Washington State University

North Puget Sound at Everett

2016-2017 AIAA DBF Competition Final Report

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1.0 Executive Summary

This report will address the process of designing, manufacturing and testing of the Washington State University – North Puget Sound Everett's Design/Build/Fly (DBF) aircraft. The AIAA will host a student 2016-2017 Design/Build/Fly competition that will take place in Tucson, Arizona from April 20th-23rd of 2017. The objective of the competition is to design a tube-launched Unmanned Aerial Vehicle (UAV) that can successfully complete the following four missions:

1) Demonstration Flight – flight with no additional payload
2) Speed Flight – timed flight with UAV carrying three hockey pucks
3) Range Flight – as many laps completed within five minutes with the maximum payload
4) Ground Mission – three drops from 12 inches onto hard surface

1.1 Design Process

The conceptual design of a successful system is dependent on the construction of the aircraft to meet and match the metrics of the competition requirements and scoring criteria. The competition requires the aircraft to compact into a launch tube, which influenced the design. Due to the safety of the aircraft, lithium-ion batteries are not allowed, and competitors are restricted to NiCad or NiMH batteries. With the limits of thrust due to the batteries required, the NACA 6514 airfoil was selected for its favorable high lift characteristics at a low Reynolds number. Analysis was performed on wing loading and power using computer-aided design to assist with determining drag and lift. The battery, motor, and propeller combination analyzed using the computer software, MotoCalc, determined the best combination of these components best suited.

1.2 Key Mission Requirements and Design Features

The total overall score of the competition is impacted by each team's written report score, total mission score and the rated aircraft cost (RAC). To obtain the highest possible score from the competition, the maximum scores for the written report and total mission scores are targeted and with the RAC minimized. The RAC is a function of the aircraft's empty weight and launch tube weight, length, and circumference.

Aircraft's Weight: The empty weight of the aircraft is a critical factor to the total score of the competition, composed of the weight of the airframe and propulsion system. Payload is not considered in the empty weight. To minimize aircraft weight, the fuselage and wing design were analyzed according to raw materials.

Launch Tube Requirement: The length and circumference of the launch tube significantly impacts the value of the RAC. Although the minimum ratio between the length and diameter of the tube needs to be at least 4, the length and circumference of the tube will be dependent on the geometry and design of the aircraft. To minimize the metrics of the launch tube, the wing folding mechanism of the aircraft was optimized to minimize the value of the aircraft's circumference.

Payload Requirement: The scoring for Mission 3 is dependent on the max payload capacity and the number of laps completed within five minutes. Increasing the scoring outcome requires the design of the fuselage to carry multiple hockey pucks and the propulsion to produce enough power with the extra payload.

1.3 Performance Capabilities of the System

The final design of the UAV was evaluated in subsystems, where each can be designed, analyzed and optimized to maximize the total score. The aircraft is designed to simultaneously minimize the weight, maximize the additional payload to carry and maximize speed.

Aerodynamics: Analysis was performed on a wing aerodynamic structure for the UAV. A design was formulated allowing for both adequate lift for hand launching by the operator (while carrying a maximum 1.875 lb payload) and compactness such that it can be conveniently stowed in an approximately 30" length tube. The constraining aspect of this design process was found to be generating sufficient lift during takeoff without exceeding the limits on thrust imposed by the NiMH battery chemistry. The NACA 6514 airfoil was selected for its favorable high lift characteristics at low Reynolds numbers. The resulting wing successfully met ambitious targets for both lift and compactness.

Fuselage: The fuselage was tested to withstand the stresses of takeoff, flight, and landing while carrying the required payload. Its design accommodates the wing folding mechanism efficiently, conserving space and minimizing weight.

Tail Design and Mechanism: The tail was designed purely to serve as a control surface rather than generate any appreciable lift. Each foil designed has a 4" by 6" constant chord profile at 20° sweep, using a Wortmann FX 76-100 symmetric airfoil. The three foils incorporate a hinge into the leading wing root so that they may swing forward alongside the tail boom for storage, and are fixed into operating position by small plastic tabs. The folding mechanism was 3D printed using ULTEM material with foils made from wire cut foam core wrapped in two plies of carbon fiber. The rudder also controls steering of the rear landing gear.

Wing Folding Mechanism: The wing folding mechanism is designed to move the airfoil from flight position to an overlapping collapsed position above the fuselage along the length of the plane. This mechanism attaches to the top of the fuselage structure and the carbon fiber rod for added strength.

Propulsion: The propulsion system consists of a direct-driven motor, 2 collapsible propeller blades, and 14 Nickel Metal Hydride (NiMH) batteries. A motor mount, attached to the front of the aircraft, prevents slight movements of the motor and additional stresses on the structure of the UAV.

2.0 Management Summary

The WSU-Everett Design Build Fly team consisted of 23 active members, including 12 seniors and 5 juniors from Washington State University North Puget Sound at Everett, and 6 manufacturing students from Everett Community College's Advanced Manufacturing Training and Education Center (AMTEC).

2.1 Team Organization

The team followed a hierarchical structure to establish leadership roles similar to those in industry, assigning core responsibilities to elected subsystem leads to perform their required tasks shown in Figure 2.1.1. The Project Manager is responsible for ensuring the success of the project by facilitating productivity between all design groups by consulting with faculty advisors, leading team meetings, scheduling, and delegating tasks. He is supported by the following teams and their respective team leads to perform the following functions:

- **Aerodynamics** analyzes the aircraft's size, flight performance, and characteristics.
- **Manufacturing** is responsible for all fabrication, material selection, and build of aircraft components.
- **Fuselage/Structure** designs and creates detailed drawings of mechanisms and components through Solidworks® modeling and is responsible for their integration.
- **Landing Gear** focuses on the design and analysis of landing gears and undercarriage of the aircraft and its integration with the fuselage.
- **Propulsion** focusing on propulsion optimization through motor, battery, and propeller selection.

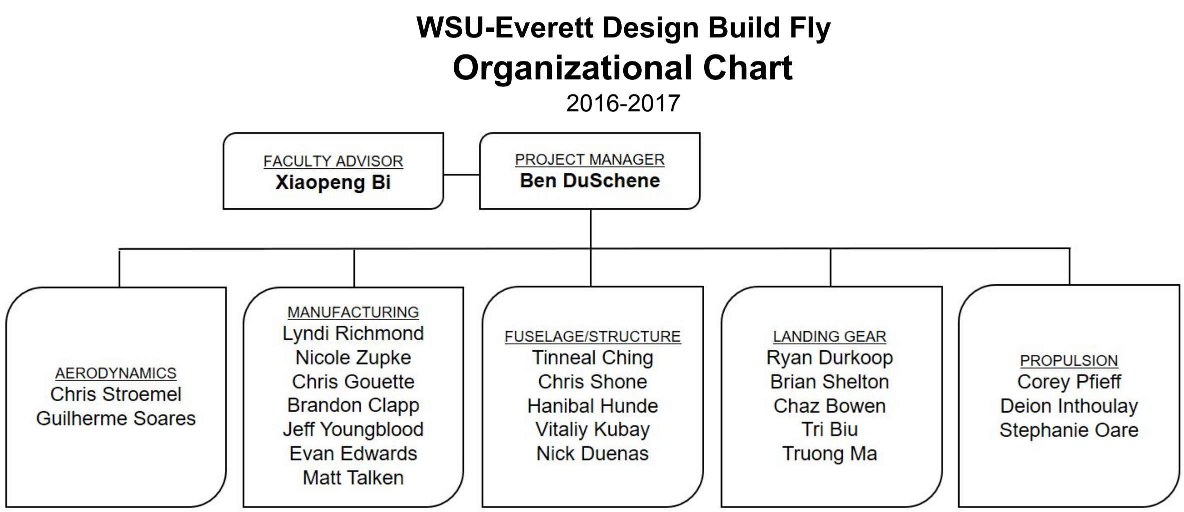


Figure 2.1.1: Team organization chart.

2.2 Milestone Chart

A milestone chart was created prior to concept generation to implement a design schedule used in developing a competitive aircraft for WSU-Everett's first Design/Build/Fly Competition entry. This design project was initially established as a Senior Design Project to be completed over a period of two semesters. A schedule of the project's development (Figure 2.2.2) outlines a sequence of the team's critical build tasks.

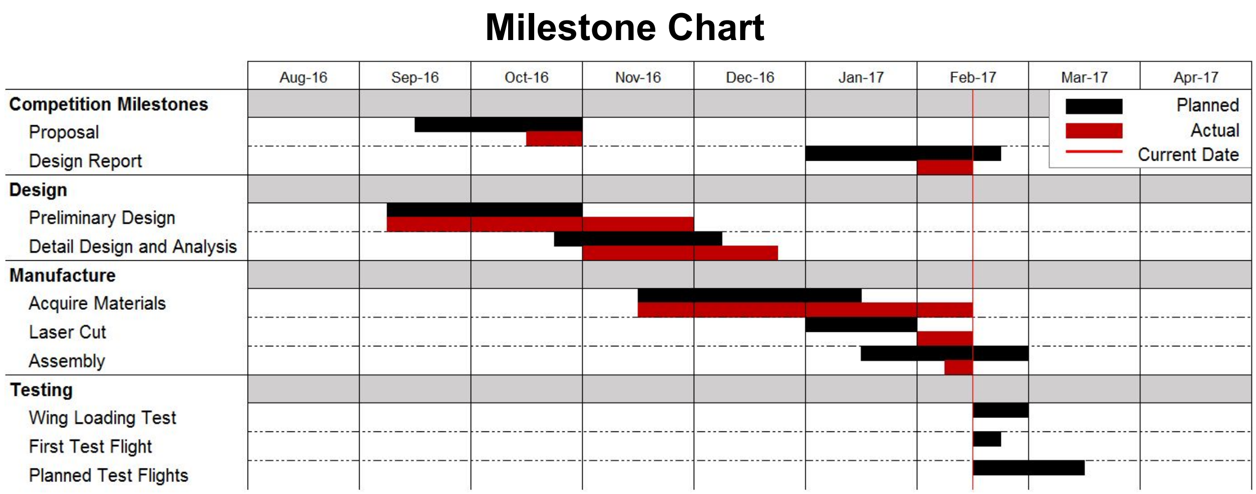


Figure 2.2.2: Milestone chart.

3.0 Conceptual Design

To maximize our expected score as per the AIAA DBF guidelines, a comprehensive analysis was completed to evaluate customer requirements and constraints, effectively weighing different design configurations.

3.1 Mission Requirements

Customer requirements and constraints were retrieved from the rules and mission requirements stipulated by the AIAA for the 2017 design build fly competition. After careful inspection of the rules, the WSU Everett Design Build Fly team summarized the requirements and constraints in a table (Table 3.1.1). All this information is vital to the success of the project as a whole, since any design decision will have to agree with the requirements. Having a clear and summarized compilation of the requirements and constraints helped the team to move in the right direction, minimizing possible erroneous decisions.

Table 3.1.1: Requirements and Constraints

Requirements	Constraints
• Aircraft features must move to flight position using hinges, pivots or other captive mechanical mechanism	• Minimum payload of 18oz • Minimum size of load is a cylinder with a 3 in diameter and 3 in long

• All Features must self-lock into the flight condition • Tube length to diameter (L/D) must be a minimum of 4 • Payload must be carried internally • Must be propeller driven and electric powered • No structure/components may be dropped from the aircraft • Must use NiCad or NiMH batteries	• Aircraft should complete 3 laps of a track with 1000 foot straight-aways with minimum payload in 5 minutes or less • Aircraft should complete 3 laps or more with maximum payload in less than 5 minutes • Aircraft in launch tube with maximum payload should be able to withstand two end drops and a flat drop from a minimum height of 12 inches without visible damage • Take-off weight should be less than 50 lbs

Overall Scoring and Total Mission Scoring are Written Report Score (WRS), Rated Aircraft Weight (RAC), and all three individual Mission scores M1, M2, and M3 using the formulas (Table 3.1.2) below.

Table 3.1.2: Summary of Competition Scoring

	Scoring Formula or Criteria	Terms
Overall Score	Overall = (WRS * TMS) ÷ RAC	*WRS* = Written Report Score *TMS* = Total Mission Score
Total Mission Score	TMS = M1 + M2 + M3	*M1* = Mission Score 1 *M2* = Mission Score 2 *M3* = Mission Score 3
Rated Aircraft Cost	RAC = (EWmax + TW) * (L + C)	*EWmax* = Max Aircraft Empty Weight excluding payload *TW* = Tube Weight *L* = Tube Length *C* = Tube Circumference

Mission 1: Demonstration Flight

This first mission has no payload and has a hand launch requirement with a maximum of 3 launch attempts during a single flight attempt. The aircraft must complete 3 laps within a 5 minute flight window. The aircraft must complete a successful landing to obtain a score.

- M1 = 1.0 (Aircraft completes a successful flight)
- M1 = 0.1 (Aircraft does not complete a successful flight)

Mission 2: Speed Flight

The second mission has a 5 minute window to complete 3 laps with an internal payload of three hockey pucks. The time begins with the aircraft leaves the launcher's first hand launch attempt and ends when a lap when the aircraft passes over the finish line at the end of the third lap. To achieve a score, the aircraft must complete a successful landing as outlined in the competition rules.

- M2 = 2*(Min_time / N_time) (Min_time is the fastest time to complete 3 laps for any team)

Mission 3: Range Flight

The third mission has the same launch parameters as Mission 2 with the exception of carrying the maximum number of hockey pucks determined by each team prior to competition with no lap requirement. The score is based on the number of hockey pucks carried and the number of laps flown within the 4 minute window.

- M3 = 4*[N_(laps*pucks) / Max_(laps*pucks)] + 2

Mission 4: Ground Mission

The Ground Mission must be completed prior to attempting Mission 2 and consists of three drop tests from a minimum height of 12 inches onto a hard surface. Drop tests will be conducted on the UAV collapsed and stowed in the launch tube with the maximum payload. A mission official will check for any major cracks or damage and verify all flight controls and propulsion are fully functional.

- GM = 1.0 (Aircraft completes a successful flight with no major damage and controls functional)
- GM = 0.0 (Aircraft/launch tube suffers major damage or controls lose functionality)

Weighting

Ultimately the UAV, being designed for a competition, would need to have a competitive score. To maximize our Overall Score, analysis was performed on the score and a weighting chart was created. The score weighting, Figure 3.1.1 was used to assess these parameters. The weight of the UAV was found to be the most important factor in winning the competition.

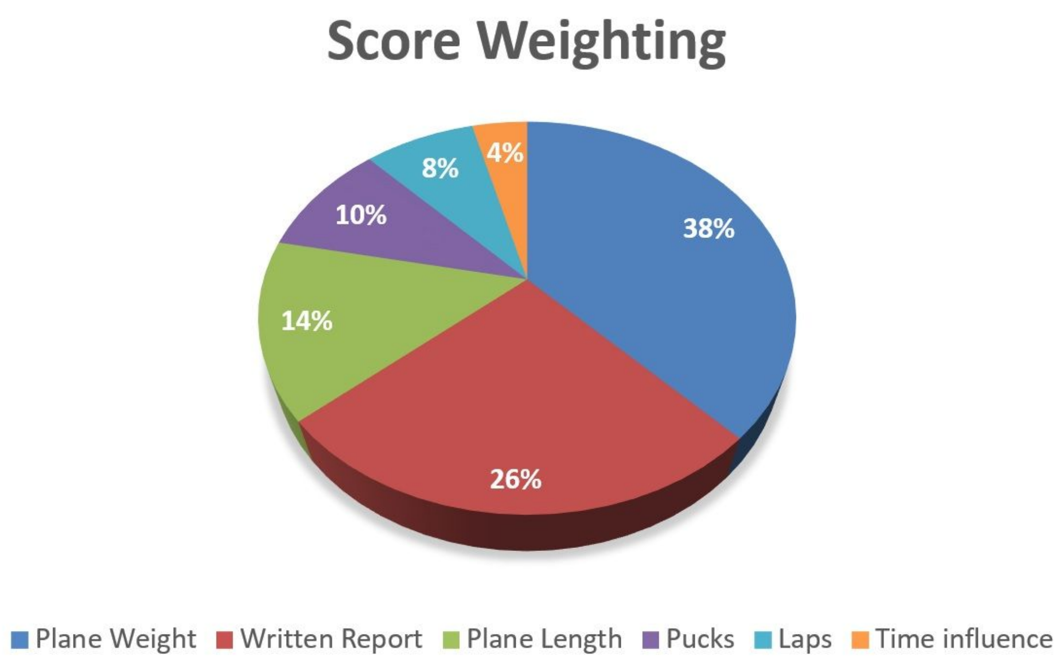


Figure 3.1.1: Competition weighting of scoring parameters

3.2 Solution Concepts

Function Diagram

In order to break down the process between inputs like the energy from the batteries and the desired outputs like the remote user control, the function diagram shown below in Figure 3.3.1 was created. The energy from the battery powers the communication devices which receives user input and allows remote user control. The control servos and motor are also powered by the battery which move control surfaces and the propeller to provide maneuverability and thrust control. The physicals structures like the wing and tail create a stable flight through generating lift and the use of ailerons and stabilizers. The fuselage contains the payload and the landing gear protects the payload during landing.

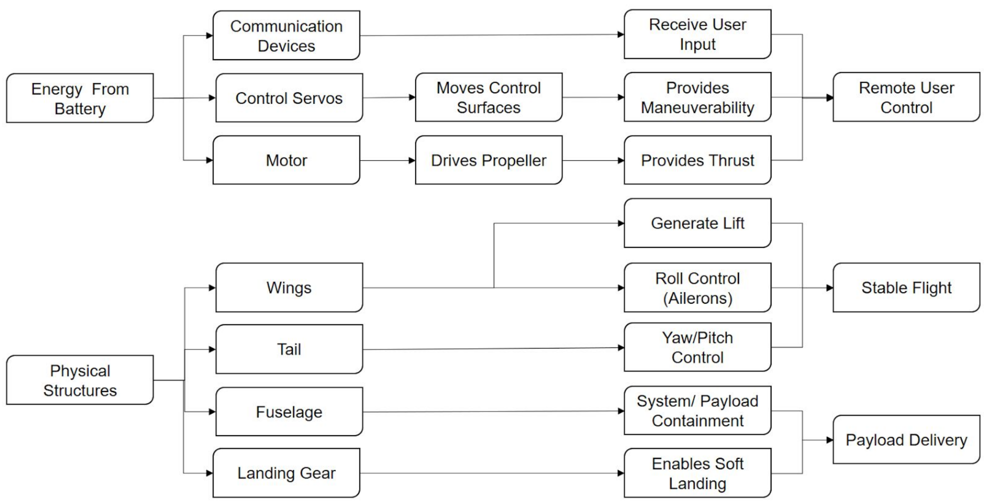


Figure 3.3.1: Function Diagram

3.3 Concept Selection and Results

Design solutions for propeller and wing arrangement were considered and screened to generate 10 conceptual designs used in our concept selection, screening, and scoring processes. The concept screening process was broken down into the following criteria based upon feasibility and maximizing aircraft performance. The criteria used in screening included manufacturability, size, cost, stability, speed, weight, durability, increasing ease of folding, safety, complexity, and payload capacity. For the screening process, the concepts were scored using the screening scale below and the scores were tabulated into the Table 3.3.2 below. The concepts A, B, D, E, and J were approved to continue to the scoring process.

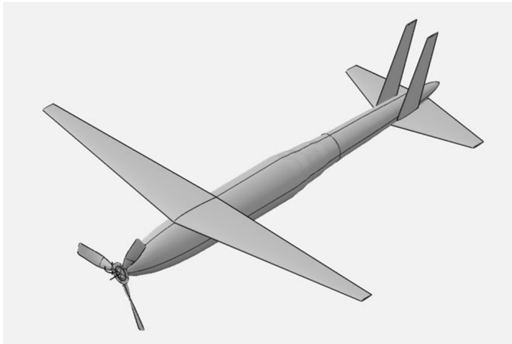
Table 3.3.2: Concept Screening Matrix

	Concept Variants									
Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Manufacturability	+	+	0	+	+	-	-	-	0	+
Size	+	+	+	+	+	0	0	-	0	0
Cost	0	0	0	+	+	-	+	-	0	+
Stability	0	0	+	0	0	+	+	+	0	0
Speed	0	0	+	-	-	+	-	+	+	-
Light-Weight	-	0	0	+	0	-	0	-	-	+
Durability	+	0	+	+	+	-	0	0	-	0
Ease of Folding	0	0	-	+	+	-	-	-	-	+
Safety	0	0	0	+	+	0	0	+	0	0
Least Complex	0	0	-	+	+	-	0	-	0	+
Payload Capacity	0	0	0	0	0	+	0	0	0	0
Sum +'s	3	2	4	9	7	3	2	4	1	5
Sum 0's	7	9	5	1	3	2	6	2	7	5
Sum -'s	1	0	2	1	1	6	3	5	3	1
Net	2	2	2	8	6	-3	-1	-1	-2	4
Rank	**4**	**4**	**4**	**1**	**2**	**7**	**5**	**5**	**6**	**3**
Continue?	**Yes**	**Yes**	No	**Yes**	**Yes**	No	No	No	No	**Yes**

Table 3.3.3, the scoring matrix used combined concept variants from Table 3.3.2. Each combined concept design was ranked from 1-5 for each criteria (1 = not good and 5 = very good), then multiplied that rank by the relative weighting of the particular criteria. These values were then summed up for the concepts final net design quality. The chosen concept was DE shown in figure 3.3.2.

Table 3.3.3: Concept Scoring Matrix

		Concept Variants											
Criteria	**Weight**	**AB**		**AB+**		**DE**		**DE+**		**J**		**J+**	
Manufacturability	**0.1**	4	0.4	2	0.2	5	0.5	3	0.3	5	0.5	3	0.3
Size	**0.1**	5	0.5	2	0.2	5	0.5	3	0.3	5	0.5	3	0.3
Cost	**0.05**	3	0.15	2	0.1	4	0.2	3	0.15	4	0.2	3	0.15
Stability	**0.15**	2	0.3	4	0.6	3	0.45	4	0.6	3	0.45	5	0.75
Speed	**0.05**	4	0.2	4	0.2	2	0.1	2	0.1	2	0.1	2	0.1
Light-weight	**0.1**	4	0.4	3	0.3	5	0.5	3	0.3	5	0.5	3	0.3
Durability	**0.05**	3	0.15	2	0.1	3	0.15	2	0.1	3	0.15	2	0.1
Ease of Folding	**0.15**	4	0.6	2	0.3	4	0.6	2	0.3	3	0.45	1	0.15
Safety	**0.1**	3	0.3	3	0.3	4	0.4	4	0.4	5	0.5	5	0.5
Complexity	**0.05**	4	0.2	2	0.1	5	0.25	4	0.2	5	0.25	3	0.15
Payload Capacity	**0.1**	2	0.2	2	0.2	4	0.4	4	0.4	3	0.3	3	0.3
Net	**1**	**3.4**		**2.6**		**4.05**		**3.15**		**3.9**		**3.1**	
Rank		**3**		**6**		**1**		**4**		**2**		**5**	
Continue?	**Y/N**	No		No		**Yes**		No		No		No	



Concept DE

Figure 3.3.2: Final aircraft concept with single compactable front propellor, large shoulder wing, small boom-tail tail wing, and a telescoping fuselage.

4.0 Preliminary Design

After a concept was selected, preliminary design and analysis was conducted on the airfoils, wing dimensioning, propulsion, motor, and battery. Initial sizing began with wing dimensioning to determine the approximate wing loading for the Propulsion team to size the motor, propellers, and batteries required.

4.1 Design and Analysis Methodology

Wing Baseline Dimensioning

Wing dimensions were given starting values, known as baseline values, by evaluating models with similar design metrics. Knowing that the wingspan was important to equally distribute the lift and minimizing chord was important to reduction of drag, initial values for chord length were established at 8 inches. A constraint of the competition determined that the chord to length ratio of the tube the UAV would be contained in was 1:4. Having established a 8 inch chord, and having decided that the wings would be folded on top of the fuselage the wing span baseline was established at 56 inches. This enables calculations for reynolds number, and the coefficient of lift to be evaluated. Table 4.1.4 below indicates the baseline values established to start analysis of the UAV wing structure. These values would be used as a reasonable starting point that could be refined through iterations.

Table 4.1.1: Wing parameters established to perform refinement iterations

Wing Span	Wing Chord	Wing Planform Area	Wing Loading
56 in	8 in	448 in²	2.16 lb/ft²

Propulsion

Using the concept screening matrices in Tables 3.3.2 and 3.3.3, a single motor, pulling compacting propellor was selected to power the plane. The propulsion system for the 2017 competition is designed to win missions 2 and 3. The key component to both missions is top speed. Mission 2 and 3 scoring can be seen in Section 3.1. If our team is able to win mission 2 and 3, we have the possibility of diminishing our competitions mission 2 and 3 score. To meet these requirements the team chose a 900kV motor paired with a 14-cell 4200mAh NiMh battery. Using Motocalc, the motor and battery can be analyzed using motors and batteries with similar characteristics from different manufacturers. Motocalc offers static simulation with various propeller sizes. The propeller tests ranged from a 9" diameter by 6.5" pitch to a 14"x12" propeller in 0.5" increments. To achieve the mission goals previously stated the motor will operate at 80-100% maximum throttle. The limiting factor for maximum air speed is the minimum current allowed in the propulsion system.

For testing purposes a 900kV motor of similar characteristics will be used in Motocalc to test the different amount of 4200mAh battery cells and propellers. The options for the optimal amount of thrust will be shown in Table 4.1.2.

Table 4.1.2: Optimal Battery and Propeller Combinations for 900kV Motor (Motocalc)

Motor		Battery Cells	Current	Propeller Size	Static Thrust	Plane Empty Weight	Flight Time
	kV	*#*	*Amps*	*in.*	*lbs*	*lbs*	*m:s*
Scorpion HK-3226-900	900	8	33.7	13x8.5	2.84375	6.475	7:29
Scorpion HK-3226-900	900	10	43	14x6.5	4.2375	6.79375	5:51
Scorpion HK-3226-900	900	14	57.3	14x6.5	5.73125	7.43125	4:24

4.2 Airfoil Selection

Hundreds of different airfoils were analyzed using XFLR5 to determine viable ranges of the coefficient of lift, coefficient of drag, lift to drag coefficient, angle of attack of the wing, and the pitching moment coefficient. The results of these analyses were used to determine the airfoil that would best fit our application.

Six airfoils that fit predetermined aerodynamic ranges were selected for further analysis. The airfoils selected for further analysis were: AG18, AG35, AG36, NACA 6514, MH32, and MH 38. Figure 4.2.2 below shows the selected airfoils with the coefficient of lift as a function of drag. It can be seen in figure 4.2.1 that the Cl for the NACA 6514 and MH38 are the airfoils with the highest coefficient of lift. In figure 4.2.1 below a graphical analysis was performed on the selected airfoils for the coefficient of lift as a function of the angle of attack. The MH32 represented in figure 4.2.3 shows that the pitching moment is the lowest value compared to the other airfoils across the varying angles of attack of the wing. These analyses were airfoils at 15 (mph) the determined necessary speed to gain altitude in figures 4.2.1, 4.2.2, & 4.2.3.

Figures 4.2.4, 4.2.5, & 4.2.6 compare the maximum lift, maximum drag, and the pitching moment of each airfoil. It is shown in figure 4.2.4 that the highest lift coefficients are from the NACA 6514. From figure 4.2.5 the lowest drag coefficients are from the AG36 and MH32. From figure 4.2.6 the lowest pitching moment is from the AG36, NACA 6514, and the MH32. Later on it will be shown that the MH32 airfoil was chosen due to its low drag and low pitching moment along with a sufficient lift coefficient achieve flight.

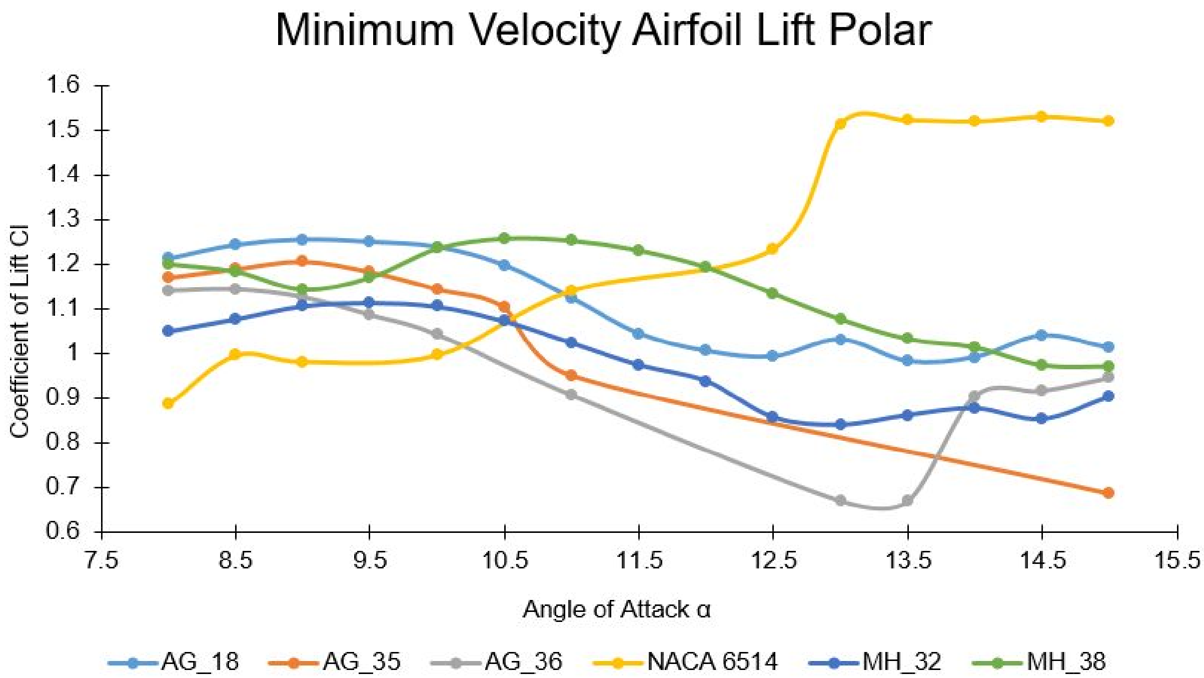


Figure 4.2.1: Comparison of airfoil lift polar at minimum lift velocity

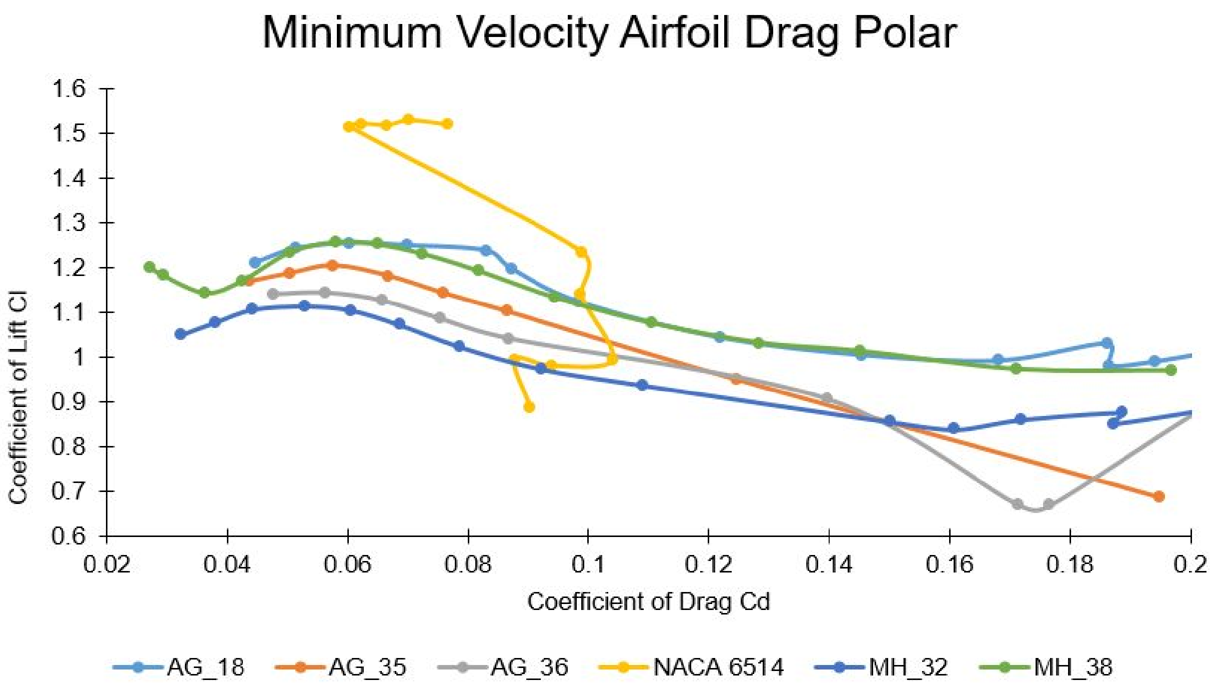


Figure 4.2.2: Comparison of airfoil drag polar at minimum lift velocity

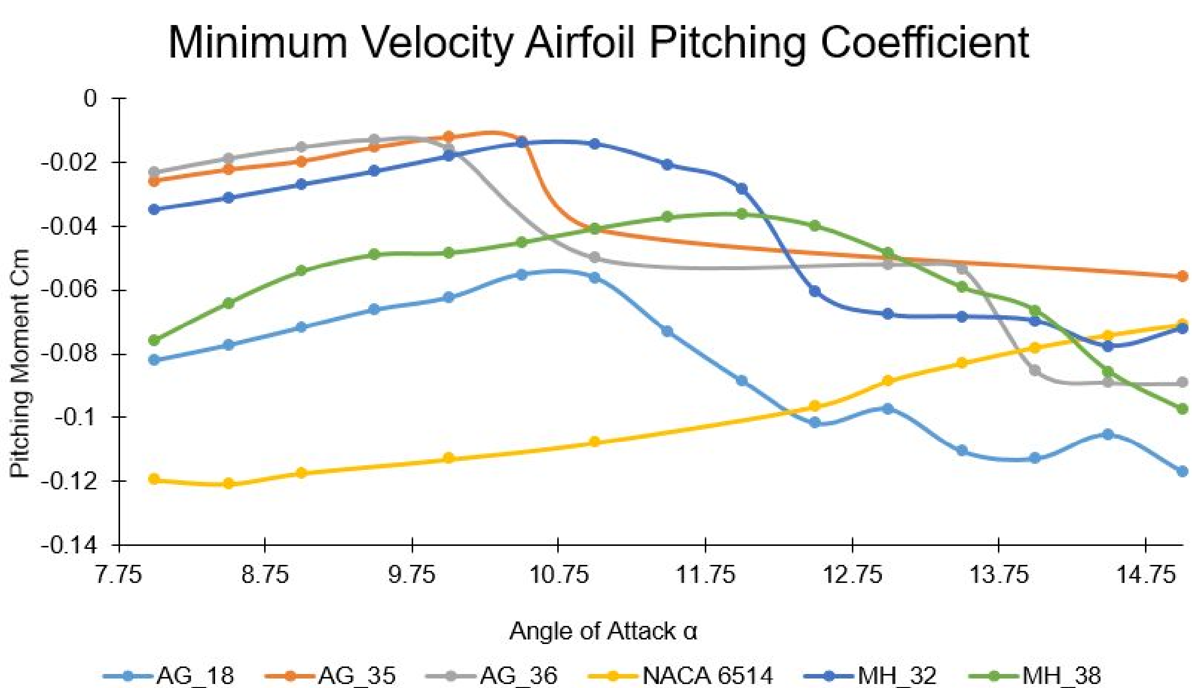


Figure 4.2.3: Comparison of pitching moment at minimum lift velocity

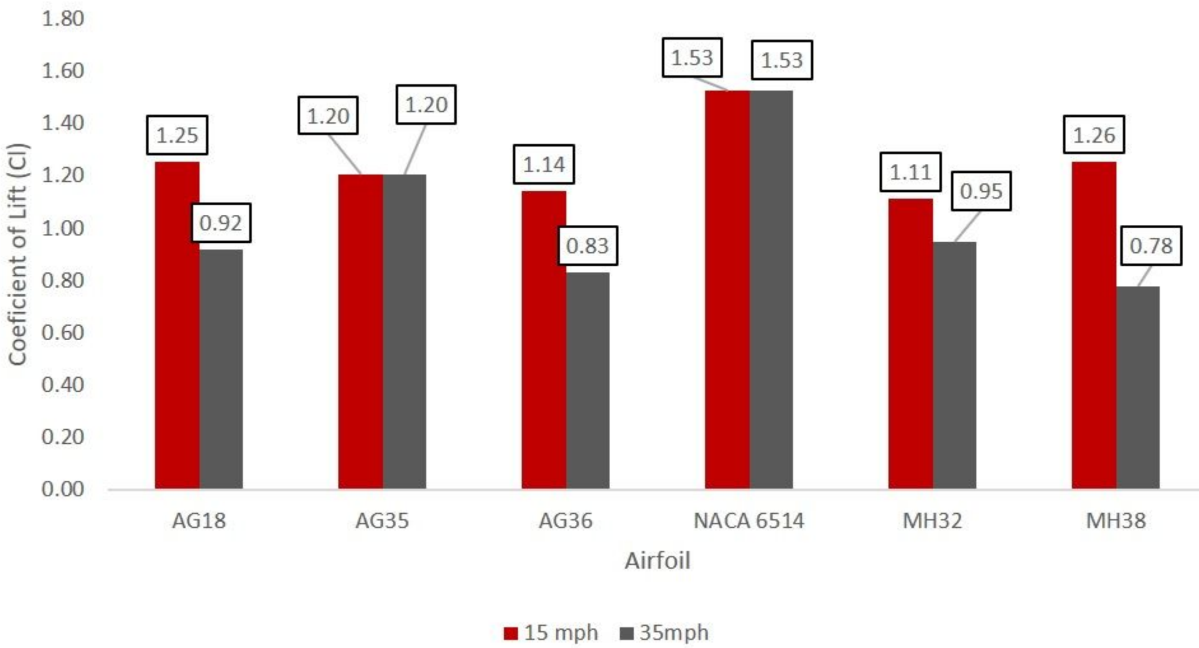


Figure 4.2.4: Comparison of airfoil lift polar at lift velocities of 15 and 35 mph

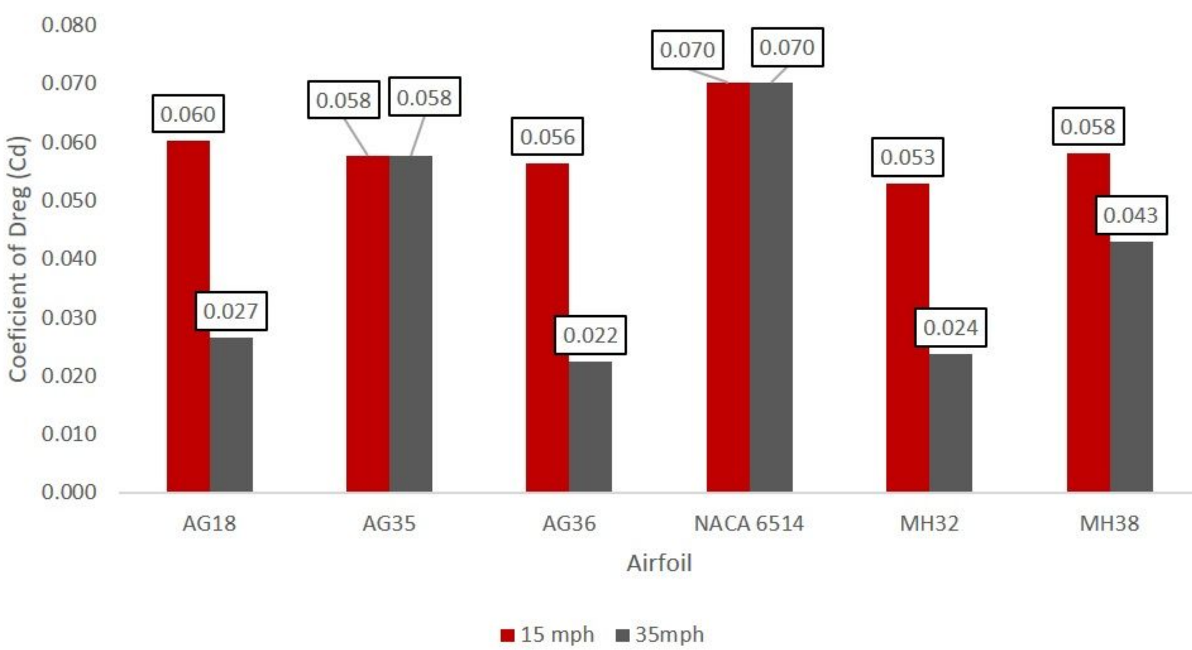


Figure 4.2.5: Comparison of airfoil drag polar at lift velocities of 15 and 35 mph

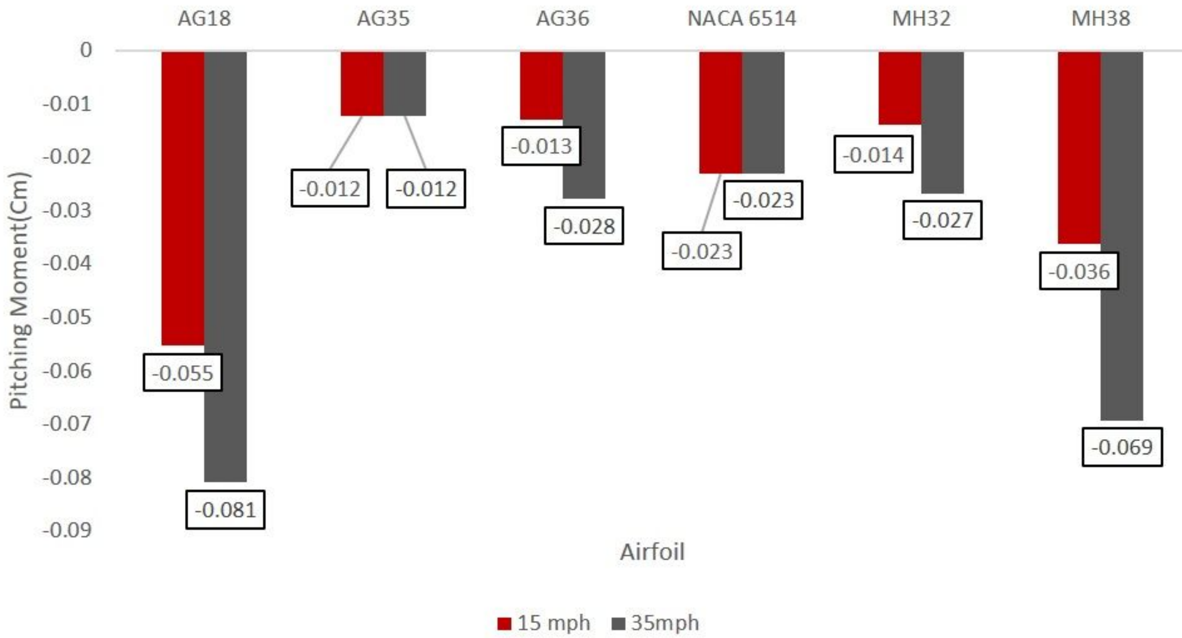


Figure 4.2.6: Comparison of pitching moment at lift velocities of 15 and 35 mph

Careful consideration was given to the balance between maximizing aircraft performance and minimizing the aircraft's RAC (Rated Aircraft Cost) value. Of key concern is the ability to carry the maximum number of pucks possible, for as many laps as possible within the allotted five minute mission window. In opposition to these objectives, the team must also produce a design which minimizes the overall dimensions of the stowed aircraft, as well as the combined aircraft and storage tube weight.

Preliminary analysis of the scoring criteria suggested that minimizing the RAC value would offer comparatively better scoring returns than maximizing aircraft payload capacity and cruise speed. Of the three missions, two are scored on a pass/ fail basis. The third mission is the only in which aircraft performance is directly correlated to the resulting score, however the scores for this mission are normalized with respect to the other team's performance, such that there is an upper limit on the possible points available for this mission as well.

In contrast, the RAC value has an unbounded, non-normalized relationship with with the final score, where the product of the written report score and total mission score is divided by the RAC. As such, producing a plane with a small RAC value will allow for unlimited scoring potential. With this in mind, the aircraft was designed in order to meet minimum acceptable performance criteria, with greater emphasis placed on minimizing weight and maximizing foldability.

Early design concepts included aircraft in tandem wing, canard, and conventional wing-and-tail configurations. The canard and tandem configurations were initially favored for their compactness, which would both reduce the dimensions of the stowed aircraft and reduce the amount of heavy fuselage and wing structures needed for flight. However, both the canard and tandem configurations suffer from static stability issues which would necessitate the use of an active control system such as a gyro in order to prevent a stall. A conventional aircraft configuration was thus pursued because the complexity and aerodynamic stability issues associated with the other two configurations were deemed to outweigh the performance benefit.

With an aircraft configuration selected, work was done to determine optimal sizing. The two primary constraints on aircraft sizing are generating appropriate amounts of lift in order to remain airborne, and fitting within a storage tube with a length that is four times its diameter. A MATLAB script was created which accepts estimated aircraft takeoff weight, coefficient of lift, and takeoff airspeed, and then uses these values to solve for tube length as a function of chord length. The plot in figure 4.2.7 below was created for a 5lb aircraft with a coefficient of lift of 1.1, being launched at 22mph. With the objective of minimizing the aircraft's dimensions, the optimum occurs at a chord length of approximately 8 inches for these conditions.

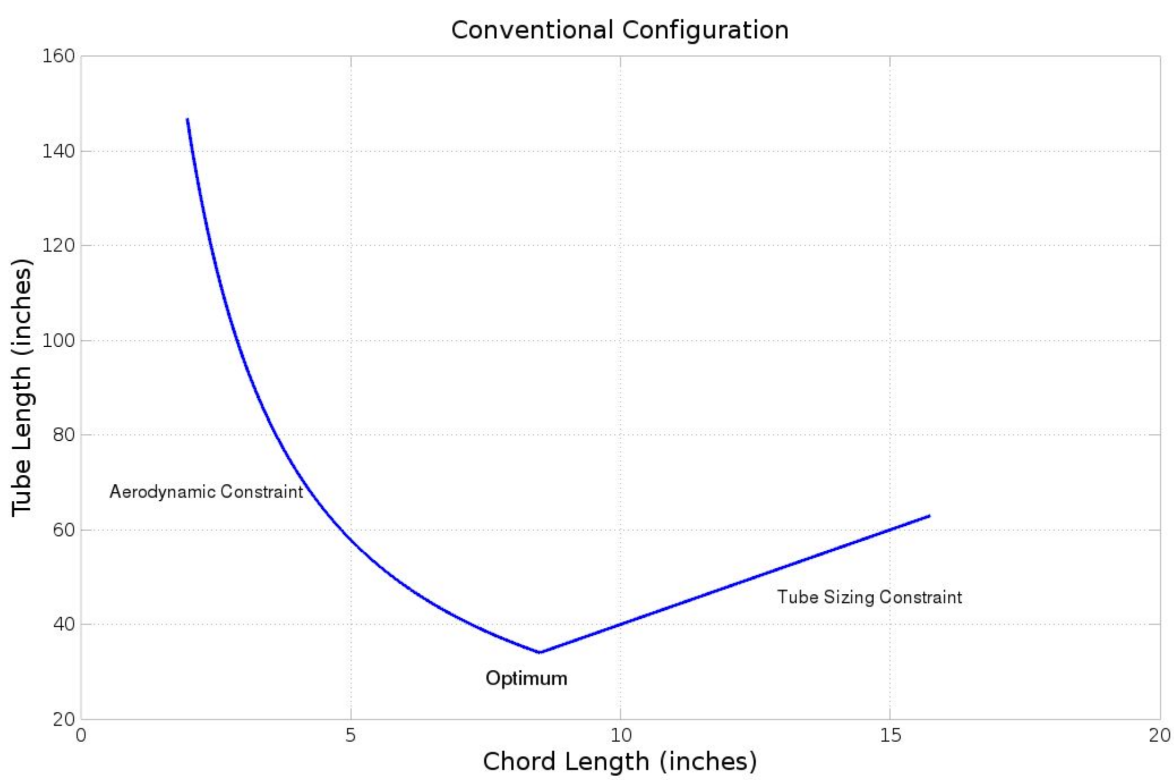


Figure 4.2.7: Aircraft Sizing Survey

During the design process, additional methods for minimizing the aircraft's size and weight were also pursued. A great amount of effort was placed in determining the optimal airfoil geometry in order to maximize lift and minimize planform area. Although more exotic airfoils with large coefficients of lift and high camber, like the NACA 6514, were heavily considered, concerns were raised about the stall characteristics of these foils, as well as their manufacturability. The NACA 6514 offered a 60% greater peak coefficient of lift than the MH 32 foil, however at low Reynolds numbers it was found that there was a sudden sharp drop in lift as boundary layer separation occurred, whereas the lift performance of the MH 32 varied more gradually. The MH 32 also offered superior manufacturability to the NACA 6514, since simulations indicated that slight defects to the cambered trailing edge of the foil would result in drastic reductions of lift versus the ideal foil.

The aircraft experiences the most difficulty generating sufficient lift to stay aloft during takeoff when it has not yet built up much speed, and creating a method of producing extra lift at takeoff would allow for a smaller and lighter aircraft to be constructed. One method which was pursued for accomplishing this was the idea of moving the props to the wings such that the airfoils are located in the aircraft's own propwash and gain the lift benefits of effectively operating at a higher Reynolds number than the aircraft's true airspeed would otherwise allow, making it possible to generate more lift. However, this approach was abandoned due to the extra complexity of increasing the number of motors and props, as well as packaging difficulties with wing-mounted props when the wings must also fold.

Another method for generating additional lift at takeoff is by the introduction of either flaps or flaperons. By extending the length of the aircraft's wing control surfaces, they can operate as flaperons during takeoff and provide additional lift. This approach was used due to the minimal increase in complexity of lengthening the control surfaces.

Uncertainties of concern are weather conditions in Tucson Arizona. The wind and temperature conditions have been approximated and can not be predicted. If either of these conditions are extreme our light aerodynamic design could impact flight performance. Since this is the first time WSU-NPSE has entered the DBF competition there is also unpredictability in the turning radius of our UAV given the provided track. Since the competition track is not available to practice only simulated tracks can be used. This will add a parameter of unpredictability to the competition.

5.0 Detail Design

5.1 Dimensions

Determining weight to be the most important design factor to the competition the next step, logically was to determine each of the UAV component weights. Initially this was done by weighing components from models previously hand launched and establishing those as baseline weight values for each component. Table 3.3.1 below shows the UAV component weights that were initially established and a reevaluation of the weights after a trade study was performed on airfoils and their lift potential. The trade study on lift potential simulated that the UAV with the current wing loading and wing planform area would not maintain flight.

Table 3.3.1: UAV Component Composition and Weight Summary

Component	Composition	Weight (lb)
Wing	Balsa and carbon fiber	0.52
Fuselage	Light plywood with carbon fiber rod	0.28
Servos		0.04
ESC		0.13
Receiver	AR6260 DSMX 6-channel carbon fuselage receiver Futaba NR4QB NiCd Square 4.8V 600mAh	0.23
Payload	Three standard hockey pucks	1.13
Tail	3D printed, foam core, 2-ply carbon fiber	0.32
Batteries	14 Sanyo Cp-2400scr	1.85
Motor	Xpwr T3520 “XPWR-T3520”	0.49
Total		**4.98 lb**

5.2 Structural Characteristics

Fuselage: Consists of interlocking components constructed of light plywood - four ribs, top, middle, and side panels, five slotted stringers along the bottom of the fuselage to support the payload, electrical components, wiring. All components are fitted with slots and teeth to lock together before gluing.

Fuselage contains the payload compartment constructed from two cardboard half tubes with a taped hinge. The payload will be secured shut with a Velcro tab.

Wing: Consists of a traditional spar and rib structure split in two segments. A pivot will sit on the top of the fuselage to allow the wing segments to pivot into a storable position. The attachment of the two wings will be reinforced with foam. This foam will provide stability against bending in the wing. The wings will also be reinforced with carbon fiber on the leading edges which are expected to face the most force. This carbon fiber reinforcement will prevent damage to the wing during flight and drop.

Empennage: Consists of ULTEM printed plastic hub and mount pieces that work as a hinged folding mechanism. The tail will be constructed similar to the wing support structure using foam structure and a carbon fiber skin.

Landing Gear: Consists of a thin aluminium drag and a piece of thin aluminium which will connect the wheels to the body of the UAV. The aluminium drag will allow the UAV to slow to a stop without allowing the tail to touch the ground. The aluminium wheel connection and wheels will allow for a safe land on the front of the fuselage before the drag touches the ground and further slows down the UAV. The wheel connecting piece will provide enough strength to withstand the loads of landing. This will be connected to the fuselage by wrapping over the top and attaching with glue.

Launch Tube: Consists of a thin walled carbon fiber tube, approximately 9 inches in diameter with a foam interior cut to the shape of the UAV. The carbon fiber tube will have one end permanently closed using a carbon fiber plug and the other end will be accessible with a hinged plastic plug.

5.3 System and Subsystem Design

Propulsion: A 14-cell TYSONIC TY-SC-4200mAh battery was selected to meet mission goals for obtaining the maximum amount of thrust. A variety of tests including different battery cell numbers and propellers were completed using Motocalc and can be seen in Section 4.1. Due to a lack of time, the team has chosen a Xpwr T3520 900kV motor capable of achieving a max current of 100 Amps which will meet all mission requirements. An APC 14"x6.5" propeller will work best for our competition goals. Using Motocalc for analysis, the 14" diameter paired with a 6.5" pitch propeller will result in maximum air speed and longer flight times at max throttle. The final design for the 2017 AIAA DBF competition includes a Xpwr T3520 motor, 14-cell TYSON TY-SC-4200mAh NiMH battery pack, 14"x6.5" APC propeller and a Hitec 80A speed controller.

Controls: To control the aircraft a Spektrum AR6260 6 channel receiver has been selected because it offers a fail safe mechanism that is required by the AIAA and is designed to transmit through carbon fiber.

Radio Control: A Spektrum DX7s 2.4GHz transmitter will be paired to the Spektrum AR6260 receiver.

Servo Selection and Integration: The servos selected for the aileron, elevator and rudder are the Dymond D47S precise servos. Using the top 3 teams from the past 3 years, each servo that was used in a AIAA DBF plane was documented for weight, torque and actuation speed. The D47S servo offers 16.0oz-in of torque and an actuation speed of 0.08s/60° at only 4.7g of weight. The selected components to fly the aircraft can be seen in table 5.3.1.

Table 5.3.1: Flight Components

Components	Description
Motor	Xpwr T3520
Battery	14-Cell TYSONIC 4200
Speed Controller	Hitec 80A ESC
Receiver	Spektrum AR6260
Transmitter	Spektrum DX7s
Aileron 1 Servo	Dymond D47s
Aileron 2 Servo	Dymond D47s
Elevator Servo	Dymond D47s
Rudder Servo	Dymond D47s

5.4 Weight and Balance

The total weight and center of gravity of the aircraft will change depending on which mission is being attempted. During the first mission the aircraft will hold zero hockey pucks, during the second mission the aircraft will hold three hockey pucks, and during the third mission the aircraft will hold four hockey pucks. The center of gravity positions in the chart below are measured from the origin being the front edge of the fuselage along the axis of the canister. The z-axis decreases from the front of the aircraft to the tail, the y-axis increases from the underside of the aircraft to the top, and the x-axis increases from the right wing to the left wing.

Table 5.4.1: Weight and Balance Chart

Empty Weight				
Component	*Weight (lbs)*	*X-Position (in)*	*Y-Position (in)*	*Z axis (in)*
Fuselage	0.270	0.000	1.300	-3.930
Carbon Fiber Rod	0.044	0.000	3.570	-13.500
Wing Fold Assembly	0.285	0.050	4.110	-6.980
Canister	0.131	-0.000	-0.025	-6.050
Motor	0.480	0.000	2.440	1.750
Motor Battery	2.220	0.000	0.000	-1.300
Receiver Battery	0.206	0.000	2.440	-0.500
Receiver/ESC	0.199	-0.900	2.330	-0.450
Wings~	0.600	0.000	4.800	-7.240
Tail~	0.500	-0.02	4.120	-29.120
Servos~	0.067	0.000	4.260	-7.000
Total	5.002	-0.195	9.039	-23.826
Center of Gravity		-0.039	1.807	-4.763
Mission 1				
0 Pucks	0.000	N/A	N/A	N/A
Total	5.002	-0.195	9.039	-23.826
Center of Gravity		-0.039	1.807	-4.763
Mission 2				
3 Pucks	1.125	0.000	0.000	-6.610
Total	6.127	-0.195	9.039	-31.262
Center of Gravity		-0.032	1.475	-5.102
Mission 3				
4 Pucks	1.500	0.000	0.000	-6.050
Total	6.502	-0.195	9.039	-32.901
Center of Gravity		-0.030	1.390	-5.060

5.5 Mission Performance

The mission performance was estimated by approximating the aircraft's turning radius. Based on the wing loading, structural integrity of the wing, and calculated cruise speed, it was found that the Aircraft will have a turning radius ranging from 94 to 98 feet for both Missions with estimated maximum cruising speed of 51 mph. Considering the aircraft's turning radii and the course layout, a single lap should be about 2000 ft. Further calculations indicated that the Aircraft should complete a single lap in in about 53 seconds for Mission 1 and 64 seconds for Mission 2. The aircraft will need to fly three laps in under five minutes for Mission 1, and the total flight time comes out to 2.65 minutes.

5.6 Drawing Package

Drawing package:

- 3-View drawing with dimensions
- Structural arrangement drawing
- Systems layout/location drawing
- Payload(s) accommodation drawing(s)

6.0 Manufacturing Plan

6.1 Materials Selection Process

Materials for this UAV are chosen with the overall goal of minimizing weight and maximizing durability. With the technologies available including 3D printing, laser cutting, and vacuum molding, there are several options available for materials. Due to their ease of manufacturing foam and balsa wood are the primary materials being used. Since these materials are not as durable as we would like, some reinforcements will be done using molded carbon fiber segments.

6.2 Manufacturing

Balsa wood, basswood, and lite plywood were chosen as the primary materials due to the weight restrictions of the plane and material available. A relatively easy material to work with and manufacture, our team had easy access to a laser cutter compared to alternative composites manufacturing. Because these raw wood materials are weak in comparison to other materials such as carbon fiber, reinforcement was added in locations predicted to withstand high forces. These materials will make up the structure of the aircraft with a mylar or carbon fiber skin which will enhance the aerodynamics and help reduce drag.

Wing: Each wing will consist of 11 ribs made out of balsa wood as seen in figure 6.2.1. Carbon spars will run the length of the wing on the top and the bottom of the ribs at the wing center of gravity. The spars will be adhered to the ribs and fishing line will help provide additional support to the spars and distribute the load across the wing span. The wing skin consists of three molded parts. The parts are the upper wing skin, the lower wing skin and a wing skin cap that will wrap around the leading edge of the wing and adhere to the upper and lower wing skins. The upper and lower wing skins will adhere at the wing trailing edge along with adhering to the ribs.

Figure 6.2.1: Laser Cut, Balsa Wood Rib

Each wing will contain one flaperon, constructed in the same manner as the wing, composed of an upper and lower wing skin. The flaperons hinges will be constructed of pliable kevlar and adhered to a wing block at the end of the rib. Each wing will contain a single servo that will control each flaperon. Balsa wood profiles in the wing will be cut on a laser cutter to ensure accurate profile modelling.

Fuselage/Payload: These light plywood structures will be glued together with wood glue and coated in mylar. The carbon fiber tube along the top of the fuselage will be held together with light plywood supports which will also be laser cut. Table 6.2.1 itemizes the fuselage components and sheet dimensions of light plywood required for laser cutting.

Table 6.2.1: Fuselage Bill of Materials

Part No.	*Part Dimensions*	*Qty.*	*Sheet Dimensions Required:*
fuselage_sidewall	3" x 5.6" x 0.125"	6	4" x 12" x 0.125"
fuselage_floor	9" x 3.75" x 0.125"	3	4" x 12" x 0.125"
fuselage_rod supports	8.5" x 0.65" x 0.125"	2	1" x 12" x 0.125"
fuselage_stringer	9" x 0.75" x 0.125"	5	1" x 12" x 0.125"
fuselage_rib	6.25" x 3.75" x 0.25"	4	4" x 12" x 0.25"

The construction of the fuselage is composed of laser cut ribs, stringers, and supports and will be constructed out of laser cut light plywood and assembled like a puzzle as seen in Figures 6.2.2 and 6.2.3. These pieces are held together using a wood epoxy. The laser cutter at SnoCo Makerspace in Everett will be used, which has a maximum cutting area of approximately 18 in. x 12 in. Prior to any component cutting, the laser cutter must be calibrated for the height of the material. The laser cutter is programed to cut on the line of a sketch in pdf form, which will result in cutting inside the line approximately 3mm. All sketches must be resized larger to account for this by using the offset entities tool in SolidWorks. The components will be assembled by joining all pieces and checking for alignment. See attached assembly drawing for component assembly. All components will be clamped down and glued using a pipette for accuracy in applied location. Wax paper will be used to cover areas that should not be glued. The assembled fuselage will be allowed to set for 24 hours. After setting, the assembled fuselage will be lightly hand sanded to remove sharp edges.

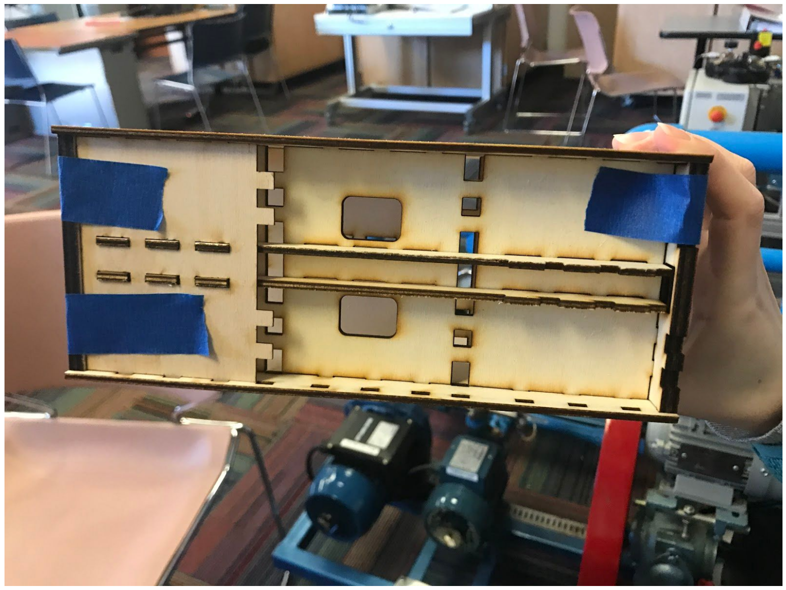


Figure 6.2.2: Top View of fuselage with laser cut structural components before gluing.

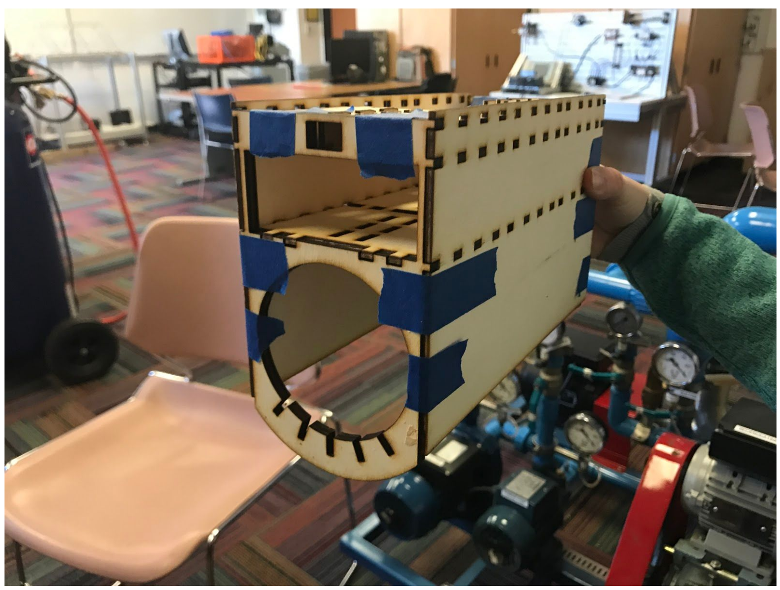


Figure 6.2.3: Side View of fuselage with laser cut structural components before gluing.

The team plans to install a cargo canister into the fuselage design. The canister will have the ability to hold up to four hockey pucks. The team agreed to use an Extra Strong 3-Ply Spiral wound construction mailing tube as the canister's base design. The dimension of the mailing tube has a diameter of 3 inches and a length of 24 inches. This material is rigid and strong so it can resist bending and crushing during shipment. Also, by purchasing the mailing tube, production time is reduced. The tube is cut down to 6 inches in length using a bandsaw. With the length of the tube reduced to 6 inches, the canister is capable of holding four hockey pucks and fitting within the fuselage. To make the puck holder accessible the tube is cut in half along the diameter. After deburring the edges using sandpaper, duct tape is applied to one side of the tube which will serve as a hinge. Then EVA foam is used to seal the endings.

Figure 6.2.4: Payload canister (Without the Foam sealing)

Integration: The fuselage will be joined to the wing mechanism, propeller mount, and the carbon fiber rod tail. The wing mechanism will be incorporated into the fuselage using fitted slots and a wood-plastic epoxy during the process of joining the fuselage components together. The carbon fiber rod tail will be incorporated into the fuselage using an epoxy during the process of joining the fuselage components together.

Landing Gear: The landing gear will be made out of a drag near the tail with two wheels in the front. The drag will be created using a shaped and heat treated thin aluminium sheet. The purpose of this part is to create a landing surface for the back of the aircraft while preventing a hard stop. So, the drag will be designed similar to spring to allow for a cushioned stop and to prevent excess forces due to landing. The wheels and their connections will be created using thin, shaped aluminium that wraps around the fuselage.

6.3 Manufacturing Milestones

A manufacturing plan was created at the beginning of the assembly of the team and is seen in figure 6.3.1. This plan includes choosing and acquiring materials, cutting the materials and assembly of our UAV.

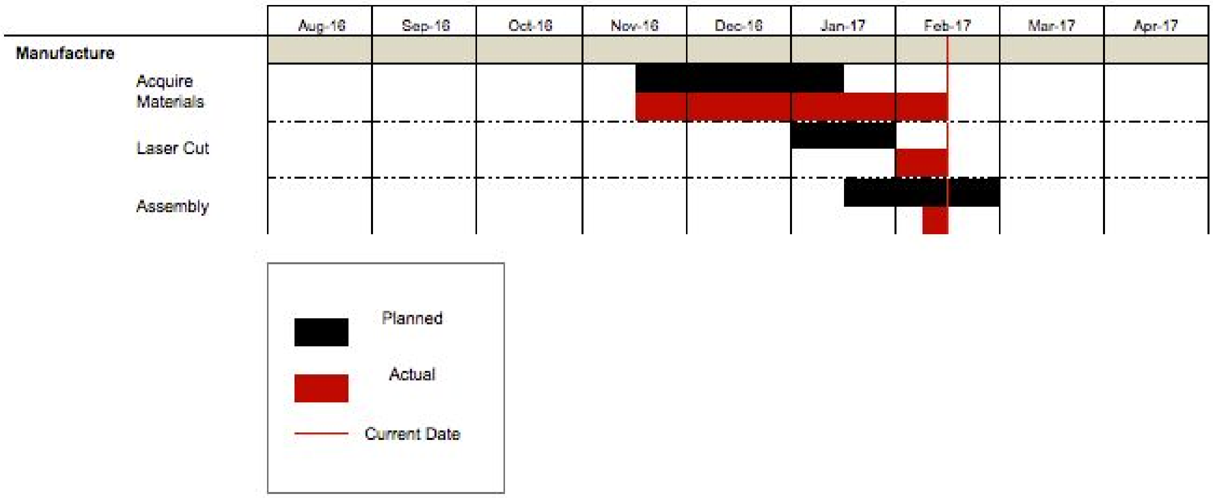


Table 6.3.1: Manufacturing Plan

7.0 Testing Plan

To date, aircraft testing has primarily focused on computer simulations, materials characterization, and static propulsion tests. Parametric airfoil design studies have been conducted in XFLR5, while more large scale aerodynamic analysis has been performed in Siemens Star-CCM+. ANSYS has been employed to perform structural finite element analysis of the airframe. Tensile tests have been performed to study the material properties of some of the custom composites which will be used in constructing the aircraft. In addition, static thrust tests have been carried out to study the effect of different prop designs on thrust output.

As the aircraft increasingly nears completion, testing is shifting more towards large-scale tests to verify both earlier simulation results and smaller scale bench-tests. Of particular interest are verifying aerodynamic stability with respect to the expected mass distribution within the aircraft, as well as ensuring that the aircraft's wing structures can successfully stand up to a 2.5G loading case as predicted. These tests will cover the interaction and integrity of multiple systems, and will allow sufficient time to apply interim fixes if any unforeseen problems are identified.

7.1 Tests Conducted

Wing Structure Testing: The wing structure will be tested for the ability to withstand a load applied to the wing tips of 2.5 times the total weight of the loaded plane. Several endurance flights will also be performed to ensure the plane can complete each mission.

Propulsion Testing: The purpose of propulsion testing is to determine whether Motocalc is accurate compared to real world examples. Motocalc offers the simulation of maximum current drawn from the motor, thrust, and voltage used while having the ability to test different battery cells and propellers. While this is beneficial, actual simulation will be done to test the maximum thrust with components the team has selected.

To calculate the thrust from the propulsion system a platform has been constructed to hold all of the components in the system. The platform uses a strain gauge to measure the deflection of a thin bar of aluminum. The thrust of the propulsion system will press an aluminum rod into the bar resulting in deflection. To measure the strain gauge an Agilent 34972A data acquisition system will read the excitation voltage from the strain gauge resulting in the actual thrust of the motor. Being the first year of the competition, WSU-NPSE does not currently have a wattmeter to measure the current or voltage used, but will be purchased and used for later testing.

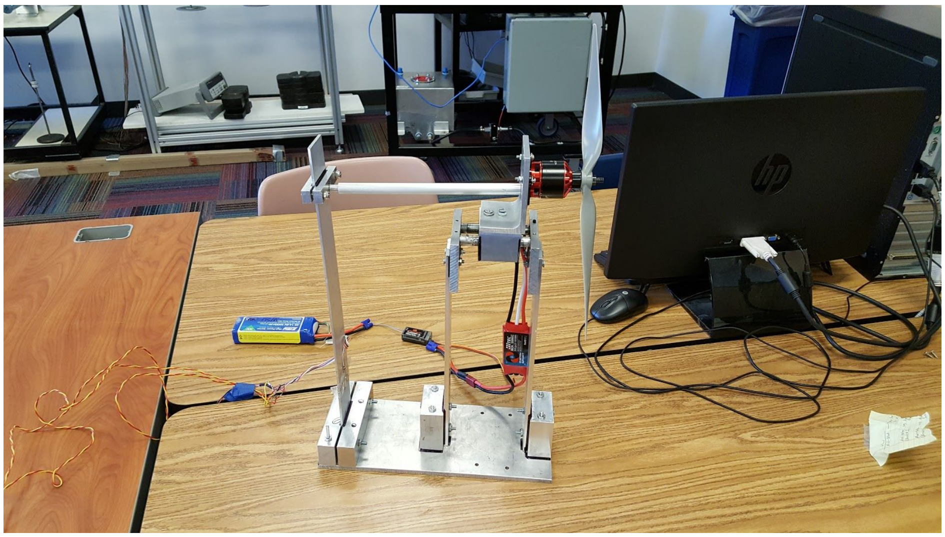


Table 7.1.1: Propulsion Test Apparatus

Test Flight

The first flight will consist of no payload to test the function of the flight components and to test the ability of hand launching. Once the servos are trimmed for steady flight, the plane will be loaded with 3 hockey pucks to further test hand launching. If the plane can perform the hand launch with 3 hockey pucks it will be launched with full payload. When the plane has the ability to fly with full payload, speed runs will be conducted using the AIAA designed track.

7.2 Test Schedule

Integrated system testing is to begin within the next two weeks as the manufacturing of individual aircraft components is increasingly completed and they are assembled together. This testing phase is largely dependent on completion of the prerequisite systems and is to be completed as soon as they are ready. The first stage of this testing will focus on verifying the structural integrity of the wings, with a bend test simulating a 2.5G loading case. As soon as the aircraft has been assembled, CG placement will be verified and corrected with ballast if necessary.

Powered flight tests are scheduled to begin in late March. Prior to powered flight, a series of taxi tests will be performed to verify correct servo wiring. Once sufficient confidence about aircraft control and airworthiness has been established, the the aircraft will make series of taxi hops before graduating to full powered flight.

7.3 Test and Flight Checklists

Table 7.3.1 was created using the FAA Inspection Fundamentals checklist manual. To remain simple, the pilot will run through the checklist to check for deformations in any of the described aspects.

Table 7.3.1: Safety Checklist

Fuselage and Hull		*Initials*
A. Fabric/Skin	*for deterioration, distortion, other evidence of failure, and defective or insecure attachment of fittings*	
B. Systems	*for proper installation, apparent defects, and satisfactory operation*	
C. Flight/Motor Controls	*for proper installation and operation*	
D. Batteries	*for proper installation and charge*	
E. All Systems	*for proper installation, general condition, apparent defects, and security of attachment*	
Engine and Nacelle		
A. Studs/Nuts	*for proper torquing and obvious defects*	
B. Engine Mount	*for cracks, looseness of mounting, and looseness of engine to mount*	
C. All Systems	*for proper installation, general condition, apparent defects, and security of attachment*	
Landing Gear		
A. All Units	*for condition and security of attachment*	
B. Linkage/Trusses	*for undue or excessive wear, fatigue, and distortion*	
C. Wheels	*for cracks, defects, and condition of bearings*	
Empennage		
A. Fixed Surfaces	*for damage or obvious defects, loose fasteners, and security of attachment*	
B. Movable Control Surfaces	*for damage or obvious defects, loose fasteners, loose fabric, or skin distortion*	
C. Fabric/Skin	*for abrasion, tears, cuts or defects, distortion, and deterioration*	
Propeller		
A. Assembly	*for cracks, nicks, and bends*	
B. Bolts	*for proper torquing and safetying*	

C.	Control Mechanisms	*for proper operation, secure mounting, and travel*
Communication and Navigation		
A.	Radio/Electronics	*for proper installation and secure mounting*
B.	Wiring/Conduits	*for proper routing, secure mounting, and obvious defects*
C.	Bonding/Shielding	*for proper installation and condition*
D.	Antenna	*for condition, secure mounting, and proper operation*

8.0 Performance Results

8.1 Propulsion Results

Motor and Propeller: The Xpwr T3520 motor and 9x7.5 propeller was tested using the Motor Test Platform from figure 7.1.1. The Motor Test Platform was initially calibrated to represent the relationship between force in pounds correlating with the deflection of the thin bar. Then, the static thrust of the motor and propeller was determined at various levels of motor throttle percentage. The greatest deflection of the thin bar was assumed to correspond with the motor at its full potential (motor throttle at 100%).

Table 8.1.1: Thrust Generated at Various Motor Throttle

Motor Throttle Percent (%)	Thrust Generated (*lb*)
40	0.45
50	0.81
60	1.18
70	1.54
80	1.90
90	2.26
100	2.63

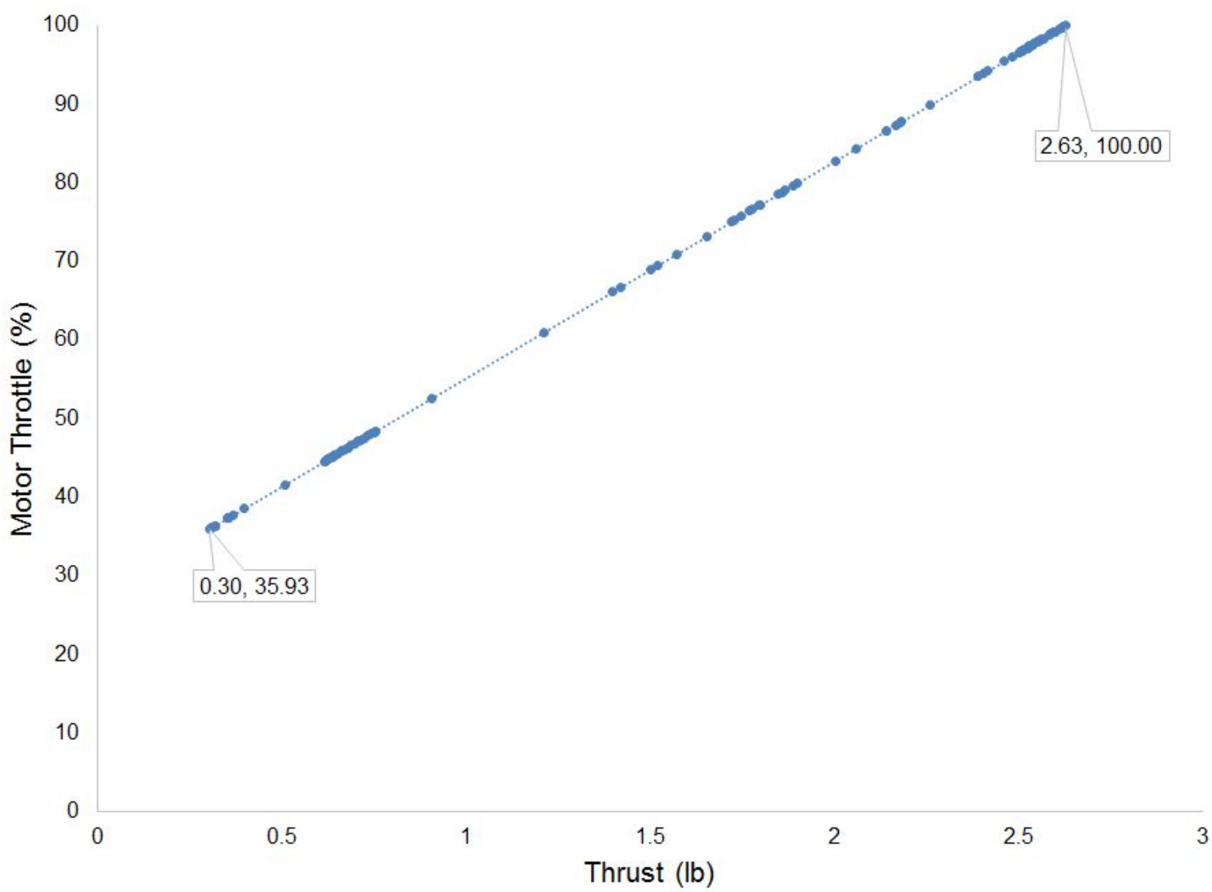


Figure 8.1.1: Motor Test Platform

Figure 8.1.1 shows the amount of thrust generated up to its full potential. At maximum motor throttle, 2.63 pounds of thrust was produced.

The Xpwr T3520 motor and 9x7.5 propeller was powered by a 4-cell 3200mAh Lipo battery for test purposes until the competition batteries arrived. Using the battery characteristics, the propulsion system can be modeled in Motocalc to compare results. Using the 4-cell 3200mAh battery, Scorpion HK-3226 motor paired with a 9x7.5 propellor, Motocalc computed a thrust of 2.64 lbs. The calculated results produced by Motocalc are within 99% accuracy of actual testing data. Since the results were accurate, the propeller selected in Section 4.1 will be modeled in Motocalc to predict the capable thrust using a 14x6.5 propeller. The Scorpion HK-3226 paired with a 14x6.5 APC propeller is predicted to produce 7.2 lbs of thrust at 14.2V and 71.5A.

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