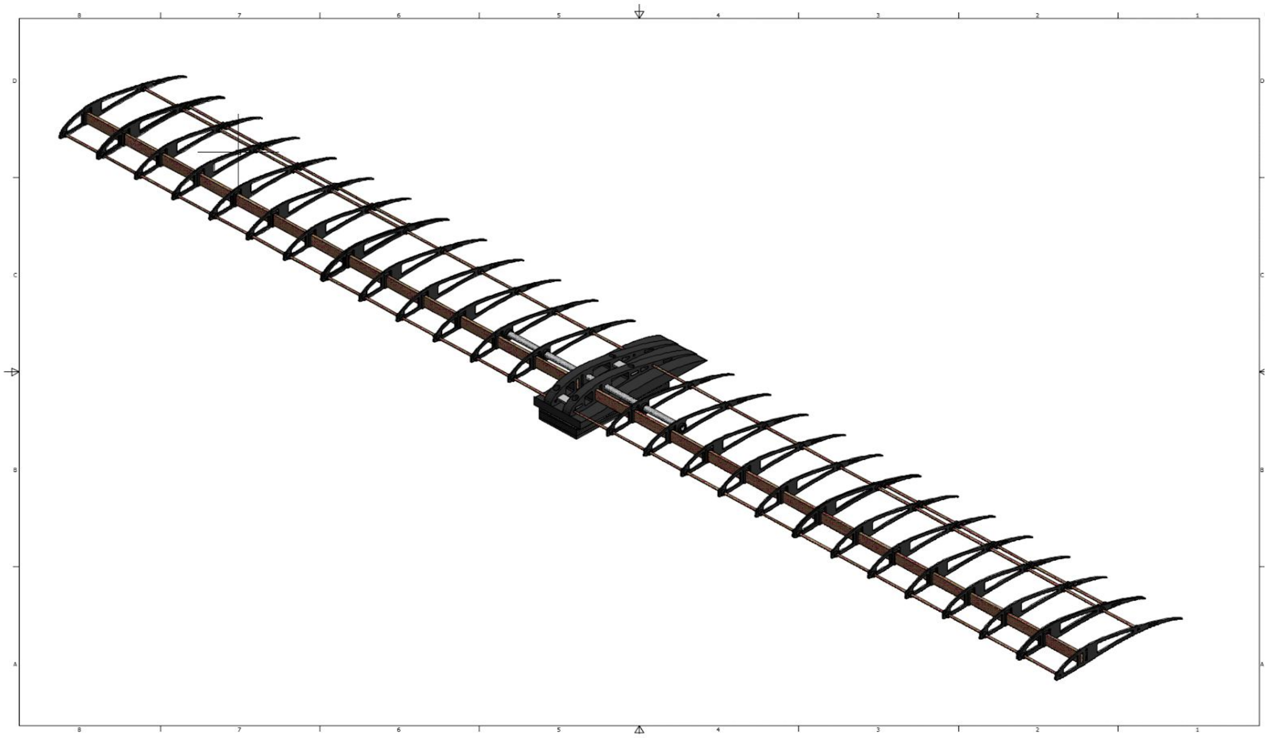


Figure 01. Final Wing Design

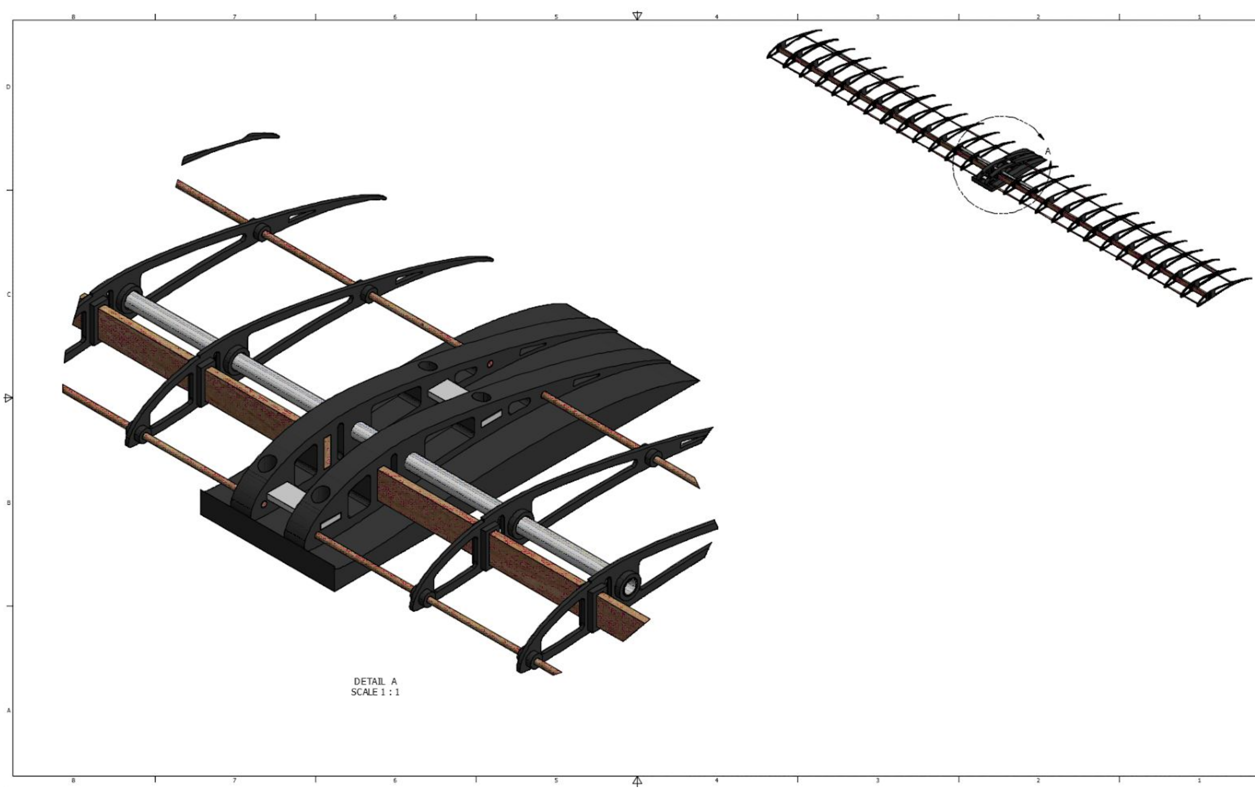


Figure 02. Center Piece of Wing

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

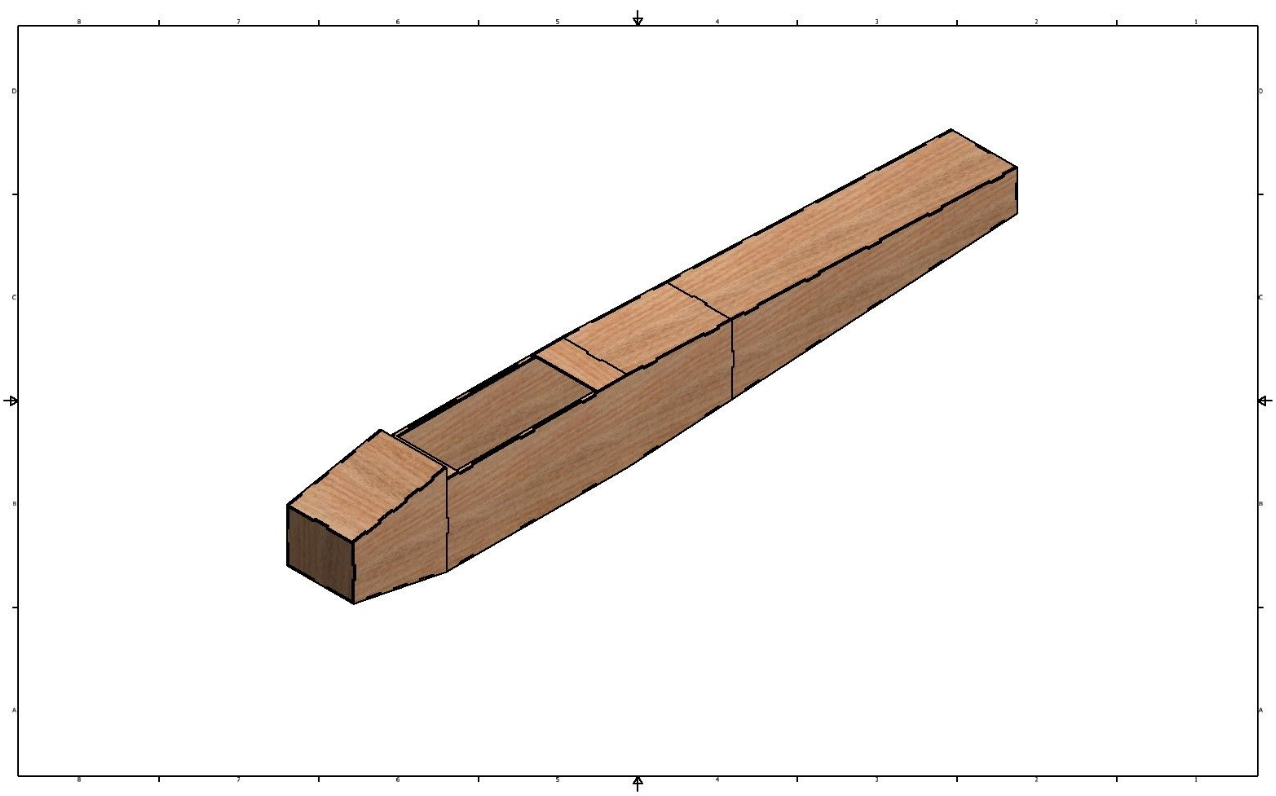


Figure 03. Final Fuselage Design

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

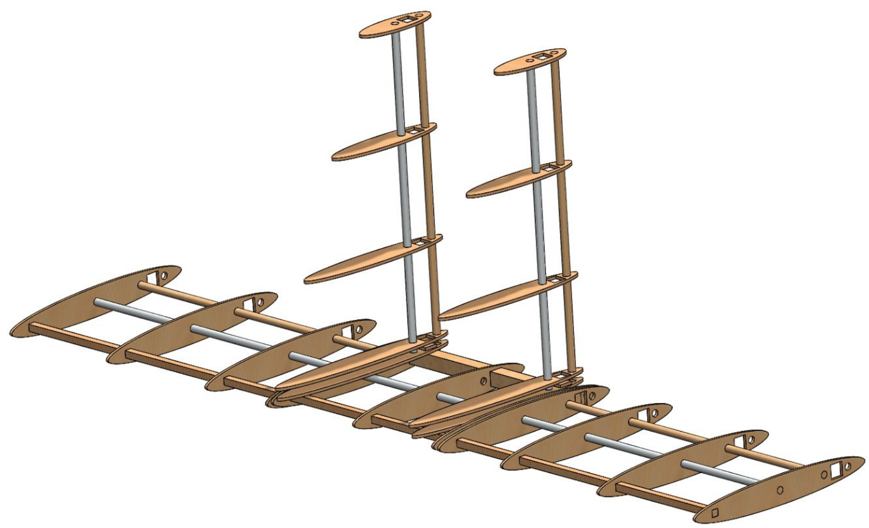


Figure 04. Tail Design

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.

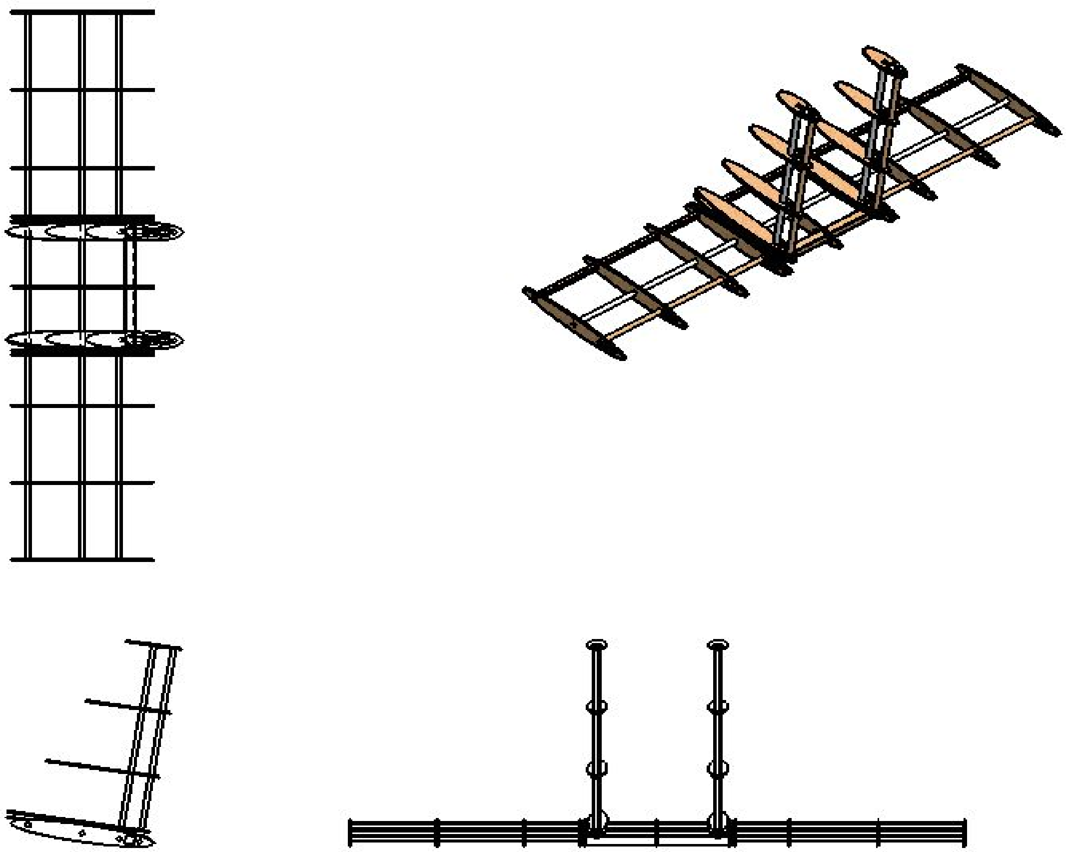


Figure 05. Tail design views

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

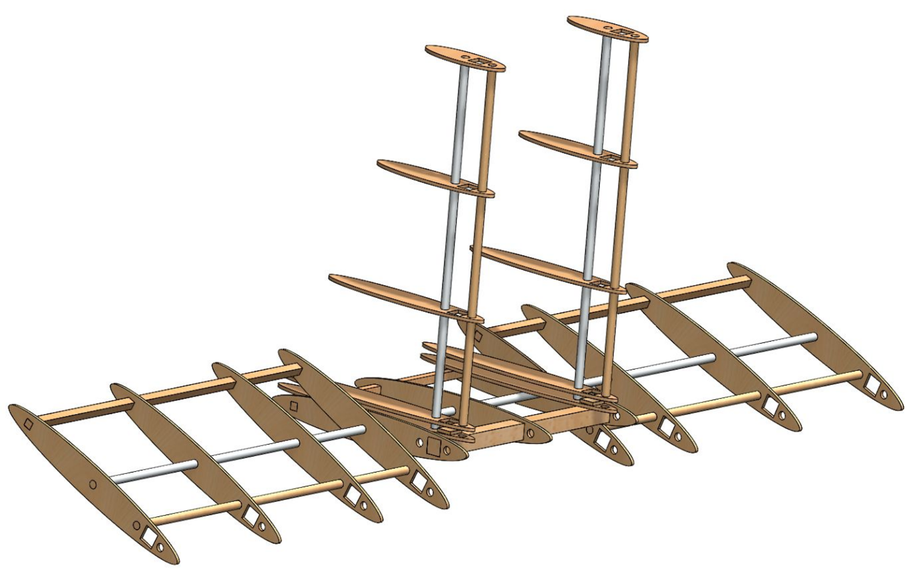


Figure 06. Tail design

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

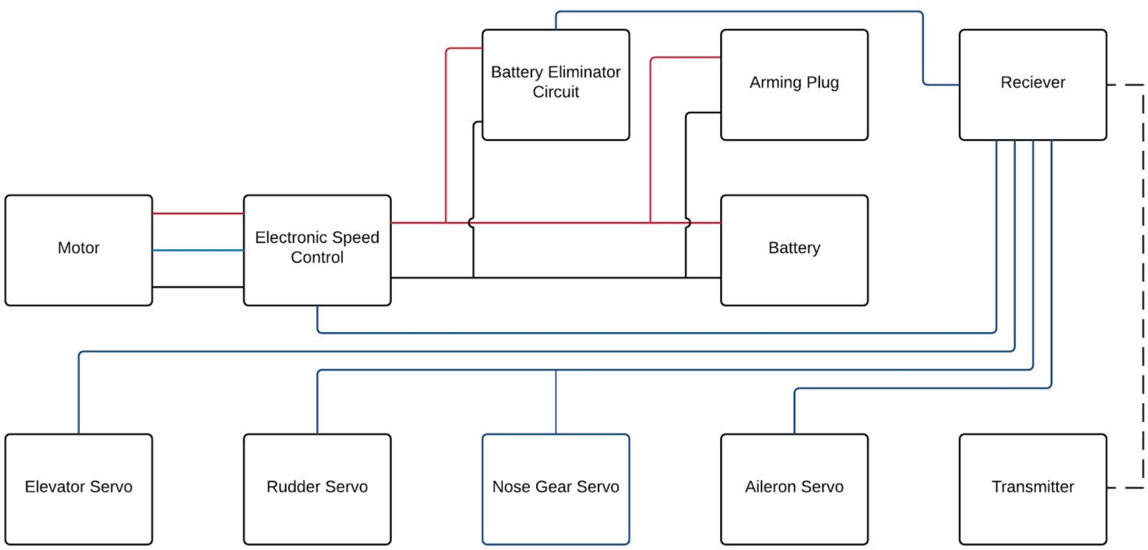


Figure 10. Functional Diagram

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.

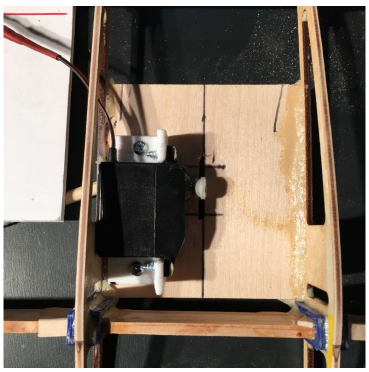


Figure 11

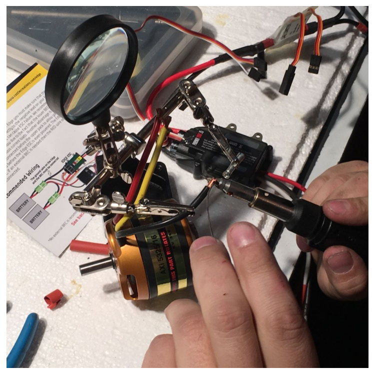


Figure 12

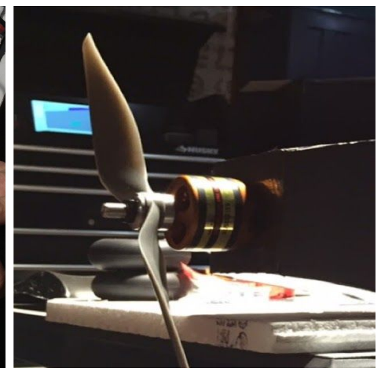


Figure 13

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

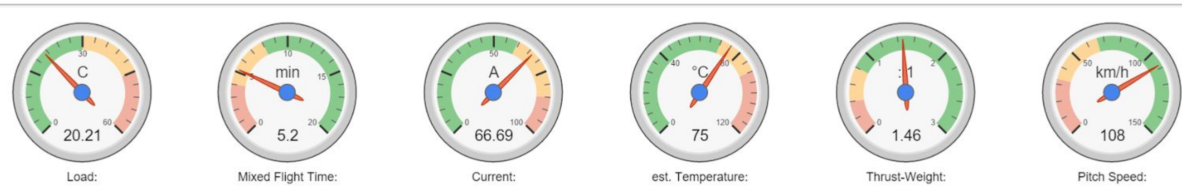
The team ran into many obstacles throughout the fabrication of the plane. Most of the obstacles that we came across were simply buying things like nuts, washers, bolts, glue, sticks and balsa sheeting to complete the components in the best manner possible. One of the biggest difficulties that the team 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.

5) Flight Calculations

General	Motor Cooling: medium	# of Motors: 1 (on same Battery)	Model Weight: 4536 g, 160 oz (incl. Drive)		Wing Area: 96.8 dm², 1500 in²	Field Elevation: 500 m ASL, 1640 ft ASL	Air Temperature: 25 °C, 77 °F	Pressure (QNH): 1013 hPa, 29.91 inHg
Battery Cell	Type (Cont. / max. C) - charge state: LiPo 3300mAh - 30/45C - normal	Configuration: 6 S 1 P	Cell Capacity: 3300 mAh	Total Capacity: 3300 mAh	Resistance: 0.0052 Ohm	Voltage: 3.7 V	C-Rate: 30 C cont., 45 C max	Weight: 93 g, 3.3 oz
Controller	Type: CC Phoenix Edge 75	cont. Curent: 75 A	max. Current: 75 A		Resistance: 0.010 Ohm			Weight: 114 g, 4 oz
Motor	Manufacturer - Type (Kv): AXI 5325/16 (350)	KV (w/o torque): 350 rpm/V	no-load Current: 2.1 A @ 30 V	Limit (up to 15s): 85 A	Resistance: 0.026 Ohm	Case Length: 59 mm, 2.32 inch	# mag. Poles: 14	Weight: 575 g, 20.3 oz
Propeller	Type - yoke twist: APC Electric E - 0°	Diameter: 18 inch	Pitch: 12 inch	# Blades: 2	PConst / TConst: 1.08 / 1.0	Gear Ratio: 1 : 1	Flight Speed: 32.2 km/h, 20 mph	calculate

Figure 14. Flight calculation inputs.

Above is the inputted information into the online calculator that solves for the performance of the aircraft with the selected final components.



Remarks:

Battery	
Load:	20.21 C
Voltage:	20.12 V
Rated Voltage:	22.20 V
Capacity:	3300 mAh
Energy:	73.26 Wh
Flight Time:	3.0 min
Mixed Flight Time:	5.2 min
Weight:	558 g
	19.7 oz

Motor @ Optimum Efficiency	
Current:	33.62 A
Voltage:	20.81 V
Revolutions*:	6725 rpm
electric Power:	699.8 W
mech. Power:	633.1 W
Efficiency:	90.5 %

Motor @ Maximum	
Current:	66.69 A
Voltage:	19.45 V
Revolutions*:	5927 rpm
electric Power:	1297.3 W
mech. Power:	1136.6 W
Efficiency:	87.6 %
est. Temperature:	75 °C
	167 °F

Propeller	
Static Thrust:	6615 g
	233.3 oz
Revolutions*:	5927 rpm
Stall Thrust:	3844 g
	135.6 oz
Thrust @ 32.2 km/h:	4650 g
Thrust @ 20 mph:	164 oz
Pitch Speed:	108 km/h
	67 mph
Tip Speed:	511 km/h
	317 mph
specific Thrust:	2.96 g/W
	0.1 oz/W

Total Drive	
Drive Weight:	1372 g
	48.4 oz
Power-Weight:	326 W/kg
	148 W/lb
Thrust-Weight:	1.46 : 1
P(in) @ max:	1480.5 W
P(out) @ max:	1136.6 W
Efficiency @ max:	76.8 %

Airplane	
All-up Weight:	4536 g
	160 oz
Wing Load:	47 g/dm²
	15.4 oz/ft²
Cubic Wing Load:	4.8
est. Stall Speed:	33 km/h
	20 mph
est. Speed (level):	97 km/h
	60 mph
est. Speed (vertical):	33 km/h
	20 mph
est. rate of climb:	10.1 m/s
	1982 ft/min

Figure 15. Flight calculation results

Motor Partial Load

Propeller rpm	Throttle %	Current (DC) A	Volage (DC) V	el. Power W	Efficiency %	Thrust g	Spec. Thrust g/W	Pitch Speed km/h	Thrust oz	Spec. Thrust oz/W	Pitch Speed mph	Flight Time (85%) min
800	11	0.3	22.2	6.2	45.3	121	19.6	15	4.3	0.69	9	599.9
1200	17	0.7	22.2	14.8	63.9	271	18.4	22	9.6	0.65	14	250.2
1600	22	1.4	22.2	30.0	74.5	482	16.1	29	17.0	0.57	18	122.9
2000	28	2.5	22.1	54.1	80.6	753	13.9	37	26.6	0.49	23	67.8
2400	34	4.1	22.1	89.6	84.1	1085	12.1	44	38.3	0.43	27	40.8
2800	40	6.4	22.0	138.9	86.2	1476	10.6	51	52.1	0.37	32	26.2
3200	47	9.5	21.9	204.5	87.4	1928	9.4	59	68.0	0.33	36	17.7
3600	53	13.6	21.8	288.9	88.1	2440	8.4	66	86.1	0.30	41	12.4
4000	60	18.7	21.6	394.9	88.4	3013	7.6	73	106.3	0.27	45	9.0
4400	**67**	**25.2**	**21.4**	**525.1**	**88.5**	**3646**	**6.9**	**81**	**128.6**	**0.24**	**50**	**6.7**
4800	75	33.2	21.2	682.3	88.4	4339	6.4	88	153.0	0.22	55	5.1
5200	83	42.9	20.9	869.2	88.2	5092	5.9	95	179.6	0.21	59	3.9
5600	92	54.9	20.5	1088.9	88.0	5905	5.4	102	208.3	0.19	64	3.1
5927	100	66.7	20.1	1297.3	87.6	6615	5.1	108	233.3	0.18	67	2.5

Figure 16. Flight calculation results.

Above is the results that was given from the online calculator that shows how the aircraft will perform at the competition. It uses the elevation of the airfield and the weight and power from each component to solve for the performance.

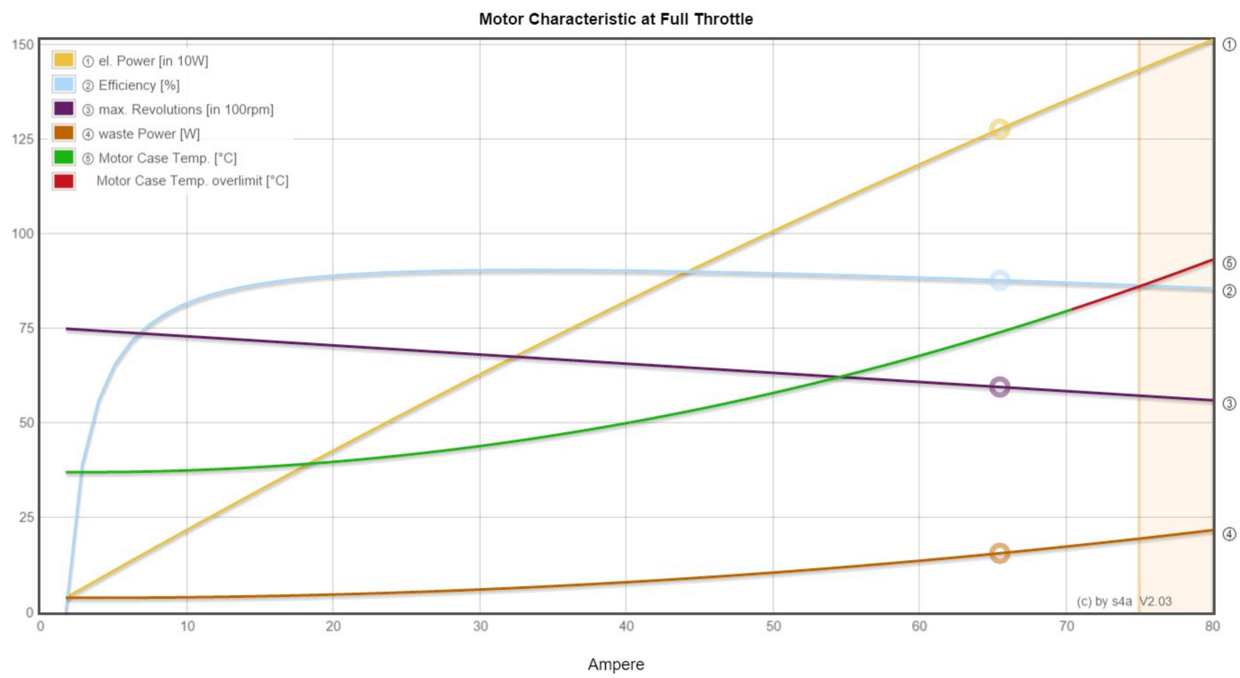


Figure 17. Flight calculation results.

A graph of the results are given graphically above.

6) 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

In addition, the team made multiple modifications to the final prototype. 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. Shown in Figure 17 below is the team's final prototype with the modifications added.

Figure 17. Final Prototype with modifications.

7) Testing

To test the aircraft we followed the competition objectives. The team was going to have the plane take off and land within the same 200 feet of runway and fly a 360 degree degree turn in order to complete these objectives. From start to finish the pilot had 3 minutes to finish the entire process.

During the testing the team had to make some on the scene modifications to ensure the test could be done. A modification that the team had to make was adding size to the front tire so that the propeller would not hit the ground while taking off and landing. The team did this by adding material around the tire continuously all around the tire. This was a necessary fix because when the propeller would hit the ground the plane would naturally start to turn. This fixed the team's problem and allowed for effective testing of the plane.

The testing of the aircraft ended in a crash. The team evaluated the testing videos and the plane after the crash carefully. The team concluded that the aileron horn lost connection to the aileron itself resulting in a loss of a critical control surface to the plane. The pilot had no way of getting the plane back into control without this feature on the plane. This caused the plane to dip and weave out of control to an inevitable nose dive into the ground. The test had poor results but the team was still able to get useful information that can help modify future manufacturing process of a plane. Figure 18 below illustrates the testing result.

Figure 18. Testing Result

8) Bill of Materials

Table 18. 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.

9) Project Plan

Tables 19 and 20 below show the project plan that the SAE Aero team followed throughout the year.

Table 19. Project Plan 1st Semester

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
Client meeting		■													
Define problem and layout project plan			■	■											
Research design			■	■											
Research protocol writing			■	■											
Research parts of design					■										
Functional diagram					■	■	■								
Concept Generation					■	■									
Decision Matrix						■	■	■							
Sketch Parts								■							
Pick a final design (decision matrix)									■	■	■				
Proof of Concept Discussion											■	■			
Project Proposal Discussion													■		
Finalize design													■	■	■
Problem Definition and Project Plan Presentations				◆											
Concept Generation and Selection Presentations							◆								
Proof of Concept Demonstrations												◆			
Project Proposal Presentations															◆

Table 20.. Project Plan 2nd Semester.

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															30	◆

10) Conclusions

The SAE Aero design team was tasked by Dr. John Tester to design and build an RC aircraft for the SAE Aero Regular class competition. The team constructed the aircraft, which fulfilled all design constraints and objectives. The majority of airplane was constructed out of birch wood and rapid prototyped components. Testing resulted in loss of the aircraft and revealed design flaws in the connections of the control surfaces. These flaws will be rectified in future iterations of the aircraft. Overall, the team gained invaluable knowledge in the mechanical engineering design process, which will be demonstrated in industry for years to come.

11) Acknowledgements

Dr. Srinivas Kosaraju

- Capstone Advisor

Dr. John Tester

- Technical Advisor

NAU Mechanical Engineering Department

- Machine shop
- Provided many materials/components of the aircraft

Mr. Craig Howdeshell, Coconino High School

- Provided use of wood laser cutter

Mr. Seth Lawrence

- Technical Advisor

12) 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.

[4] M. H. Sadraey, Aircraft design: a systems engineering approach. Hoboken, New Jersey: Wiley, 2012.

[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/