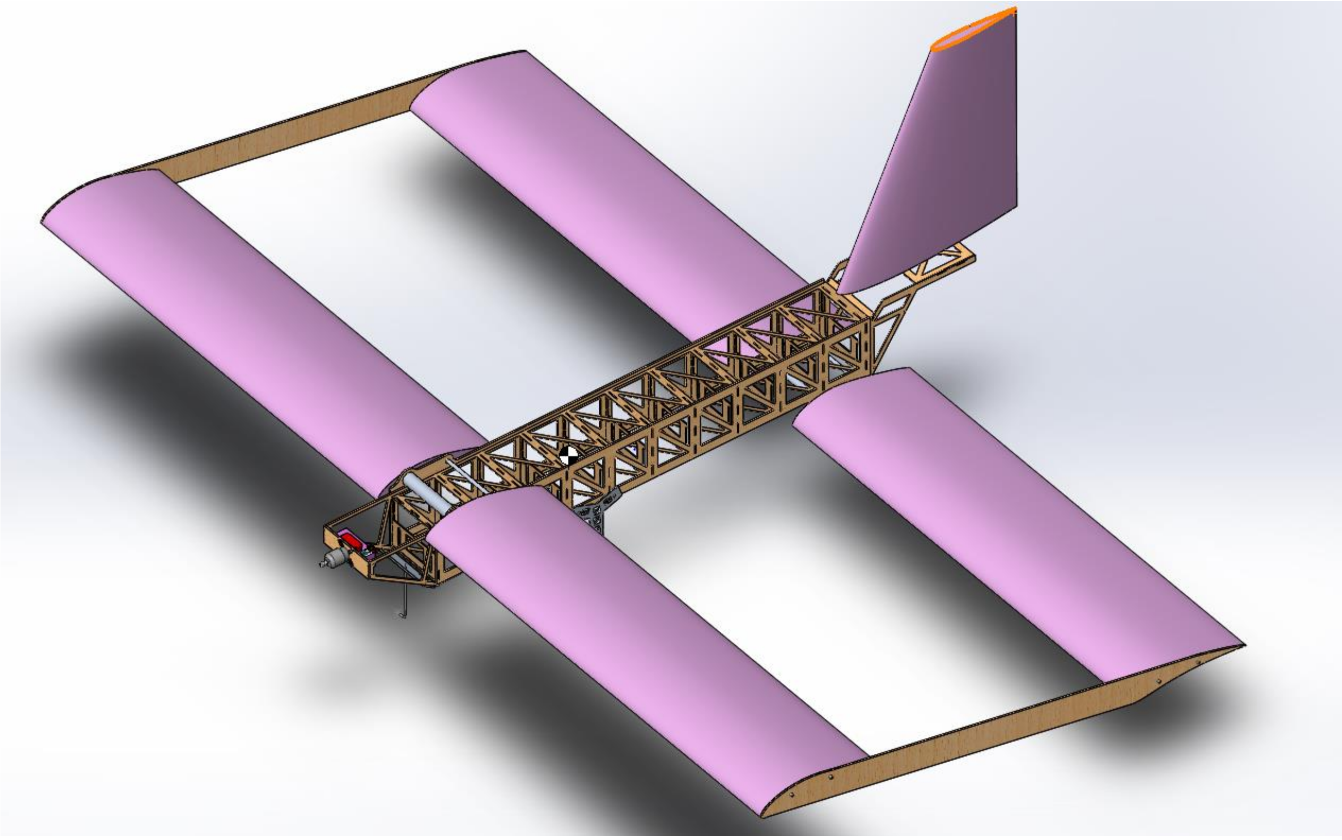

Kennesaw State University Aerial Robotics
SAE Aero Design East 2018
Team Number # 021
Kennesaw State University

Chase Hughes, Lorenzo Stewart, Robert Zenko, Liam Hutton,
Alex Resnick, Joel Morel, Alisa Machiwalla, Biya Haile, John Ruggeri, Joshua Hunter

STATEMENT OF COMPLIANCE

Certification of Qualification

Team Name	AERIAL ROBOTICS - REGULAR	Team Number	021
School	KENNESAW STATE UNIVERSITY		
Faculty Advisor	DR. ADEEL KHALID		
Faculty Advisor's Email	AKHALID2 @KENNESAW.EDU		

Statement of Compliance

As Faculty Advisor, I certify that the registered team members are enrolled in collegiate courses. This team has designed, constructed and/or modified the radio controlled aircraft they will use for the SAE Aero Design 2018 competition, without direct assistance from professional engineers, R/C model experts or pilots, or related professionals.

1/30/18

Signature of Faculty Advisor

Team Captain Information:

Team Captain:	ROBERT ZENKO
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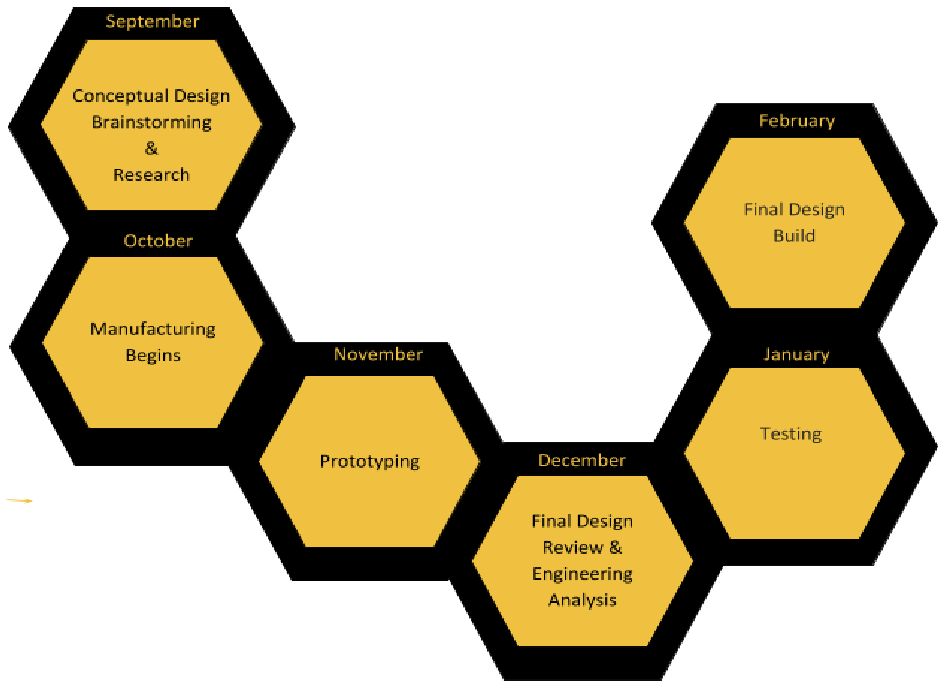
Captain's Phone:	(678) 281-4503

Note:

A copy of this statement needs to be included in your Design Report as page 2 (Reference Section 4.3)

Team Member	Role
Chase Hughes	President & Assembler/Designer (Electrical)
Liam Hutton	SAE Lead, Lead Team Designer & Design Researcher
Alex Resnick	CAD Designer, Assembler
Robert Zenko	Regular Lead, Manufacturer
Lorenzo Stewart	Vice President & Design Researcher
Joel Morel	CAD Designer, Assembler
Alisa Machiwalla	CAD Designer, Assembler
John Ruggeri	CAD Designer, Assembler
Biya Haile	Assembler
Joshua Hunter	CFD, Assembler



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1.0 Executive Summary

This year, the KSU Aerial Robotics Team designed an aircraft capable of meeting the requirements of carrying as much of a payload of passengers (tennis balls) and luggage (payload weights) as possible within the predetermined design constraints.

The design approach for the aircraft this year features a unique design implementing tandem-wings with a single, large rudder, and box fuselage design. The tandem wing has the main benefit of allowing for the same amount of lift of one large wing, but less of a moment as the wing area is separated among two wings.

Three phases make up the team's competition season: a three-month long research and design phase, a month long test-fabrication phase, and a month long final fabrication and testing phase. A scale model of the aircraft was built to test and confirm flight performance calculations and solidify the manufacturing processes that will be used in the final model.

The expected airspeed is 32 ft/s or roughly 22 mph, while the aircraft wingspan is twelve feet per wing. The total aircraft weight is expected to be below 55 lbs while carrying 48 tennis balls and 24 pounds of luggage.

The KSU Aerial Robotics Team has found that the aircraft design that has been brought forth meets both internal team requirements and SAE Aero Design Competition Requirements. The team would like to thank the Society of Automotive Engineers (SAE), the judges, and staff for hosting the SAE Aero Design Competition.

2.0 Design Approach

The design goal that was set was to get maximum flight conditions out of the design craft. The previous design from last year contained a traditional single fixed wing. The team decided to take a step back from a traditional simple configuration and tried a new design. The team wanted to push the maximum dimensions of wing span that the competition had offered, so it was made twelve feet. The team designed a tandem-wing aircraft that can sustain our objective goal of fifty-five pounds. Then the next stage in the design process for the aircraft became to classify the aircraft to sustain a three phases: take-off, flight, and landing. This was based off of initially the team wanted three conceptual design: a constant chord fixed wing monoplane, tandem wing biplane, and to effectively carry our desired load. It was decided to agree on the Tandem Wing due to its ability to minimize induced drag theoretically as much as fifty percent reduction in the drag due to lift also known as Induced Drag(Raymer).

3.0 Aircraft Specifications and Dimensions

Data Field	Value
Wingspan	144 in (12 ft)
Wing Chord	18 inches
Overall Length	107 inches
Height(from the ground)	53.15 inches
Empty Weight	19lbs
Total flight Weight	55lbs
Theoretical max flight weight	55lbs
Wing Area	5184 sq-in
Maximum Payload	36lbs
Number of Tennis Balls	48 Tennis Balls
Calculated Takeoff Speed	23.9 ft/s
Projected Cruise Speed	32 ft/s
Wing Loading at Max Payload	1.5 lbs/sq-ft
Power to Weight Ratio	0.184
Front Wing Airfoil	E423 (18 x 67.395in)
Rear Wing Airfoil	E421 (18 x 67.395in)
Vertical Stabilizer Airfoil	NACA 0012
Motor	Cobra 4130/20 KV 300

ESC	5v 3A Battery Eliminator Circuit
Power-Plant battery	6s 5000mAh 60c
Propeller	APG 20 x 13 E

4.0 Wing & Configuration Sizing

Drag Analysis

Figure 1. Picture of CFD on Plane

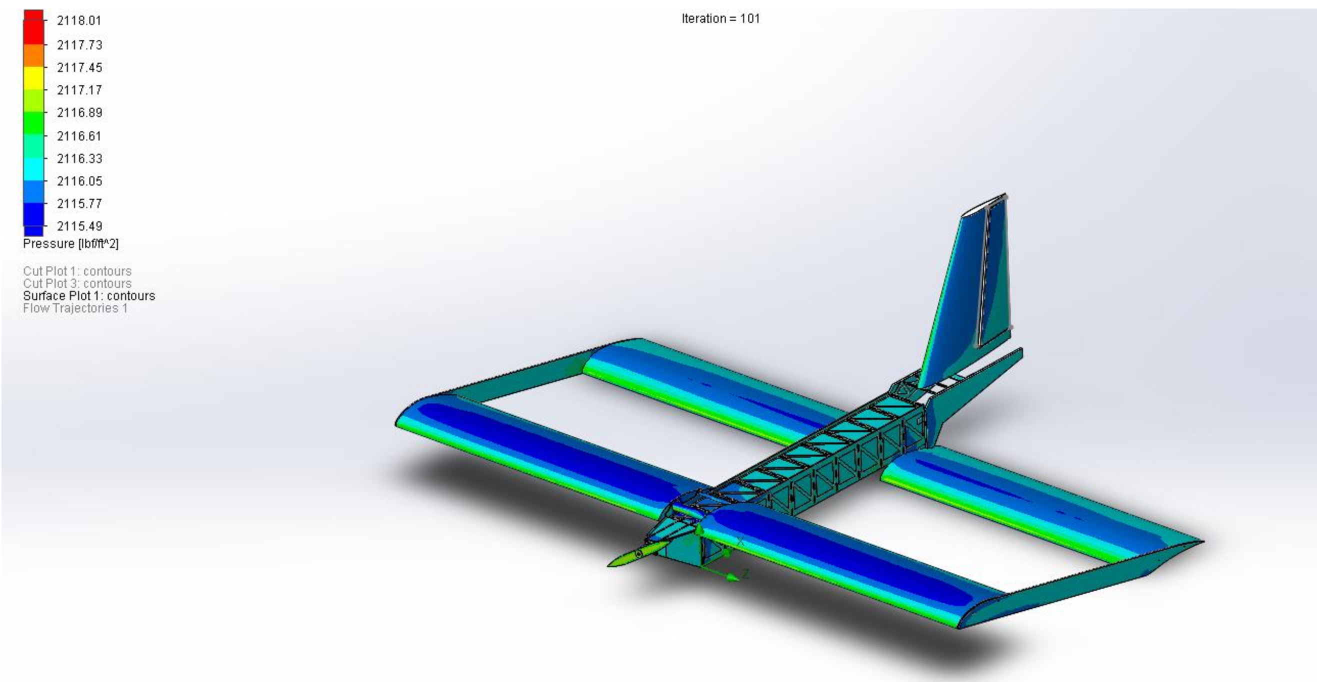


Figure 2. Picture of Side view of CFD through fuselage

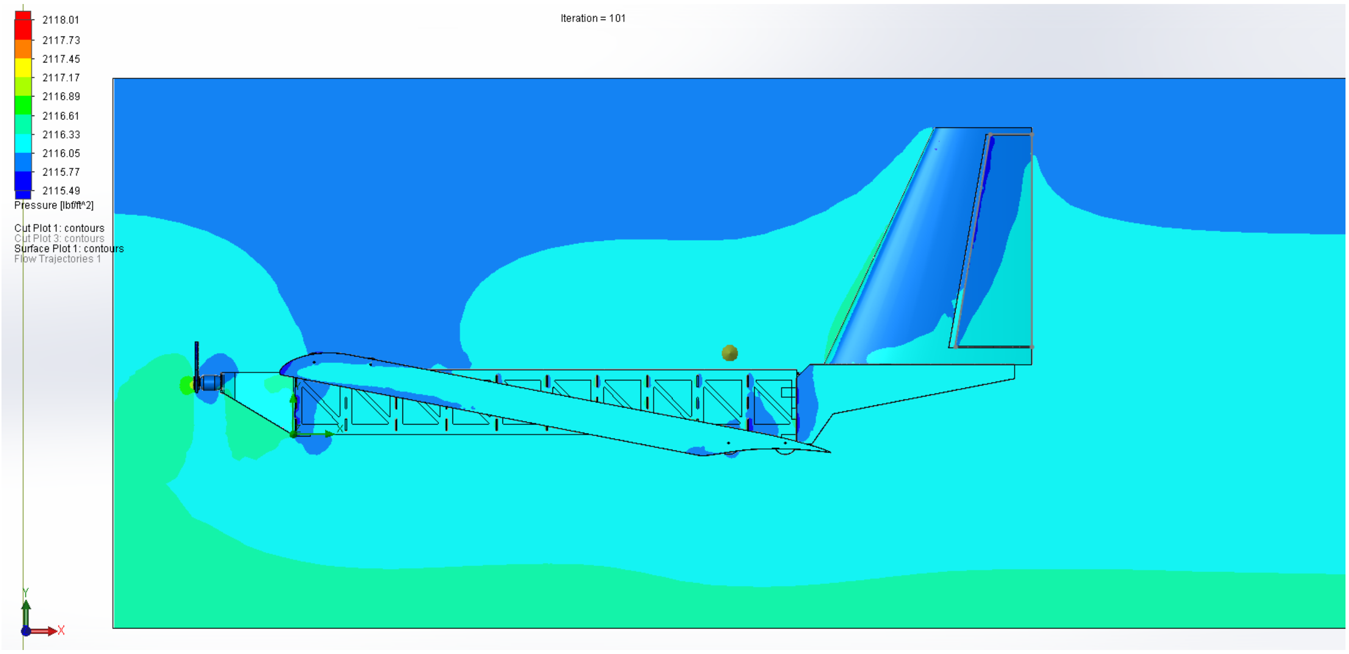
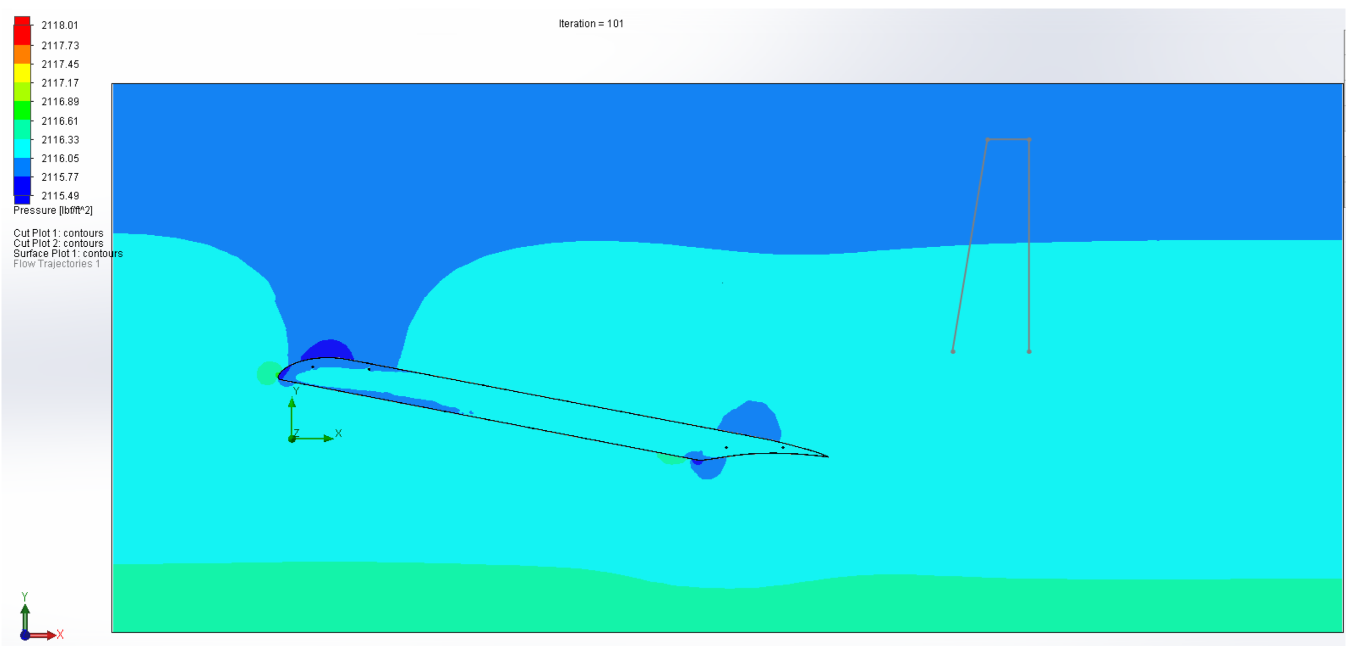


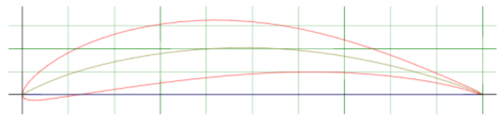
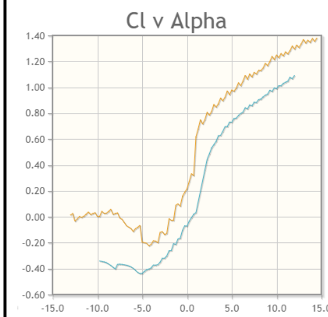
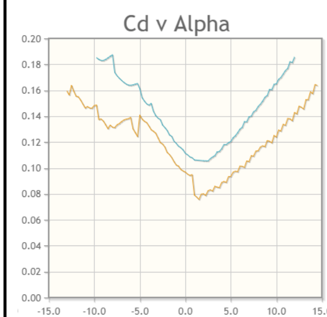
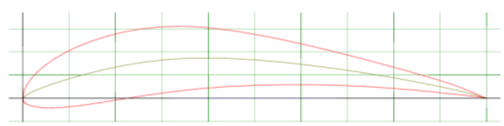
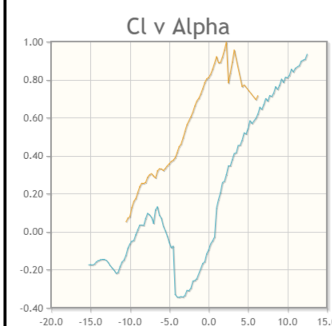
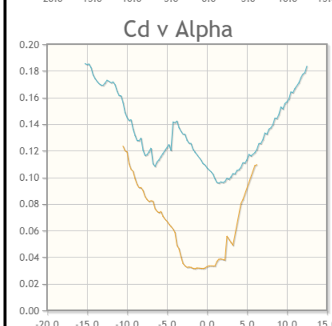
Figure 3. Picture of Side view of CFD at wing

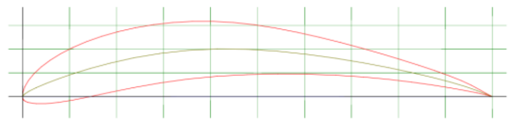
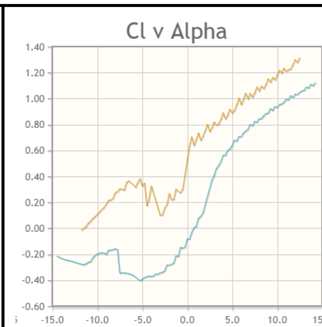
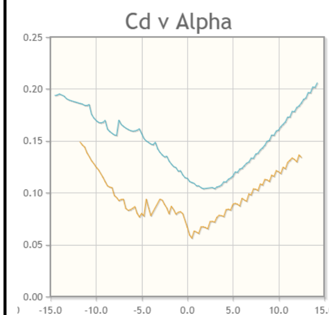
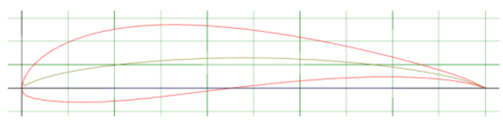
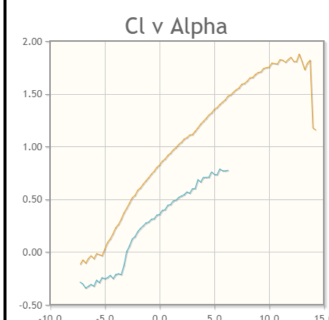
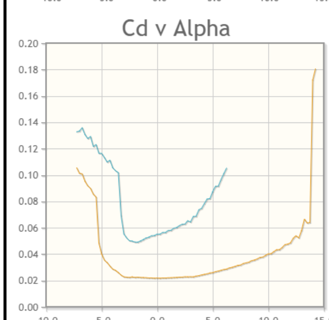


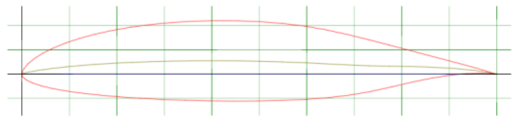
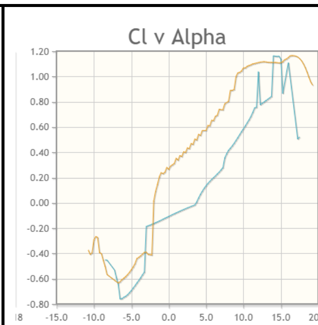
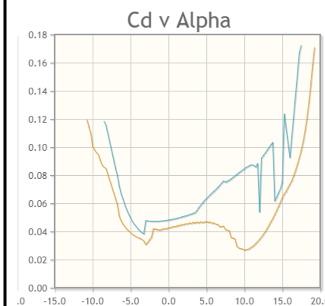
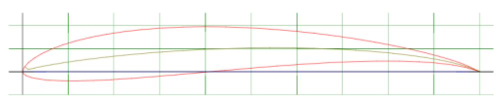
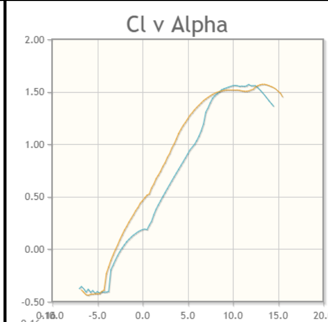
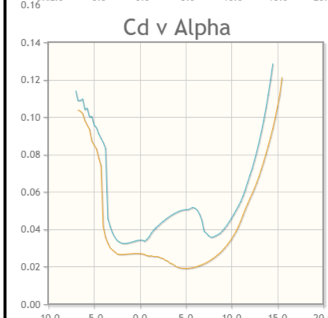
Airfoil Comparison

Through the creation of the plane, the selection of airfoil had to be addressed. A catalog of airfoils were presented within a document called the *Study of Low-Speed Airfoil Data* by a group of publishers called Michael S. Selig, James J. Guglielmo, Andy P. Broeren and Philippe Giguere in nineteen ninety-five. This study contained six high lift airfoils that the team found of particular interest: CH10, Eppler 421, Eppler 423, Eppler 591, Eppler 664, and Eppler 216. These airfoils were compared on their Coefficient of Lift(C_l), Coefficient of Drag(C_d), and Angle of Attack(AoA,α). The following airfoils were compared through an online database called *Airfoil Tools* at certain flight conditions through a range of fifty-thousand and a hundred thousand Reynolds Number. The reasoning beyond this was to see reasonable turbulent as the flight conditions will be subsonic and characteristically turbulent flow. Now that the parameters are based on a turbulent fluid flow, the next condition for the condition was to compare the boundary layer at a laminar level as the boundary layer condition for turbulent flow would be beyond five-hundred thousand Reynolds Number as per research presented by Schlichting Herrmann in the *Boundary-Layer Theory* in the year two-thousand.

Table 4: Airfoils / Coefficient of Lift & Drag vs Angle of Attack in a 50,000-100,000 Reynolds number range(Gold is 100,000 and Blue is 50,000)

Name	Airfoil	α Graphs
CH10		 
Eppler 421		 

Eppler 423		 
Eppler 591		 

Eppler 664		 
Eppler 216		 

Wing Length

The wing length is based off of the desired performance of the plane. The performance desired is based on maximum loading of net weight according to the rules. It was decided that if such weight requirements were to be met, then the Aspect Ratio(A.R.) would need to be of optimum capability. The decision given to the implementation of such mission specifications was a max twelve feet per wingspan for a total of twenty-four feet for maximum lift.

Desired Configuration

The desired wing configuration the designers had chosen decreased the torque on the fuselage to wing mounting points, this resulted in a tandem wing design. The team had chosen Eppler 423 and Eppler 421 as the designated airfoils with relation of comparison at 100,000 Reynolds Number of the candidate airfoils. E421 has a high initial C_d response to lift and a very high C_d ceiling so the pick was an easy choice as per the graphs provided. E423 has the most linear consistency in terms of C_d with little angle of attack increment, so on that factor this airfoil was chosen. The E423 was selected as the front wing due to angle of attack for stalling being lower, providing a “safe stall”, similar to a canard configuration. The rear wing uses the E421 airfoil due to it having a zero lift angle of attack closer to zero degrees angle of attack when compared to the E423. This is to ensure longitudinal stability, whereby in a nose down attitude will not induce an uncontrollable nosedive due to the lift imbalance between the wing will bring the aircraft back to level flight. It was chosen to maximize our configuration by spreading the horizontal distance to the furthest points on the fuselage. The team had concluded this most efficient when the distance between the wings are furthest from each other horizontally and vertically to maximize lift and reduce induced drag as much as possible. We have chosen our wings to be made from Foamular 150 Polystyrene insulation foam board. Templates of the E423 and E421 were cut from masonite board and pinned to the foam boards, and a hotwire follows these templates to cut the wing out in 3’, top and bottom sections. Eight of the sections glued together to form one wing set. Spar material choice was settled on aluminum early on, though in hindsight, this material proved to be too heavy for this competition. Early choices for the main spars were 1” diameter 6061 aluminum tubing with 0.035” running the full 12’, but this proved to be too weak and would yield beyond a load factor greater than 1.5. The next choice was found in a concrete float handle, as it had a relatively large diameter at 1.75”, and 6’ sections that can bolt together were easily found in at Lowe’s or Home Depot for spares. A rear spar of ½” diameter runs the full wingspan to fasten the wingtip, as two connections per wingtip are needed to prevent the wingtip from spinning on the main spar connection. The wings slide over the spars and become sandwiched between the fuselage and wingtip. Transportability was kept in mind, so the whole wing set can be broken down into four, 6’ main spar pieces, two rear spars, and the two front wings, as well as two rear wings. With a design goal of a flying weight at the max allowable 55 lbs as per rule 2.4, the design team calculated wing sizing and separation distances. With guidelines given in Nicolai’s White Paper, the design required a wing loading of around 1-3 lbs/sq-ft. The team considered an aspect ratio of 8 for both the front and rear wing. Adhering to rule 7.1, the wingspan for each wing was set at 144”. The chord lengths were calculated to be 18”, giving a total wing area of 5184 sq-in, or 36 sq-ft. This gives a total wing loading of 1.5, on the lower side of the White Paper guideline. Using the equation given by Laitone for downwash angle induced by the front wing onto the rear wing as the driving equation, the design team calculated dimensions for wing set stagger and horizontal gap. As the equation exhibits an inverse relationship between stagger and induced downwash, the greatest distance between the front and rear wings was chosen, with manufacturability also being considered for fuselage components. Guidelines on stagger give a minimal separation distance of at least one and half rear wing chord length. The max allowable dimensions of the mill used for cutting the fuselage side panel necessitated a max stagger distance of no more than just over three chord lengths, giving a separation of 56.369” from front quarter chord to rear quarter chord. This corresponds to a front trailing edge to rear leading edge separation distance of 38.369”, or 2.13 chord lengths. The vertical separation was again constrained by the milling machine, and so a maximum distance of 10.31” was chosen from chord line to chord line. When plugging these values into Laitone’s equation for a uniformly loaded wing, the downwash angle was found to be 0.0517 radians or 2.96 degrees, multiplied by the lift coefficient of the front wing. As such, the rear wing generates a smaller amount of lift compared to the front. In order to mitigate any possible torsional rigidity problems associated with two large wing sets, a set of structurally integral wingtips have been incorporated into the design. The wingtips attach to threaded plugs in the main and rear spars of front wing and connect to the spars of the rear wing in a similar manner to the front. This couples the rolling moment of the front wing set to the rear wing set, boxing the wing sets together for greater structural integrity.

Stability and Control

Control surface sizing estimations come from Raymer's guidelines, but modifications made due to the tandem wing design. The ailerons are found on the front wing, running 40% of the span with a chord length one quarter that of the wing, giving each control surface an area of 28.8" by 4.5". The elevators are found on the rear wing, running 90% of the wingspan with a chord length 35% that of the wing chord, giving a surface size of 64.8" by 6.3". For rudder sizing, an all moving vertical tail is used to give good yaw authority over the much larger than typical wing area. Vertical tail sizing was again undertaken using Raymer's Aircraft Design as guideline, with a vertical tail volume of 0.04 used to give a tail volume of 4.55sq-ft.

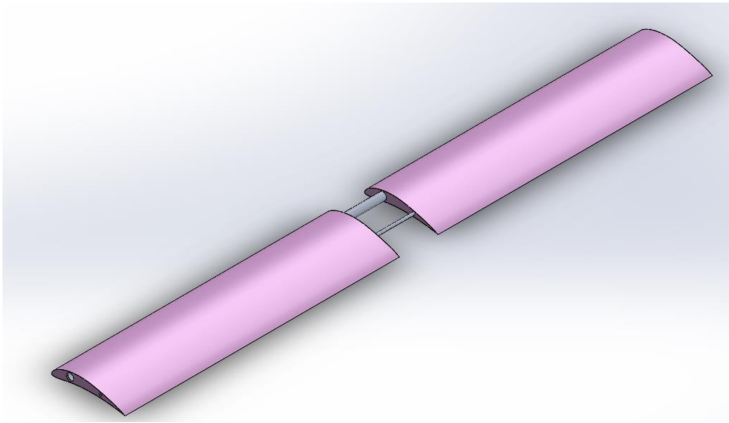
Center of gravity calculations used a web resource, eCalc, for assistance in estimating center of gravity placement based on static margin. Using the online calculator, the wing dimensions give the neutral point be 28.52" behind the leading edge of the front wing. A cautious static margin of 15% is used, giving an empty CG placement of 25.82" aft of the trailing edge of the front wing.

Takeoff and Level Flight Speed

Using Nicolai's White Paper, takeoff performance calculations used the predicted takeoff weight, wing area, and airfoil coefficient(s). The design team used the given equation, but with a modification of having two wing areas with two different max lift coefficients. The equation found in the White Paper gave a predicted takeoff speed of 23.9 feet per second.

Calculating for a flight weight of 55lbs, the level flight speed required was found to be 32 feet per second, with the front wing carrying 36lbs, and the rear wing lifting the remaining 19lbs.

Figure 5.Picture of one set of wings



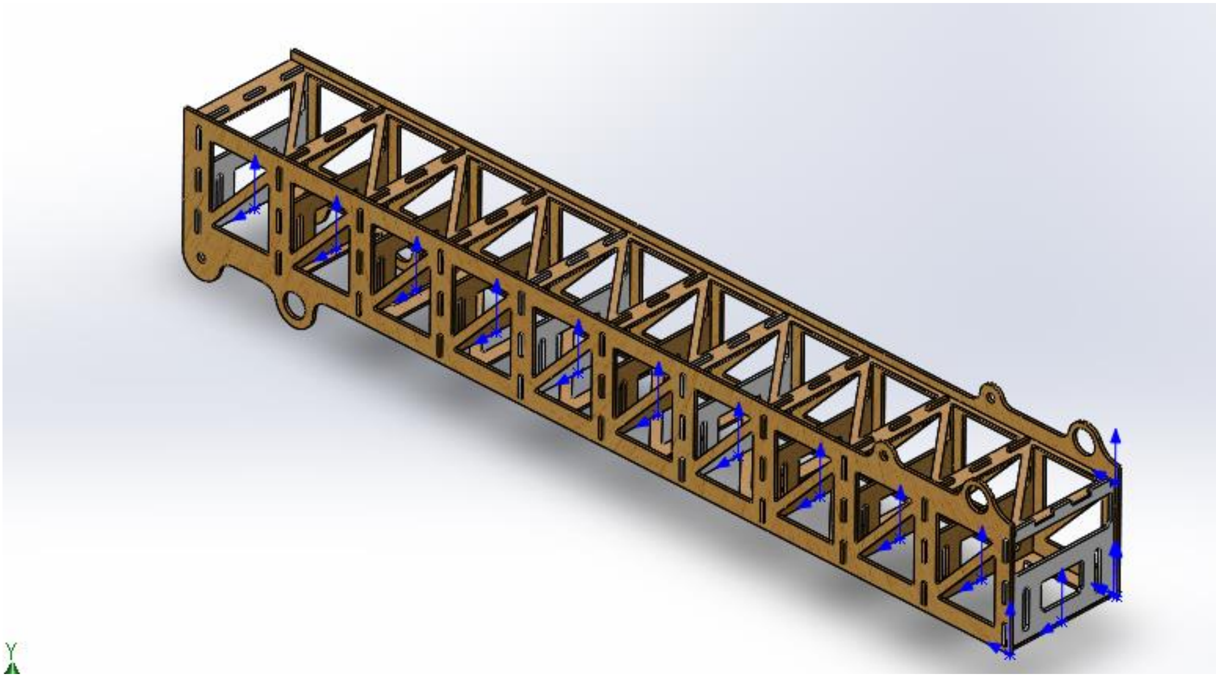
5.0 Fuselage Overview

The fuselage objective is to carry fifty-five lbs of payload effectively. This loading was decided to be of two loading compositions. The first loading composition that was chosen included tennis balls which represent passenger loading. The final weight that was selected included metal plates on the top level of the fuselage. The fuselage side panels include holes for the spars. These spars in turn will serve as the structural security for accommodation of the forces within flight on the wings and to combine the wings into one single airfoil.

Fuselage Composition

The materials composition consists of cedar plywood for the sides. The ribs vary in composition. Seven of the ribs are laser cut from balsa sheets, and four of the ribs cut using a water jet from white polycarbonate material. The placement of the four white polycarbonate ribs in the fuselage will be at the positions one, five, seven, eleven, and of the total eleven ribs.

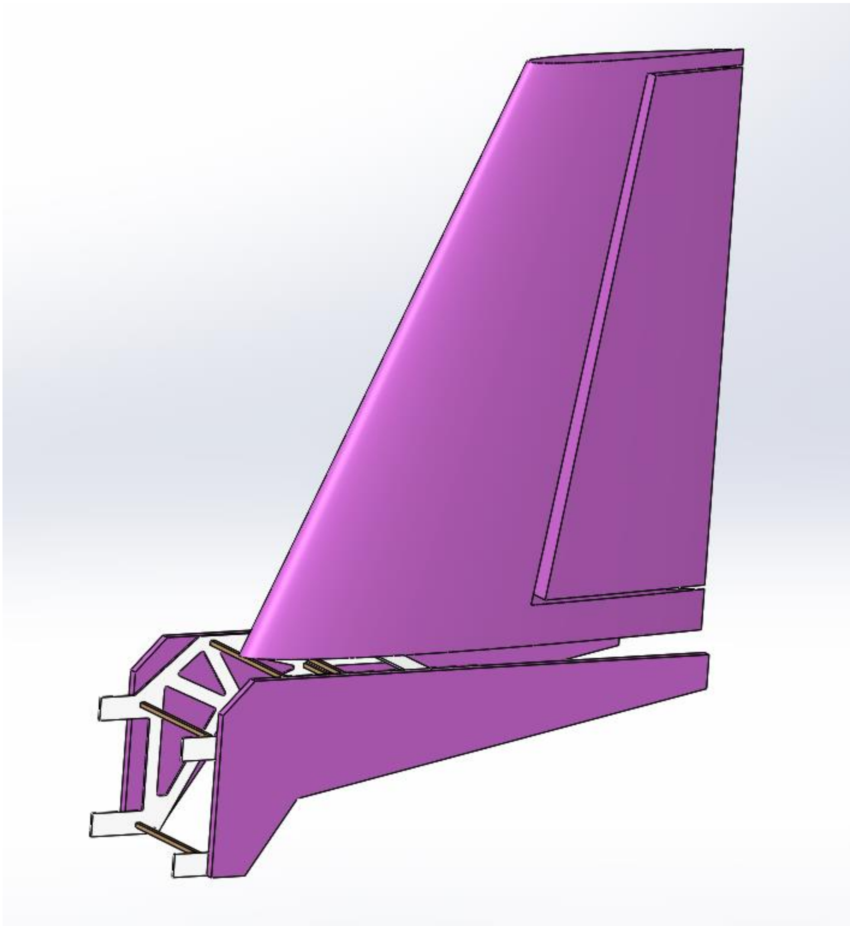
Figure 6. Picture of View of Fuselage



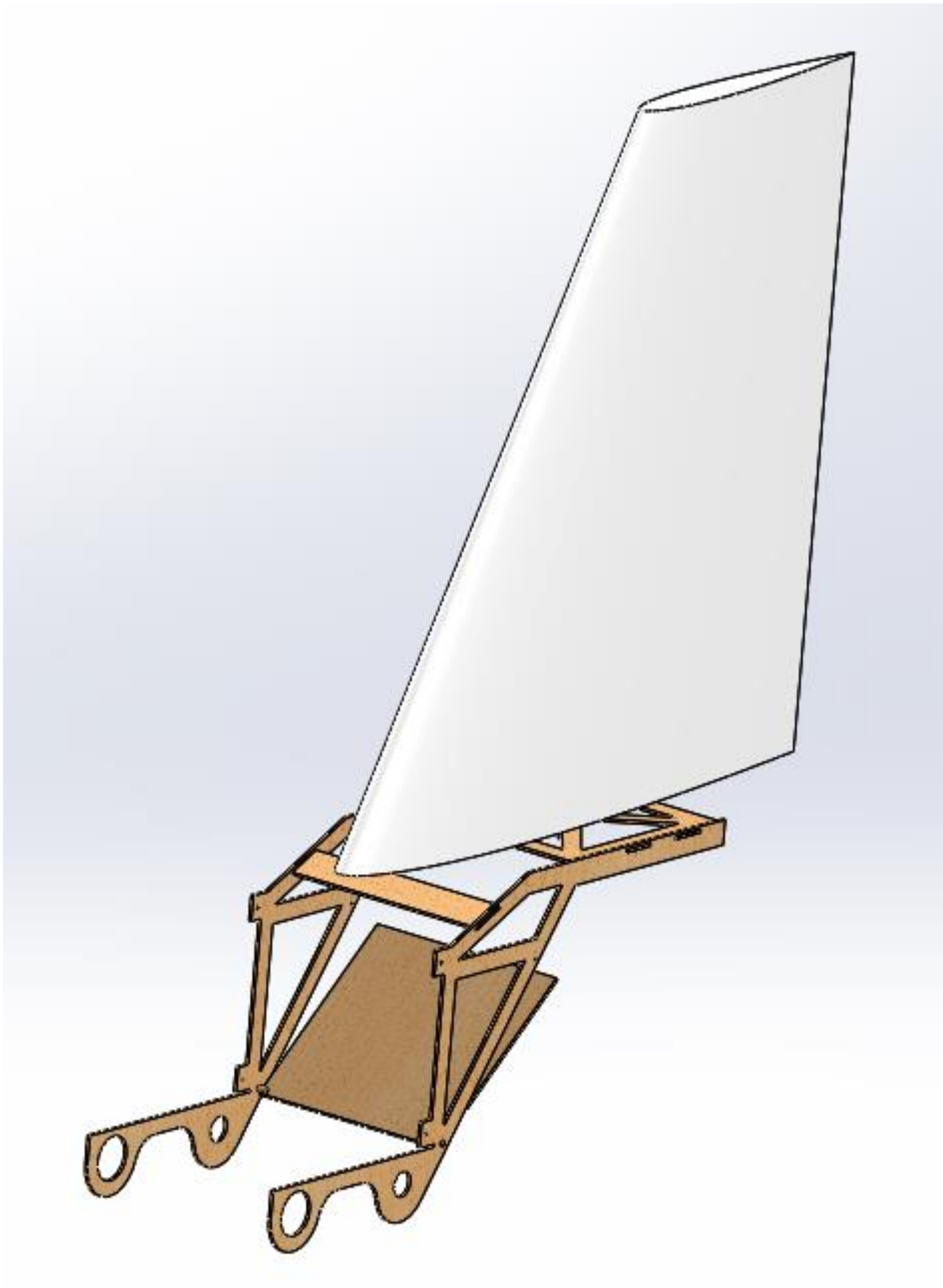
6.0 Empennage Design

The aircraft features a unique empennage design that, unlike most aircraft, a dynamic tail where the entire tail articulate and acts as both the vertical stabilizer and rudder. This design was formulated after a previous iteration depicted below (figure 5) was deemed to be unnecessarily bulky.

Figure 7. Picture of Tail



The above empennage is a combination of polycarbonate(white) and foam(pink) components that connect to the fuselage via four mid-size, high strength bolts. This tail design had two large flaws: a) it was heavy and b) had a large surface area that would make crosswinds dangerous. These two problems were solved by making the entire tail articulate which would allow the tail to be smaller as the tail would now act as a rudder. In other words, each square inch of surface area on the tail works as both a vertical stabilizer and a control surface.



8 Picture of Tail

Above in figure 8, the current design of the tail is shown. Significant structural improvements were made to the support for the tail itself after some prototyping with the scale model aircraft revealed that the old support structure was prone to collapse. The foam on the sides from the previous iteration were removed in favor of monkoating the sides to help reduce the tail weight.

7. Landing Configuration Design

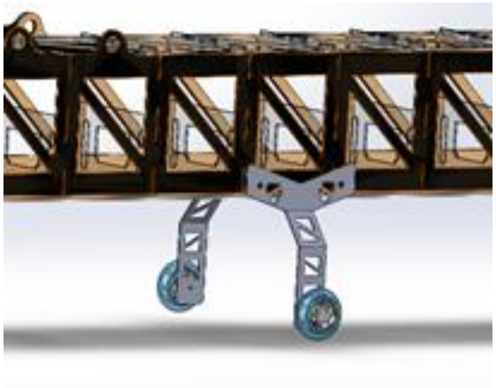
The design chosen contained a nose gear and a landing placed onto the fuselage for balancing of the aircraft. The placement of the second landing gear is behind the center of gravity.

Main Landing Gear

The first iteration was based on the concept that the landing gear would be attached to the spars that would connect to the fuselage. The spars would be made from 1.75” OD 1/16” wall aluminum tube 6061 – T6. The team utilized CAD to create a part that would fit around the spars to attach them to the fuselage. One spar would connect to the outside of the fuselage and one would connect to the inside of the fuselage and at the ends of each spar would be a CAD connector piece. Between the two spars would fit a wheel. This design would then be mirrored to the other side of the aircraft. There were numerous problems that arose. The first of which was the spars would have to bend in ways difficult to calculate the most efficient design. The next problem was that the area between the two spars did not allow enough clearance to put a wheel in between. However, the largest problem found was that if a rough landing were to occur, the force would simply bend the spars and potentially destroy the landing gear.

9 Picture of Landing Gear

The second iteration was a ‘Y’ shape plate that would bend in 23 different ways to look like a ‘Z’. The initial thought was that it would attach to the sides of the fuselage. The angle that the plate would bend was less than 45 degrees to minimize the plate from bending upwards. The problem that arose was that if we had a rough landing the plates might bend and potentially damage the fuselage apart.



10 Picture of Fuselage with landing gear

The third iteration and final design was a classic aluminum obtuse 'U' shape part that we already had on hand that attaches to the bottom of the fuselage. It fastens to the fuselage by both bolting through fuselage side panels as well as being epoxied on the backside to further distribute the shearing load of a landing impact.

8. Powertrain

This year, the team has chosen to run new powertrain equipment as it was thought to be a necessity for competitive standards due to factors such as wear, tear, and calibration issues. The battery chosen for this competition is the Turnigy Heavy Duty 5000mah 6S 60C Lipo Pack. The motor that has been chosen is a Cobra 4130/20 running at 300 kv, and to go with the motor, we chose to use a Turnigy Plush 60Amp Speed Controller and a 20x13 APC propeller, expecting to give at less than 11.67 lb-f of static thrust. The team did a thrust on the motor, ESC, propeller, and battery combo at 1kw of power running at 25.1v we got 4.53Kg of thrust before the watt limiter turned the motor off. With a 1kw max power usage running at 22.2 nominal volts running at 45 Amps and landing at 80 percent battery usage the aircraft would fly for five and a half minutes if the batteries are in the optimal condition. We chose to use this combination because the power to thrust ratio from the manufacturer was one of the most efficient and was just above the max wattage allowed. Having the power usage be slightly above allows the pilot to go almost full throttle without hitting the limiter and gives a better throttle curve for the pilot to feel more comfortable with the planes throttle response. .

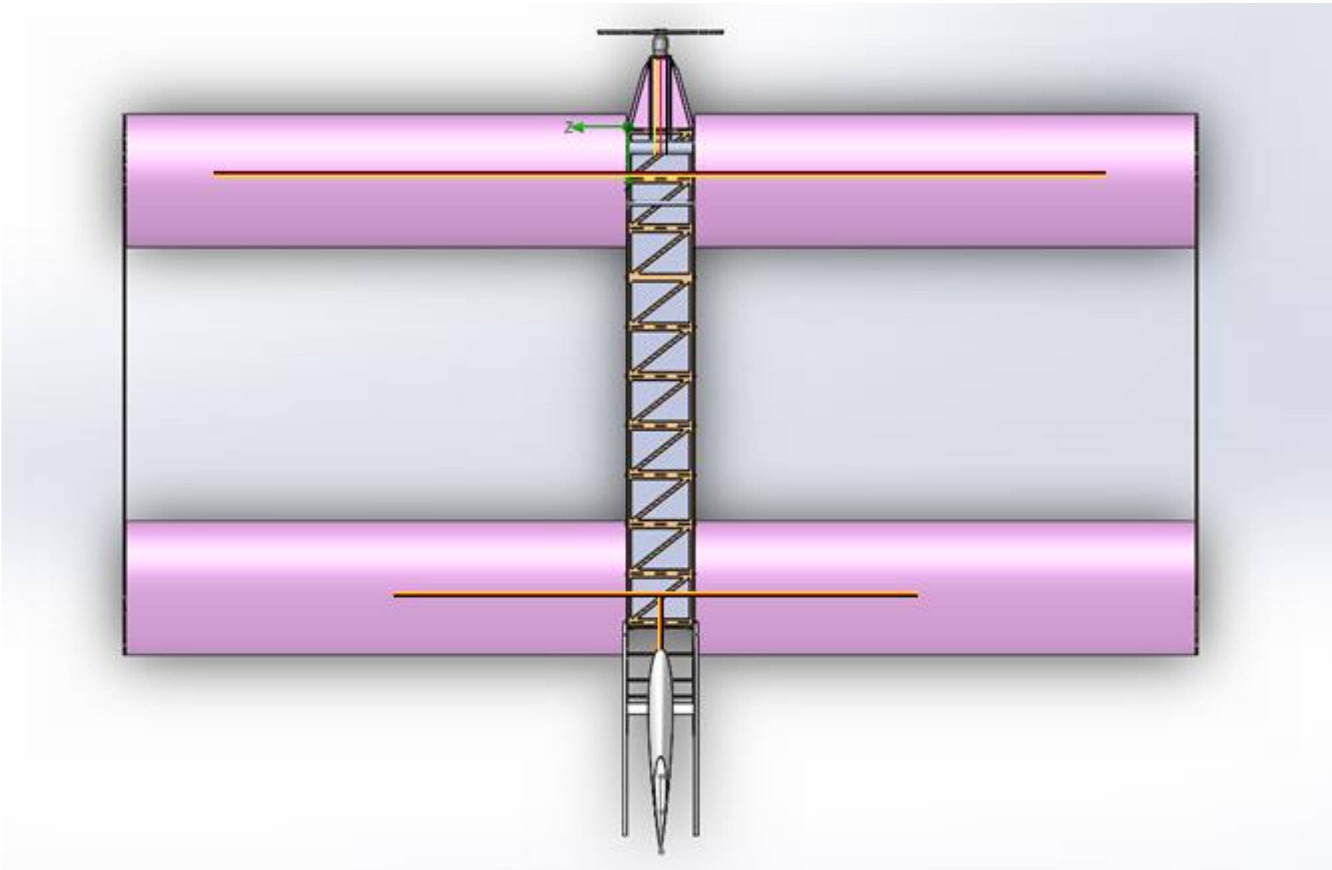
$$Flight\ Time\ = (Battery\ Capacity\ /\ Average\ Current\ Draw)\ *\ 60\ min\ *\ 0.80$$

Prop Manf.	Prop Size	Input Voltage	Motor Amps	Watts Input	Prop RPM	Pitch Speed	Thrust Grams	Thrust Ounces	Thrust Eff. Grams/W
APC	20x8-E	22.2	37.37	829.5	5,228	39.6	5046	177.99	6.08
APC	20x10-E	22.2	41.52	921.7	5,021	47.5	5227	184.38	5.67
APC	20x11-E	22.2	45.11	1001.5	4,973	51.8	5233	184.59	5.23
APC	20x13-E	22.2	46.25	1026.8	4,836	59.5	5294	186.74	5.16
APC	20x15-E	22.2	58.00	1287.5	4,533	64.4	4558	160.78	3.54
APC	21x12W-E	22.2	54.50	1210.0	4,679	53.2	6062	213.83	5.01
APC	21x14-E	22.2	51.27	1138.3	4,733	62.7	5887	207.66	5.17
APC	22x10-E	22.2	52.60	1167.7	4,703	44.5	6362	224.41	5.45
MAS	16x8x3	22.2	23.37	518.8	5,719	43.3	3256	114.85	6.28
MAS	16x10x3	22.2	29.07	645.2	5,415	51.3	3744	132.06	5.80

11 Table of electrical data

Electronics

For electronics this year the team chose to use six Trackstar TS417MG servos, two for each set of wings, nose gear, and the tail. The easiest way for the aircraft to be wired is to have two different batteries and receivers to allow a cleaner and more efficient use of wire. The battery for the rear is a two cell 1000 mah battery which will be ample amount of power for rear flaps and receiver. While the front will be using a 6s 5000mah 60c battery connected to the esc which has a 5v 3A Battery Eliminator Circuit which would get rid of the need for a secondary battery in the nose. The 3A Battery Eliminator Circuit will only be powering the front flaps and the front landing gear wheel to control which way the aircraft turns on the runway.



9. Flight Calculations

Takeoff Speed:

$$V to \ = \ [2W/(S\rho 0.8C_{\ lmax})]^{\ 1/2}$$

$$= \ [(2 * 55lbs) \ / \ (36ft^{\ 2} * 0.0023769slug/ft^{\ 3} * 0.8 \ * ((18ft^{\ 2} * 1.8) + (18ft^{\ 2} * 1.935))$$

= 23.9 feet per second

Level Flight Speed:

$$L_{total} = L_1 + L_2$$

$$L_1 = \frac{1}{2}\rho v^2 S_1 C_{l1}$$

$$v = \sqrt{(2 * 36lbf)/(18ft^2 * 0.0023769slug/ft^3 * 1.6)}$$

$$v = 32\, feet\ per\ second$$

Lift Curve Slope

$$C_{l\alpha} = \frac{C_{l\alpha} * AR}{2 + (4 + AR^2)^{1/2}}$$

$$= \frac{2\pi * 8}{2 + (4 + 8^2)^{1/2}}$$

$$C_{l\alpha} = 4.906\ per\ radian$$

Spar Stress Analysis

Basic analysis of the main spar was conducted using the flexure formula to ensure safe operation during flight. The stress was calculated as:

$\sigma = -\frac{My}{I}$, and when calculating a 2g load factor on the more heavily load front wing, the lift was treated as a distributed load and resolved at a distance of 67.55" away from the root, giving a moment of 2431.8 lb-in. The given spar section was a 1.75" diameter tube with 1/16" wall thickness. Calculating the area moment of inertia and find the stress at point furthest from the neutral point, the stress was given to be 18,017 psi. Comparing to the yield stress of the 6063 alloy at 31,000 psi, this gives a factor of safety of 1.72 at a load factor of 2.

Reynolds Number

Reynolds Number was calculated by the following equation:

Power plant Performance including both Static and dynamic thrust, performance prediction

Center of Gravity

10. Payload

There would be two trays on the aircraft that will contain the load. The upper tray is the larger of the two trays. This tray would contain the tennis balls. We plan on utilizing 12 lbs worth of tennis balls. On the other hand, the lower tray would be considerably smaller than the upper tray. The second tray will contain AISI 1020 steel. This will weigh approximately 24 lbs. Ultimately causing the payload to weigh a total of 36 lbs.

11. Manufacturing

The fuselage consisted of balsa, polycarbonate, and birch. With ⅛" birch plywood as sides, the part was milled using a five axis Computer Numerical Machine (CNC). The sides were then smoothened by files.

The ribs were hybrid, with consistency between ⅛" Balsa and polycarbonate sheets. The polycarbonate ribs are manufactured from the waterjet. Four were needed per assembly. The balsa ribs were laser cut over the course of two hours. Sand paper was used to smoothen out any rough spots on the ribs.

The tail contains several parts. The side plate contains birch, that was milled, and polystyrene foam covering, which was hot-wired. The vertical stabilizer was hot-wired in halves, and was connected by a ½" Aluminum 6061 T6 tube as an acting spar.

The wings are also polystyrene foam, that was hot-wired in halves. The spars for the wings was aluminum 6061 T6. Foam glue was utilized to secure both halves on the assembly. Connector is the end piece that holds both front and back wings in place during the flight. The connector is made from birch, by 5 axis mill.

The nose was constructed of birch plywood and a layer of monokote. The birch plywood was cut by vertical band saw. Holes were created by drilling. The outer shell was hotwired, and is supported by the aluminum skeletal piece. The skeletal piece was cut from the water jet.

The landing gear components the team opted for included a Dubro 5/32” shock absorber, with a 3” diameter roller blade wheel at the nose, and two 3” diameter roller blade wheels and steel rod, bent into bent into triangular shape, which will be located below the fuselage.

All parts are held to the assembly by six-minute epoxy. This is to ensure stronger strength than other glue at the team’s disposal. Due the short cure time, components can be constructed or repaired rapidly and easily.

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Acronyms

SAE: Society of Automotive Engineers

CFD: Computational Flow Dynamics

C_l:Coefficient of Lift

C_d: Coefficient of Drag

AoA: Aircraft of Attack

CNC: Computer Numerical Control

A.R.: Aspect Ratio