Designing a Tube-Launched UAV

Aerial Robotics

University of Pennsylvania

PennAiR
Aerial Robotics

Table of contents

1. Executive summary

The purpose of this report is to detail the design, manufacturing, and testing of the University of Pennsylvania's Aerial Robotics aircraft entry for the 2017 AIAA Design Build Fly (DBF) Competition. The primary objective is to create a tube-launch aircraft capable of carrying a payload of at least three pucks for at least three laps around the airfield. Our aim is to build an aircraft that will outperform other entries by holistically maximizing the number of points across all missions for the smallest raw aircraft score as specified in the competition rules.

The theme of this year's competition is a tube launched UAV. This means that aircraft must be designed to fit within a cylindrical tube while still being able to carry as much payload, in the form of hockey pucks, as possible. Mission 1 is a basic airworthiness test, while Mission 2 tests the speed of the aircraft with a small 3 puck payload. Mission 3 tests the endurance of the aircraft, with the aircraft having to carry as many 6 oz hockey pucks as possible while flying the most amount of laps in a 5 minute time frame. Additionally, there is a ground mission which verifies the strength and security of the containing tube and aircraft inside by dropping the tube-aircraft assembly along each axis.

Our initial score sensitivity analysis showed that to perform well at the competition, aircraft must be designed to have the lowest weight possible while maintaining a large internal volume and lift capacity to carry pucks for Mission 3, the heaviest weighted mission in the scoring equation. The main challenge for this year is making the most efficient use of limited tube space, such that the as much of the internal volume as possible is used to provide power, lift or cargo capacity. All foldable aircraft features must be secured with self-locking mechanisms in flight. Finally, the hand-launched requirement imposes the requirement of maximizing lift at low speeds.

Our team's proposed aircraft design features a rectangular, balsa-frame aircraft with folding, "switchback" wings, and a v-tail. It is powered by a single brushless outrunner DC motor turning a large (16x10) folding propeller with high voltage (19.2V). The 5000 mAh battery pack is designed to provide just enough power for the aircraft to complete entire 5 minute duration of Mission 3. To satisfy the hand launch requirement, the Selig 1223 was chosen as it is an undercambered airfoil with an extremely high coefficient of lift (2.3) at low Reynold's numbers. Overall, the aircraft is designed to maximize the number of hockey pucks carried while minimizing tube weight and dimensions.

The main body was made out of balsa due to its extremely low weight and high strength. A light-weight, square carbon fiber rod was used as the tail boom. Both EPS foam and balsa with caron-tube reinforcements were considered as wing materials, and the tail stabilizers are made out of balsa with a plastic mount.

Our proposed main wing folding mechanism features two uniquely-shaped pieces that are designed to lock into place when correctly aligned. When stowed inside the tube, the wings lie on top of each other, however once unfolded a spring snaps the two separate parts of the hinge into place and a self-locking pins locks the parts together such that they are flat and level during flight. The hinge is 3D printed, while the rod acting as the pivot and the pin carrying the weight of the aircraft are aluminum. When stowed, the V-tail folds forward, so that it is under the wing. This overlap reduces the tube length. When rotated back into the flight configuration, aluminum pins spring into place to mate with reinforced holes in the ruddervators, locking them in place.

Our current empty aircraft weight with the battery pack and no hockey pucks is 7.1 pounds. We expect to reduce this to approximately 5.95 pounds using methods described in this paper. The maximum expected take-off weight is 15 lbs, corresponding to 20 hockey pucks. We expect to pass the ground mission and Mission 1. Based on simulations and models, the average cruising speed of the aircraft is 55 ft/s, our predicted flight time for Mission 2 is approximately 140s, and we expect to carry 20 pucks for 5 laps for Mission 3.

2. Management summary

The Penn Aerial Robotics team consists of nine students: two seniors, four sophomores, and three freshmen. All team members are participating in the AIAA DBF competition for the first time.

2.1 Team organization

The team relies on a specialization structure to divide tasks. Students focus their efforts towards designing a single part of the aircraft and the entire team meets regularly to collaborate on ideas, offer opinions and constructive criticism, and vote on the final component design that will go on the plane if multiple options were simultaneously developed. An illustration of the team structure can be seen in Figure 2.1.

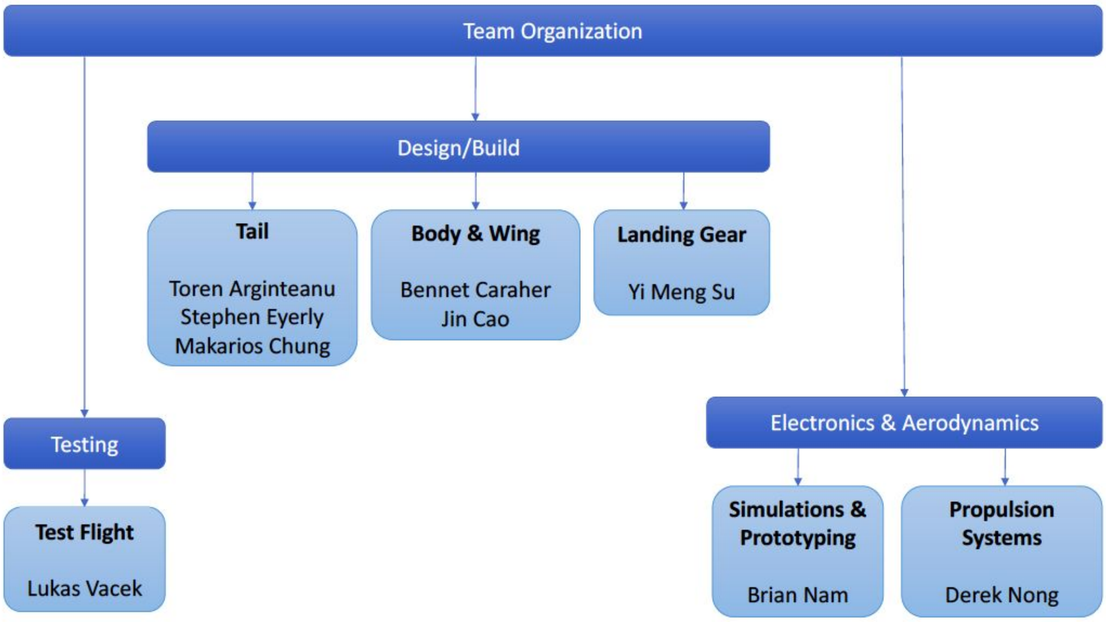


Figure 2.1 Team organization

The following are the responsibilities and job descriptions of each working group:

:

- Simulations & Prototyping
  - To research and simulate airfoil designs to determine the ideal airfoil shape for aircraft.
  - To prototype designs by crafting them out of foam
- Propulsion systems
  - To research electronic components and determine the ones that best fit the desired performance results within budget constraints
  - To assemble electronics circuitry
- Tail:
  - To research and prototype different tail designs and the mechanisms they will use to transform between travel mode and flight mode
  - To assemble tail when building aircraft
- Body & Wing:
  - To research and prototype different fuselage designs
  - To research and prototype how the wings will transform between travel mode and flight mode
  - To assemble body and wings when building aircraft
- Landing Gear:
  - To research and prototype different landing gear designs and how they will best fit onto the aircraft
  - To assemble landing gear when building aircraft

- Test flight: To test the plane's performance according to a variety of testing and mission objectives

2.2 Project milestone timeline

The design project was conducted over two semesters at the University of Pennsylvania. A preliminary schedule for milestones in the project was created at the beginning of first semester. The planned timelines were used as reference throughout meetings in order to keep track of progress towards major milestones, such as completion of all CAD parts and manufacturing the aircraft. A Gantt chart visualization of the planned schedule and the actual progress is shown in Figure 2.2.

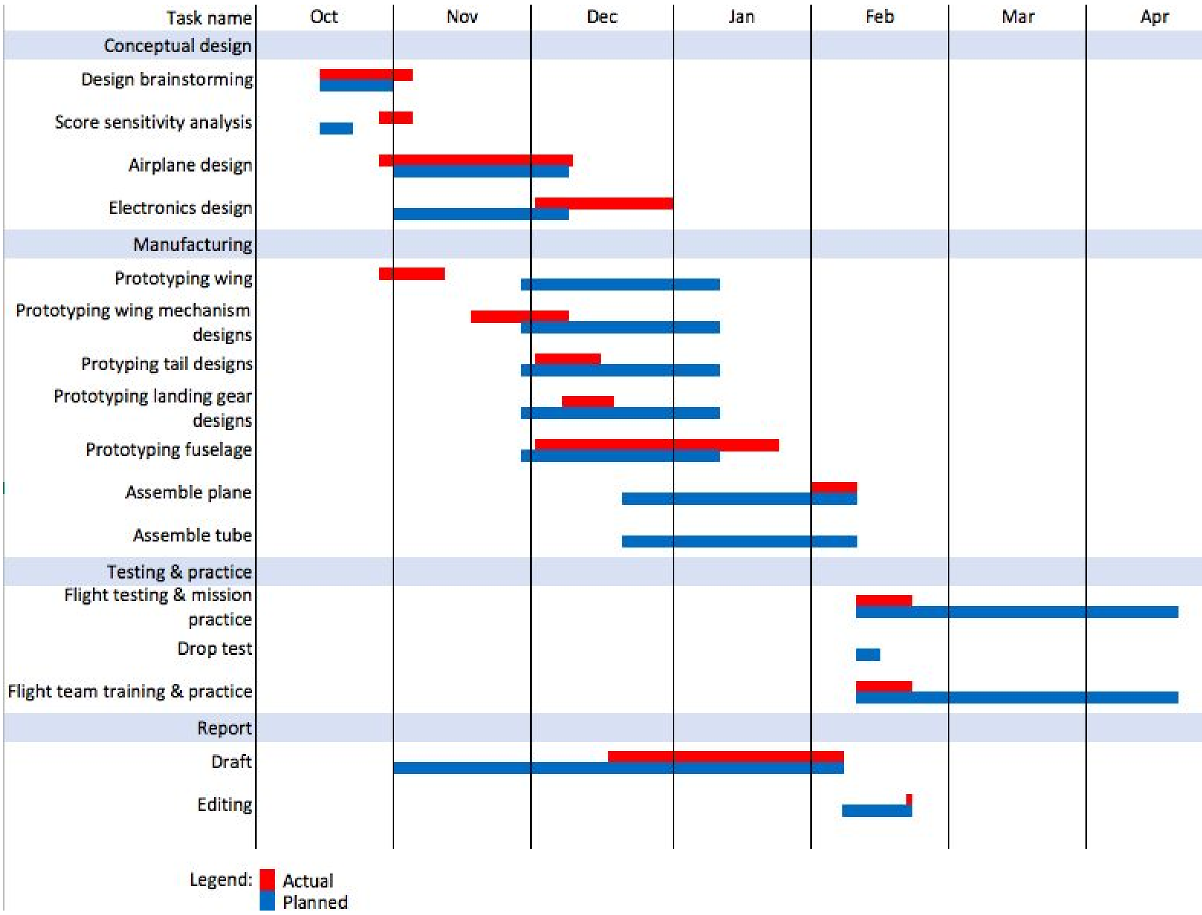


Figure 2.2 Gantt chart of scheduled project milestones and actual progress

3. Conceptual Design

Different design choice options were explored through the use of sensitivity analysis, simulations, and prototyping parts. Specifically, the team met once a week during the conceptual design phase in order to fully investigate the different designs and deciding which one would be best. A large part of this was done through the prototyping of different parts through 3D printing. A graphical representation of the whole design process can be seen below in figure 3.0.1.

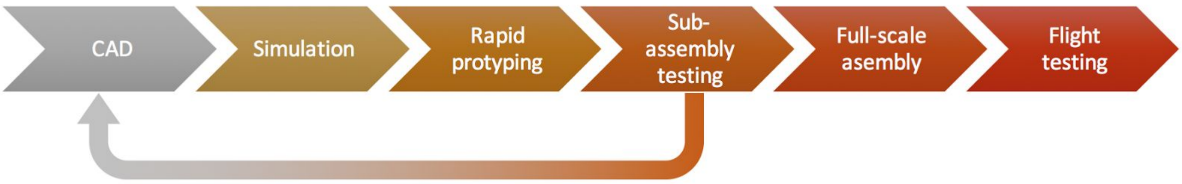


Figure 3.0.1: diagram of design process

3.1 Design Constraints

The aircraft must meet several design requirements in order to qualify for flight. In addition, it must meet prerequisite requirements by completing certain missions before it can compete in subsequent missions. Each of the missions have different formulas for score calculation and total mission score is the sum of individual mission scores.

The main constraints for the 2017 DBF competition are:

- The aircraft must fit in a tube with a Length to Diameter ratio of 4 or greater
- The aircraft must be able to be configured into its flight position from the tube position in less than 5 minutes.
- All parts of the aircraft must be attached when in the tube position and remain attached such that they move along a fixed path when
- All fasteners must be stored in the aircraft when inside the tube
- The aircraft and tube must not sustain noticeable damage during the Ground mission.
- All hockey pucks must be carried internally
- A hand launch is required for take-off, and the landing must be on concrete without bouncing and without significant damage
- All batteries must be NiCad or NiMH

3.2 Scoring Formula

Final score = Report * Total mission score / RAC

Total mission score = M1 + M2 + M3

Rated Aircraft Cost = RAC = (EW + TW) * (L + C)

Mission	Description	Payload	Score
Ground	Tube drop test 3 times	Max planned payload	0 (pass to qualify for other missions)
1	1 lap in 5 minutes	None	1.0
2	3 laps	3	$2 * \frac{Min\_time}{N\_time}$
3	Fly as many laps as possible	Max planned payload	$4 * \frac{N(laps * pucks)}{Max_{laps*pucks}} + 2$

Report is the score assigned to the Design Report.

M1, M2, and M3 are the mission scores

EW is the maximum weight of the aircraft after any mission flight, including the battery, excluding the payload.

TW is the weight of the containing tube and any support structures for the aircraft inside the tube.

L is the length of the containing tube.

C is the circumference of the containing tube.

3.3 Mission sequence

The competition is composed of three flight missions, with a mandatory ground mission and wingtip check. The ground mission and M1 may be completed in any order. Only teams passing both missions may fly M2 and M3 in that order.

3.3.1 Ground Mission

The purpose of the ground mission is to demonstrate the facility of transporting the aircraft while maintaining strength and airworthiness. For the ground mission, the aircraft starts stowed in the tube, which is then subjected to drops of 1 ft both horizontally and vertically. Given that no significant damage has been done to the aircraft, aircraft support structure, and tube, the aircraft is then removed from the tube. Teams will then have 5 minutes to reconfigure the aircraft into a flying position. Teams must complete the ground mission to receive a score.

Since the tube measurements factor into the RAC calculation, we want to minimize tube weight, length, and circumference of the tube in order to maximize our score.

3.3.2 Mission 1

The purpose of M1 is to demonstrate the airworthiness of the aircraft. For takeoff, a team member must throw the aircraft, providing adequate speed for liftoff. The use of tools and mechanisms to increase the throwing power is prohibited, although a team member may have a running start. The plane must then fly 3 laps, and land without bouncing on the concrete to complete M1. The scoring for M1 is either a 0 for incomplete or 1 for a successful completion.

In order to succeed at mission 1, the wings must be able to provide enough lift for the aircraft to continue flying when it is thrown for liftoff with no payload. In addition, the aircraft's center of gravity must be reasonable enough to fly well without any payload and to land without bouncing. The landing gear system must be designed such that it doesn't cause bouncing.

3.3.3 Mission 2

The purpose of this mission is to test the speed of the aircraft while carrying a small payload of 3 pucks. It is scored as a ratio of the minimum time of any team to fly 3 laps to time our aircraft takes to fly 3 laps. The ratio is then multiplied by 2 to scale it up.

In order to succeed at mission 2, we must have mechanisms to lock the three hockey pucks in place because there will be much more space in the cargo hold than the space that 3 pucks will need, so the pucks will move around unless they are locked in. Movement of pucks could negatively affect flight by making the center of gravity inconsistent.

3.3.4 Mission 3

The purpose of mission is to push the aircraft to its limit by having both a payload and a speed component. Teams fly with a selected amount of pucks for as many laps as possible within a 5 minute window. The aircraft is hand launched and must land successfully to receive a score. It is scored as a ratio of our team's Laps * Pucks value to the maximum Laps * Pucks ratio of any team. It is then multiplied by 4, and 2 points are added it.

In order to succeed at mission 3, we must find out the optimal balance between payload and wingspan. We also have to make sure that the payload we select will still allow the aircraft to pass the wing tip test. Also, the total weight of the aircraft must be low enough to still allow the motor and wings to continue flight when the aircraft is hand launched.

3.4 Sensitivity Analysis

The scoring consists of the design report score multiplied by the mission scores divided by the RAC. The design report score is independent of the mission performance and the RAC. Separate analyses were performed on the mission performance parameters and the RAC.

3.4.1 Mission performance

In order for an aircraft to even receive a score the ground mission must be passed, so for the purposes of the mission performance analysis, it was assumed that the aircraft and tube would be designed to complete the ground mission. M1 is a basic airworthiness test, and so any plane capable of flying M2 or M3 should be able to complete M1.

The M2 score is calculated as a fraction of our team's laps divided by the maximum number of laps achieved. The number of laps is a discrete number, meaning that the M2 score can be fairly accurately predicted looking at historical data. The 2015 DBF had very similar design constraints to this year's competition in needing to carry a heavy 5lbs load. Thus, a similar aircraft configuration can be expected at this year's competition as in 2015. The 2015 M1 is similar to this year's M2, and so data can be taken from the published scores and the expected times of top teams extrapolated. This gives an upper bound of estimated min M2 time of 120s. Furthermore, the distribution of speeds is narrow, so the range of scores is expected to be narrow. This means that an aircraft with a similar airspeed would have an acceptable M2 score. Assuming that our final aircraft has an average speed, our M2 score will not be much lower than that of faster teams.

The M3 score is calculated as a fraction of our team's laps*pucks(L*P) value divided by the maximum value. The value is then multiplied by a constant, adding weight to the M3 score. This mission is also weighted the heaviest in terms of points. This event lacks clear historical evidence on how other teams have performed in the past. 2015 M2 gives a baseline value, as teams were required to carry a 5 lbs. payload and fly for 3 laps. A 5 lbs payload corresponds to 13 hockey pucks in this year's M3, given that there is adequate space. Top performing teams are expected to have a minimum L*P value of 39. To determine an upper bound, the number of laps from 2015 M1 was taken, and calculated to be 91. There are two inaccuracies regarding this estimate. The first is that the planes in M1 were flying with no payload, and so would have a higher airspeed than a burdened aircraft. It is uncertain whether the difference in airspeed would cause less laps to be flown. The second inaccuracy is that planes could potentially be designed to carry additional pucks while flying a similar number of laps. However, the upper bound serves as a good reference for estimating performance of other teams.

In general, a high M3 score is achieved by carrying large amounts of pucks without sacrificing significant airspeed. In terms of design parameters, this favors body configurations with large internal volumes, powerful motors, and high lift wings. Given that increases in aircraft speed for M2 are unlikely to produce significant score increases, the M3 score is prioritized. It has the largest scale factor of 4, and there are a wide variety of possible scores meaning that M3 scores are likely a deciding factor.

3.4.2 Aircraft Design Parameters

The Rated Aircraft Cost consists of two terms, multiplied together. The first term is the combined weight of the aircraft and the containing tube. The two weights can be assumed to be independent. The second term consists of the tube length added to the tube circumference. The relationship between these terms is dependent on the aircraft design and folding configuration. For the purpose of the analysis, they are assumed to be independent to see the effect of each parameter on the final score, and this analysis can be seen below in Figure 3.4.2.1.

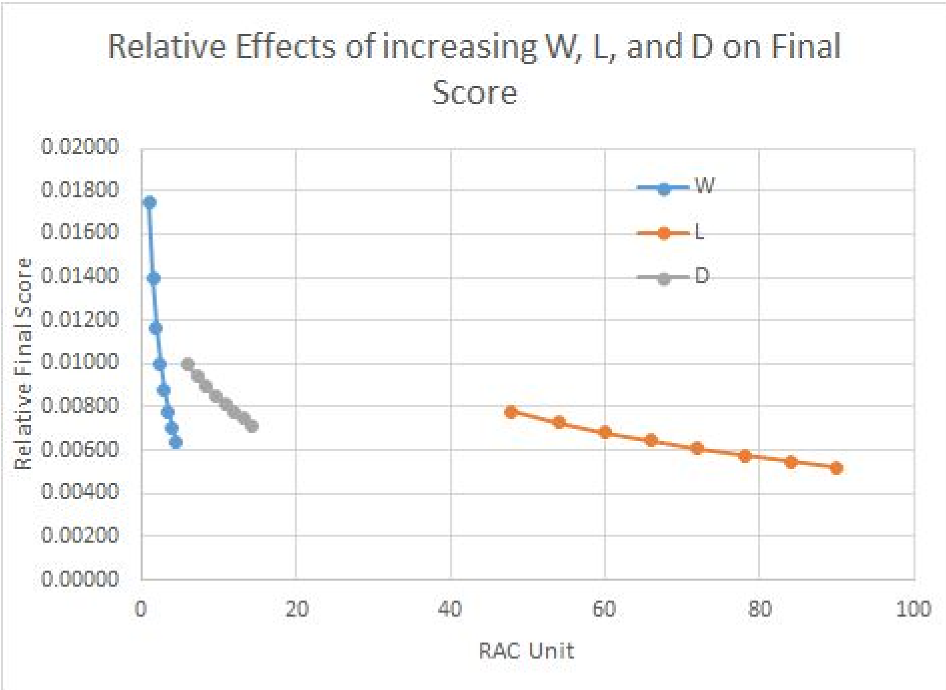


Figure 3.4.2.1: A graph of how weight, length, and diameter affects the final score

The RAC treats the numerical values of weight and length equally, so in order to compare the relative effects of varying one parameter, a dimensionless “RAC Unit”, representing 1 inch for length and 1 lbs of weight, was constructed. When varying one parameter, all other parameters were held constant. The tube weight was estimated to be 1 RAC Unit. From the graph, it is apparent that varying weight has the largest impact on the final score. This is due to the fact that the tube weight is low, so changes to the aircraft weight have relatively larger impact on the weight component of the RAC. The second most impactful parameter is the diameter, due to the fact that it is expressed in the RAC as circumference. Thus, each unit of diameter is equal to 3.14 units of length. It can also be seen that increasing the length is increasingly less impactful on the final score.

3.4.3 Wing Length Design Parameters

The relationship between mission performance and RAC was also explored. Specifically, we looked at how changing the wingspan of the aircraft affected M3 performance while increasing RAC. We assumed that the critical point would be during the hand launch, in which the aircraft is travelling the slowest and produces the least lift. The relationship between the final score and wing length can be seen below in Figure 3.4.3.1.

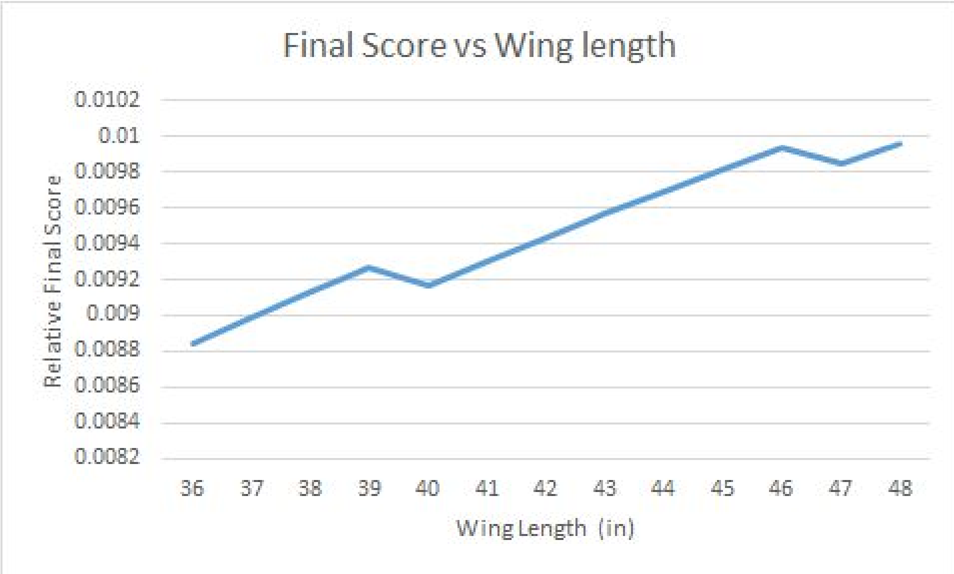


Figure 3.4.3.1: A graph that shows how the final score and wing length are related

The general trend is that increasing wing length to produce additional lift to accommodate more pucks, provided that the propulsion system is able to generate enough thrust. The dips in the trendline occur when the additional wing length does not produce enough lift to accommodate the weight of an extra puck. The line is expected to increase until the maximum number of pucks of any team is reached.

3.5 Configuration Selection

Given the results of the sensitivity analysis, the team rated each configuration choice based on its effect on the weight, and its ability to carry pucks, and its mechanical complexity. We had 2 materials realistically available for construction of the plane: 3D printed plastic and balsa. Other materials such as composites were discarded as potential body materials because of cost concerns and our inexperience producing them.

Balsa- Balsa is the traditional building material for RC aircraft due to its high strength and low weight. However, manufacturing quality plays a large role in the final structural strength of the plane. Additionally, there may be challenges when mounting components to the wood frame.

3D Plastic (ABS)- A 3D printed body is significantly heavier than a balsa one. In addition, there is also the challenge However, it allows for much greater design flexibility, such as a cylindrical body design. A

CAD of the 3D printed body can be seen below in Figure 3.5.1, along with its excessively high predicted weight.

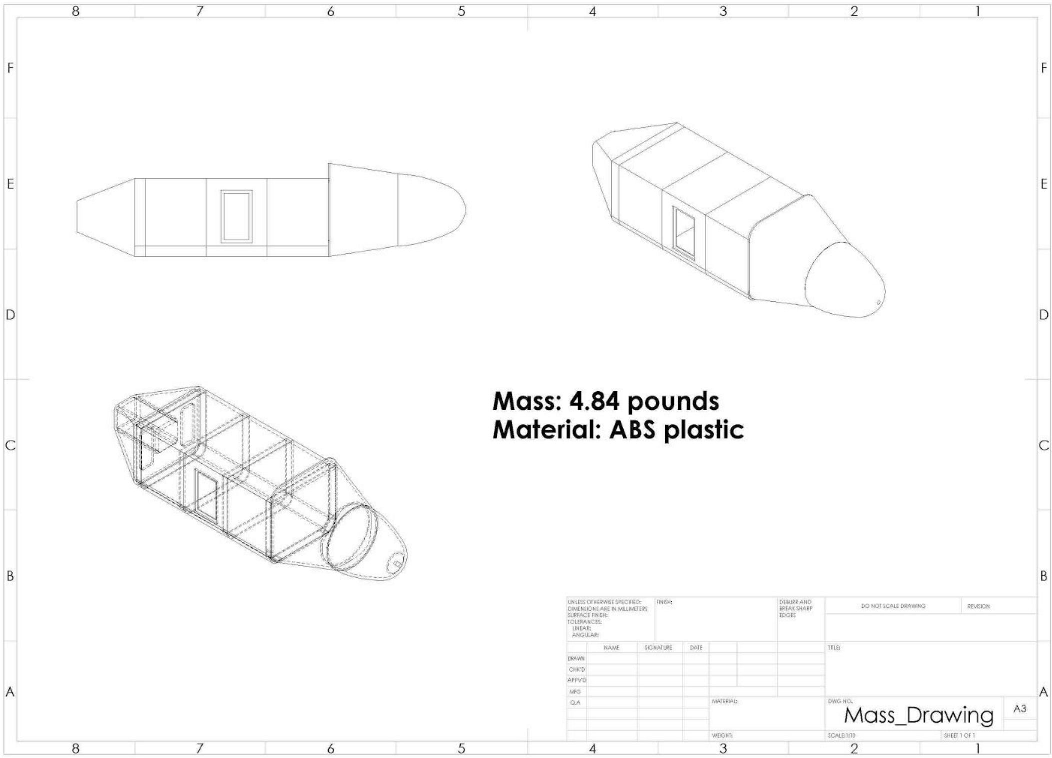


Figure 3.5.1: The 3D printed body design

Ultimately, the team decided on a balsa body due to the significantly lighter body. Separate designs of a 3D printed body and Balsa were modelled, and the 3D printed body was estimated to weigh 4.5 lbs heavier, especially considering the fact that a 3D printed body would have to be printed in several parts and assembled at the very end, which would add additional weight in the form of the bolts and nuts needed for connections. Additionally, the loss of design flexibility is not significant to inhibit the design of mechanisms.

3.5.1 Body Shape

Cylindrical- A cylindrically-bodied aircraft fits more efficiently inside the containing tube and allows for a larger internal storage space inside the aircraft to carry more pucks. Additionally, a cylindrical body would be able to better survive the ground mission as the impact force of the drop would be more evenly distributed along the entire body. Aerodynamically, a cylindrical body would cause less turbulence and produces less form drag than a rectangular body. However, it is significantly more difficult to manufacture with balsa wood.

Rectangular- A rectangular body shape is the default for small unpressurized aircraft. It is simpler to manufacture and allows for both easier and more secure mounting of other aircraft components. If properly supported inside the tube, a rectangular body can also survive the ground mission, and the differences in aerodynamics with respect to a cylindrical body are negligible.

Ultimately, the rectangular body shape was selected primarily due to ease of manufacturing. Additionally, the strength of the body can be increased by adding additional or thicker struts to help the body survive the ground mission. The loss of volume was not deemed to be a significant detriment, as the constraining factor for maximum number of pucks carried will most likely be an insufficient propulsion system.

In order to ensure our proposed design was capable of sustaining the maximum aircraft payload and weight, we performed a stress-test analysis in SolidWorks to identify weak points and the maximum loading. At a payload of 40 lbs, it had a safety factor of 2.5x when pulling 2.5 Gs.

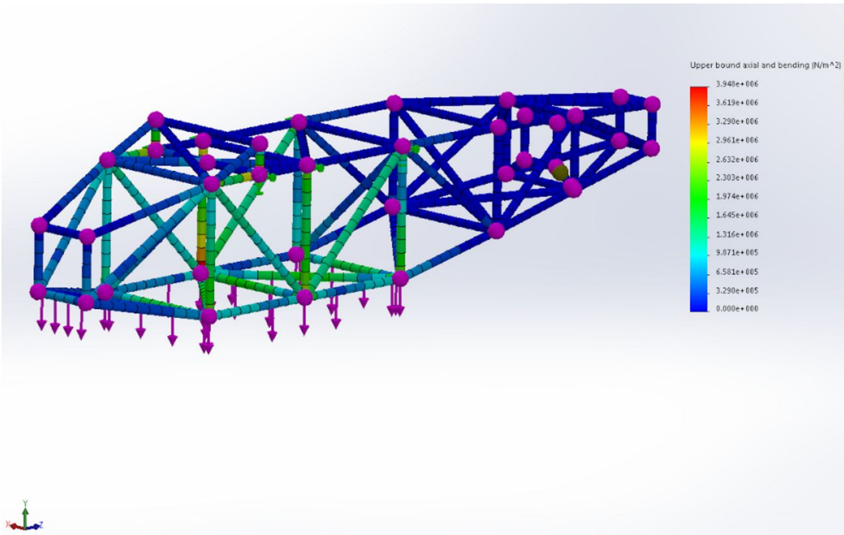


Figure 3.5.1.1: Stress-test anaylisis of the proposed body shape and structure

3.5.2 Wing Storage Configuration

Due to the tube fitting requirement, the wings must contain some rotation mechanism.

Folded 'switchback' Wings- This design consists of a folding mechanism in which each side of the wings fold so that they are adjacent to each other. This design has a low RAC, as the wings could potentially be folded over the tail, reducing size. Mechanically, this design is more complex, as the wings must be self-locking.

Single Continuous Wing- A single wing design would allow for greater wing rigidity at the cost of a significantly larger length when completely folded up, and thus, a higher RAC. In addition, a single wing would also necessitate a longer storage tube.

A folded 'switchback' wing design was ultimately chosen, due to the lower RAC. With proper iteration, a reliable folding wing design should be mechanically feasible.

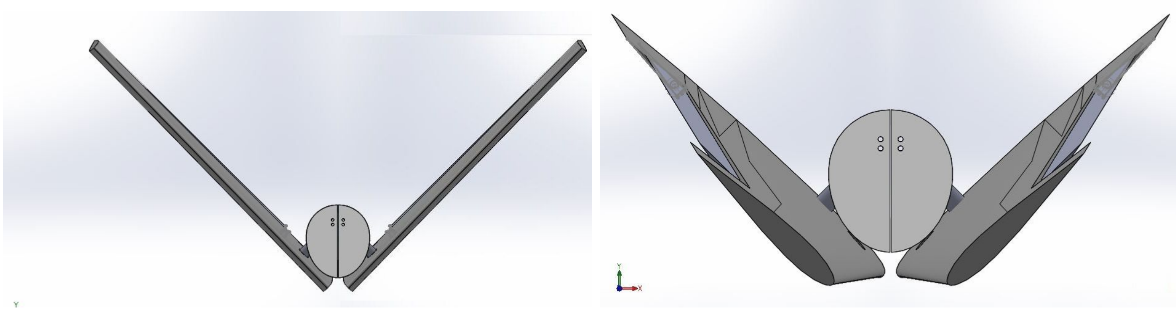
3.5.3 Tail Design

A non-folding tail significantly adds to the tube diameter as it is usually the highest point of an aircraft. Thus, to minimize the tube size, the tails were also designed to be folding.

Conventional (T-tail)- This configuration offers good stability and control. However, a conventional design requires more parts than the V-tail design in order to fold, which makes it harder to design a moving mechanism for this configuration. Additionally, a folding conventional tail may conflict with the folding wings.

V-Tail- This configuration allows for easy and compact folding, in which the two tail components are rotated about an axis perpendicular to the plane body. It can be locked in place for flight using a spring-loaded locking pin. However, the configuration might provide less stability and control during flying and therefore require a more experienced flyer.

The team ultimately decided on a V-Tail design, due to the lower expected RAC and more efficient use of tube space. The weight of each tail is expected to similar, with the additional weight of the extra control surface of the conventional tail offset by the need for larger ruddervator. The CAD for this tail can be seen below in figure 3.5.3.1.



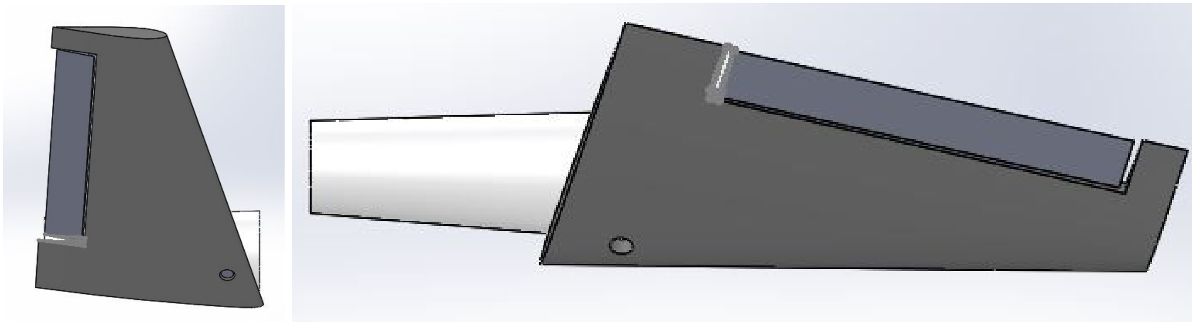


Figure 3.5.3.1: The CAD for the V-tail

3.5.4 Motor Configuration

Single tractor- A single tractor motor configuration is most common for model airplanes and has a high motor efficiency as the propeller is able to act on undisturbed air.

Double tractor- Two motors can use smaller propellers to produce enough thrust to carry a large payload. However, two motors add significant amount of weight, and would require more complicated wiring to the folding wings. The motors and propellers protruding from the folding wings add unnecessary levels of mechanical complexity for very little benefit.

The team decided on a single tractor design due its mechanical simplicity.

3.5.5 Wing Folding Mechanism

Slip-on - Two wing hinges with matching profiles that will rotate and snap into place about a vertically placed rod. The advantages of this design include evenly leveled wings and far less hinge bending. The disadvantages include more parts to manufacture and friction about rotation.

Bearing - Wings are connected to two ball separate bearings via an adapter. A torsion spring and a pin between the bearings will rotate the wings from the folded position into a fixed 180 degree deployment position. The advantages include wings opening into position automatically and near frictionless rotation. The disadvantages include unbalanced lift moment about center of gravity due to offsetted wings and possible hinge bending due to bearing fittings.

The slip-on mechanism was chosen over the bearing mechanism due to the better control offered by level wings in addition to the lower amount of mechanical complexity.

4. Preliminary design

The objective of the preliminary design was to perform tests and specific optimizations on the conceptual design ideas in order to arrive at one aircraft concept. To do this, the team examined the tradeoffs between different designs and calculated the performance results for different combinations.

4.1 Design and Analysis Methodology

To achieve an optimized configuration for the aircraft, the team identified two areas for optimization: wings and propulsion system. Simple calculations were performed to provide an initial estimate for the weight of the aircraft. It was expected that a competitive aircraft should be able to carry at least 13 pucks for M3. In total, the weight of the aircraft was estimated to be about 8 lbs. The lower bound for acceptable speeds was 65 ft/s.

4.2 Airfoil Selection

In order to maximize the M3 score, the wings of the aircraft must be able to produce a large amount of lift to counteract the weight of the pucks while having a low drag coefficient so an appropriately sized battery, motor, and prop can be selected. Accordingly, a search through airfoil databases for high lift, low drag airfoils at low (100,000 - 200,000) Reynolds numbers.

We selected two airfoils for further research: the Selig 1223 and the NACA 6412, mainly for their high lift-to-drag ratios when compared to other airfoils. The Selig and the NACA differ in two key aspects: Cl_{max} and cross sectional area. The Selig has a Cl_{max} of 2.313 at an alpha of 13, while the NACA only has a Cl_{max} of 1.33. However, the NACA has a much larger cross sectional area, which allows for easier mounting of supporting carbon fiber rods. Ultimately, both airfoils were ordered for better comparison and to allow for direct testing.

Calculations were done both at takeoff speed (15ft/s) and cruising speed (65 ft/s) to ensure that the selected wing configurations could produce more than 8 lbs. of lift. Takeoff will consist of a team member running with the plane, providing it an initial speed for the wings to generate enough lift. Both airfoils generated the necessary 12 lbs of lift at takeoff speed, but the Selig had significantly higher drag forces at cruising speed.

After testing, we selected the Selig 1223 due to its much higher coefficient of lift than the NACA. The additional drag bucket was considered to be less of an issue due to the availability of powerful motors. The outlines of the two airfoils are shown below in figures 4.2.1.1 and 4.2.1.2.

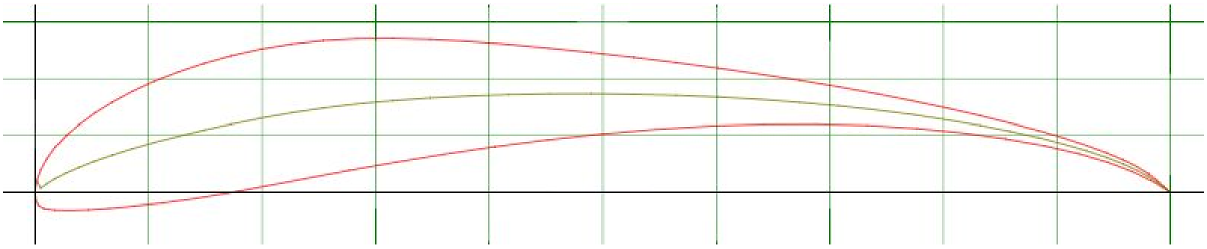


Figure 4.2.1.1: Selig 1223

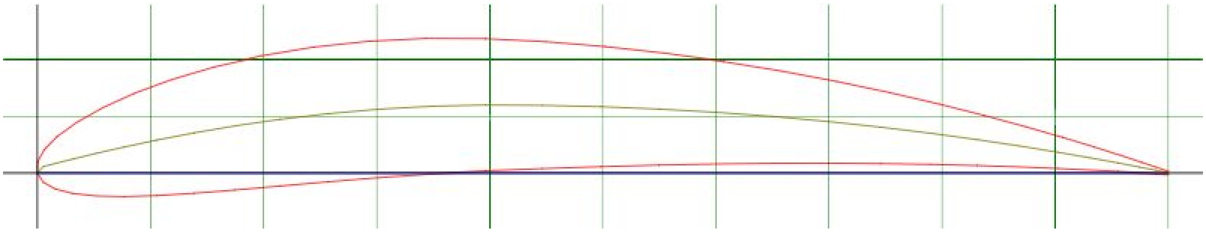


Figure 4.2.1.2: NACA 6412

Since our primary goal was to maximize score during mission 3, which requires long distance flight instead of high speed, the aircraft is not expected to travel very quickly. Keeping this in mind, it is important that the aircraft has a high lift to drag ratio– otherwise it would be hard to maintain lift at low speeds. The graphs for the coefficient of lift versus drag, at a Reynolds number of 50,000, for the two airfoils can be seen in figure 4.2.2 below.

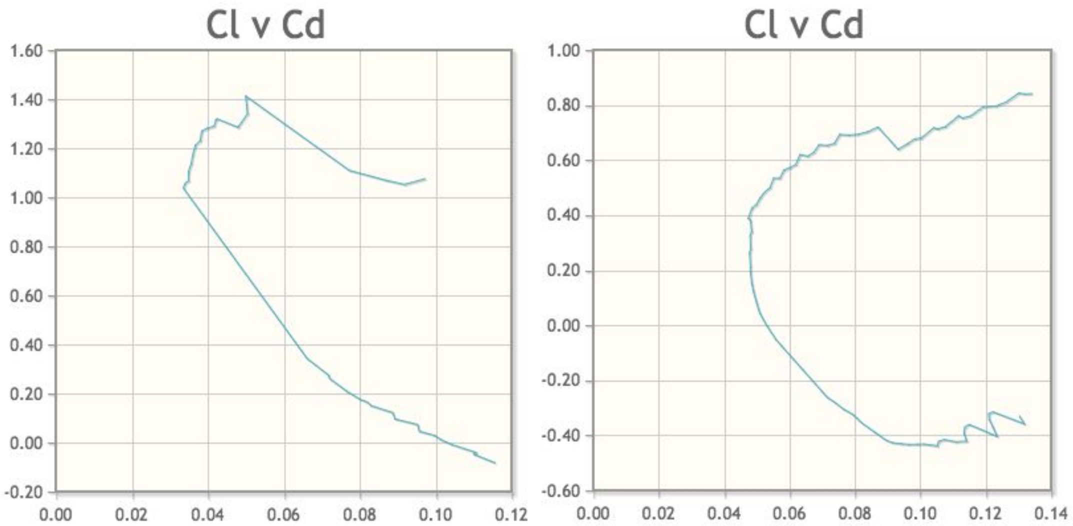


Figure 4.2.2: The coefficient of lift and drag graphs for the Selig on the left and NACA on the right

Based off the graph, the Selig is able to provide more lift than the NACA airfoil because for the same amount of drag, the Selig provides more lift. In addition, the Selig’s superior lift characteristics can be seen when the lift to drag ratio is calculated and compared to the angle of attack. This can be seen in figure 4.2.3 below.

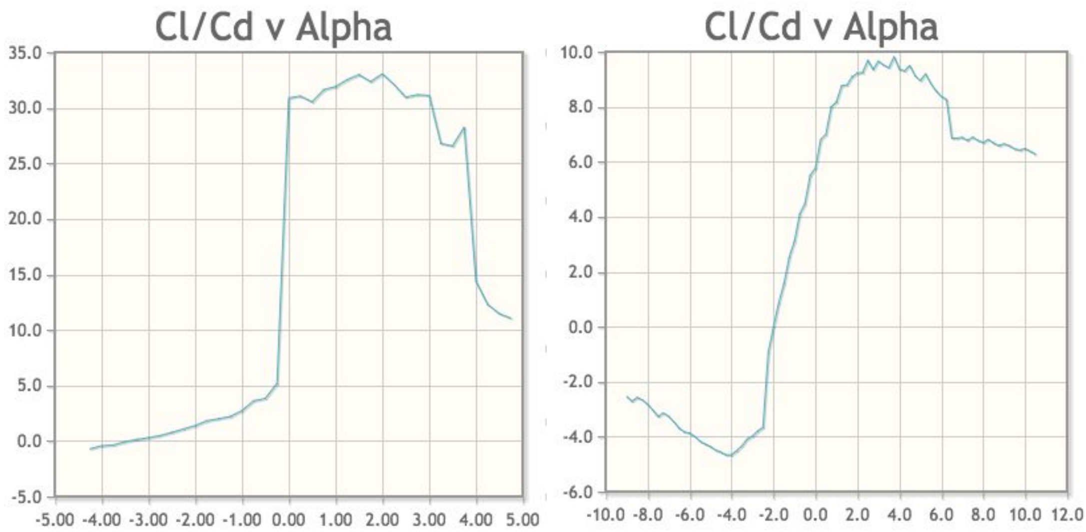


Figure 4.2.3: The coefficient of lift to coefficient of drag ratio vs the angle of attack for the Selig on the left and NACA on the right

Given the same angle of attack, the Selig produces a significantly better ratio. Since it can be argued that different airfoils are meant to have different optimal angles of attack, the maximum ratio is more important. The Selig’s maximum ratio is more than three times that of the NACA, which further reinforced our decision to choose the Selig.

4.2.1 Wing Material

Foam and Balsa were considered as materials for wing construction. Initially, foam wings were manufactured using a hot wire tracing an outline of the airfoil. However, a smooth cut was unable to achieved, and the methodology scraped. Instead, foam wings were purchased from a manufacturer and installed onto the plane. The wings had holes for carbon tubes to help prevent bending during flight.

Balsa Selig 1223 wings were also constructed as stiffer alternatives to the foam wings. ½ “ carbon tubes were inserted through the ribs to provide additional rigidity. Mono-coating the wings also provided additional support.

As of this design report, the team intends to fly with 9-in chord Selig 1223 foam wings, with ½” in carbon tube supporting the wings. The foam wings offer a significant weight reduction over the balsa wings. If the thicker carbon tube is unable to prevent significant flexing of the wings during flight, then the balsa wings would be used.

4.2.2 Lift Analysis

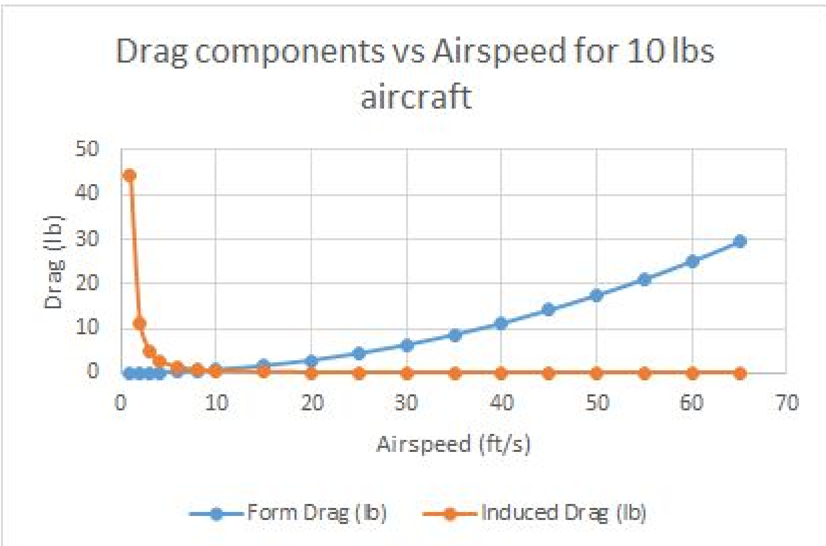
When performing the lift analysis, we calculated the max lift at maximum cruising speed and also the maximum lift at the takeoff speed. The results of the lift analysis, showing the max payload the aircraft is capable of carrying at takeoff, are shown below.

Inputs			**Outputs**				
Max Cl	2.2919	(alpha = 13)	Reynold's number	1.43E+05			
Velocity	10	m/s	Wing area	0.49548288	m^2		
Chord length	0.2032	m	Lift	69.55532928	N	7.097482579	kg
Wing span	2.4384	m					
Kinematic visc.	1.42E-05	m^2/s	Max weight	7.0974826	kg	(50% excess lift at takeoff)	
Density of air	1.225	kg/m^3	Aircraft weight	3.225	kg		
Acceleration on earth	9.8	m/s^2	Payload	3.8724826	kg		
			Puck weight	0.1701	kg		
Take-off Speed			Number of pucks	22.76591757	pucks		
Average wind-speed in Tucson, AZ in April	4	m/s					
Throw' speed	4	m/s					
V from motor (estimate) before it hits the grou	2	m/s					
Max payload is limited by the speed at which one can throw the aircraft; since we cannot takeoff using the runway and a rocket-assisted takeoff is not permitted.							

Figure 4.2.2.1: Lift analysis showing the maximum lift at takeoff speed and the inputs and assumptions in our model

4.2.3 Drag Analysis

When analyzing the drag on the airplane, two main types of drag are considered, parasitic drag and induced drag. Comparing the relative values reveals that induced drag becomes a non-issue at high airspeeds.



4.3 Propulsion System Selection

The score analysis showed that significant improvements in airspeed corresponded with very little, or nonexistent increases in score. As such, propulsion systems were chosen to be able to carry more weight at the potential tradeoff of speed. To calculate the performance of potential systems, we used eCalc, an online propulsion system calculator. The goal of this search was to find combinations which would produce the most amount of thrust while maintaining a reasonable flight time with a battery that weighed less than 2.0 lbs. The propeller was chosen such that the motor would be able to generate over 7.0 lbs of thrust while having a pitch speed of at least 65 ft/s.

Battery:

Per the safety regulations, all batteries must be either NiMH or NiCad. Of the two options, NiMH is preferable due to its higher capacity and high capacitance needed when performing under load. In addition, NiMH batteries do not suffer from memory effect, meaning that they do not need to be fully discharged before recharging. 1500 mAh and 2000 mAh NiMH batteries were compared.

The 1500 mAh batteries have less internal resistance, and so they allow a higher current flow; However, they have smaller capacities, and may not be able to supply enough energy to complete the entire flight mission. The 2000 mAh batteries have slightly higher internal resistance, and should be considered a viable alternative should a propulsion set-up require additional flight time.

Propeller:

In order to minimize the tube diameter, the team decided to use a folding propeller. There should be no significant downside to using a folding propeller, as the spokes automatically extend once the motor reaches a certain speed. M3 prioritizes high amounts of thrust over speed, so props with large diameters were first considered when choosing a motor-prop combination.

Motor:

A wide range of motors were considered, and the eCalc database was consulted to find the optimal propellor for each motor. The idea of a gearbox was considered, but then discarded due to the additional complexity, space, and weight of the setup. The specifications of the various motors that we considered are shown below in Figure 4.3.1.

Motor Name	Hacker 50-14XS-V3 520	Scorpion SII 4020-540	Hacker A40-14L V4 14-Pole	Turnigy Aerodrive SK3-4250-500kv
kV	520	540	355	500
Weight (oz.)	10.2	10.2	9.6	9.5
Prop diameter (in)	13.5	14	17	14
Prop pitch (in)	8	8	9	9.5
Batteries (series)	15	15	15	14
Batteries (parallel)	2	2	2	2
Total weight (oz.)	40.17	40.17	39.5	37.25
Thrust produced (lbf)	7.73	8.033	7.21	7.9
Estimated flight time (min)	6.7	5.8	6.9	5.5
Pitch speed (ft./s)	90.2	83.8	65.6	94.7
Efficiency (%)	90.3	88.3	88.8	89.6

Figure 4.3.1: A graph detailing the various specifications of the motors we considered

Based on the above graph, the Hacker A40 provides the longest flight time, leaving the largest margin of error for landing. However, it provides significantly less thrust than all other motors, causing a decrease in maximum cargo capacity. In addition, its estimated pitch speed is on the lower bound of acceptable aircraft speeds.

The Hacker 50 provides slightly less estimated flight time, while producing significantly greater thrust than the A40.

The Scorpion II provides even more thrust, at the expense of a full minute of flight time. However, an experienced pilot and a well-coordinated ground team should not experience difficulty in hand-launching and successfully landing the aircraft within the shortened timeframe. The Turnigy Aerodrive sacrifices additional flight time for a lighter battery. The short extra time for takeoff and landing could potentially be a severe inhibiting factor. However, testing can still be safely done to determine if a higher capacity battery pack is needed.

Ultimately, the team decided on the Turnigy motor setup due to its high thrust and low weight. It also has the added benefit of being US-manufactured and has a significantly faster shipping time than the other models. Thus, testing can occur sooner to determine if any changes to the setup are needed. In particular, the team can swap out the 1500 mAh batteries for 2000 mAh batteries to obtain an even greater predicted flight time of 7.7 minutes.

4.4 Stability Analysis

The aircraft must be statically and dynamically stable in order to maximize maneuverability and predictability, thus increasing performance. The purpose of analyzing stability is to determine the horizontal tail volume, vertical tail volume, and center of gravity.

4.5 Predicted mission performance

We predicted that the maximum speed of the aircraft will be negligibly affected by the payload because the only difference is that it might take longer to accelerate to maximum speed. However, acceleration is hard to estimate, so we took the aircraft's max speed to estimate how long it would take to complete each mission. A table of the predictions can be seen below in figure 4.5.1.

Parameter	Mission 1	Mission 2	Mission 3
Max speed	65 ft./s	65 ft./s	65 ft./s
# pucks	0	3	23
Time for 1 lap	41.7s	41.7s	41.7s
Time to complete mission	125.1s	125.1s	300s

Figure 4.5.1: Predicted mission performance

5. Detail design

5.1 Final design characteristics

The final design is very similar to the conceptual design as no significant changes needed to be made when designing the specific mechanisms for the conceptual design.

Overall Dimensions	
Length (folded)	68.5 in
Length (unfolded)	68 in
Width	8 ⅞ in
Height	8 ¾ in

Wing Dimensions	
Span	96 in
Chord	8 in
Aspect ratio	12
Wing area	768 in^2
Airfoil	Selig 1223

Propulsion system	
Speed controller	Aerostar 60A Electronic Speed Controller
Radio receiver	FrSky X8R
Servo type	Turnigy
Number of servos	4

Motor	
Type	Turningy Aerodrive SK3-4250-500kv
Kv	500
Max RPM	9500
Propeller size	14 in

Battery Specifications

Specification	Value
Type	Elite 1500 2/3A Battery High Rate Cells
Nominal Capacity	1600 mAh
R	12mΩ
V	1.2
Max I	60
Number of cells	16S2P
Pack energy	61.4 Wh

5.2 Structural characteristics

5.2.1 Wing

We ultimately decided on the Selig 1223 airfoil for its high lift at low speeds. This matches our goal for an aircraft which prioritized flight times and heavier loads over high speeds.

5.2.2 Motor mount

The motor mount is a laser cut piece of mdf secured onto the front face of the aircraft by epoxy and screws. The motor itself attached to the mounting plate by inserting screws through specifically cut holes in the plate and screwing them into the screw holes built into the back of the motor.

5.2.3 Control surfaces

Our aircraft uses a total of four control surfaces: One aileron on each wing and one ruddervator on each V-tail. The decision to use a v-tail instead of a more traditional t-tail was made in light of the requirement that the aircraft had to be folded up into a tube: it was deemed simpler and more space-effective to have a mechanism that folded two v-tails inwards instead of having to work with a tail and two halves of a rudder. We are also considering adding flaps to increase lift on takeoff, time permitting.

5.2.4 Payload restraint

Our goal when designing the Payload restraint was to make them as minimalist as possible in order to minimize weight, neglecting aerodynamic properties because of their being secured inside the fuselage of the aircraft. In order to accomplish this, and as well as for ease of manufacturing, the restraints were 3D printed. The final puck holder design varied minimally from the preliminary and conceptual designs. After manufacturing, the containers were secured to the aircraft frame through epoxy. The pucks are inserted through the top of the holders, then secured by a lid and a rubber band. Because the plane was not designed to pull negative G-forces, we determined that this was sufficient to secure the pucks.

5.2.5 Landing gear

The landing gear was designed as two fixed wheels on the underside. Folding landing gear was initially considered, but it was considerably heavier. Furthermore, fixed landing gear close to the center would not add to the total diameter of the aircraft. When landing, the wing tips scrape the ground due to the instability of the fixed wheels. However, even with wing scrape, we found fixed landing gear to be superior to folding landing gear.

5.2.6 Fuselage

The final fuselage was constructed out of square interlocking balsa rods with a 3D-printed swiveling, locking attachment point for the wing.

5.2.7 Tail boom

The tail boom is a 0.394” x 0.394” (1cm x 1cm) carbon fiber tube. The decision use a single carbon fiber tube was made in order to reduce the weight towards the rear of the aircraft, keeping the center of gravity in front of the main wings. Additional justification can be found in the fact that any cargo space located in the tail of the aircraft would not be used to hold cargo or electronics in order to keep the center of gravity as far forward as possible.

5.2.8 Electronics

5.2.8.1 Servo selection

For the servos, we decided to go with slim servos that have high-torque and metal gears. The slim casing was chosen as the Selig S1223 and our v-tail wing surfaces both have very narrow profiles. Without a slim casing, the servos would excessively stick out of the airfoils disturbing airflow. Metal geared servos were chosen for their durability and lower chance of failure. Finally, the torque for the servos (3.5 kg/cm or 3.0 lbs/inch) was chosen by observing the servos used in RC aircraft with similar sized control surfaces and cruising speeds.

5.2.8.2 Speed controller selection

The drive calculator predicted a maximum of 57A being drawn by the motor. Accordingly, the Turnigy Aerostar 60A ESC which was recommended by the manufacturer was chosen.

5.3 Weight and balance

Firstly, different components on the aircraft were individually weighed because they were not included in the software estimation for the plane's frame weight.

Structure components

Component	Weight (lbs)
Wing	0.77
Fuselage	2.00
Tail	0.38
Landing gear	0.30

Electronic components

Component	Weight (lbs)
Battery packs	2.60
Propeller	0.04

Motor	0.59
Radio battery	.24
Electronics (ESC, receiver & servos)	0.20

A weight table was created for each mission using estimates for the plane's final weight, including electronics and other components that were not in the initial estimate, and estimates of the expected amount of payload for mission 3.

5.4 Flight performance parameters

	Weight
Aircraft with no payload	7.1 lbs.
Aircraft with 3 pucks	8.2 lbs.
Aircraft with 23 pucks	15.7 lbs.

For all missions, the same 18S2P 5000 mAh battery will be used. The 5000 mAH should provide enough capacity for the plane to fly for the full duration of M3. For M1 and M2, it is estimated that about half the pack capacity will be used. As M2 and M3 both have a speed component in their scoring, the aircraft will be at full throttle for the full duration of the missions. We expect the max airspeed to be 55 ft/s.

5.5 Rated aircraft cost

RAC

= (EWmax + TW) * (L + C)

= (7.11 lbs + 3 lbs) * (70" + 12")

= 829.02

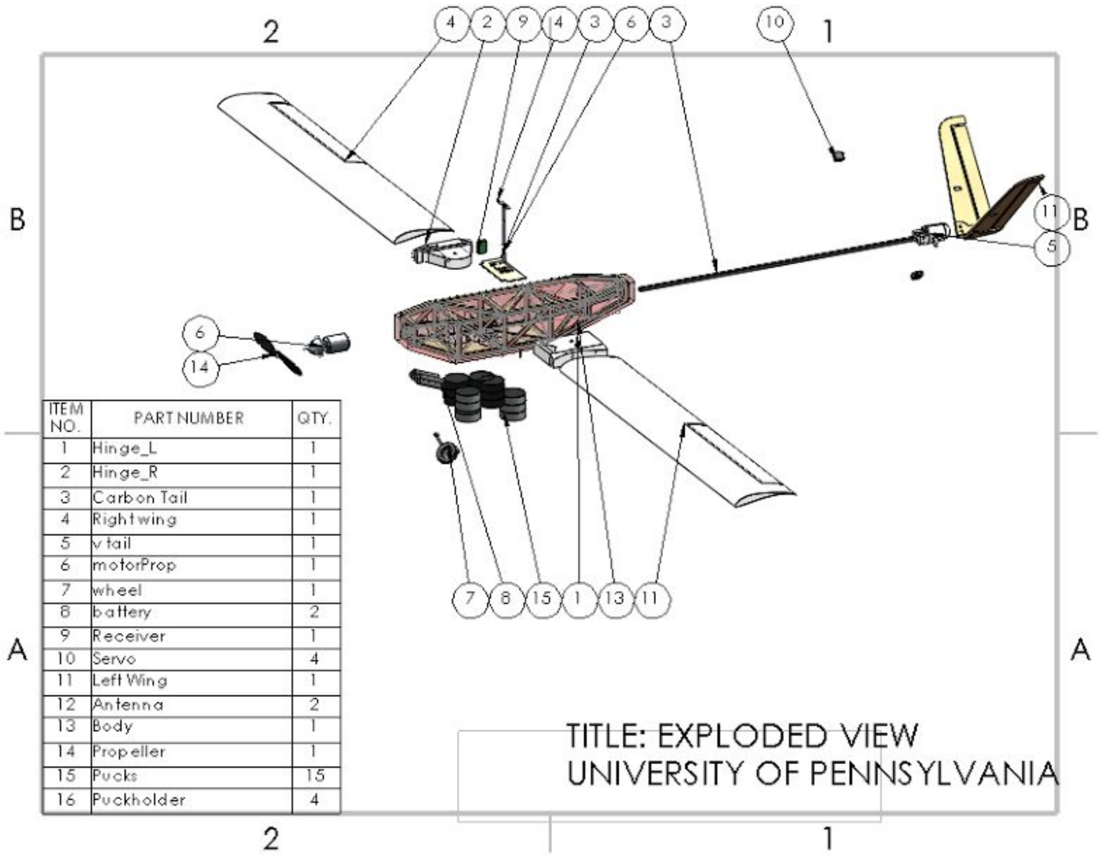
5.6 Mission performance

The aircraft underwent mission 1 and 2 simulation flights; however, the aircraft crashed and could not be repaired in time to do a test for mission 3 before the report deadline, so we did not acquire any data for that mission. After submitting this report, we intend to repair the aircraft and try mission 3. The results for the test flights can be seen below in figure 5.6.1.

	Mission 1	Mission 2	Mission 3
Average speed	50 ft. /s	50 ft. /s	Not tested
# pucks	0	3	Not tested
Time for 1 lap	50s	50s	Not tested
Time to complete mission	150s	150s	Not tested

Figure 5.6.1: Mission results of test flights

5.7 CAD Package



ITEM NO.	PART NUMBER	QTY.
1	Hinge_L	1
2	Hinge_R	1
3	Carbon Tail	1
4	Rightwing	1
5	v tail	1
6	motorProp	1
7	wheel	1
8	battery	2
9	Receiver	1
10	Servo	4
11	Left Wing	1
12	Antenna	2
13	Body	1
14	Propeller	1
15	Pucks	15
16	Puckholder	4

Figure 5.7.1: Component breakdown of the UAV

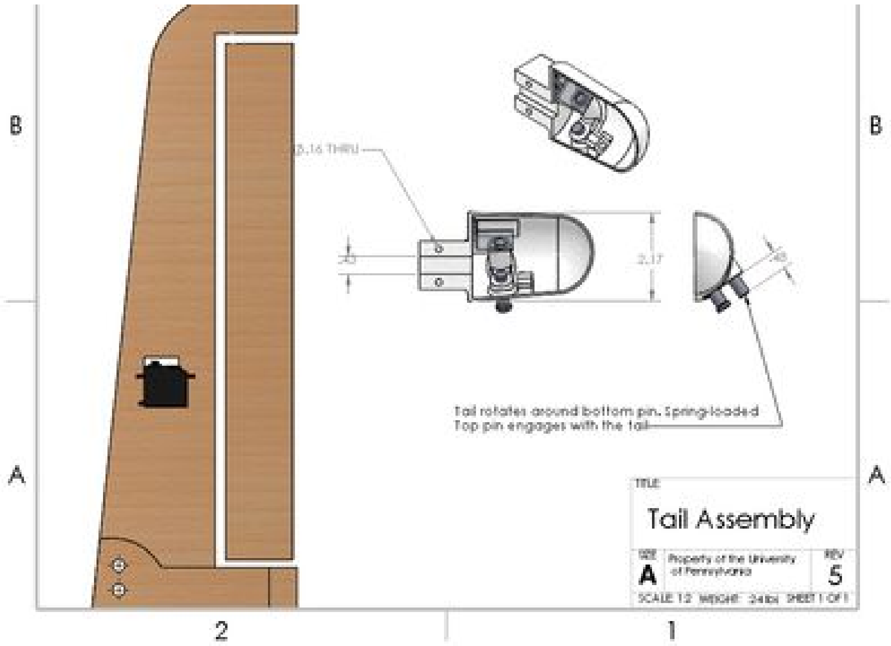


Figure 5.7.2: V-Tail CAD Design

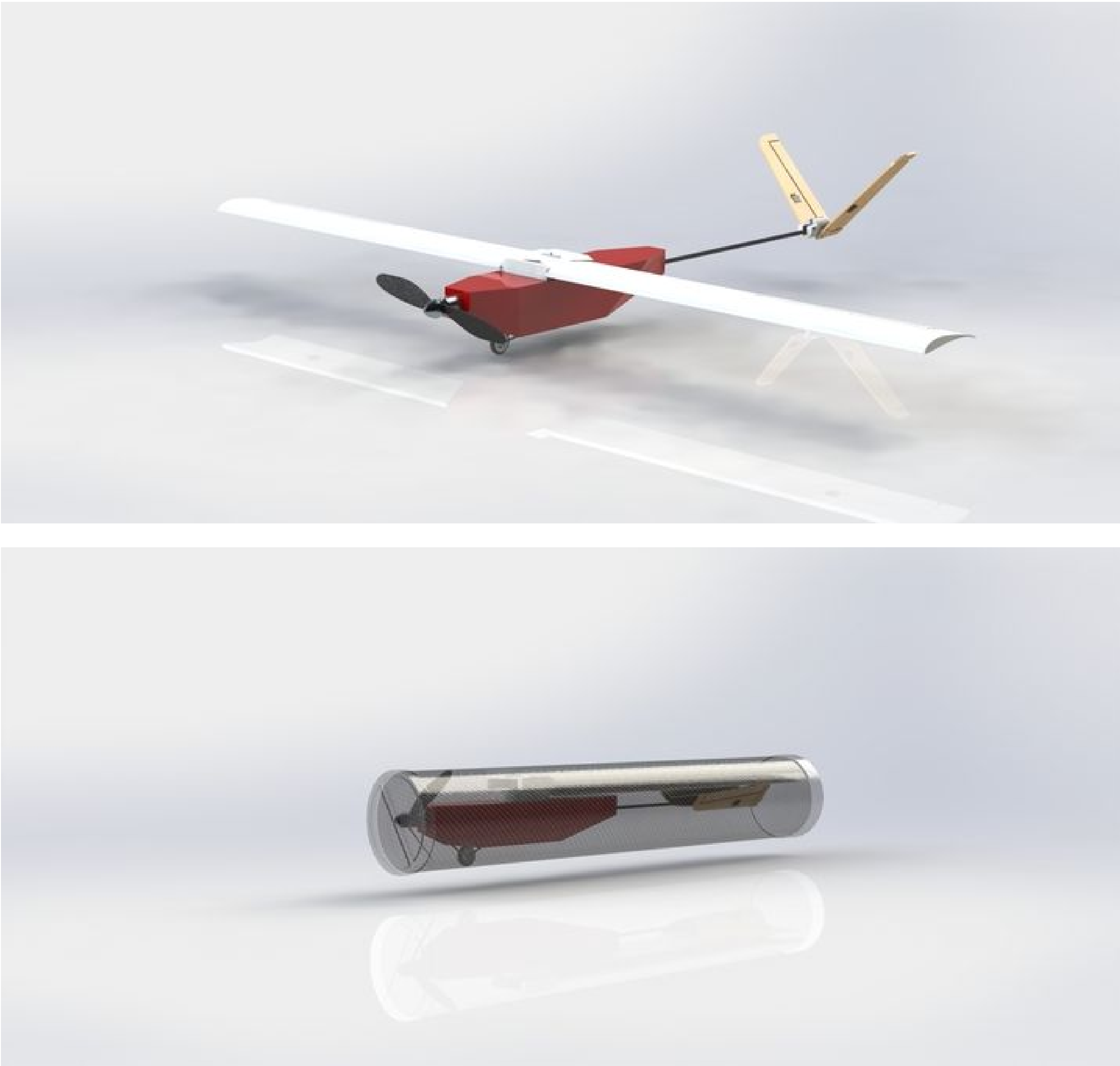


Figure 5.7.3: SolidWorks Renderings of the Final Aircraft Design

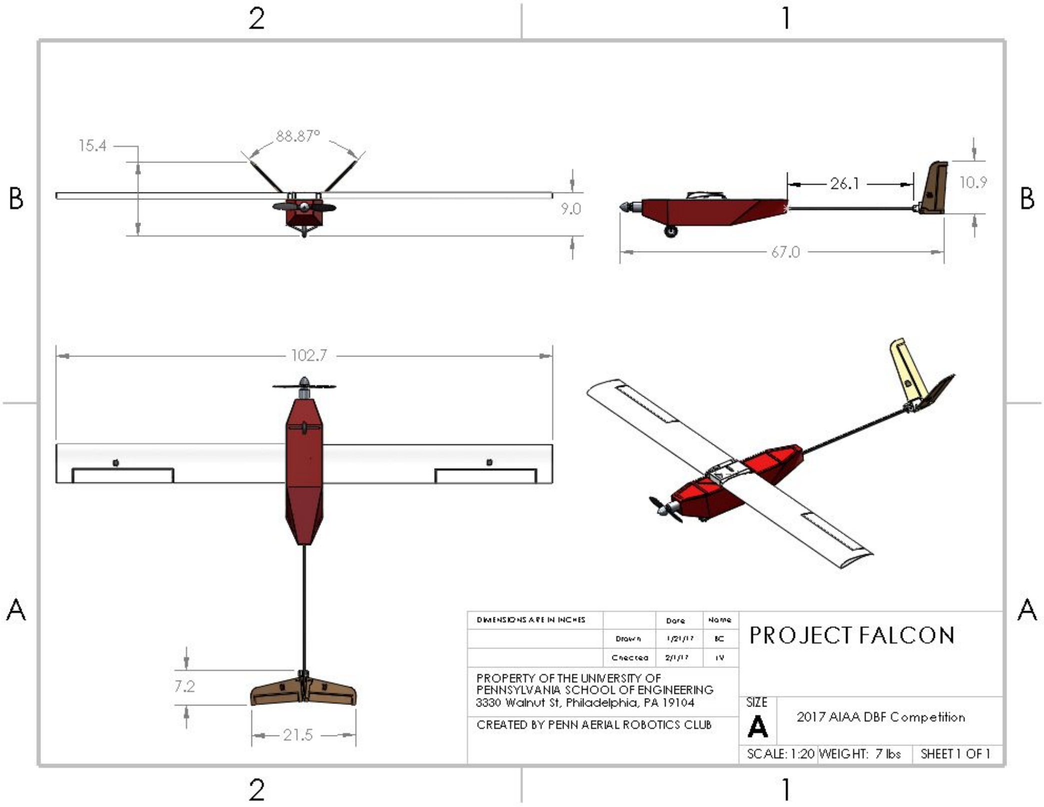


Figure 5.7.4: Three-View Diagram of the Final Aircraft Design

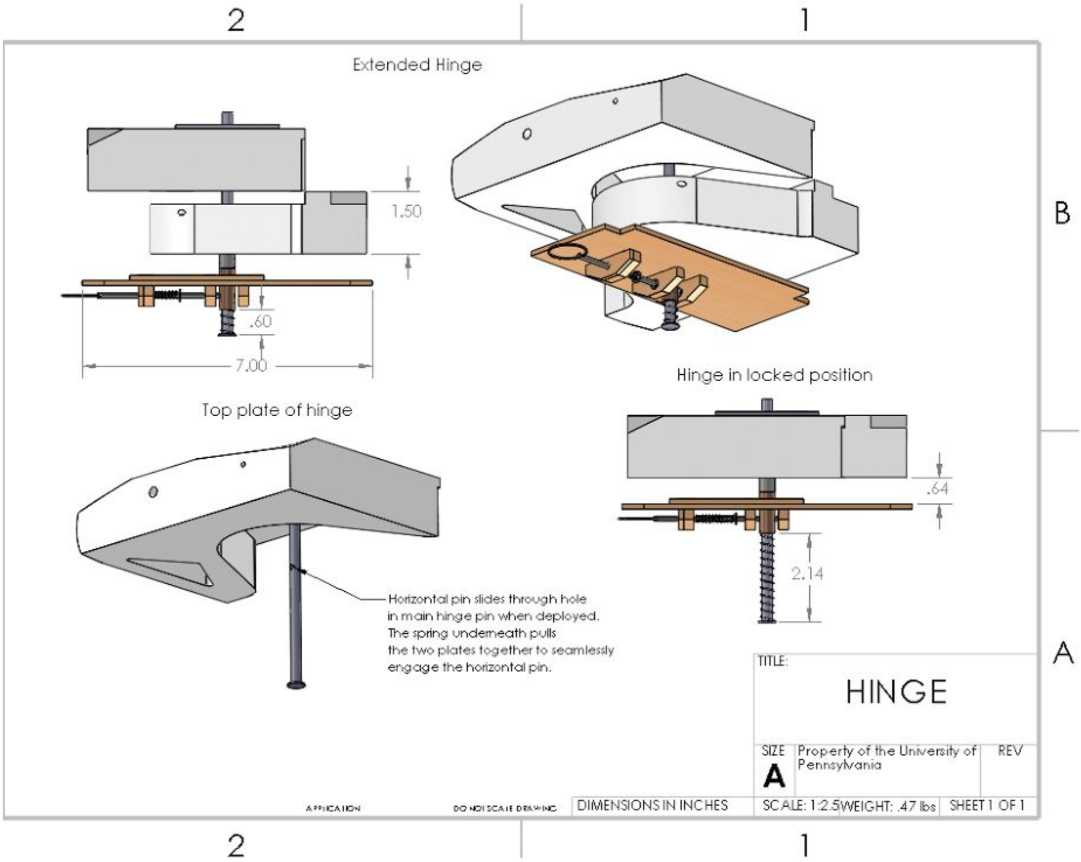


Figure 5.7.5: Main Wing Hinge Folding Mechanism

6. Manufacturing

The team had the option of choosing between a variety of possible materials. However, each type of material has its own advantages and disadvantages. The main considerations are listed below.

- **Weight:** Weight is inversely related to final score and also affects the optimal performance of the aircraft such that it will require more energy to sustain flight; therefore, the team has an incentive to reduce weight.

- **Durability:** The ideal material would be durable enough to survive through all practice fights and the competition. In the event of broken parts, the material must be reasonably replaceable.

- **Ease of manufacturing:** If a part is to be constructed in-house instead of outsourced, the material should not take too long to work with.

- **Price:** If materials or parts are to be purchased, they should ideally fit within the team's budget and leave enough left in case of emergencies.

6.1 Wings

The materials investigated for manufacturing the wing were foam and balsa. However, after prototyping foam wings and unsuccessfully flight testing, the team discovered that foam wings were too flexible to support the weight of the aircraft, even after being reinforced with multiple carbon fiber rods. The bendiness of foam wings can be seen below in figure 6.1.1 when the wingtip test was performed on an early version of the aircraft, with only the fuselage's frame with no other weight.
A second wingtip test was performed on a much stiffer foam with the same carbon fiber tubes. As shown figure 6.1.2, the bending is slightly more but the plane is loaded with electronics, motor, landing gear, and tail.

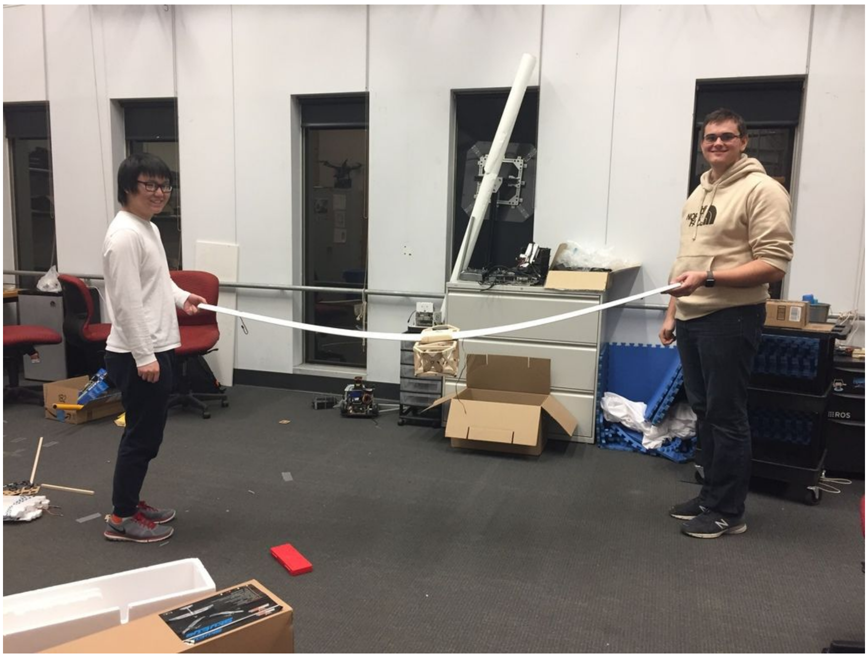


Figure 6.1.1: Picture of prototype aircraft with foam wing with no electronics, tail or cargo lifted by the wingtips

Figure 6.1.2: Picture of 2nd prototype aircraft with foam wings

The final wing was manufactured by cutting out cross sections of balsa wood with holes in each cross section and putting 2 carbon fiber rods through the cross sections to form them into the shape of a wing. Carbon fiber rods were chosen as opposed to other types of rods because they are lightweight, which is important for the score, and durable, which is necessary for strengthening the wings to pass the wingtip test and for flight use. The airfoil cross sections were kept in place on the rods using fast acting cyanoacrylate glue and firmly secured using epoxy. The skeleton of the wing was wrapped in monokote in order to have an actual surface.

The mechanism that allows the wings to rotate between flight mode and transport mode is 3D printed because 3D printed plastic is lightweight, unlike metal, and also less brittle than balsa. In addition, as the design of the aircraft wing prototype changes, it is not expensive or difficult to design a new mechanism and print it. The axle on which the wings rotate is an aluminum rod. Even though aluminum is heavier than plastic, it is durable; this is a more important factor than weight for this particular part due to the fact that it is the only part that connects the wings to the rest of the plane and is holding the entire weight of the plane.

6.2 Tail

The materials investigated for creating the tail were foam and balsa. After the foam main wings turned out unfavorably, foam tails were not tested because foam no longer has a lightweight advantage over balsa when it requires so much reinforcement to be useable. Since there is no advantage to foam, balsa was chosen.

The elevators were manufactured out of balsa boards that were sanded down to have a more aerodynamic shape on its edges. It is not necessary to do cross sections for the tail because the design was so thin that the small advantage from making them identical or shaped like airfoils would not be worth the amount of extra time and effort it would take, especially when there were more important parts that needed attention. The result of this manufacturing method can be seen below in figure 6.2.1.

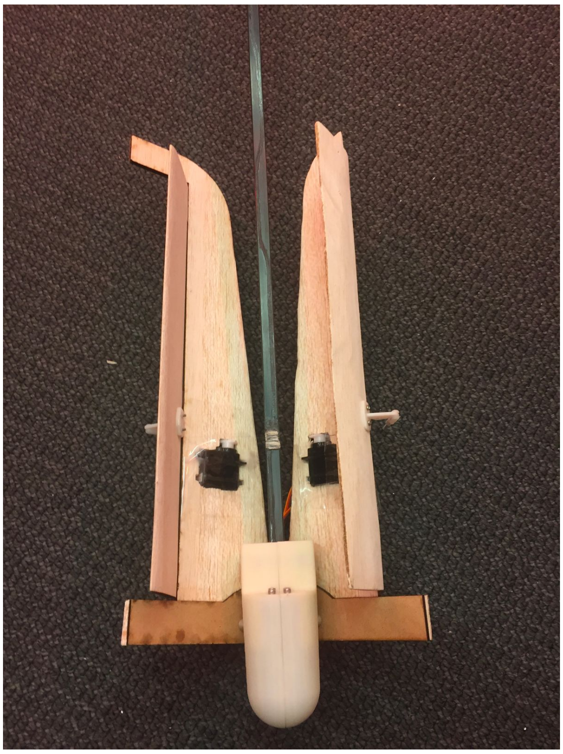


Figure 6.2.1: The balsa board tail

6.3 Landing gear

The landing gear was purchased pre-assembled and installed on the aircraft using screw mounts and glue.

6.4 Motor mounts

The motor mount was constructed out of Medium Density Fiberboard because due to its lightweight yet strong nature. Since the plane depends on the motor to fly, it is very important for the motor to stay still, especially during flight. so it was necessary to use a material that does not risk breaking. However, other materials such as plate aluminium were considered too heavy, and the extra strength unnecessary.

6.5 Control surfaces

The control surfaces, which included the 2 ailerons and 2 ruddervators, were made the same way that the wings were made. In the balsa wing, the ailerons were secured to the rest of the airfoil using ¼” thin carbon fiber rods that. On the foam wing, and for the tail, several plastic hinges are used. The movement was controlled by linkages connected to servos. Each of the control surfaces had its own servo, so there were a total of 4 servos on the aircraft. Turnigy servos were used and attached to surfaces by packing tape. The tail airfoils had servo shaped holes cut into them and the servos were taped inside, in order to reduce the amount of unaerodynamic surface on the airfoil. In addition, the servos were powered with radio battery. Note that this battery is separate from the one used to power the motor.

6.6 Fuselage

The materials that were considered for the fuselage were PLA plastic and balsa. The original CAD design for the fuselage was rounded in order for improved aerodynamics over an angular body. However, calculations estimated that a 3D printed fuselage with nothing inside would already weigh 4.84 pounds, as estimated by Solidworks. In addition, due to the inaccessibility of high-quality 3D printers required for printing something the size of the complete fuselage, this manufacturing method was deemed unviable.

The fuselage frame is built out of interlocking balsa wood beams for lightweight and ease of reparability: In the event of a crash, beams can simply be swapped out. The beams are locked together through interlocking slots cut into each beam, finally secured with CA glue. A progress picture of the fuselage can be seen below in figure 6.6.1.

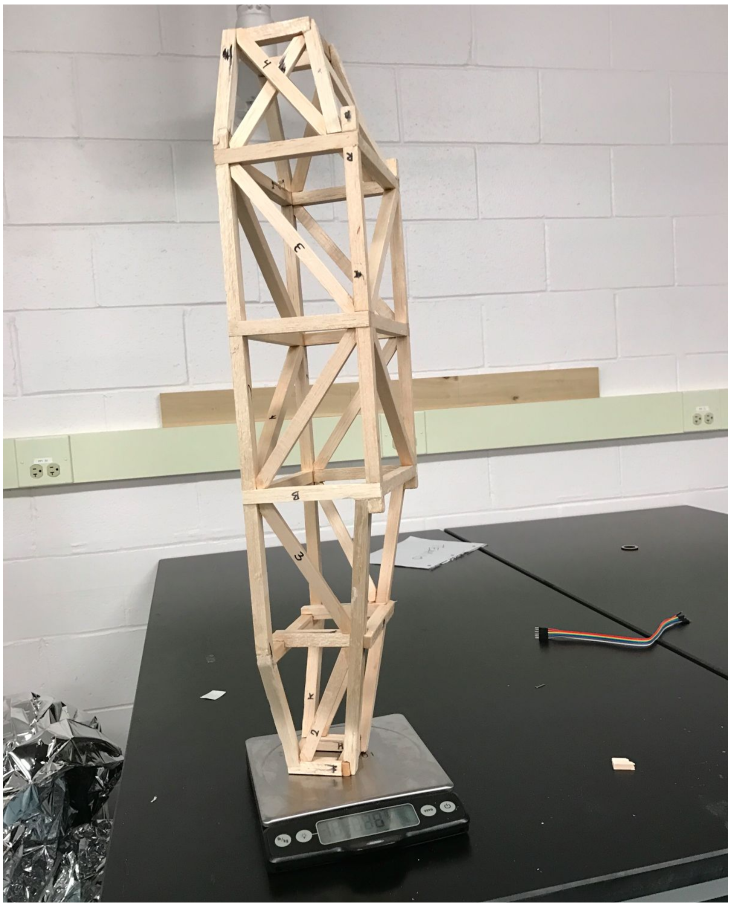


Figure 6.6.1: Balsa fuselage partway built

Due to the fact that a frame would not be able to reliably contain any objects, ⅛" inch thick balsa boards were glued to the sides of the fuselage to create walls. They were chosen because they are easily replaceable in the event of a crash and do not add much weight to the aircraft.

6.7 Battery

The battery consists of two battery packs, each made up of 14 Elite 1500 2/3A NiMH Batteries connected in series. The two packs are were then connected in parallel. Nickel solder tabs were used to connect individual cells, and 12 guage wire was used to connect the packs in parallel. The batteries were then fully shrink-wrapped and protected at all electrical contact points. In order to comply with regulations as well as increase safety, all connections to and from the batteries used fully insulated XT60 connectors.

6.8 Manufacturing milestones

A milestone chart was created to keep track of the various manufacturing steps necessary for constructing the aircraft. Progress was recorded and shown next to the scheduled milestones, as shown below in figure 6.7.1.

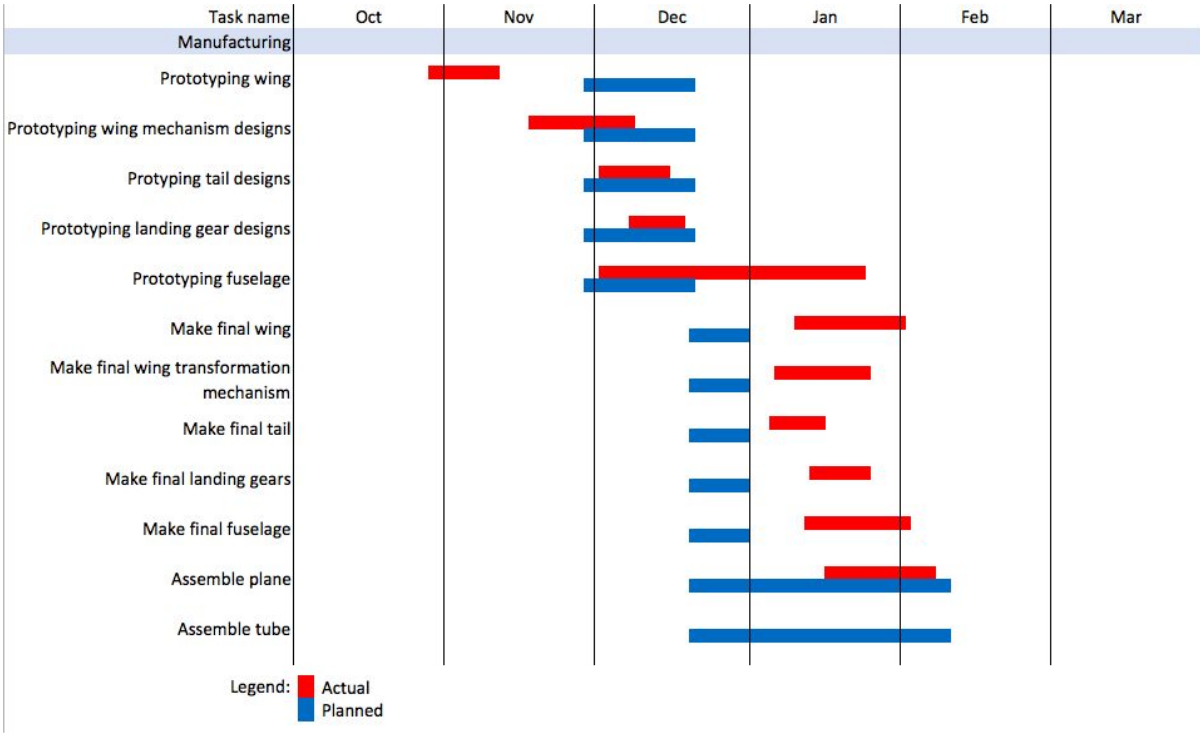


Figure 6.7.1: Gantt chart of planned manufacturing milestones and actual progress

7. Testing plan

Components of the aircraft are tested for their empirical numeric performance. The aircraft is tested according to the mission expectations that the team hopes to achieve during the competition.

7.1 Objectives

The objective of the testing plan is to provide information about the capabilities of components and the aircraft. The test results will help us decide whether or not we need to make changes to the design in order to achieve or improve upon the performance goals that we had in mind.

7.1.1 Propulsion tests

The propulsion system was tested for a variety of performance variables in order to determine the optimal flight speeds that we should maintain during flight when maximizing speed or distance. Different propellers were tested on the same motor.

The tests were performed by setting up a scale and putting it vertically against a wall, and then pressing the nose of the plane into the scale and running the motor. Though there may be some inaccuracies that result from the how the test was set up, it still helps differentiate different propellers relative to one another.

7.1.2 Wing tip test

The wings were tested for bending to determine what forces it can sustain without breaking, so that we know the limits on cargo weight. A person held up each wing and slowly lifted up the plane to determine how far upwards it could bend without breaking. Then weights were slowly added to the aircraft to determine how much payload weight it could sustain.

7.1.3 Flight tests

Each of the flight tests intended to gauge aircraft performance with respect to particular mission requirements. The specific test numbers and goals of each test can be seen below in figure 7.1.3.1 and the scheduled timeline for performing the tests can be seen in the Gantt chart in section 7.3.

Test #	Goals
1	• Determine flight quality with no payload • Identify necessary changes
2	• Determine effects of changes on plane flight quality
3	• Simulate mission 1
4	• Determine effects of small payload on flight quality • Identify necessary changes
5	• Simulate mission 2
6	• Determine effects of large payload on flight quality • Identify necessary changes
7	• Attempt long distance flight with no payload • Record endurance length • Identify necessary changes
8	• Attempt long distance flight with no payload • Identify necessary changes
9	• Simulate mission 3

Figure 7.1.3.1: Table of the intended goals of each of the missions

7.2 Checklists

Checklists were created in order to ensure that all systems will function as intended and to avoid forgetting important details. A general pre-flight checklist can be seen in Figure 7.2.1 because many procedures are repeated for the missions. The mission-specific checklists can be seen in Figure 7.2.2 to specify the differences that are relevant to each mission.

Preflight Checklist
☐ Propeller is secured?
☐ Main batteries are charged?
☐ Main batteries are connected?
☐ Main batteries are secured?
☐ Motor is secured?
☐ Radio is working?
☐ Radio batteries are charged?
☐ Radio batteries are connected?
☐ Radio batteries are secured?
☐ Wires are secured/out of the way?
☐ Control surfaces are properly linked?
☐ Arming plug is in the correct position?
☐ Pilot is ready?
☐ Plane launcher is ready?
☐ Ground crew is clear?

Figure 7.2.1: Preflight checklist

Ground Mission Checklist
☐ **All movable parts are in transport mode?**
☐ **All movable parts are locked in place?**
☐ **Plane is secured inside of tube?**
☐ **Tube caps are secured?**

Mission 1 Checklist
☐ **Plane is in flight mode?**
☐ **All movable parts are locked in place?**
☐ **Correct propellers were installed?**
☐ **General flight checklist is completed?**
☐ **No payload was loaded?**

Mission 2 Checklist
☐ **Plane is in flight mode?**
☐ **All moveable parts are locked in place?**
☐ **Correct propellers were installed?**
☐ **General flight checklist is completed?**
☐ **Exactly 3 pucks were loaded?**
☐ **Payload is secured in place?**

Mission 3 Checklist

- ☐ Plane is in flight mode?
- ☐ All moveable parts are locked in place?
- ☐ Correct propellers were installed?
- ☐ General flight checklist is completed?
- ☐ Max expected payload was loaded?
- ☐ Payload is secured in place?

Figure 7.2.2: Mission checklists

7.3 Testing milestones schedule

A schedule was constructed to plan out the tests that we intend to perform. The Gantt chart in figure 7.3.1 is a visualization of this schedule. Each of the numbered flight tests on the chart correlates with the flight tests presented in section 7.1.5.

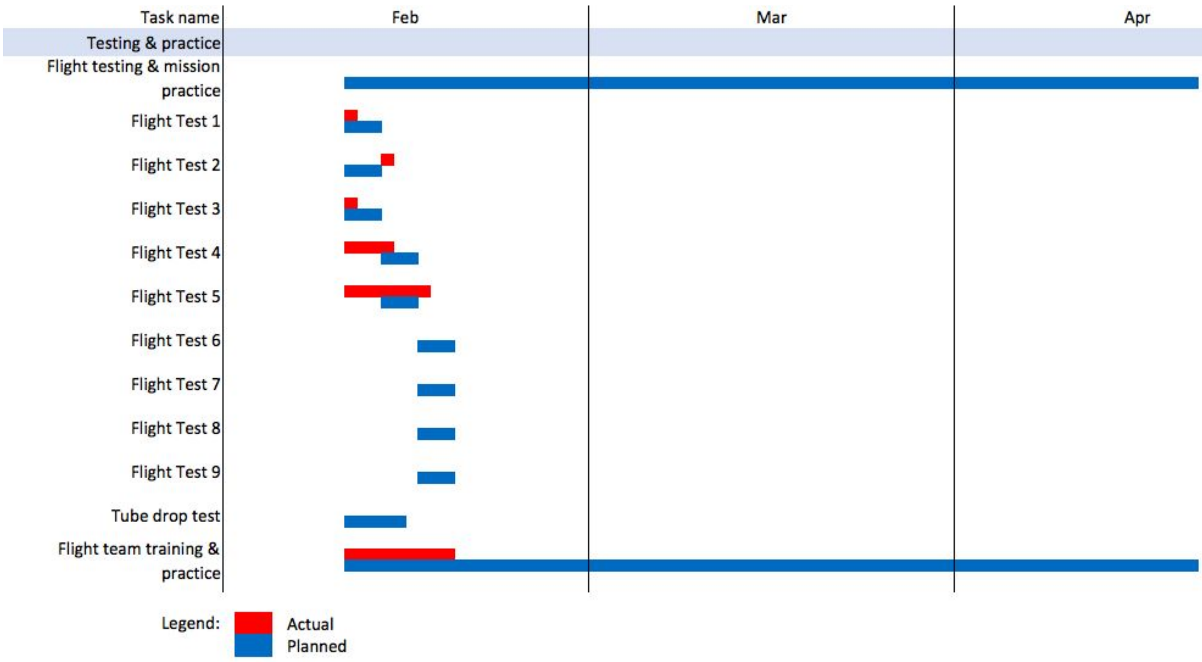


Figure 7.3.1: Gantt chart of planned tests and actual progress

8. Performance results

The components in the aircraft was tested to determine their performance capabilities relative to our predictions, in order to help us make improvements on the design.

8.1 Component and subsystem performance

We tested each component in our aircraft to ensure that its stated specifications matched real-world performance. For subsystems in our aircraft, we performed both mechanical and electronic tests. The results of the tests are outlined below.

8.1.1 Batteries:

The discharge rate of the battery is graphed relative to the voltage in figure 8.1.1.1 below.

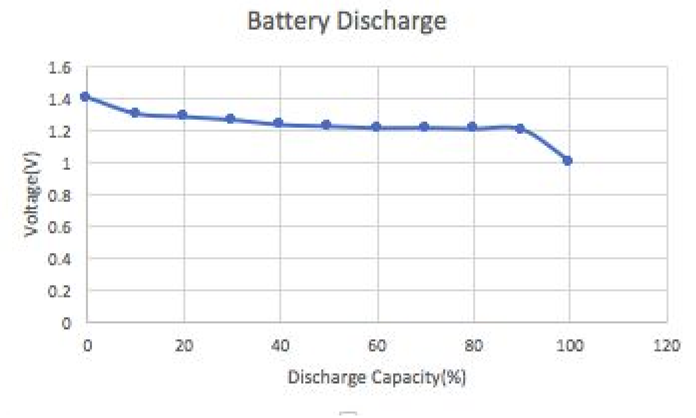


Figure 8.1.1.1: Battery discharge graph

8.1.2 Motors and propellers:

A static thrust test was performed with the turnigy motor and a 14x9.5 prop. The setup produced a maximum of 5.73 lbs of thrust while being powered by a 19.8V battery. A second, 16x10 prop was also ordered, although was unable to be tested due to limitations with the test set-up.

	14 x 9.5	16 x 10
Thrust	5.73 lbs	No Data

However, other individuals who purchased these propellers posted online that they found 130 oz. and 160 oz. of thrust, respectively.[5]

8.1.3 Wingtip test performance

The plane underwent the wingtip test to simulate the technical inspection that will be performed at the competition. This was done by loading the plane with its maximum expected payload and lifted by its wingtips. A wingtip test in progress can be seen below in figure 8.1.2.1. The plane with balsa wings was able to pass the wingtip test with a 10lbs payload, although some ribs became unsecured from the central carbon rods. Something of note is the wingtip test was performed with un-monocoated wings, which are expected to be stronger and able to pass the wingtip test.


Figure 8.1.2.1: Two team members lifting up the aircraft for the wingtip test while using laptops to simulate the expected weight

A similar wingtip test was also performed using foam wings instead of balsa. However, it was noted that the foam wings experienced much greater bend with less loading, and a full 10 lbs load was not applied. This leads to the conclusion that the foam wings need thicker carbon tubes to properly pass the wingtip test and maintain shape while flying.

8.2 System performance

A total of 2 test flights were able to be performed. During both flights, a phone was used to record videos of the plane's performance. However, we did not have monitoring decides or sensors on the airplane, so we could only estimate the performance from the videos. In addition, mission 3 was not simulated, but we do intend to perform test flights for this mission before the competition. The estimated results from the test flights are shown below in figure 8.2.1.

Mission 1	Predicted	Actual
Average speed	45 ft./s	50 ft. /s
# pucks	0	0
Time for 1 lap	41.7s	50s
Time to complete mission	125.1s	150s

Mission 2	Predicted	Actual
Average speed	45 ft./s	50 ft. /s
# pucks	3	3
Time for 1 lap	41s	50s
Time to complete mission	126s	150s

Mission 3	Predicted	Actual
Average speed	45 ft./s	Not tested
# pucks	23	Not tested
Time for 1 lap	40s	Not tested
Time to complete mission	300s	Not tested

Figure 8.2.1: Mission performance estimates and results

First Flight

A balsa airplane with the NACA 6412 foam wings was successfully hand launched into the air. The Turnigy motor was turning a 14x9.5 prop and was powered a with 16.8V 3000mAh battery. We observed that the foam wings experienced extreme flexing, and that the aircraft struggled to produce enough lift. The pilot noted that he was having difficulty turning the aircraft, although vertical control was adequate.

After the first flight, several key changes were made to improve the performance of the plane. First, the airfoil was changed from the NACA to the Selig, to improve the lift generated. The chord length was also increased from 6 to 8 in order to further generate additional lift. To help prevent fluttering, carbon strips were inserted lengthwise into the wing, to add additional support to the existing carbon rods. A higher voltage battery was also purchased, and the prop size increased to 16x10 to compensate for the additional drag caused by the wing changes.

Second Flight

A balsa airplane with 9 in Selig 1223 foam wings was successfully hand launched into the air. The changes performed admirably, and the plane was able to climb easily. However, the wing was still undergoing significant fluttering despite the addition of carbon strips.

The continued fluttering of the wings led to further consideration of balsa wings, which are much more rigid. Due to complications in the manufacturing of balsa wings, we were unable to finish construction before the submission deadline of the design report. However, the balsa wings and foam wings both easily interface with the hinge, and should the balsa wings fail, additional modifications to foam wings can be made. For example, increasing the main carbon tube to a diameter of ½” over the current diameter of ¼” was estimated to have a 11 times greater moment. As such, a final decision over the material of the wings has not been made.

Proof of Flight

Figure 8.2.1: Proof of flight for our aircraft design taken during second flight test

8.3 Conclusion

Project Falcon has shown tremendous potential to perform well in its first year of participation in the AIAA DBF competition. Our score analysis showed that for the 2017 competition, the most important factors in scoring well was maintaining a low aircraft weight while having a high M3 Laps * Pucks value. These guidelines drove the configuration selection, preliminary design, detail design, and even manufacturing. Accordingly, we converged on a final design of a large aircraft with folding wings and a V-tail. We believe that our aircraft can achieve an extremely high M3 score, while having a relatively low RAC among other large aircraft. Falcon is ready to compete in the 2017 AIAA DBF competition.

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