AAE 45100 T10 – Final Report

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I. Nomenclature Used

Name	Description	Unit
CDR	Critical Design Review	None
FRR	Flight Readiness Review	None
RFP	Request for proposal	None
Max	Maximum	None
Min	Minimum	None
P_{motor}	Motor power	$Watt$
c_T	Thrust coefficient	None
c_P	Power coefficient	None
J	Advance Ratio	None
kV	Motor constant	rpm/v
α	Angle of Attack	Degrees
E	Elastic modulus	MPa
I_{ij}	Product of inertia about the j axis when rotated about the i axis	$kg \cdot m^2$
V	Velocity	m/s
n	Load factor	g
EAS	Estimated Air Speed	ft/s
AR	Aspect Ratio	None
η	Efficiency	%
RoC	Rate of Climb	m/s
S	Wing Area	m^2
b	Wing Span	m
c	Wing Chord	m
ρ	Density	kg/m^3
CoG	Center of Gravity	m
C_L	Coefficient of Lift	None
C_D	Coefficient of Drag	None
C_M	Moment Coefficient	None

Table 1: Introduction and description of variables used

II. Project Description

A. Abstract

The conception, design problems and solutions to creating an easy to assemble foam airplane racer kit are discussed in detail below. RFP constraints as well as real life global, social and economic factors were considered in the creation of the kit. The kit's intended goal is for anyone of any reasonable age to be able to buy the kit and assemble the aircraft with minimal help using the tools recommended for assembly by the kit. The choice for pre-laser-cut foamboards is used to increase simplicity and ease of assembly like a jigsaw puzzle with minimal glue. The aircraft is designed with pylon racing in mind but can easily cruise as a "park flyer" for more relaxed flying. Documentation such as detailed manufacturing instructions will be included in the kit as well to aid in assembly.

B. Executive Summary

The goal of this design project is to design, manufacture and sell easy to assemble autonomous fixed wing foam pylon racer kits. The purpose of this system is to provide an airplane kit consisting of pre-cut foam board pieces and electronics to any audience, but younger children are specifically the target audience. The goal is for this kit to be able to compete against other foam racer kits on a designated racecourse containing inflatable pylons to signify the turns of the course. Although our kit is intended for autonomous flight, it can also be used for manual flight and offers the same capabilities through both control methods.

Our engineering principles were utilized throughout the entire design process. First, we started with initial sizing. This was mostly based on intuition as well as a sizing code provided via excel. From this, we were able to generate a general design point in terms of power loading and wing loading. We could then extrapolate exact sizing and electronics requirements from this initial constraint analysis. From there we moved to structures and aerodynamics where experiments were conducted to determine the strength of the foamboard material that would be used in order to provide a good theoretical model of wing loading. Aerodynamics analyses were also conducted via XFLR5 as well as ANSYS fluid simulations to determine critical Reynolds numbers and more accurate 3D wing loading. This entire process was iterative and multiple integral changes were made like a reversal of the wing airfoil design as well as a complete reshape of the fuselage and tail structure. Several iterations of the propulsion system were also carried out to optimize weight, power and performance to meet our goals of being the fastest racer to win the race, being as maneuverable as possible to tackle the tight turns of the course and having as much endurance as possible to carry out the race in any condition.

Specific design constraints were integrated to give us a solid starting point for the design of the aircraft. These include, but are not limited to, total takeoff weight, takeoff width and takeoff length. The total takeoff weight was used to gain a general idea for the appropriate weight fractions of each component including total fuselage weight of foam, and allowable weight of electronics. The takeoff width and length constraint were provided as a 2m x 5m box. This effectively limits the overall size of the aircraft in addition to the weight. It cannot be too large otherwise it will weigh too much and will also be much more difficult to take off and land within the required area.

The design of the aircraft also incorporates consideration to many other factors than just engineering. Public safety concerns were addressed by keeping the total takeoff weight low and using cheap plastic propellers in order to reduce momentum in flight and the overall danger of a spinning propeller. Global factors were addressed by sourcing all parts from distributors within the United States. This is especially important in times like these where the global supply chain has effectively been halted by limits on imports/exports to preserve safety due to the ongoing global pandemic. Cultural factors were not addressed as they were deemed unrelated to the project. Social and environmental factors were addressed by marketing the product as an aircraft that can be raced against others both indoor and outdoor. Finally, economic factors were addressed in multiple ways. We chose parts source within the US to cut down on shipping costs, as well as used standard parts like standard brushless motors and batteries to avoid the expense of specialty brushless out-runners or unique battery chemistries. We also included multiple spare parts on the foam sheets in order to replace components that were most likely to be damaged in a crash to avoid the consumer needing to buy a whole new kit or foam board.

The final status of our product is fully designed and ready to manufacture. The aircraft has “flown” theoretically in a Gazebo simulation but not in real life. Our team was usually divided into areas of expertise so that each member could contribute the most according to their knowledge specialty. We were able to meet all objectives as a team by working together and planning ahead of time order to provide enough time to work as a team and meet objectives on or ahead of schedule.

The nature of this project requires written instructions to be generated detailing the assembly of the entire plane from start to finish. This needed to be written so that all ages can easily understand and complete the assembly by themselves or with the help of an adult. These instructions were generated by first generating the laser cut files in order to understand how each foam piece must be assembled on its own and then how it must be assembled with the rest of the aircraft in order to create a fully functioning aircraft.

The design reviews were composed for a different intended audience than the final product is intended for. These design reviews, including the CDR, were created and presented to engineering peers and an engineering teaching team so they were designed to be higher-level with more technical data and explanations than the final product requires. The final product is geared towards an audience with any level of expertise in engineering and can be understood, assembled and enjoyed by even a 10-year-old child who has no knowledge of physics, math or engineering.

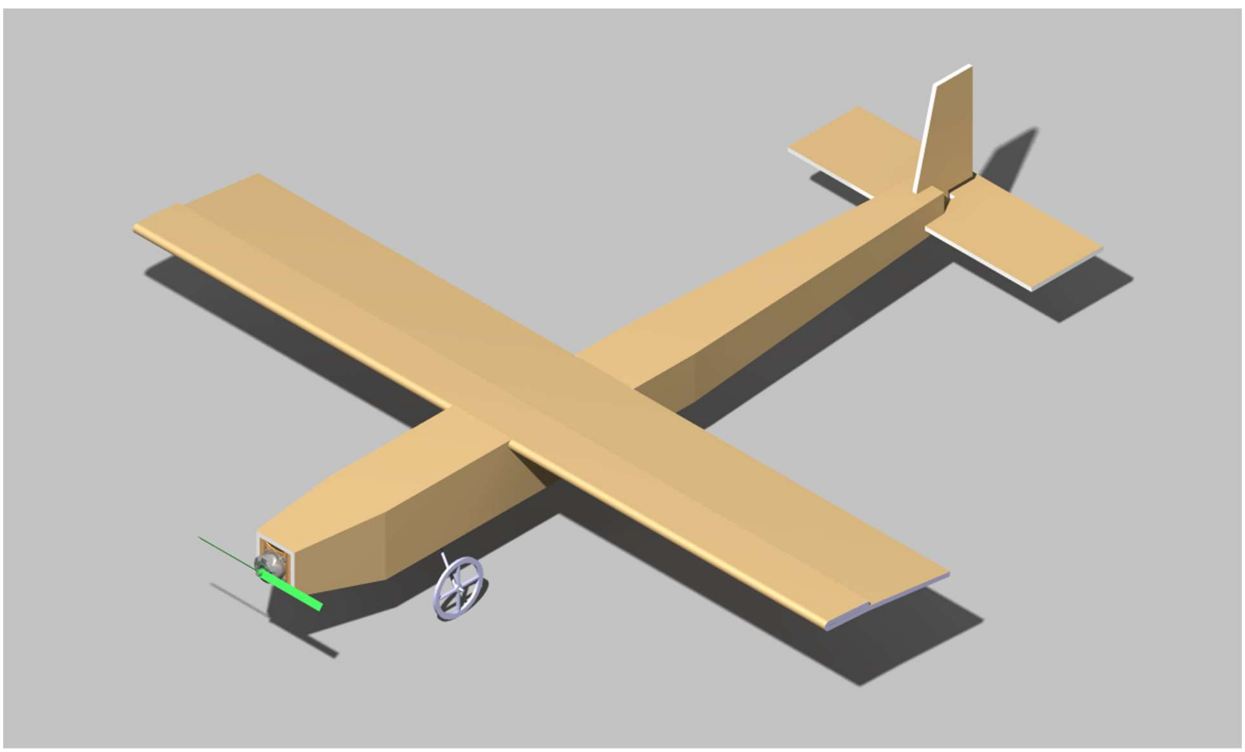

Figure 1: Final Aircraft Design Render

III.Aerodynamics

The aircraft we wanted to design had interesting engineering requirements, such as the need to be fast while being quite maneuverable to make tight turns in the flight course given to us. This all needed to be done with limited material and manufacturing capabilities due to the fact that we were designing a marketable toy/ hobby item. This put quite bit of emphasis on aerodynamic properties of the aircraft and required out of the box solutions.

A. Stability

In order for our design to be able to make really tight but also coordinated turns, we needed our aircraft to be maneuverable, but stable. Initially, we wanted to make the aircraft as unstable as it could be and implement a flight controller to help the pilot fly it safely, but this idea was scrapped due to cost and weight concerns. We finally settled on a moderately stable design with some unstable characteristics to help maneuverability.

We first wanted to calculate stability prerequisites, such as CoG location, static margin, neutral point, and stability derivatives. Main stability parameters of our aircraft are as following, seen in Table 2:

Neutral Point	Center of Gravity	Static Margin	Static Margin (Non-Dim by MAC)
2.69 in	1.887 in	0.803 in	12.93%

Table 2: Static Properties of our Aircraft

In order to be sure about the performance of our aircraft, we designed it initially by checking stability derivatives. After each design iteration, we referenced these values to have a rough idea if the plane was statically stable or not. These values can be viewed in Table 3.

Derivative	$C_{M,\alpha}$	$C_{L,\beta}$	$C_{N,\beta}$
Requirement	<0	<0	>0
Value	-0.55133	-0.00214	0.09057
Status	PASS	PASS	PASS

Table 3: Stability Derivatives

After checking stability derivatives, we wanted to run a dynamic analysis on our aircraft to see the responses of our aircraft. For this purpose, we checked three different modal responses, short period mode (Figure 2), phugoid mode (Figure 3), and Dutch roll mode (Figure 4).

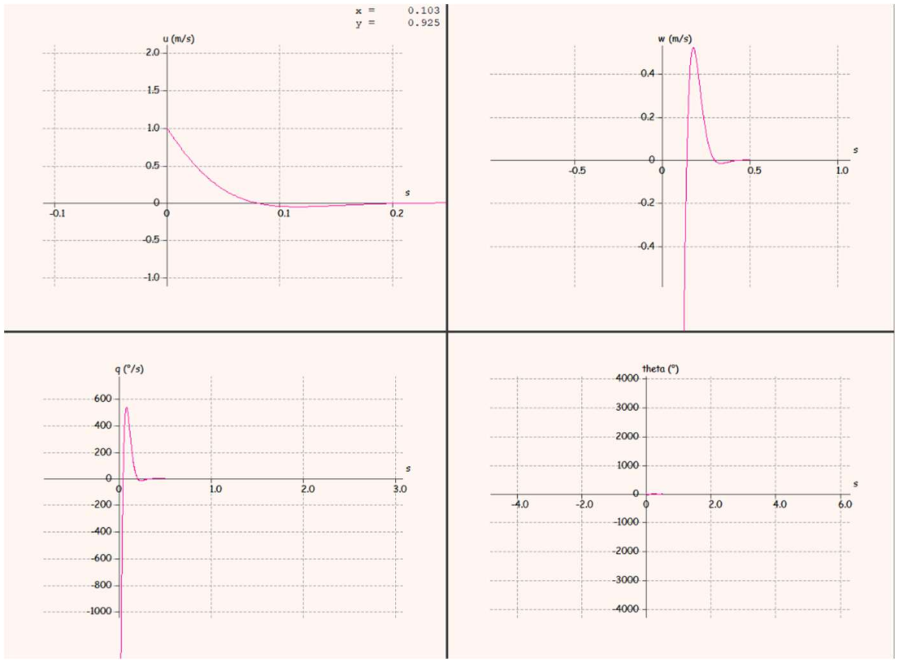

Figure 2: Short Period Response

Figure 2 shows the time response of the aircraft in short period mode. Top left graph shows the fluctuation of horizontal velocity, top right is fluctuation of vertical velocity, bottom left is pitch rate and bottom right is pitch angle. As can be seen from Figure 2, all rates converge to zero quite fast, slowest being in about half a second.

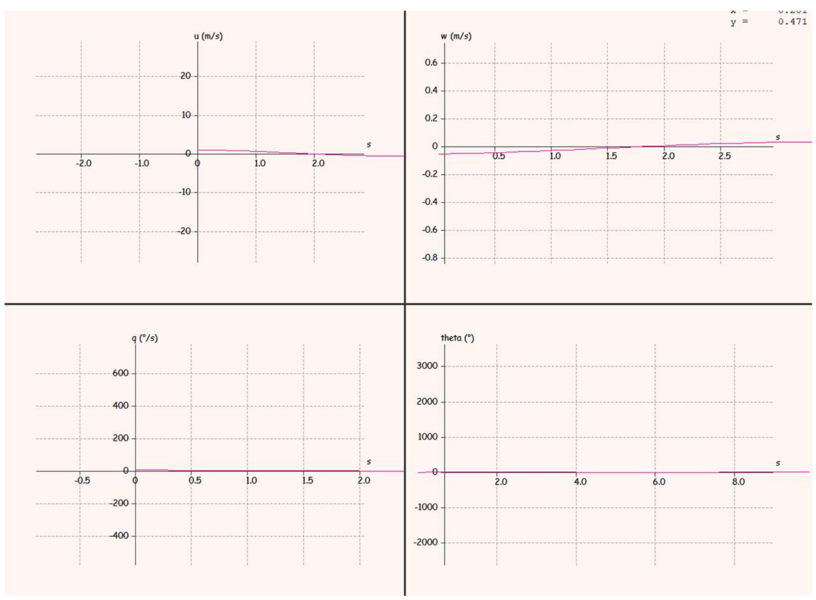

Figure 3: Phugoid Mode

Our aircraft was found to be extremely damped in the phugoid mode. Figure 3 shows the time response in this mode. The graphs are extremely damped sinusoidal waves, with almost no amplitude.

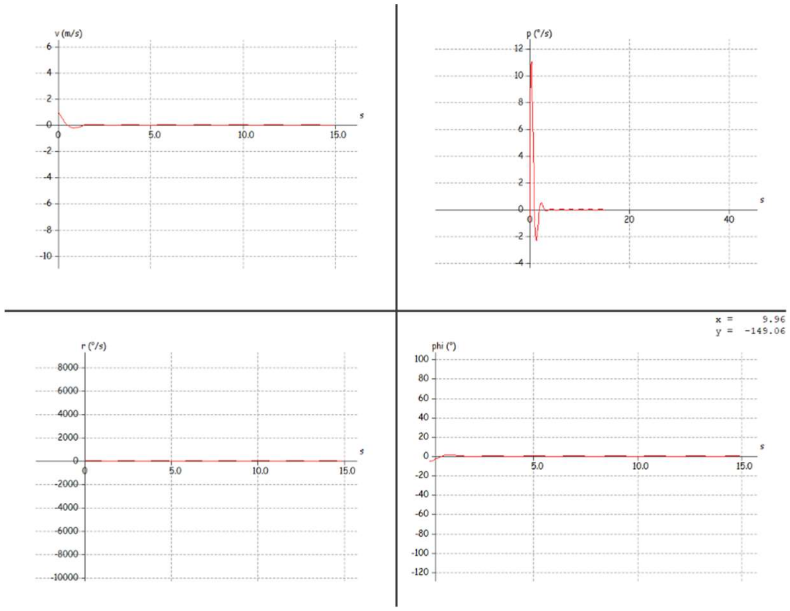

Figure 4: Dutch Roll

Figure 4 shows the Dutch Roll response of the aircraft. We generated the graph to check the lateral properties of our aircraft. The graph shows the y-velocity component perturbation on top left, roll rate on top right, yaw rate on bottom left, and bank angle in bottom right, all over time. Again, all perturbations were damped to 0 in a couple of seconds, indicating that the aircraft is laterally stable.

After checking static stability properties and the lateral and longitudinal behavior of the aircraft, we concluded that it would be desirably stable in flight, not only allowing a pilot without experience to control the plane, but also being maneuverable enough to succeed in the race.

B. Airfoils

We considered many airfoils for our plane, including both symmetrical and highly cambered airfoils, a flat plate, and a cambered flat plate. Due to manufacturing concerns, special hot-wired airfoils were immediately off the table. We did our first iteration with a flat plate airfoil at an angle of incidence, and our second iteration with a cambered flat plate. None of these airfoils gave us the lift and drag parameters we desired, so as a creative solution, we wanted to implement a Kline-Fogleman airfoil (KFm). The shape of the airfoil can be seen in Figure 5, in red, compared with a cambered flat plate, in blue.

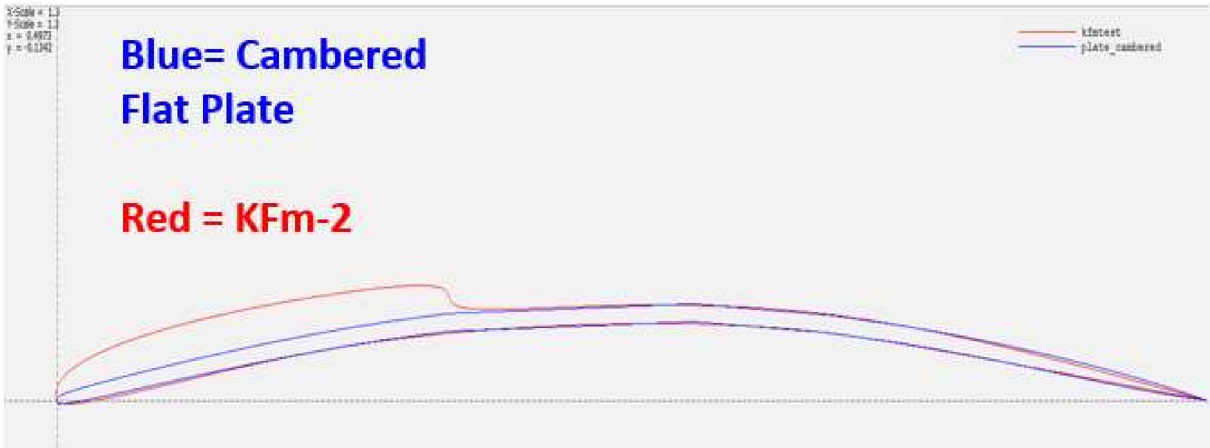

Figure 5: XFLR5 Implementation of KFm-2 (Red) compared with a Cambered Flat Plate (Blue)

The noticeable property of this airfoil is that it has a sharp change of thickness on the top surface, near c/3. This jump acts as a vortex generator on the top surface of the airfoil at low Reynolds numbers, and by creating suction increases the lift generated by the airfoil. It also reattaches flow after separation, enabling the plane to stall at higher angles of attack. In our multiple 3D analyses, seen in Figure 6, our main wing never stalled before our elevator, so the flight angle of attack was limited by the flat plate used in the elevator.

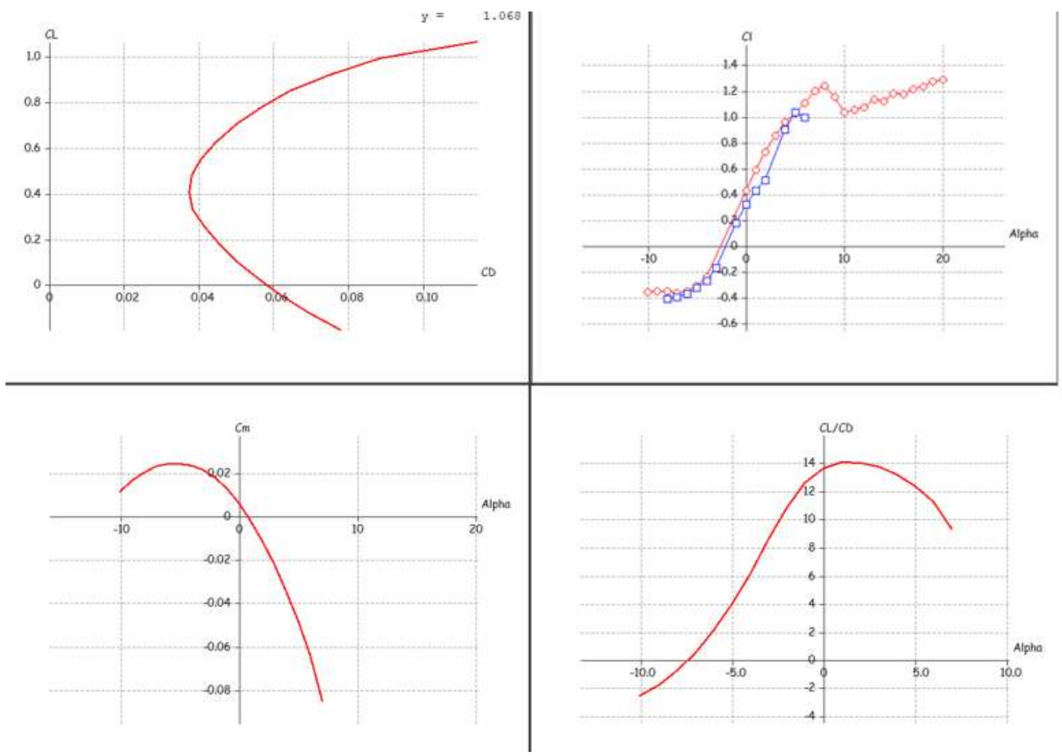

Figure 6: Aerodynamic Characteristics

Upon our calculations, we did our last 3D analysis at the fairly low Reynolds number of 56,000. At this Re, our Cl_{max} was 1.4, as can be seen in the top right subplot in Figure 6. We believe that a reattachment event occurred around 10 degrees angle of attack, decreasing and then increasing the lift as AoA increases. The blue graph overlayed represents the results of a cambered flat plate at the same configuration, which generates less lift and stalls at about 8 degrees AoA. On the bottom right of Figure 6, a CL/CD value of nearly 14 can be seen.

C. Basic Properties

The below tables and figures detail the aerodynamic properties and geometric shape of the airfoil/wing.

Property	Value
$C_{L, Max}$	1.4
$C_L/C_{D, Max}$	14
Angle of Attack	-10 to 15 Degrees
Wing Area	204 in^2
Wing Loading	14 N/m^2
Reynolds Number Range	50000 to 90000
$C_{D, \alpha}$	0.51 C_D/rad
α_0	-0.05 rad
$C_{L, \alpha}$	4.72 C_L/rad
$C_{M, \alpha}$	-0.573 C_M/rad
α_{Stall}	0.27 rad
$C_{L, \alpha Stall}$	-4.18 rad
$C_{D, \alpha Stall}$	-0.84 rad
$C_{M, \alpha Stall}$	0 rad
$C_{L,C}$	-1.1 C_L/rad
Max Lift	16.25 N
Max Drag	4.64 N

Table 4: Basic Aerodynamic Properties

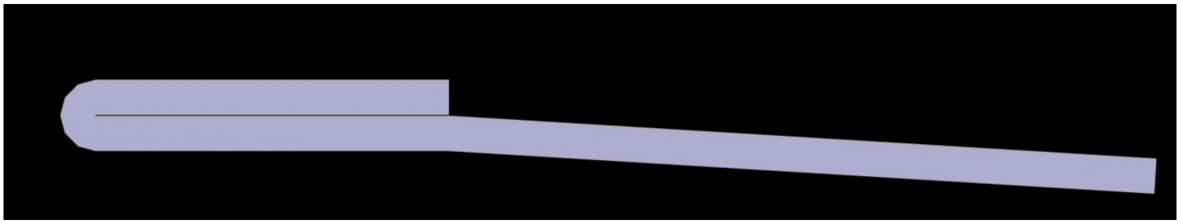

Figure 7: Model Wing Side Profile

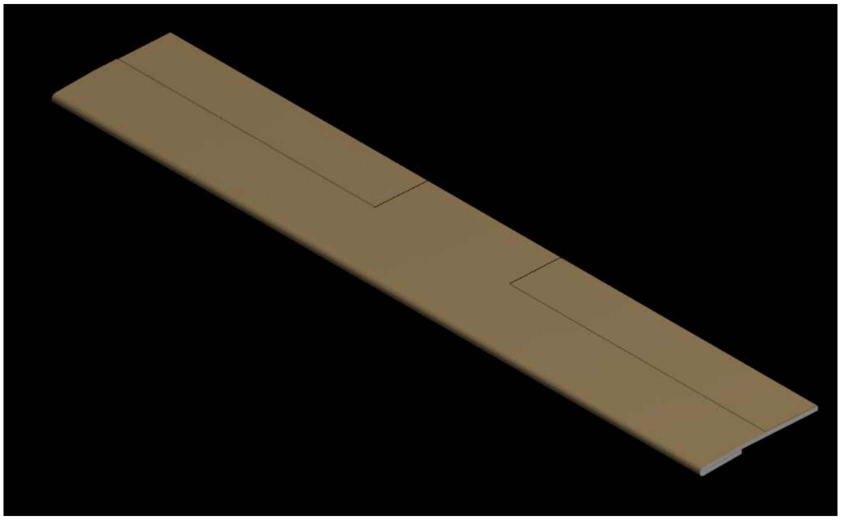

Figure 8: Model Wing Isometric View

IV. Structures

A. Weights

The initial analysis of the project goes through making sure the design point is chosen correctly to balance all the necessary actions around the course. The idea is to generate a sizing diagram that relates the wing loading and power loading capabilities of the aircraft. Combining that with the aerodynamics analysis presented before, we can then size components and determine overall weights of the aircraft. The graph below was generated using the constrain analysis. The blue circle in the middle of the graph is the design point our team considered to build our airplane.

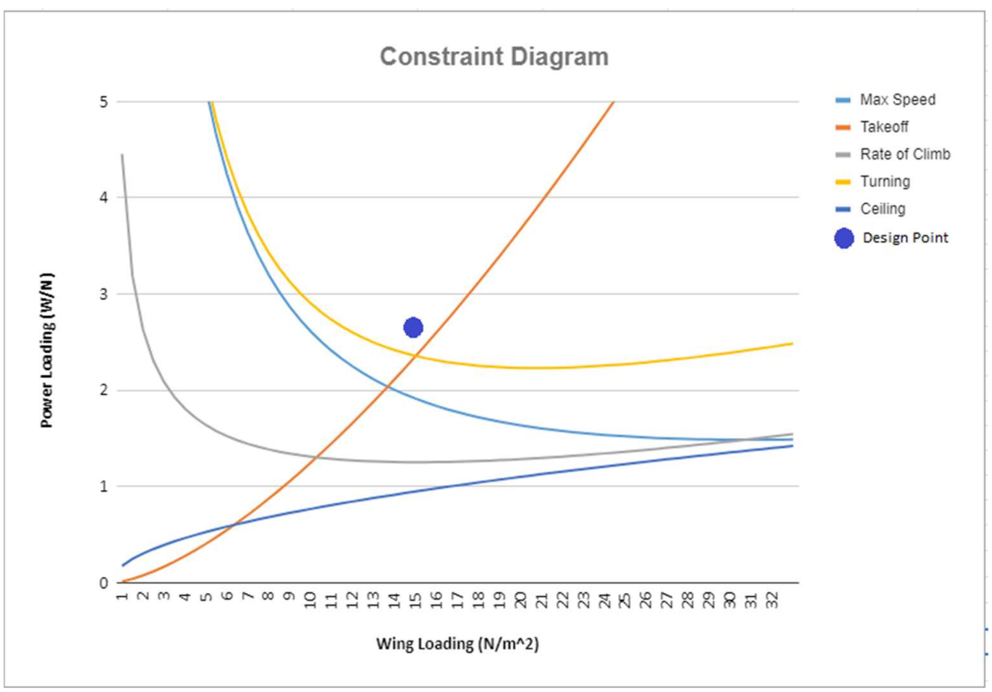

Figure 9: Constraint Diagram

Based on the design presented in the summary, the team decided to proceed with a top wing and a traditional tail configuration. The wing has a 34” span with a chord of 6”. There is an aileron in each side of the wing spanning 8” from the tip with a chord of 2”. The other two control surfaces are an elevator spanning across the whole horizontal tail, and a rudder that spans the vertical tail. The four control surfaces have control horns attached to them which are then linked to individual servo-motors. All the components inside the fuselage are listed in Part C, below, but the table below specifies the weights of the aircraft components, including the foam to be used for major components.

Item	Weight (g)
Propeller	5.1
Motor	25.2
ESC	11
Battery	49
Fuselage	51
Fixed Tail	14
Rudder	3
Elevator	2
Push Rods	14
Wing	45
Landing Gear	8
Total Weight	227.3

Table 5: List of individual and total weights

B. V-n Diagram

Our V-n diagram displays our selected Load Factors for our aircraft. We found that the maximum flight speed would not go above 40 ft/s (12.5 m/s) and this led to a load factor of 3. In level turning flight we found that the maximum bank angle would not exceed 75 degrees, and this led to a maximum load factor of 2.7. In climbing flight, a vertical turn radius of 6 feet (1.83 m) was considered reasonable and this led to a load factor of 2.8. The max diving speed in the V-n diagram was 1.4 times the max cruise speed which came to about 41 ft/s (12.5 m/s) and a load of 2. Below 18 ft/s (5.4 m/s), it is impossible to exceed the load factor as the wing would stall prior to reaching these conditions. A safety factor of 1.5 was used while making the V-n diagram and determining loads to ensure safety of our aircraft at all times. Our maneuvering speed was set at 26 ft/s (8 m/s). Our minimum cruising speed was found to be 22.5 ft/s (6 m/s) and our maximum cruising speed was found to be 36 ft/s (12 m/s) which was well within our envelope for flight speeds encountered during the course. Our team fixed our cruise speed at 26 ft/s (8 m/s). Our flight envelope has been marked with the solid green line on the V-n Diagram and we chose to fix our maximum load factor encountered at 2 g. This resulted in setting our maximum speed encountered on the course to 12 m/s and the maximum bank angle possible during maneuvers at 60 degrees as shown in the figures below.

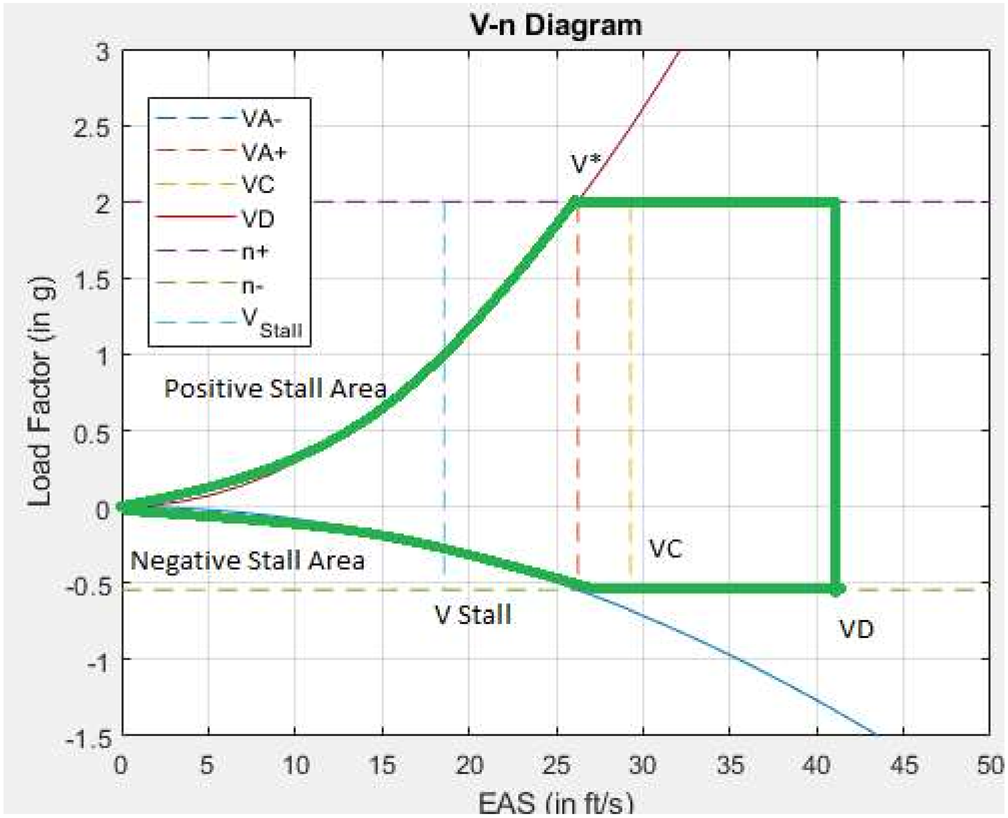

Figure 10: V-n Diagram

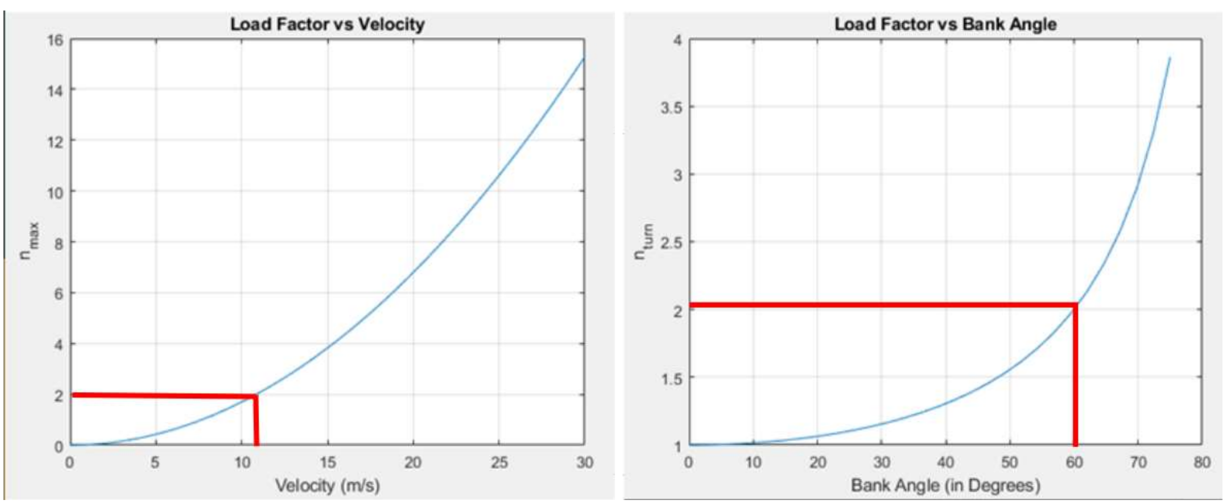

Figure 11: Load factor vs Velocity and Bank Angle

C. Parts and Costs

Our parts list is listed in the table below. We have made two assumptions to come to our total cost as displayed in the table which are:

1. We can reuse parts from the Mini-Scout build such as the landing gear assembly and the landing gear wheels and so we will not need to buy these parts for our final build.

2. The motion capture markers and the PixHawk Receiver will be provided to our teams at no additional cost by the teaching team as those are common for all teams and hence the costs are displayed as 0.

All of our parts are from vendors in the United States which will lead to 1-3-day deliveries and will avoid the blockade in trade due to the Coronavirus. This led to increase in costs and additional shipping costs as no major US vendor stocked all the parts we required to complete our build but we were still well under the $100 limit placed on our team to complete our design.

<table>
<tr><th>Number</th><th>Name</th><th>Quantity</th><th>Unit Cost</th><th>Shipping</th><th>Total Cost</th><th colspan="2">Link</th></tr>
<tr><td>1</td><td>30" x 20" Foam Board</td><td>4</td><td>$2.00</td><td>$0.00</td><td>$8.00</td><td colspan="2">https://store.flitetest.com/flite-test-waterresistant-foam-board-by-adams-25-pack-flt-2050/p674259</td></tr>
<tr><td>2</td><td>Sunnysky x2206 1500kV Motor</td><td>1</td><td>$15.00</td><td>$0.00</td><td>$15.00</td><td colspan="2">https://sunnyskyusa.com/products/sunnysky-x2206-brushless-motors?variant=45677405391</td></tr>
<tr><td>3</td><td>E-flite
800 mAh 30C 2S LiPo Battery</td><td>1</td><td>$7.08</td><td rowspan="3">$9.69</td><td>$7.08</td><td colspan="2">https://hobbyking.com/en_us/turnigy-800mah-2s-30c-lipo-pack.html</td></tr>
<tr><td>4</td><td>5g Servo</td><td>4</td><td>$6.49</td><td>$25.96</td><td colspan="2">https://store.flitetest.com/flite-test-es9051-5g-digital-servo-flt-3031/p785287</td></tr>
<tr><td>7</td><td>Pushrods (Pack of 8)</td><td>1</td><td>$4.99</td><td>$4.99</td><td colspan="2">https://store.flitetest.com/flite-test-23-push-rods-8-flt-2071/p791696</td></tr>
<tr><td>5</td><td>ParkZone 18 Amp ESC</td><td>1</td><td>$9.99</td><td>$0.00</td><td>$9.99</td><td colspan="2">https://www.amazon.com/Hobbypower-Brushless-Controller-Multicopter-Helicopter/dp/B00XKX5TBE</td></tr>
<tr><td>6</td><td>APC 6x4E Propeller</td><td>1</td><td>$2.29</td><td>$0.00</td><td>$2.29</td><td colspan="2">https://www.apcprop.com/product/6x4e/</td></tr>
<tr><td>8</td><td>Mini Scout Wheels</td><td>2</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td colspan="2">REUSED</td></tr>
<tr><td>9</td><td>Landing Gear Rod</td><td>1</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td colspan="2">REUSED</td></tr>
<tr><td>10</td><td>PixHawk Receiver</td><td>1</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td colspan="2">Provided</td></tr>
<tr><td>11</td><td>Motion Capture Markers</td><td>6</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td colspan="2">Provided</td></tr>
<tr><td colspan="4">Total Shipping Cost</td><td>$9.69</td><td colspan="2">Total Component Cost</td><td>$73.31</td></tr>
<tr><td colspan="5">Total Order Cost</td><td colspan="3">$83.00</td></tr>
</table>

Table 6: Parts List for Final Build

D. Stress and Bending Moments

Figure 12 shows the lift distribution over the span of our wing. C_l data was exported from XFLR5 and processed to get the lift distribution over the span. The total force is around 6.1 N at 13.5^{o} angle of attack (stall AoA), which is in agreement with our previous calculations. The highest local force was found to be 0.187 N at the center of the wing. On the right, the bending moments can be seen. The highest bending moment for the main wing was 0.565 Nm. For the elevator it was 0.008 Nm.

Based on these forces, we ran a finite element analysis on half span of our wing. The forces we found from XFLR5 was distributed to the area of the airfoil as pressure. While this assumption ensures that forces are perpendicular, gives a more conservative estimate due to the linearization of the force distribution instead of elliptical. Figure 6 shows the result of the analysis, with deflection exploded by a factor of 4. From the analysis, the tip deflection was found to be ~0.66 inches. To validate our results, we also ran an experiment on a wing we built and found the deflection to be 1.8 cm (measurements were done in metric), which converts to about 0.7 inches.

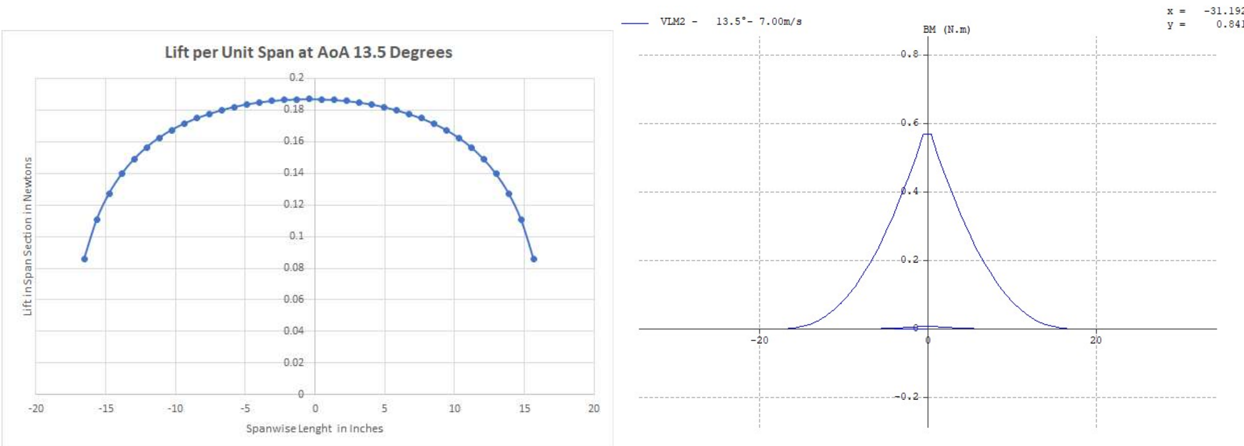

Figure 12: Lift Distribution over the Wing (left) and Bending Moments Diagram (right)

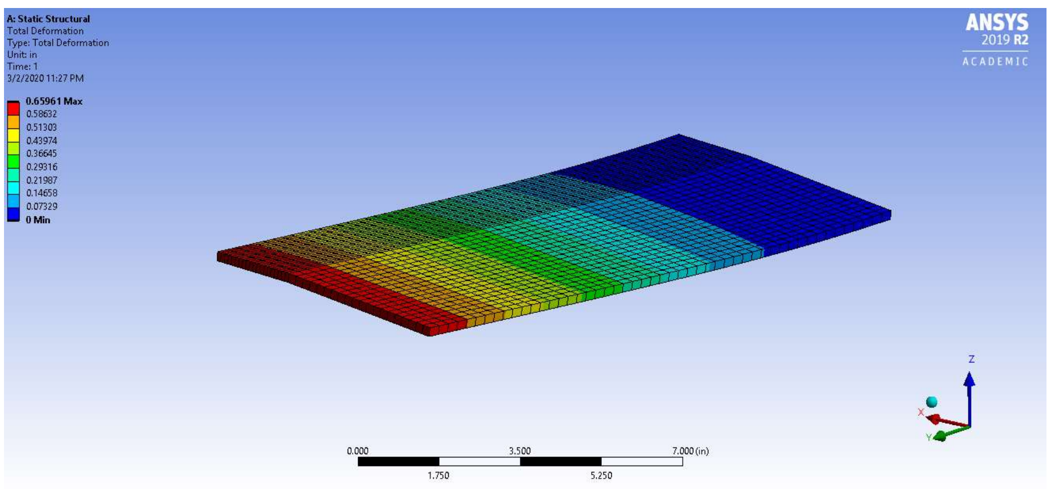

Figure 13: ANSYS Wing Deflection Analysis

From the analysis above, we have found out that our wing can endure the forces in our flight envelope. Two major assumptions on this is no sideslip, and no wind gusts to increase the applied force. We therefore did not use a wing box, or any stringers.

For failure criterion, we considered the Tresca yield criterion for our wing, since it is a bit more conservative than von Mises criterion. The FEA analysis we ran gave us safety factor values of 3.4 at lowest near the root, and more than 15 near the tip. From this data, we have concluded that the maximum pressure on the half-wing can be ~310 Pa, which converts to about 20.4 N for our wing area.

E. Landing Gear Analysis

The Landing gear chosen for the final design is an improved version of one of the test models built by the team during the beginning of the semester. This option gave minimal issues and the dimensioning that allowed for better takeoff propeller clearance. The mechanism is simple and constitutes of a bent wire of 0.125" diameter and two plastic wheels that are attached to the end. The horizontal section of the landing gear structure is to be placed in a additional support piece and glued to the bottom of the fuselage. This allows for minimum lateral deviation and tail strike issues.

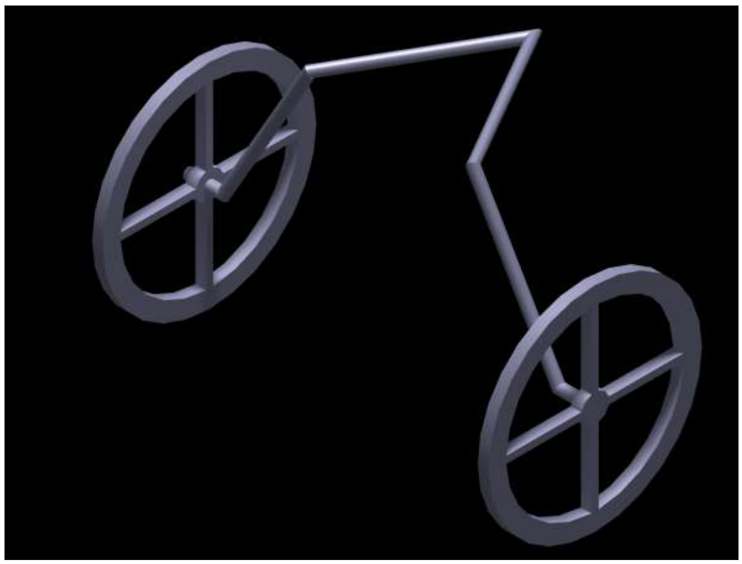

Figure 14: Landing gear CAD isometric view

3. Propulsion

To decide on our propulsion components, we had all three of our mission objectives in mind. We wanted to be able to fly within a fixed speed envelope, we wanted to maximize endurance and we wanted to be as maneuverable as possible. These conditions led us to our final iteration of our propulsion system which is detailed per part of the system below. A general overview of how our system's propulsion performs is given in tables 7 and 8.

Throttle Percentage	Current Drawn	Flight Time	Power Loading
60%	1.8 Amps	15 Mins	4.6 W/N
75%	2.2 Amps	12 Mins	5.15 W/N
100%	3.6 Amps	8 Mins	8.37W/N

Table 7: Propulsion System Statistics

Flight Speed	Drag	Lift
7 m/s	120.183 g	442.918 g
11 m/s	296.778 g	1093.737 g

Table 8: Max Lift and Drag vs Flight Speed

A. Motor

We had experimented with motors with high Kv values and motors with low Kv values and determined that a motor with less Kv would give us more torque and power while using less cells in a battery. This helped us settle on a 2S battery that would help deliver as much power as a combination with a high Kv motor with a 3S battery. This in turn meant massive weight reductions as batteries with a larger number of cells increased in weight and size exponentially. With our aerodynamics overview we determined that the maximum Power Loading for our motor during maneuvers comes out to around 4 W/N and this motor provides us with around 8 W/N which has an added in safety factor in case we were to need more power. This also gave us the capability to reach cruise flight at 70% of throttle instead of 100% which meant lower current draw from the battery that simultaneously meant increased flight time.

Figure 15: SunnySky x2206-1500Kv Motor

We decided on utilizing the Sunnysky x2206-1500Kv DC Brushless motor which gave us the following properties:

Specification	Value	Unit
P_{motor}	150	Watt
P_{motor}	0.215	Horsepower
η_{motor} (100% throttle, 6x4 prop)	83.28	%
Mass	25.2	Grams
kv	1500	rpm/v
Internal resistance	0.147	Ohms
No-load current	0.3	Amps
Rated voltage	7.4−11.1	Volts
Rated lipo cells	2−3	Cells

Table 9: Motor Specifications

B. Battery

As we have chosen a low Kv motor and our overall propulsion system efficiency is at 82% we had the ability to choose a battery pack below 1000 mAh. We went with a Turnigy 0.8 Ah 30C 2S battery pack. Our motor could support up to 3S battery packs to deliver more power but a 2 cell battery pack would mean less weight and we had already met our power goal with an included safety factor using a 2 cell battery pack. Our battery pack weighs 49 grams and gives us a maximum flight time of up to 18.2 minutes in ideal conditions. Although we could have chosen a battery pack that was below power limit, we were not able to find any batteries that were lighter than the Turnigy 0.8 Ah 30C 2S battery pack which is why we decided to keep the extra power in case it was needed.

Figure 16: Turnigy 0.8 Ah 2S 30C Battery Pack

C. ESC

We decided to use an 18 Amp brushless ESC as it is well above our max current range and also weighs a lot lesser than other ESCs that have lower current values. Our ESC comes in at 11 grams and includes an XT30 plug to connect into our battery.

Figure 17: Parkzone 18A Brushless ESC

D. Propeller

We chose to pair our motor with an APC 6x4e propeller. This gave us a 6-inch diameter and 4-inch pitch thin electric propeller that was suitable for slow speeds and high torque. It is made out of two different airfoils; the hub resembles the Eppler E63 airfoil and the root resembles the Clark-Y airfoil. The twist and aerodynamic data are shown in the figures below which were created by plotting data provided by APC on their propeller's performance using MATLAB. We plan to run our propeller at a maximum RPM of 8898 which would result in the following conditions:

Flight Condition	Value
J (Advance Ratio)	0.5
C_P (Power Coefficient)	0.052
C_T (Thrust Coefficient)	0.024
η (Propeller Efficiency)	71.23%

Table 10: Propeller Flight Conditions

Figure 18: APC 6x4e Propeller

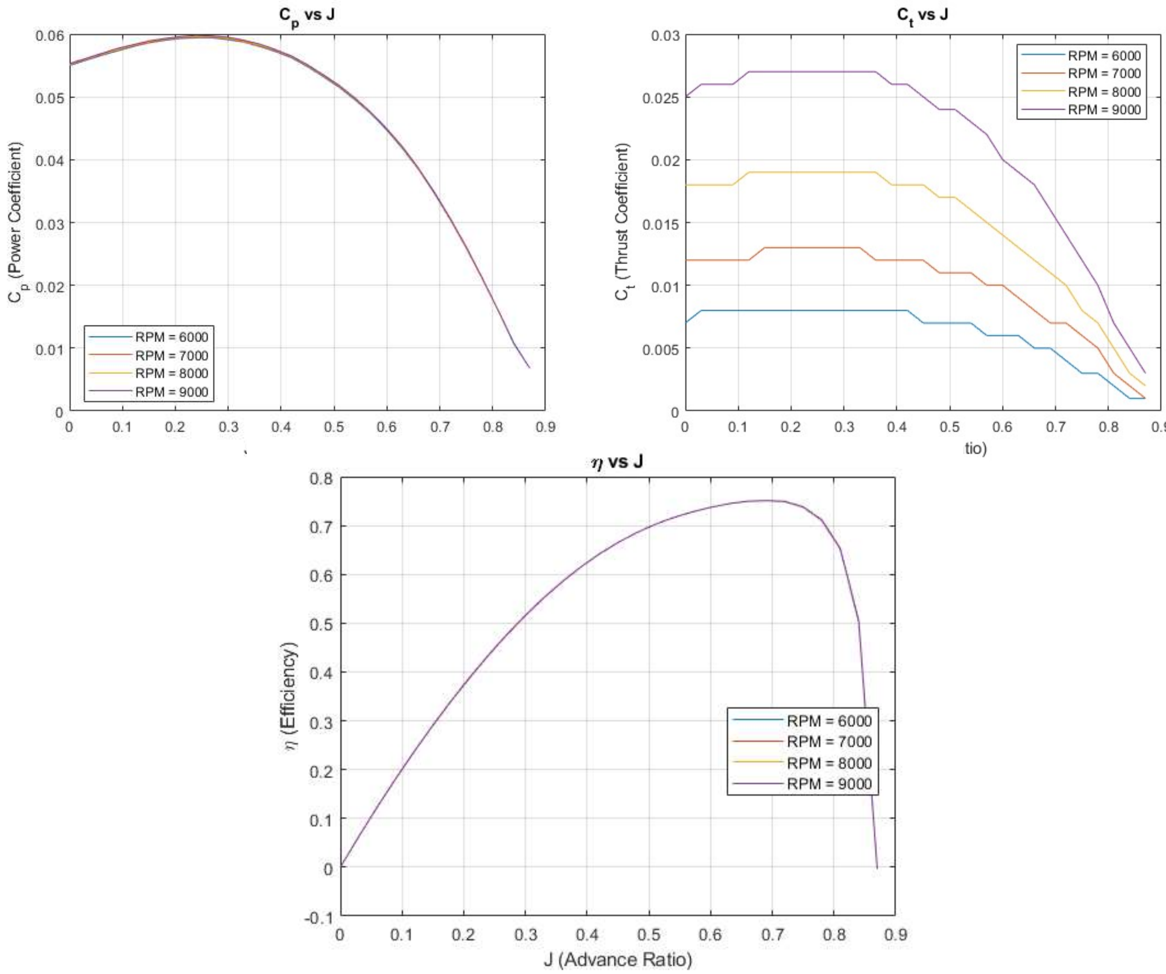

Figure 19: Aerodynamic Data for APC 6x4e Propeller

4. Mission Analysis

A. Mission Layout and Performance

While we were not able to physically build or fly our designed model, we can still postulate and justify the performance that we expect in terms of turning, cruise, power and endurance. As far as turning, we fully expect the aircraft to be able to withstand and sustain $45°$ turns in order to accomplish the $2\ m$ radius turns present in the course layout. The course layout can be seen below in figure 20. We can confidently say this due to the calculations provided as well as the $V - n$ diagram in the structures section.

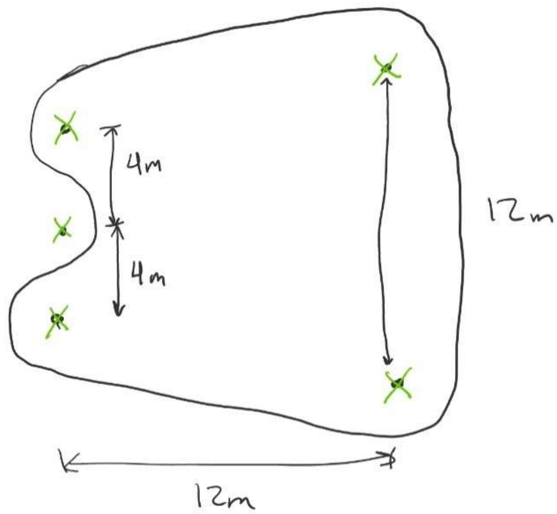

Figure 20: Proposed initial race course

Secondly, we designed the airplane and airfoil to cruise at an optimal 8 m/s. This velocity is good for cruise or "park flying" but the plane can go faster/slower depending on the desired mode of operation. For the mode of racing, the plane will easily be able to accelerate to maintain speeds around the turns as well as continue acceleration to gain speed in the straightaways.

The plane is equipped with a 150-watt motor rated at 1500 Kv and a 6x4e propeller. This combination provides a steady level flight at around 60% throttle. This results in a flight time of ~15 minutes. This gives plenty of room on the upper end of throttle for heavy acceleration and increases in speed when necessary. Flying at 100% throttle results in around 8 minutes of endurance. This is all calculated with the theoretical current drawn from the motor using MotoCalc in combination with the battery chosen of 0.8 Ah.

5. Marketing

A. Audience

We are aiming to sell our airplane kit to anyone even remotely interested in aviation or engineering. Whether they are hobby aviators or someone that is just beginning to learn how to fly, our model is easy to build and control. We did not want to limit our design to only those already interested in remote control aircraft. We also aim to sell our kit to amateur, beginner and professional autonomous racing users to get them interested in autonomous racing. Additionally, we did not want to limit the age of our audience. Creating a product that gets kids to build and assemble something that can then be used in a competition seemed obvious to us. We believe kits of this nature present an opportunity to get kids and adults alike interested in aviation and building things they can be proud of.

B. Product Kit

Our kit will come with everything needed to assemble the aircraft but will not include any of the tools that will be needed to assemble it. The only real tool needed is a hot glue gun which is fairly easy to come by as is and was deemed unnecessary to include in the kit. The kit will include 20x30 inch foam boards that are pre-cut with all the surfaces of the aircraft to allow for ease of manufacturing. The kit will also include all of the necessary parts to complete the aircraft's electronics including the motor, battery and flight control computer. Step by step instructions will also be included to make the building process easy and enjoyable. In addition, the kit will include an online access code to a website where they can set up the flight control computer and learn how to fly and compete with their newly built racing plane. This website will also contain videos of build instruction and the autopilot code along with a document that explains it so that users are free to edit this code to make it their own. We will also sell two other versions of this kit which include a much cheaper version that only has the link to the pdf plans of our build and one that has all the precut foam board parts but does not come with the electronics so that we are able to sell our product to a wide range of audiences. When buying the kits with or without the electronics, we will include a sticker kit to accompany it which can be personalized with a small fee to help build people's dream planes.

In the future, our team plans to make different wing designs that can fit onto the body with no replacements or hot glue needed as our plane is made to be modular and will only require users to build a wing to vastly change the speed and characteristics of flight.

Figure 21: Modular Wing Kits similar to FliteTest Alpha, Bravo, Charlie Series

C. Marketing Strategy

To sell our kit we will be doing a few things. We will be selling it on many RC airplane websites that already sell similar types of kits. The kit will also be made available on other websites such as Amazon to increase sales. We will also be putting advertisements on these websites to help it gain traction. These will include clips of the plane flying and the racing course it was designed for. In addition, we will advertise and promote our kit on various social media platforms to increase awareness of our product. With quality videos and advertisements on popular websites and sources of social media we are confident that our kit will be able to sell. We will also price it very competitively on the market so that we make profits when a bulk of units are sold instead of having a huge profit margin per unit. This will ensure that we are able to capture a more diverse economic market. We will include customized stickers with every user's second order for free so that we can reattract customers that have already purchased our kit. We also have included spare parts for the most broken items in our kits while they are bought so that customers do not have to purchase our kit again or buy another foam board to make new spare parts.

The autonomous fixed wing RC market still does not exist and by being the first ones to bring our product into it with these great features such as modular design, helpful guides, competitive pricing and open source code we believe we can outdo our competition with ease.

7. Appendix

Credit to our peers and the AAE 451 teaching team for providing their valuable feedback during our multiple reports and presentations this semester.