AIAA/Cessna/Raytheon

Design/Build/Fly

2012-2013

PEGASUS

Pedestrian-Operable

Electronically

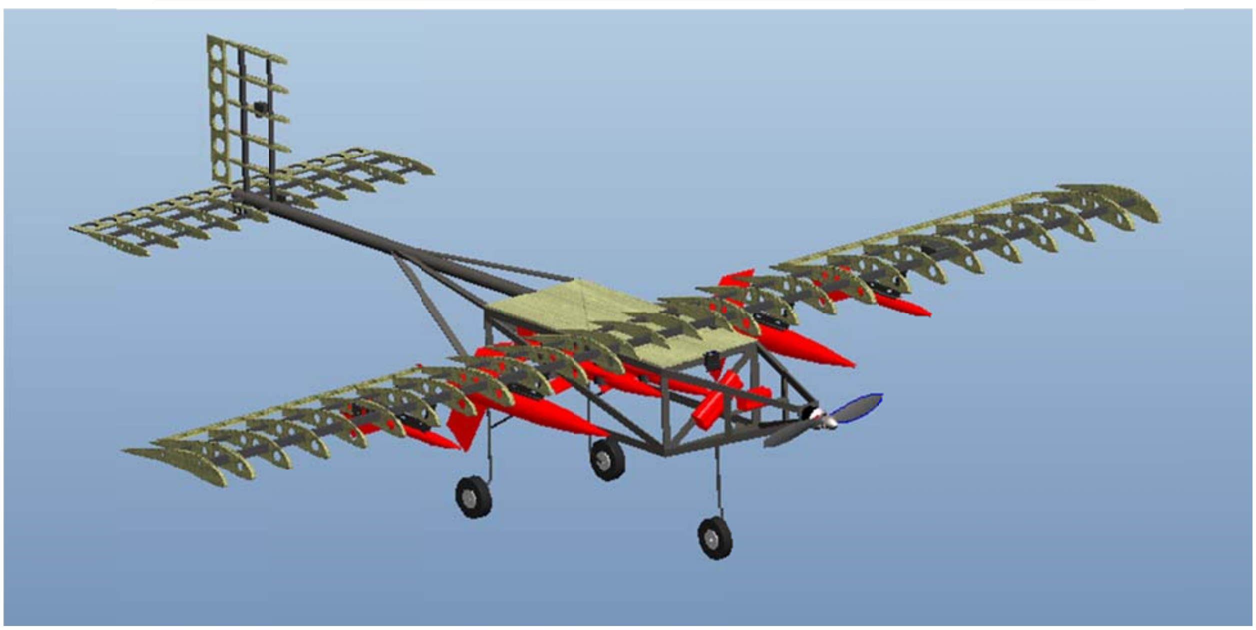
Generated

Aerial

"Stealth"

Unmanned

System



Florida A&M University - Florida State University

College of Engineering

Contents

1.0 Executive Summary

This report documents the detailed design, testing, and manufacturing of the FAMU/FSU College Of Engineering's *Pegasus* entry into the 2012-2013 AIAA Design/Build/Fly (DBF) competition. The challenge is to design an aircraft to successfully complete three different flight missions: the first is a speed mission, and the final two missions require a 3-lap flight while equipped with internal and external payloads. All of this must be accomplished while minimizing weight in order to help maximize the team score.

Pegasus was named for its ancestor: the FAMUFSU COE 2010 Team who entered Air Hercules: Air: Hand Ejected Radio Controlled Ultra-Light Electronic System, which was named for its hand launch mission of that year.

This year, we present Pegasus:

Pedestrian-Operable Electronically Generated Arial "Stealth" Unmanned System

Named for its stealth mission (Mission 2)

1.1 Design Process and Outcome

The primary objective for *Pegasus* is to compete and achieve the highest score amongst the other teams in the competition. Conceptual design was developed by achieving a complete scoring and rules analysis to determine the desirable size of the aircraft. Mostly existing, conventional configurations were used when analyzing our choices to design *Pegasus*. By doing this, we were able to construct an aircraft that we knew would perform properly. To minimize weight, a single-boom fuselage was selected, with a high mono-wing design, conventional empennage, and a single motor. The shape of the airfoil for the wing was decided based on its coefficient of drag and lift. The entire aircraft has been designed to be as minimalistic as possible, including batteries, motors, propellers, sizing, and structure, while completing all three missions.

The construction materials that were used included: balsa wood for the ribs in the wing and tail, carbon fiber fuselage, carbon fiber wing spars, and monokote shrink wrap. The top of the fuselage is covered with a light bass wood. These materials are very strong and lightweight, which was our goal during construction. The aircraft's empty weight is significant to scoring well in the competition, and is composed of the weight of the airframe and propulsion system.

The final design of *Pegasus* has a weight of 5.14 pounds without internal payloads, and a wing span of 78 inches. Competition predictions…..

2.0 Management Summary

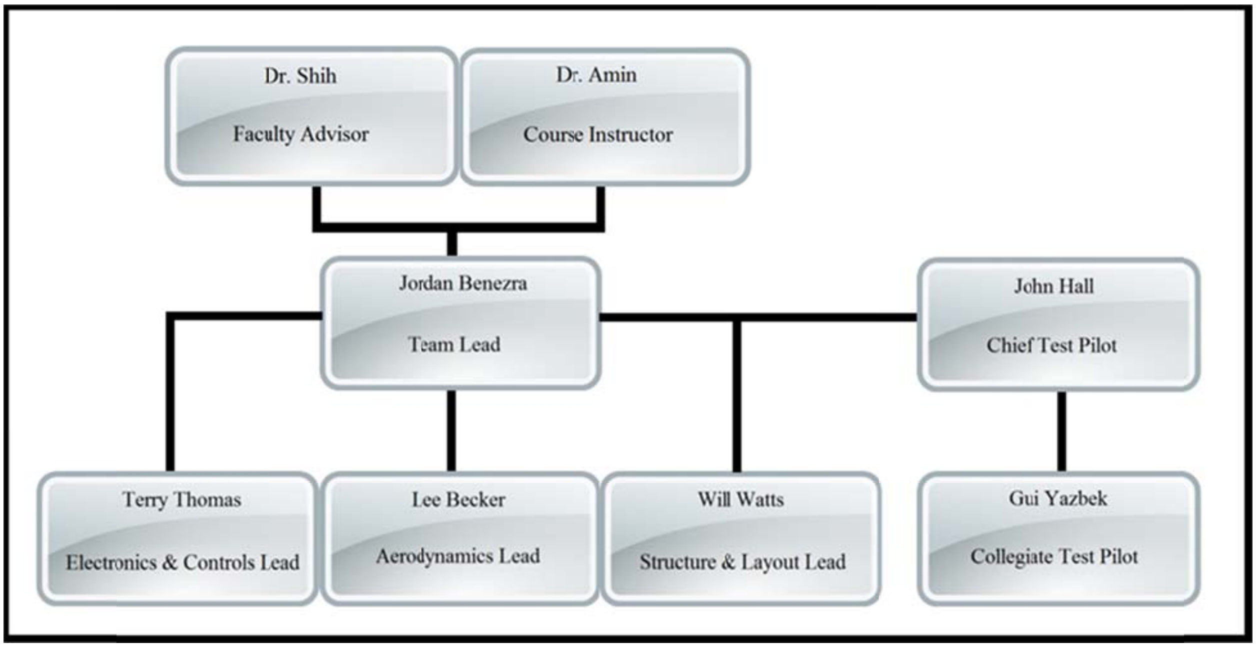


Figure 1: Team Structure

Our design team structure was based upon a simple hierarchical model in order to avoid redundancy in task delegation. The team lead's primary function here was to serve as a hub of communication between the three other subsystems leads the pilots, our advisors, and our sponsor. Team lead was responsible for structure of the design process, scheduling of meetings and large tasks, procurement of workspace and materials. Subsystem leads were responsible for all research in the field of his respective subsystem, although all final decisions were made by the core four seniors. The pilots served not only as resources in testing, but also as reliable advisors in the fabrication process, as they have the most experience in assembling small aircraft. Much research and testing was aided in by the undergraduate team members.

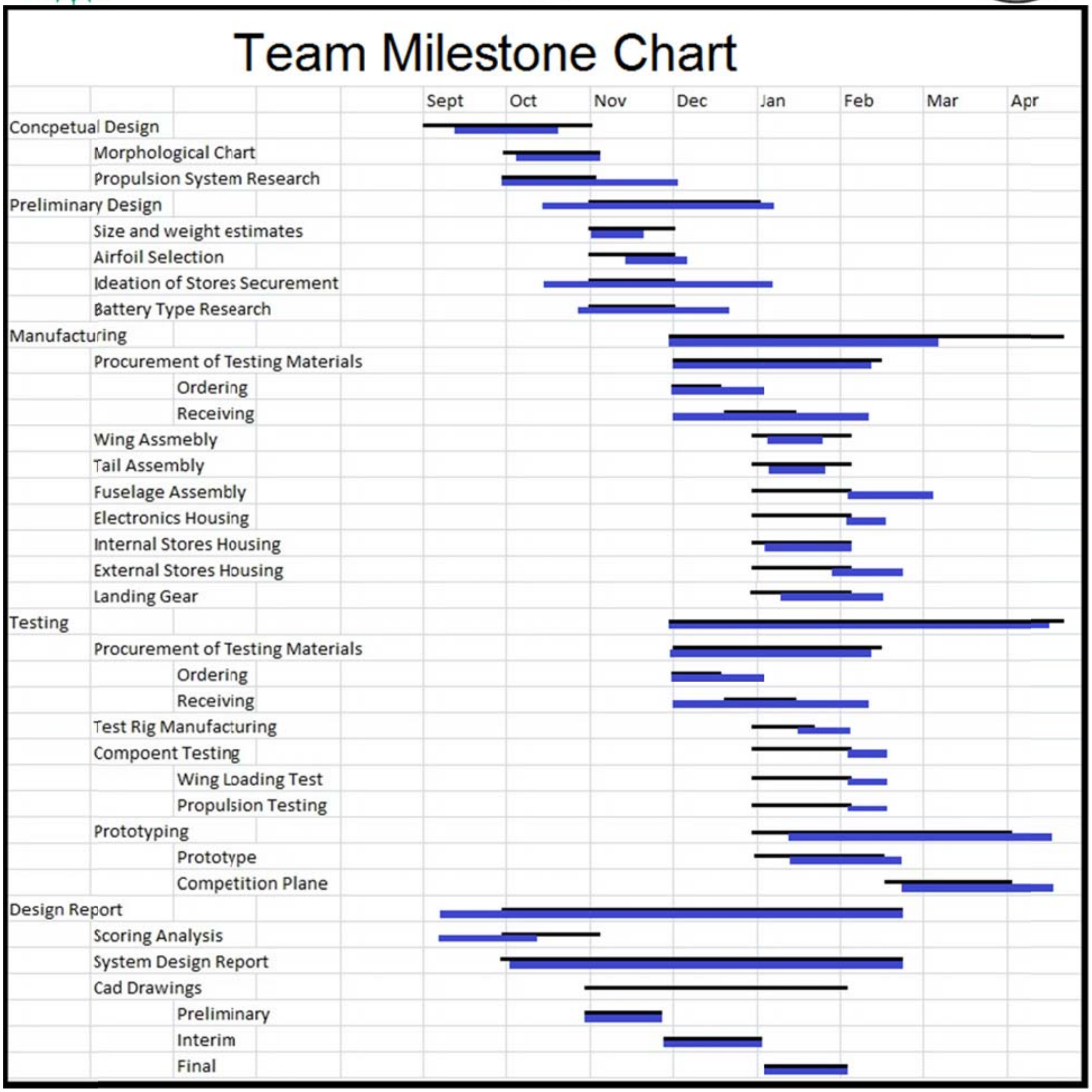


Figure 2: Milestone Chart

The Gantt chart above shows the team milestone expected completion dates in black, and the actual and/or updated estimate in blue.

3.0 Conceptual Design

The conceptual design phase of designing the aircraft was developed using the three required missions, as well as the guidelines set by the competition rules. By evaluating the competition rules and creating Figures of Merit (FOMs) based on the competition missions, we were able to develop an aircraft that would maximize the overall score of our team. The resulting configuration is a lightweight, high-mono wing with a tractor propeller.

3.1 Mission Requirements and Competition Rules

The missions this year will simulate a Joint Strike Fighter aircraft. The final design will need to meet the following requirements:

- Aircraft may not be rotary winged or lighter than air.
- Aircraft must successfully take-off before crossing any edge of a 30x30 ft^2 square, marked on the runway.
- Must be able to carry internal and external payloads, or "stores". Internal stores must completely inside the aircraft, while external stores must be at least 3 inches apart.
- Must be propeller driven and electric powered with an unmodified over-the-counter model electric motor.
- Motors may be any commercial brush or brushless electric motor.

The aircraft must also meet the following safety requirements:

- Have no more than 1.5 pounds of over the counter NiCad or NiMH batteries with shrink wrap for propulsion.
- Have a maximum propulsion current draw of 20A.
- Pass a structural safety test where the fully loaded aircraft is supported at the wing tips.
- Have a fail-safe mode for the aircraft.

3.2 Mission and Score Summary

The AIAA Design/Build/Fly 2013 Competition will award a winner based on three different flight missions, a written report, and Rated Aircraft Cost (RAC) using the following formula:

Score = Written Report Score * Total Flight Score/RAC (1)

The written report score is given based upon the quality of the written report and is scored out of 100. The Total Flight Score (TFS) is calculated by the sum of the individual flight scores, using the equation:

$$TFS = M1 + M2 + M3 \qquad (2)$$

Missions 1-3 are each scored differently, and will be discussed below. The final component of the score is the RAC, which a function of the empty weight (EW) of the aircraft and size factor (SF), is calculated using the equation:

$$\mathrm{RAC} = \frac{\sqrt{\mathrm{EW}*\mathrm{SF}}}{10} \qquad (3)$$

Where EW is the post flight weight with the payloads completely removed. The size factor of the aircraft and is determined by the equation:

$$SF = X_{max} + 2 * Y_{max} \quad (4)$$

Where X_{max} is the longest possible dimension of the aircraft in the direction of flight and Y_{-max} is the longest possible dimension perpendicular to the direction of flight. Therefore, the size of the aircraft will directly affect the overall possible score, while the missions will be comprised into one score. Each mission will require the aircraft to complete flight along the same pattern displayed below.

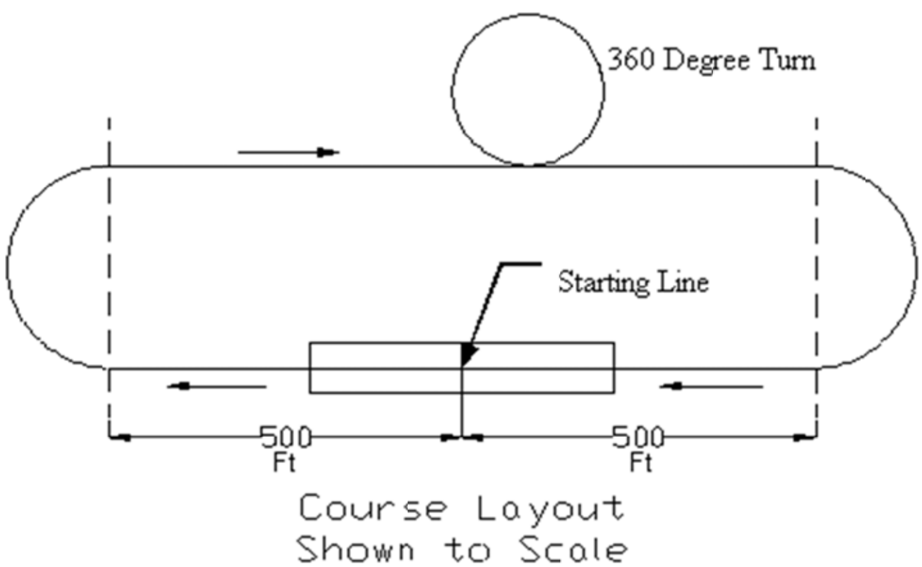


Figure 3: Flight Course For All Three Missions

The orientation (direction) of the flight course will be adjusted based on the prevailing winds as determined by the Flight Line Judge. This way, the flight course will be positioned to maintain the greatest possible safety to personnel and facilities in the area. The pattern is flown a different number of times for each mission.

Mission 1 – Short Take-off – The aircraft must the aircraft must complete as many laps as possible during a 4 minute flight time, with the time beginning when the throttle is advanced for take-off. The number of laps is counted to the last *full lap* completed within the four minute interval. To yield a score, the number of laps is normalized by the maximum number of laps completed by any team flying Mission 1, shown by the equation:

$$M1 = 2 * \frac{\text{Number of Laps Flown}}{\text{Maximum Number of Laps Flown}} \qquad (5)$$

Mission 2 – Stealth Mission - The aircraft must the aircraft must complete 3 laps while equipped with internal stores. This number is determined by the team, must not be zero, and may not exceed the number of payloads demonstrated at the time of tech inspection. To yield a score, the number of internal stores is normalized by the maximum number of internal stores completed by any team flying Mission 2, shown by the equation:

$$M2 = 4 * \frac{\text{Number of Internal Stores}}{\text{Maximum Number of Internal Stores}} \qquad (6)$$

Mission 3 – Strike Mission - - The aircraft must the aircraft must complete 3 laps while equipped with a possible mixture of internal and external stores. The number of internal stores is still determined by the team, as outline in Mission 2. The number, placement, and type of external stores are decided by the roll of one dice. To yield a score, the fastest time flown is normalized by the by any team flying Mission 2, shown by the equation:

$$M3 = 6 * \frac{\text{Fastest Time Flown}}{\text{Team Time Flown}} \qquad (7)$$

3.3 Scoring Analysis

The scoring analysis provides a visualization of what it takes to obtain a top score in each of the missions. Shown in the following three figures, the desired scores are achieved by being in the top percentage of teams receiving scores in each mission.

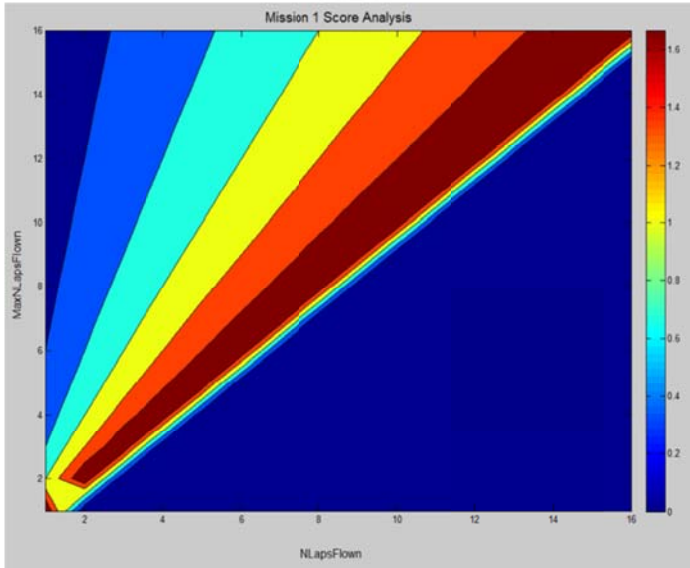


Figure 4: Mission 1 Scoring Analysis

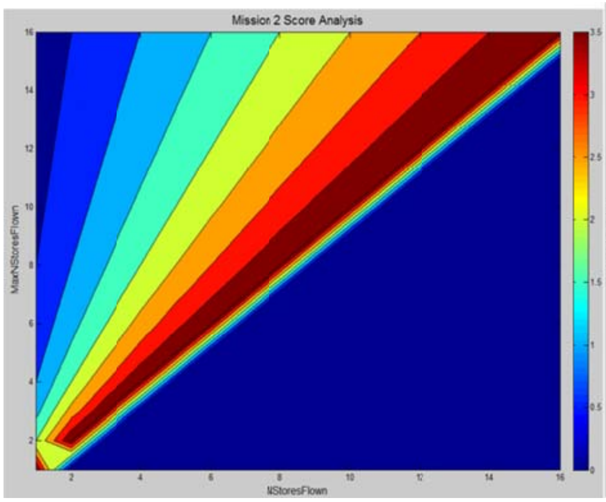


Figure 5: Mission 2 Scoring Analysis

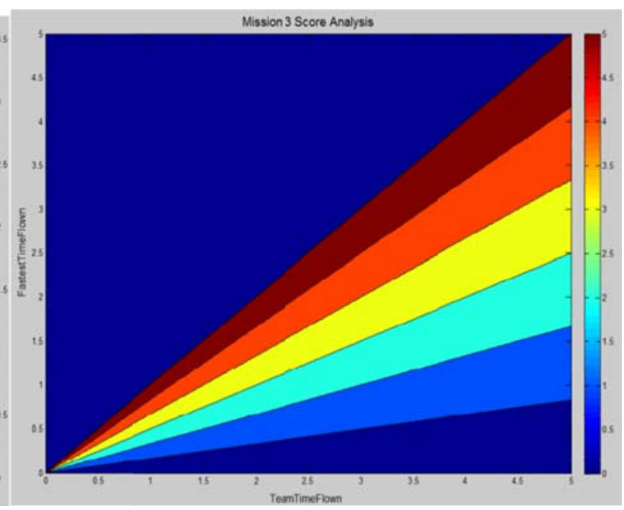


Figure 6: Mission 3 Scoring Analysis

Each of the figures show the potential score distribution based on each mission equation. From each of these figures, we were able to determine the figures of merit (FOMs) that will affect our competition performance the most and they are displayed in the following table.

Figure of Merit	Description
Complexity	Assembly must be completed with the available expertise
Cost	Fit within the team budget
Drag	Opposes the thrust force generated by the motor
Durability	Aircraft must sustain light to moderate handling and the occasional rough landing
Efficiency	The overall effectiveness
Lift	Must sustain flight with the maximum desired payload
Maneuverability	Effective control of the aircraft; perform missions with very little energy consumption
Manufacturability	Manufacturing must be completed with the available facilities
Stability	Carry out each required task reliably with very little performance fluctuation
Storage Capacity	Payloads must securely store within the fuselage of the aircraft
Weight	Total weight of the aircraft

Table 1: Figures of Merit

Each design decision did not involve each of these FOMs, but all of these were of importance at some time during conceptualization. Based on this analysis we were also able to determine a few more specifications. With a maximum payload weight of 3.25 pounds in mission three and an internal compartment capable of storing the internal stores for mission two, a maximum value for the empty weight was set at 5.5 pounds in order to still be able to take off in the prescribed distance and be able to compete with the other teams. We were also able to determine that it would be best to have no less than four internal stores in order to ensure a good Mission 2 score.

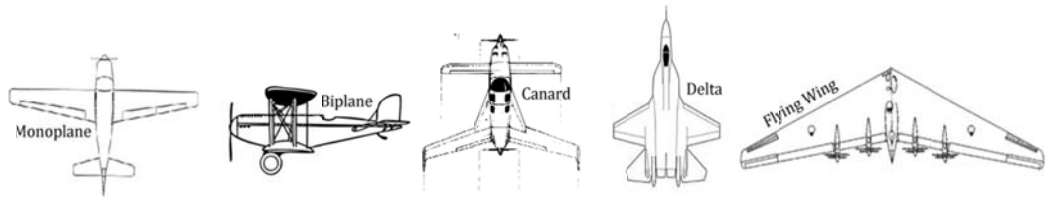
3.4 Configuration Selection

After determining the FOMs and requirements, the next step was establishing a method that would allow us to consider all possible aircraft solutions within the scope of this specific competition. Using a decision matrix for each subsystem decision, the choices were quantified by multiplying the design figures by a component weighing factor and a configuration weight for each design goal. The final score for a component is the summation of this product for all goals. The highest score is then selected.

3.4.1 Wing

The wing affects all of the competition mission goals. The main wing must be able to accommodate the external payloads, as well as the loads of the aircraft itself. The wing configuration that we will implement will be required to develop sufficient lift of the aircraft in order to takeoff in the specified runway area. It must also be limited on the induced drag that it produces such that it will be able perform the above stated task. The lifting device structure will also have to sustain loads on the scale of 2.5 g's in order to pass the preflight test, this will consist of a spar running the length of the wing structure to guarantee that it can pass the test performed by the competition judges. Five wing configurations were compared to each other based on the FOMs as seen in Table 1. The two FOMs that make the mono wing superior to the other layouts are complexity and weight.

- Monoplane - A highly conventional single wing which runs normal to the direction off low across the fuselage.
- Flying Wing – Integrated body and wing type aircraft. If constructed ideally, it has very high aerodynamic efficiency. However, it is a difficult type of aircraft to stabilize and store internally, so it is simply wrong for this competition.
- Delta Wing - Triangular shaped single wing that broadens from tip to tail. Rigid structure and large carrying capacity are two major advantages. Most delta wing aircraft are used in supersonic applications.
- Biplane - Two full-sized wings placed above one another for greatly increased lift. Greatly increased weight is a concern.
- Canard - Two smaller wings positioned forward on the aircraft which are intended to provide more lift and more control characteristics.



FOM	Weight Value	Wing Types				
		Mono	Flying Wing	Delta Wing	Biplane	Carnard
Weight	0.2	4	1	4	1	3
Drag	0.2	4	3	1	2	2
Lift	0.3	3	4	3	5	4
Stability	0.15	4	5	3	5	3
Complexity	0.15	5	1	3	4	2
Total	1	3.85	2.9	2.8	3.45	2.95

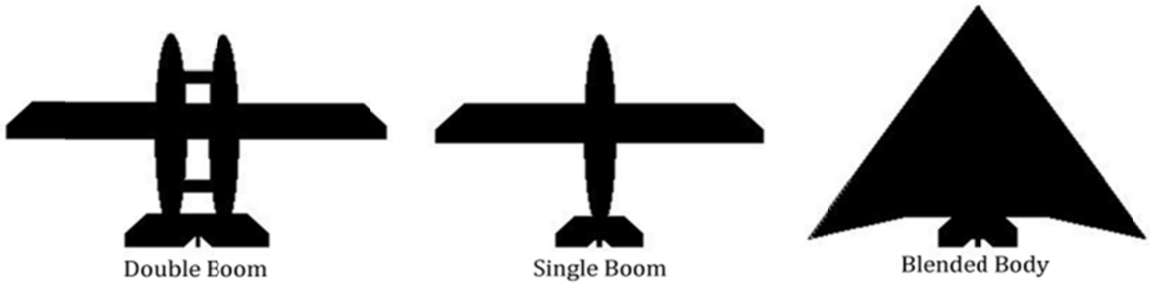
Table 2: Wing-Type Decision Matrix

Its simple design makes the mono wing ideal for this competition. It outclasses the other configurations when it comes to keeping low drag. Lift was chosen as the most important factor in deciding a wing. Despite the lift characteristics of the mono wing being lower than 3 of the other configurations, it is still comparable to other options.

3.4.2 Fuselage

The fuselage contains its own subsystem set. They include a payload area, an electronics/control systems bay, and other possible servo areas. The payload area will be strictly dependent upon the minimum amount of payloads that we will fit inside of the aircraft, while maintaining a low structural weight. Weight and storage capacity are the primary concerns in the selection process.

- Double Boom – Two single fuselages are connected together, enabling great storage area. The internal volume is its greatest advantage.
- Single Boom – A traditional, single fuselage. This is the most conventional design.
- Blended Body – A flattened, airfoil shaped body. The wing and fuselage are distinct, but the wings are smoothly blended into the body. Great reduced drag and high lift characteristics.



FOM	Weight Value	Fuselage Types		
		Single Boom	Double Boom	Blended Body
Weight	0.4	3	1	4
Drag	0.2	4	2	5
Durability	0.1	4	3	5
Storage Capactiy	0.3	4	5	1
Total	1	3.6	2.6	3.4

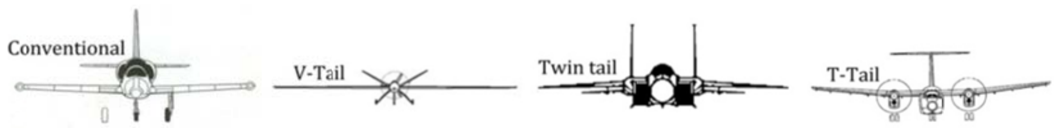
Table 3: Fuselage Decision Matrix

Three different configurations were examined during the selection of a possible fuselage. The "single boom" fuselage won over the blended body due to the fact that it has more storage potential. The storing capacity of the blended is very poor, and that is a large part of getting high marks in the competition. The double boom configuration has great storage potential, but the weight limitations are a concern, and therefore leaves it with the worst overall score.

3.4.3 Tail

The tail is largely responsible for climb rate and pitch control. Its selection is a function of balancing the lift and other moments generated by the rest of the aircraft during flight. Simply put, the tail must provide stability. The tail needs to be rigid as to prevent any tail-induced instability of the aircraft in flight. Weight is not as important here because in comparison to the entire aircraft, the tail section is relatively light.

- Conventional – Rudder normal to wing, vertical stabilizer parallel to wing.
- T-Tail – Rudder normal to wing, vertical stabilizer above rudder.
- Twin Tail – Dual Rudder, vertical stabilizer at bottom between rudders.
- V-Tail – Rudder and vertical stabilizer blended into two V-configured rudders.



FOM	Weight Value	Tail Types			
		T-Tail	V-Tail	Twin Tail	Conventional
Weight	0.15	3	4	3	3
Drag	0.2	3	5	3	4
Stability	0.35	3	2	3	5
Control	0.2	4	2	4	5
Complexity	0.1	3	2	3	4
Total	1	3.2	2.9	3.2	4.4

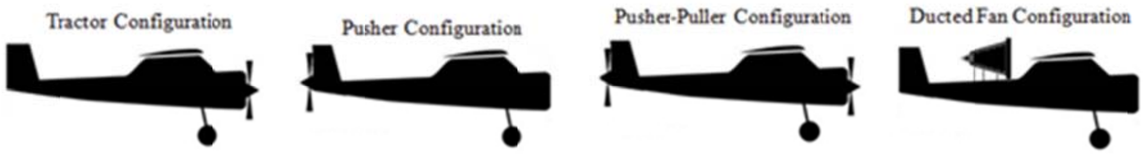
Table 4: Tail Decision Matrix

Of the four configurations considered the conventional tail type exhibit highest stability and control which are very important in the above described missions. Compared to the other options, the conventional tail easily outscores them.

3.4.4 Propeller Configuration

The propulsion system is essential to providing the thrust to the aircraft. Weight and efficiency are very important here. But it must be kept in mind that having multiple motors does not necessarily increase thrust since there is a limit to how much current can be drawn from each battery. All this would do is significantly increase the overall weight.

- Tractor – The propeller is mounted on the nose of the aircraft. Thrust is produced by the most forward part of the plane. This is the most conventional design.
- Pusher – The propeller is mounted at the tail of the aircraft. With a rear mounted engine, there would be more storage capacity in the fuselage.
- Tractor-Pusher – There is both a front mounted propeller, as well as a rear mounted propeller. This design employs “center-line thrust”, enabling the power to be maximized along the plane centerline, creating more thrust.
- Ducted Fan – The propeller is inside of a cylindrical duct. This moves the flow trajectory out of the way of the line of motion of the fuselage.



FOM	Weight Value	Engine Configuration			
		Tractor	Pusher	Tractor-Pusher	Ducted Top-Mounted Tractor
Weight/Balance	0.4	5	4	5	2
Efficiency	0.4	4	4	3	3
Complexity	0.2	5	4	2	3
Total	1	4.6	4	3.6	2.6

Table 5: Propulsion Decision Matrix

A tractor propulsion system was selected for its light weight and effectiveness. Weight is less than a pusher because the tail structure does not intersect the propeller area and the weight is less than multiple motors (tractor-pusher) because only a single motor mount is required. The simplicity in the design is also a plus, as well as providing the propeller with clean air for high efficiency.

3.4.5 Landing Gear

When selecting the landing gear, weight was the major point of emphasis. But it also must be durable and efficient enough for take-off within the prescribed area on the runway. Displayed in Table 6, four configurations were considered.

- Single Wheel – One wheel located at the center of gravity for the aircraft. This design is simple and lightweight; however, it may not be strong enough support the entire weight of the aircraft. It would also be very unstable when landing.
- Bicycle – Two wheels are centered along the longitudinal axis of the body of the aircraft. Distributes the load through the two shafts, making this design very stable, though the landing could possibly be seen as unstable.
- Tricycle – A single wheel is located toward the nose of the aircraft and two wheels are located toward the rear of the aircraft on the same rotational axis. This is a very stable design but it is relatively heavy compared to other configurations and will induce more drag.
- Tail Dragger – Two wheels located toward the nose of the aircraft and a single wheel located toward the rear. The front wheels are on longer shafts which cause the nose to point upward and the tail to “drag”. This is a stable design but the majority of the load would be supported by the smaller tail wheel. This may cause some durability issues.

Figure of Merit	Weighting Factor	Single Wheel	Tricycle	Tail Dragger	Bicycle
Weight	0.30	4	3	3	2
Drag	0.10	4	4	3	3
Durability	0.15	2	5	4	4
Stability	0.10	1	5	3	3
Manufacturability	0.15	4	3	3	2
Efficiency	0.20	4	3	2	1
Total	1.00	3.40	3.60	2.95	2.30

Table 6: Landing Gear Decision Matrix

The tricycle configuration was determined to be the optimal landing platform design. It has the best stability characteristics and is also very resilient to high impact landings.

4.0 Preliminary Design

4.1 Internal Payload

The crux of this competition is to optimize the plane around its missions. The performance in these missions is contingent upon how efficiently the internal and external stores are configured and arranged. The internal stores portion of the design is the first step in sizing the aircraft. Minimizing the space and weight required to fully house the stores is what will allow the aircraft to be optimized for size and weight, thus the fuselage is given a base volume to cover, With this parameter determined, the lift and thrust components have quantifiable marks to meet. The landing gear can then be designed around the aircraft weight as determined by other parameters.

It was determined to utilize a frame design for the fuselage in order to minimize weight. The design is centered on securing the internal stores and providing a lightweight hull for stable aero-navigation. The design encompasses a carbon fiber frame with lightweight wood walls. These walls are attached to solid polymer housings which will fully encase a section of the diameter of each Mini Max Rocket.

4.2 Wing Design

4.2.1 Airfoil Selection

The process for wing design began with analyzing airfoil sections and exploring the characteristics that would best fit this year's competition requirements. From advice from advising and time constraints, it was decided to implement a pre-existing airfoil design on this year's plane; thus, no radical new airfoil designs would be developed. Research provided a basis for choosing the fundamental airfoils to analyze. The airfoils were analyzed in a 2D panel method solver, XFOIL, where the drag polars (C_l vs. C_d), lift curves (C_l vs. α), and moment coefficients were compared for each respective airfoil.

As required in this year's competition rules; the short take off and high payload weights, the main wing should have high lift at low Reynolds numbers, low drag at cruising state and should also be relatively easy to manufacture. From estimates of the weight of the aircraft with payloads, an estimated speed range of the aircraft and the geometry of the aircraft a Reynolds number of 200,000 was chose as the value at to compare airfoil characteristics at. Low drag while at a cruising state or at a low alpha is imperative to increasing the speed of the aircraft as well as reducing the overall drag, as there will be a massive amount of drag in the third mission carrying the external stores. This is also important as the maximum aerodynamic efficiency of an airfoil occurs when it is at its design lift coefficient and expected cruise velocities. An airfoil that is relatively easy to manufacture is important in simplifying the design and reducing the empty weight of the aircraft. In the following plots, six airfoils are compared and subsequently one is chosen for the main wing of the aircraft.

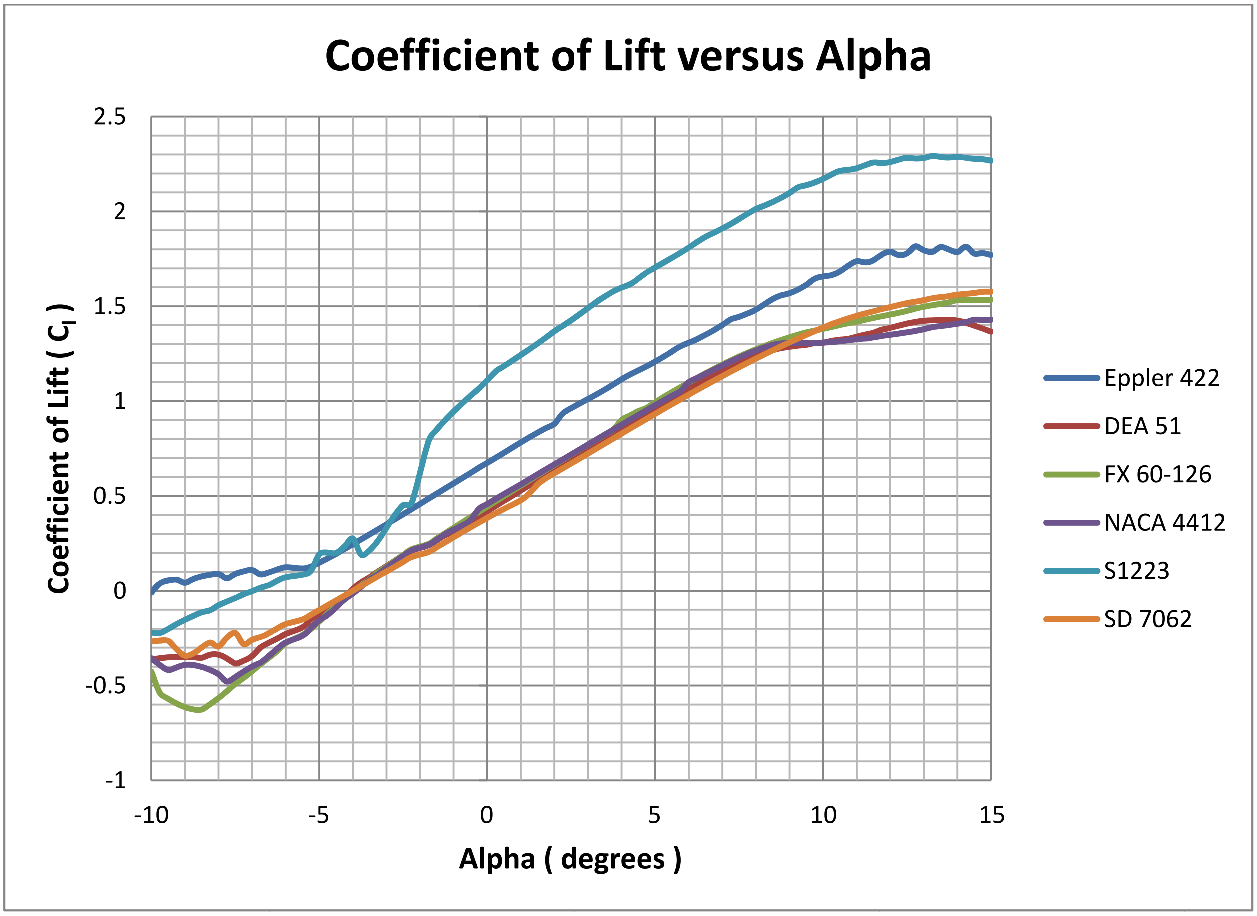


Figure 7 – Coefficient of Lift versus Alpha for airfoils under consideration for main wing.

All of the airfoils that were considered are high lift, and as shown in figure 7 all expect of two of the airfoils are grouped tightly together resembling the same characteristics in the coefficient of lift versus angle of attack. Above it can be seen that S1223 has a very high coefficient of lift compared to the others and Eppler 422 is above average while below S1223. From figure 7 alone Eppler 422 and S1223 are viable candidates for the main wing of the aircraft.

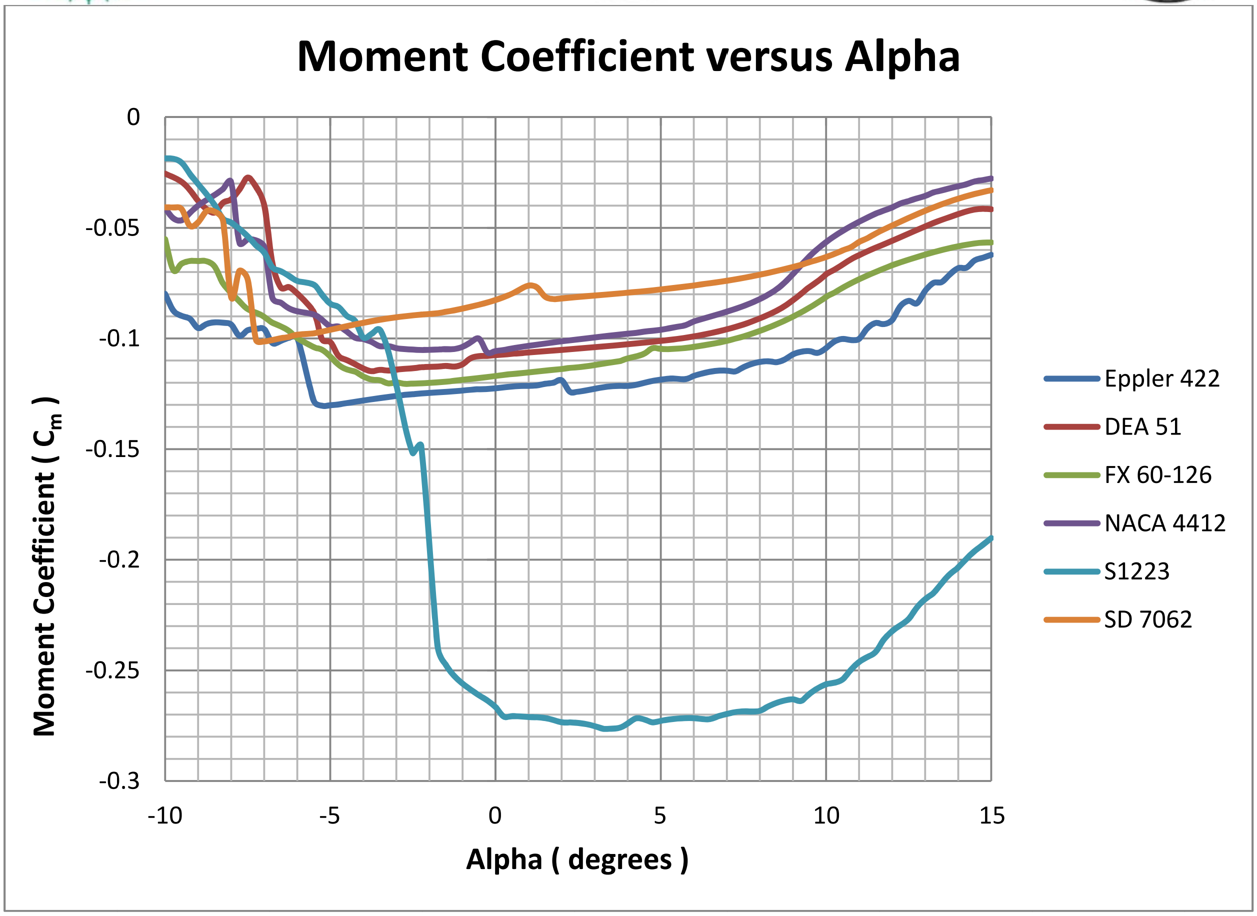


Figure 8 – Moment Coefficient versus Alpha for airfoils under consideration for main wing.

Shown in figure 8 are the moment coefficients of the airfoils under consideration versus angle of attack for each airfoil. A negative moment coefficient acts to pitch the aircraft in a nose down direction, a desirable moment coefficient is as close to zero as possible. The two airfoils that were the best performing tin the coefficient of lift versus alpha are the two worst in this category; with S1223 being far worse than the Eppler 422 while the Eppler is grouped together with the other airfoils. This suggests that Eppler 422 is the optimal chose for the main wing of the aircraft.

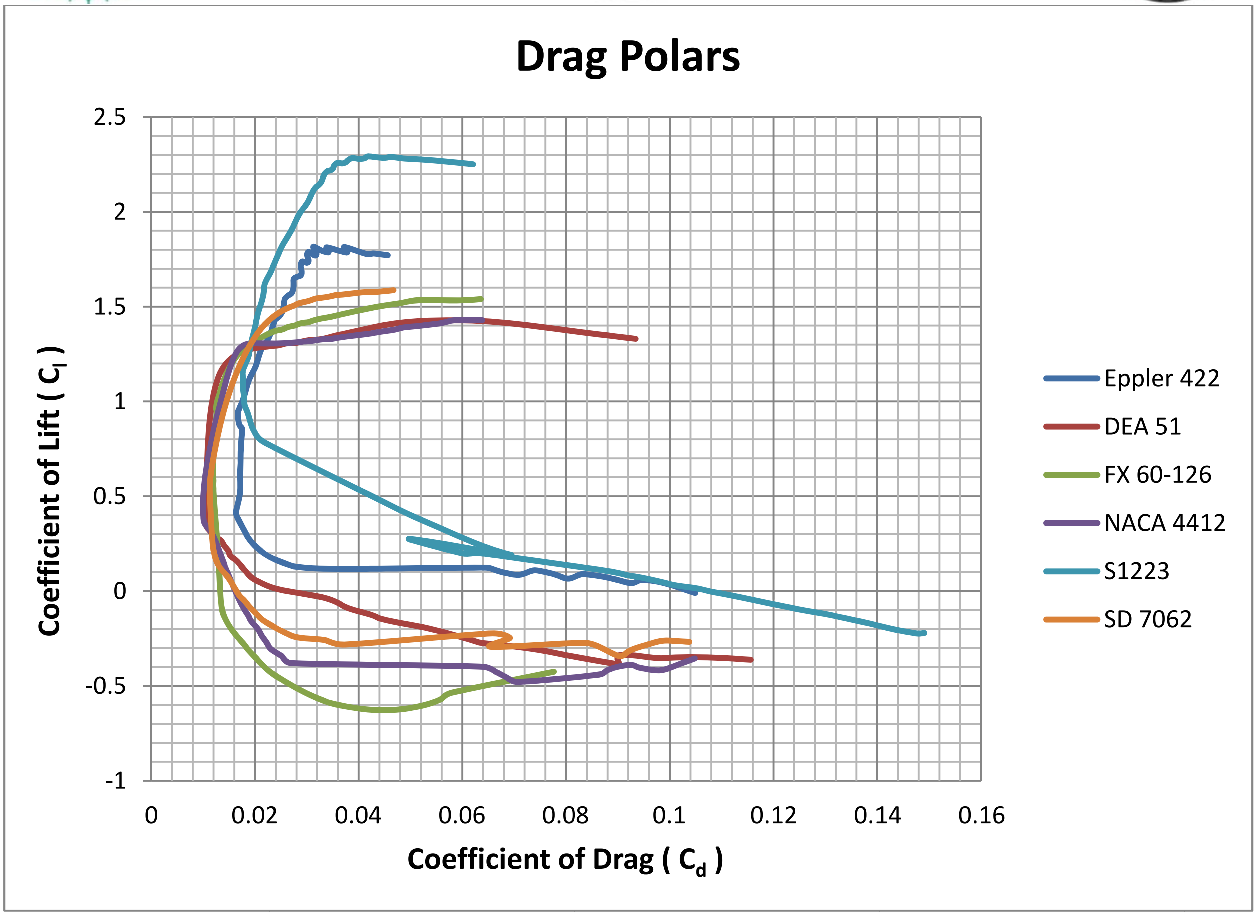


Figure 9 – Drag Polars for airfoils under consideration for main wing.

Figure 9 displays the drag polars for the airfoils tested and analyzed for use in the main wing of the aircraft that the team is designing. Drag polars show the relationship between the coefficient of lift and the coefficient of drag and is important in choosing an airfoil that will exhibit a low drag condition while the aircraft is in low angle situations such as cruise. The plot shows that the S1223 is less than satisfactory in this category as well while the Eppler 422 exhibits quantities that are suitable for the main wing when paired with the results of the other plots.

The chosen airfoil to be implemented on the main wing of the aircraft is the Eppler 422. The airfoil has a high maximum lift while producing a moment coefficient that can be balanced by the tail of the aircraft and a drag polar that will reduce the drag on the aircraft while in a cruising state. The aerodynamic characteristics of the Eppler 422 airfoil are displayed in Table7 and the profile of the Eppler 422 airfoil is shown in figure 10.

Max C_l	1.8159
Stall Angle (deg)	15
Max C_l/C_d	60.0429
C_l at Max C_l/C_d	1.2609
Angle at Max C_l/C_d (deg)	5.5

Table 7 Eppler 442 air foil Characteristics

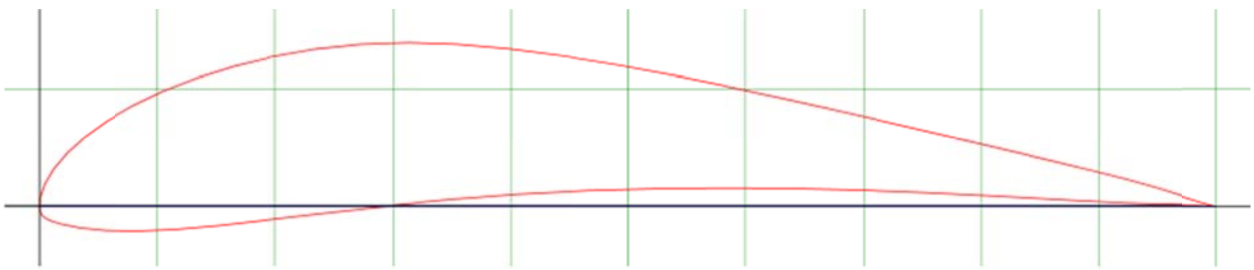


Figure 10 – Eppler 422 Profile

4.2.2 Wing Geometry

In order to perform an initial sizing of the main wing of the aircraft the total weight as estimated in the product specifications section and a wing loading value to fit the desired flight characteristics of the aircraft. From this initial value of the wing area, span and chord an iterative process was used to determine if the sizing was adequate for the estimated minimum stall speed of the aircraft, this process was repeated until suitable dimensions were reached. Basic fundamental aerodynamic equations were used throughout the sizing process. With an assumed loaded weight of seven pounds from the heaviest loading condition in mission three which would consist of five rockets in total and a wing loading value of 20 ounces per foot squared. Equation 8 shown below used these values to determine the required wing area for the estimated weight.

$$S = \frac{\text{Weight}_{\text{Aircraft}}}{\text{Wing}_{\text{Loading}}} \qquad (8)$$

After the wing area was determined the aspect ratio was chosen in the range of 6 to 8 as is standard in almost all aircrafts that have the desired characteristics that we seek. The span of the wing or the length of the wing was determined from equation 9 shown below.

$$b = \sqrt{AR * S} \qquad (9)$$

The chord length was then calculated using equation 10 shown below using the wing area and the wing span determined above.

$$c = \frac{S}{b} \quad (10)$$

The required velocity of the aircraft was then calculated using equation 11 shown below using a required lift force of 31.138 Newtons, the wing area determined above, the max coefficient of lift of the selected airfoil above, and the density of air at standard pressure.

$$V = \sqrt{\frac{2L}{\rho S C_l}} \quad (11)$$

From the above equations the wing sizing and characteristics are shown in table 9 below.

Wing Area (S)	806.4 in^2
Span (b)	77.77 in
Chord (c)	10.37 in
Aspect Ratio (AR)	7.5
Minimum Takeoff Speed	21.387 mph

Table 9 - Wing Sizing and Characteristics

4.3 Tail Design

4.3.1 Airfoil Selection

The main purpose of the tail section is to provide the aircraft a means of control with respect to the raw and roll of the aircraft. It is also necessary to design the tail to provide stability and trim to the aircraft in all flying conditions. Similar to the procedure in the main wing design the tail section design will consist of an airfoil selection and the geometry of the tail section with respect to the size, weight and geometry of the aircraft as a whole. Through research it was found that a symmetric airfoil for the vertical section and the horizontal section will provide adequate stability for the cruise conditions of the aircraft. The horizontal section is usually oriented at a small incidence angle to offset the pitching moment caused by the main wing. Many symmetric airfoils have similar characteristics so a select number of airfoils were analyzed for the tail section; the airfoils that were analyzed are commonly used on aircraft and RC planes. The selection criteria was that the airfoil produce minimal drag while being able to still control the aircraft and have an adequate size for ease of fabrication. For this analysis the drag polars were examined to find the ideal candidate.

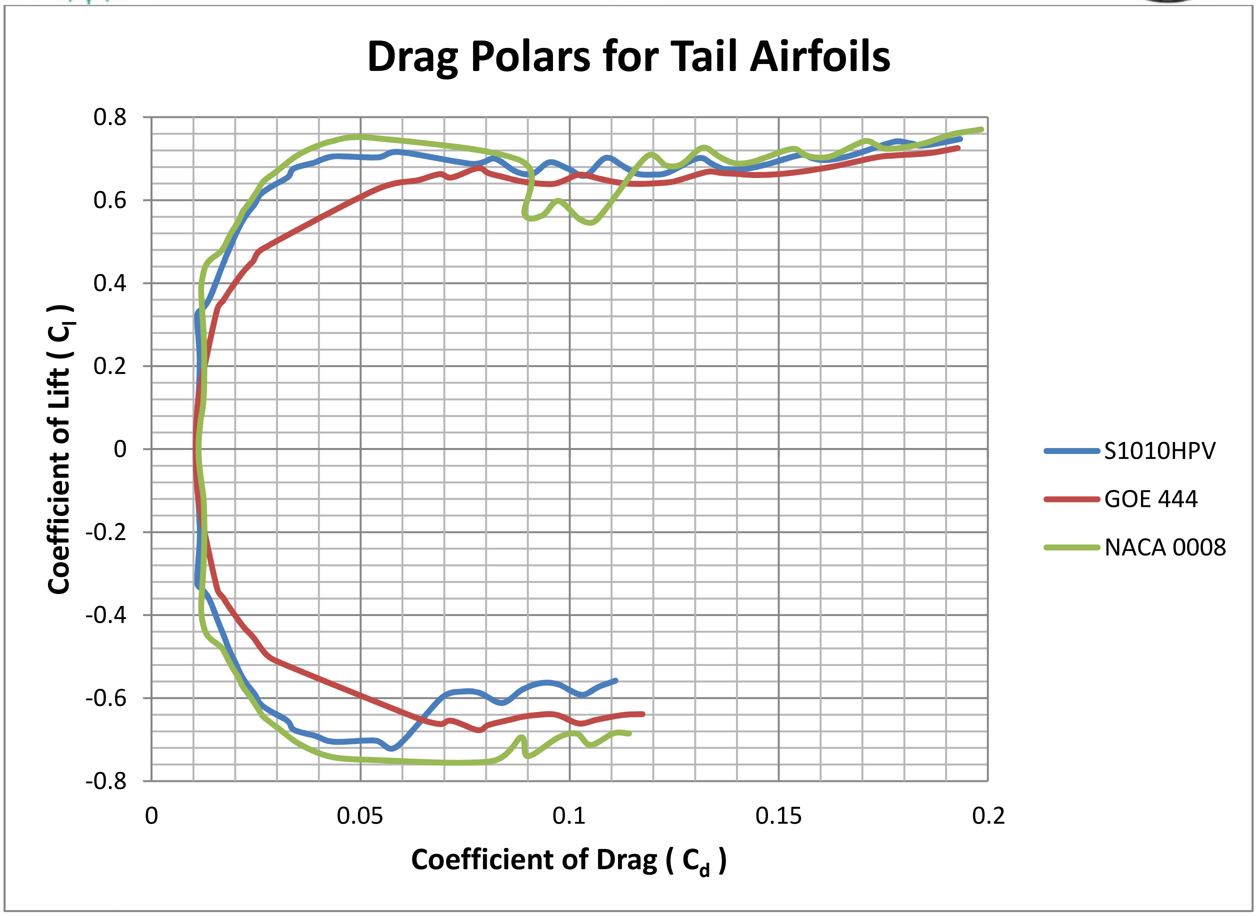


Figure 11 - Drag Polars for airfoils under consideration for the tail section

As shown in figure 11 the drag polars for the analyzed airfoils are very similar in nature, but NACA 0008 was chosen because of the slight reduction in drag at higher coefficients of lift and the slightly higher percentage of thickness relative to the chord will result in an easier manufacturing of that airfoil. Figure 12 below gives an outline of the NACA 0008 airfoil.

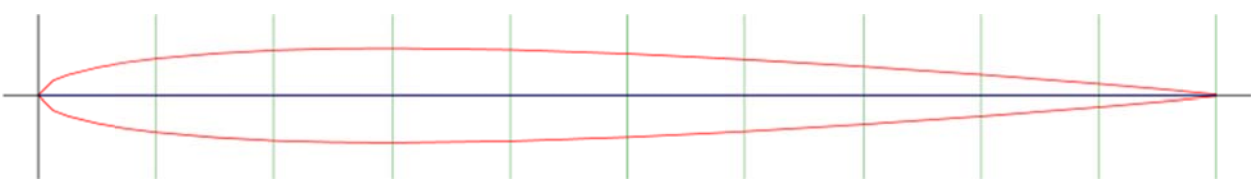


Figure 12 - NACA 0008 airfoil profile

4.3.2 Tail Geometry

The sizing of the tail section was used from calculation form Raymer. The tail areas for the vertical and horizontal tail were calculated with equations 13 and 14 respectively

$$S_{VT} = \frac{c_{VT} \cdot b_W \cdot S_W}{L_{VT}} \quad (12)$$

$$S_{HT} = \frac{c_{HT} \cdot \overline{C}_W \cdot S_W}{L_{HT}} \quad (13)$$

Where c_{xT} is the tail volume coefficient, b_W is the wingspan, C_W is the wing mean chord, S_W is the wing area, and L_{XT} is the effective moment arm. The tail volume coefficients were estimated through research from exiting data on tails of aircrafts similar to the proportions of ours and were found to be 0.04 and 0.7 for the vertical and horizontal stabilizers respectively. The geometry of the tail section is given in table 10 below. According to Raymer, the tail aspect ratio shows little variation through a wide range of aircrafts and may therefore be determined based on historical data. For aircrafts with similar proportions to this one, the desired tail aspect ratios are between 3 and 5 for the horizontal stabilizer, and between 1.3 and 2 for the vertical stabilizer.

Vertical Span	10.239 inches
Vertical Chord	7.9 inches
Horizontal Span	23.76 inches
Horizontal Chord	7.9 inches
Moment Arm	31.107 inches

Table 10 - Tail Section Dimensions

4.3.3 Control Surface Design

The control surfaces which consist of the rudder on the vertical stabilizer, the elevator on the horizontal stabilizer and the ailerons on the main wing are used in the control, stability and the maneuverability of the aircraft while in flight. According to Raymer the ailerons, rudder, and elevator should be at least approximately 20 percent of the chord of the airfoil that that the control surface is a part of. Similarly the span of the control surface should be at least 40 percent of the span of the airfoil that the respective control surface is on. Table 11 below gives the minimum dimensions of the control surface for our aircraft.

Elevator Span	>9.5 inches
Elevator Chord	>1.575 inches
Rudder Span	>4.1 inches
Rudder Chord	>1.575 inches
Aileron Span	>31.108 inches
Aileron Chord	>2.075 inches

Table 11 - Control Surface Minimum Dimensions

4.4 Propulsion System

The propulsion system for this aircraft must be capable of lifting seven pounds into the air within the allotted runway space. It must be considered that the short take-off will be done in Tuscon, Az, where the altitude is approximately 2500 ft. The propulsion system was designed as a function the combinations of motors, propellers, and batteries that were considered were selected first for static thrust that they provide for a maximum of 20 Amps. The effect on RAC due to the Motor weight must also be considered in determining whether it provides adequate static thrust. The analysis was done by considering an array of possible motors, propellers, and batteries. The procedure was to analyze numerous combinations of each of these, until trends were found, and parameters could be optimized. These combinations were analyzed one by one. The following graph shows the general relationship between our two most restrictive parameters (Thrust and Amperage). The propulsion system must pull no more than 20 amperes, and must generate at least 40 ounces of force in order to successfully take off in the runway area, given a seven pound aircraft and given the lifting capabilities of the wing which has been optimized for lift in this short-take-off competition.

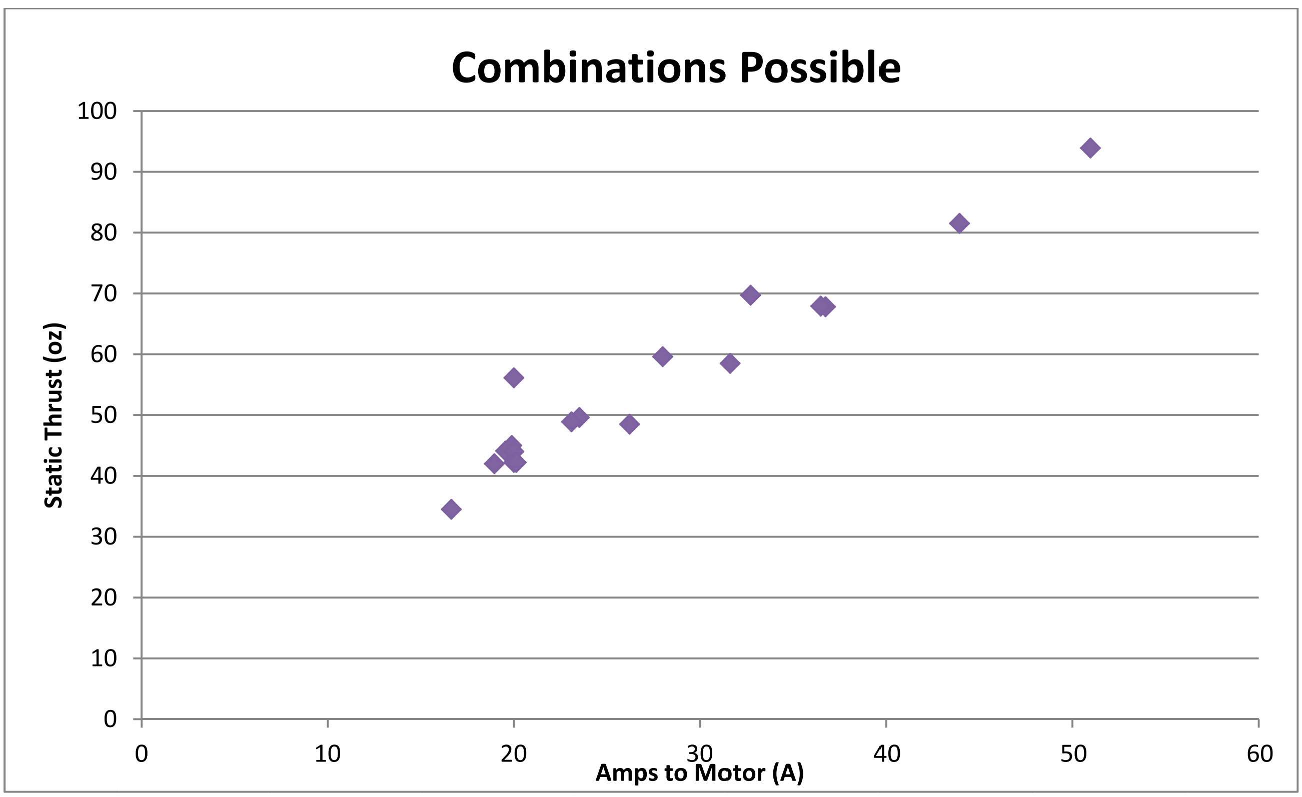


Figure 13 shows a representation of the tested array of combinations. Some of which are capable of successfully completing a take-off within the confines of the competition rules.

Once a consistent relationship was found between amperage input and thrust output, the graph was truncated to show all combinations that were suited to generate the thrust necessary to successfully lift the aircraft within the given space. The points on the graph below represent the combinations of propellers, motors, and batteries which are capable of providing at least 40 ounces of thrust, while drawing no more than 20 amps of current.

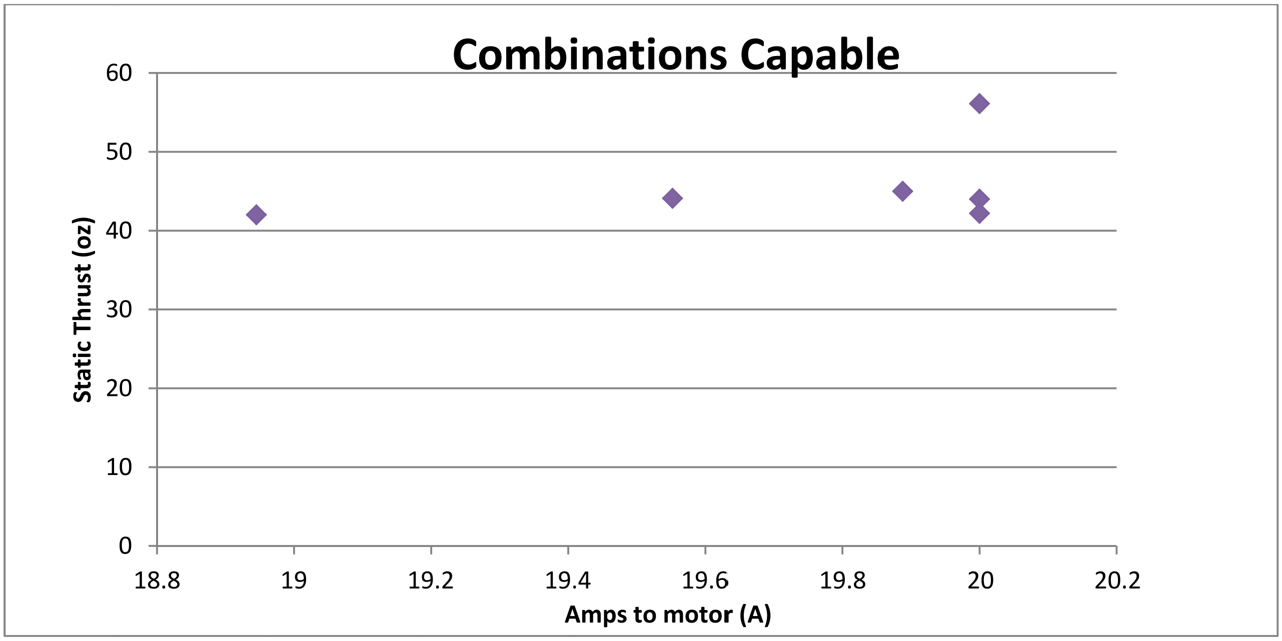


Figure 14 is a truncated version of the previous figure. This shows only the combinations that would successfully lift the plane within the rules of the competition.

4.4.1 Communication System

The communications/Controls electronics were chosen based upon the preference of our test pilot, with understanding that for the purpose of this aircraft, there are many competing models that would provide equally satisfactory service to our communication needs. We have chosen the Spektrum DX-7 2.4 GHz transmitter for its user friendly digital screen, and we chose a spektrum 6-channel receiver in the event that we decided to add control surfaces to our aircraft. Although we only need four channels, the six-channel will suffice for projects in the future.

Figure 15

5.0 Detailed Design

With the preliminary design completed, the group began work on integrating the subsystems of the aircraft into a final prototype for construction.

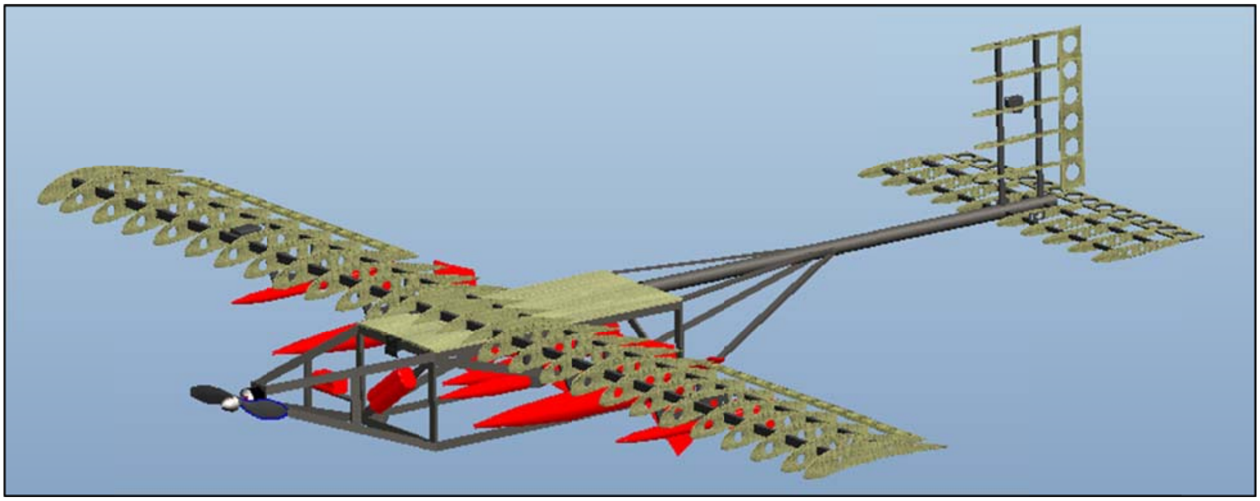


Figure 16

5.1 Dimensional Parameters

Fuselage	
Length (cm)	106.67
Width (cm)	20.32
Height (cm)	15.24

Control Surface	
Elevator Span (cm)	61.0
Elevator Chord (cm)	4.0
Rudder Span (cm)	25.0
Rudder Chord (cm)	4.0
Aileron Span (cm)	52.0
Aileron Chord (cm)	4.5

Tail Section	
Vertical Span (cm)	25.0
Vertical Chord (cm)	19.62
Horizontal Span (cm)	61.0
Horizontal Chord (cm)	19.62
Moment Arm (cm)	79.01

Overall Aircraft Size	
Length (cm)	158.55
Width (cm)	198.12
Height (cm)	59.99

Wing	
Airfoil	Eppler 422
Span (cm)	197.54
Root Chord (cm)	26.34
Tip Chord (cm)	26.34
Area (cm^2)	5202.57
Aspect Ratio	7.5
Stall Angle (deg)	15.0

5.2 Estimated RAC of Final Design

Once the final design was completely modeled, determining an estimate for the empty weight of the aircraft was possible through the use of Pro Engineer's analysis system. This weight, combined with the overall exterior dimensions of the plane, can be used to predict the "Rated Aircraft Cost" of the aircraft.

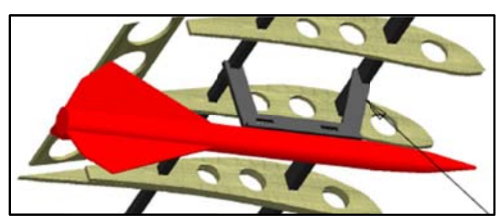
$$RAC = \frac{\sqrt{Empty\ Weight * Size\ Factor}}{10}$$

$$Size\ Factor = X_{max} + 2 * Y_{max}$$

At the current weight and size, this aircraft design will yield an RAC of 0.483, effectively doubling the product of the team's written report score and total flight score.

5.3 Structural Characteristics

The "Joint Strike Fighter" mission requires a plane that can house both internal and external loads during flight missions, these stores will be added and removed as dictated by the individual missions and translates to a need for high structural rigidity at flight speed. The way our team chose to tackle this issue was through designing the internal assembly as part of the actual fuselage construction as well as the wing attachment point. The internal stores will be mounted to a basswood plate that will be sandwiched between the main wing and carbon composite fuselage frame. This allows the upper portion of the fuselage to be reinforced by the strength of the wing and also creates a firm mounting platform for the internal stores. A similar technique is employed for the external store attachment design, combining the ability to add a wide array of stores to the wing with an added structural component as well. The carbon composite attachment bars are slim line in the direction of flight and also provide a point of reinforcement between the main and secondary spar on the main wing.



Figures 17 and 18 are to the right, illustrating the internal and external (respectively) stores attachments.

5.4 Subsystem Design and Integration

5.4.1 Wing Mounting

As previously discussed, the one-piece wing attaches to the upper portion of the composite fuselage. Small L-brackets and associated hardware will connect the two horizontal carbon composite reinforcement strips on the top of the fuselage frame to the main and secondary spars of the wing. Sandwiched between the two is a basswood plate that is permanently mounted to the fuselage's composite frame. The carbon mounting strips provide a solid point for the L-brackets to attach, while the flat basswood plate yields a large surface area for the flattened portion of the underside of the center of the wing to contact the fuselage. This orientation spreads the reaction forces between the wing and fuselage contact points over a sizeable surface area minimizing their overall magnitude.

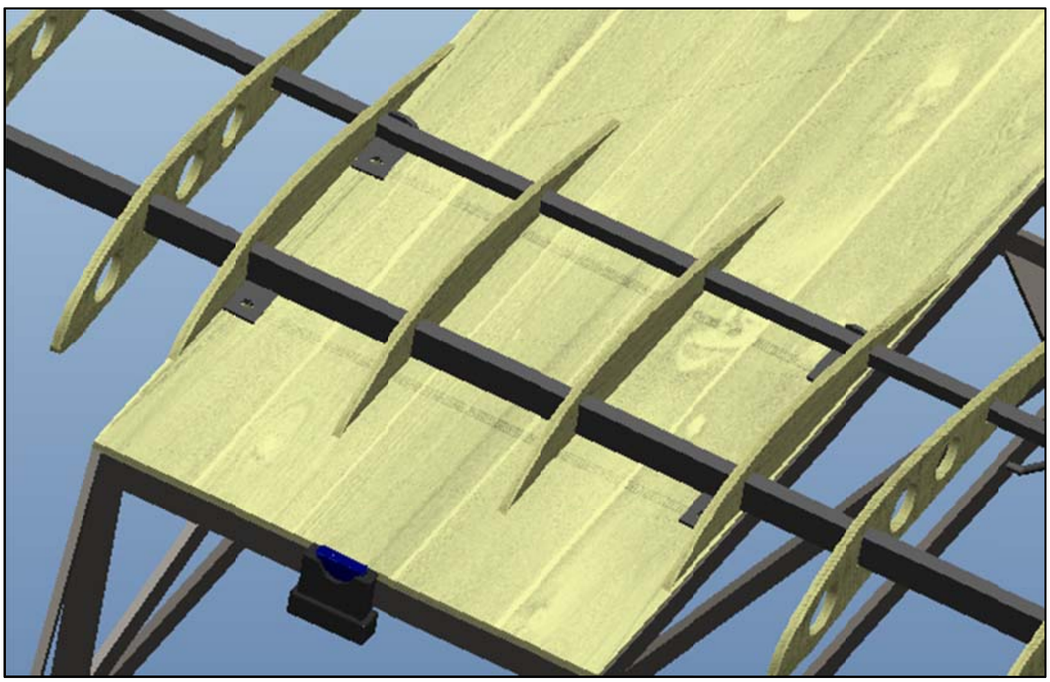


Figure 19 shows how the ribs are spars mount to the fuselage.

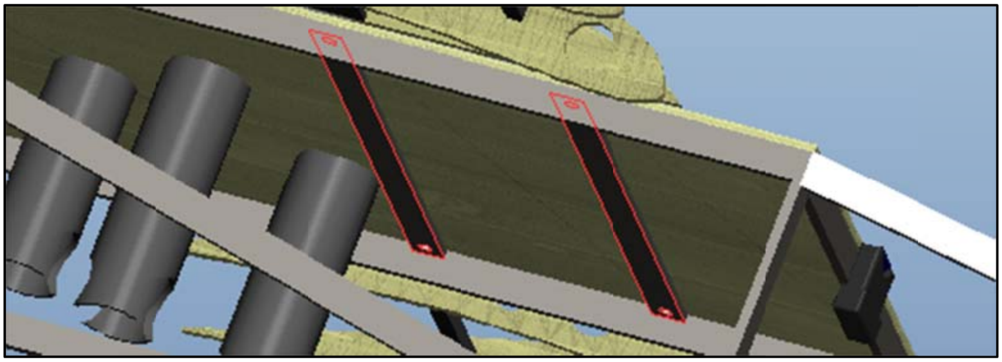


Figure 20 shows the wing attachment from the underside of the fuselage roof.

5.4.2 Tail Mounting

In designing an attachment method for the tail, the team objective was to combine simplicity with strength. The tail's general purpose lies in the stabilization of overall flight characteristics, to ensure this function is performed adequately it is important to eliminate any unnecessary flex between the fuselage and tail section. By employing a carbon fiber tube as the connection point between the main fuselage frame and the tail section, this twisting motion can be limited greatly by running the horizontal and vertical spars through this tail tube's center.

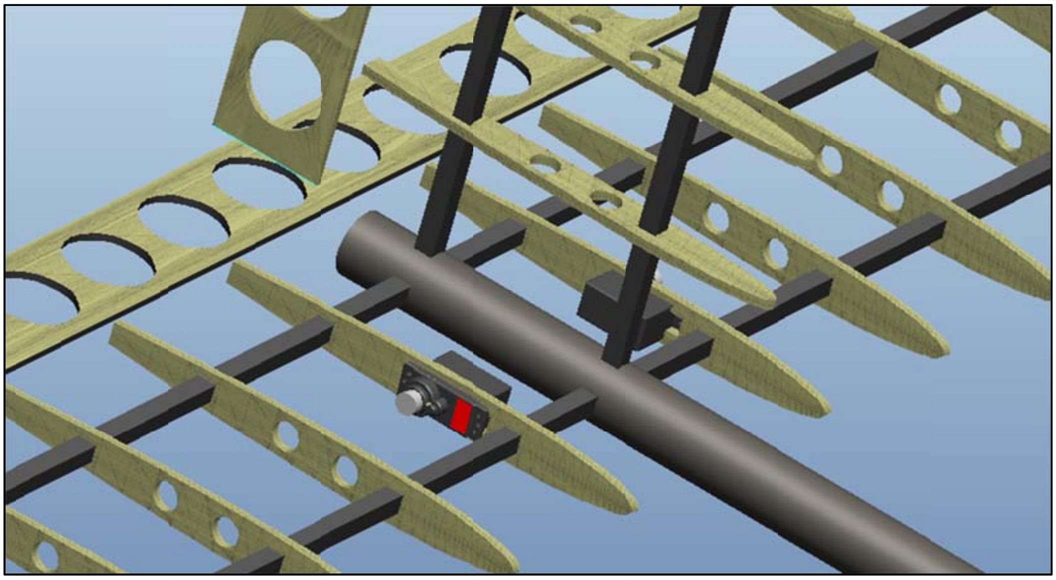
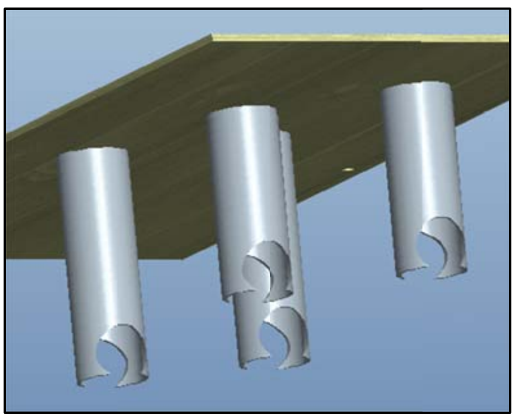


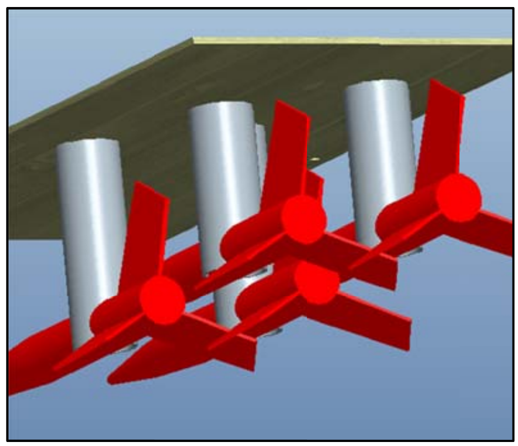
Figure 21 shows how the tail is connected through the spars of the rudder and elevator.

With both the tail connection tube and tail-section spars being composed of carbon fiber, the amount of axial movement during flight should be minimal.

5.4.3 Internal Store Configuration and Mounting

One of the greatest challenges of the 2013 design competition is carrying the large “MiniMax” rockets internally within the fuselage during flight. The rules dictate specific orientations, as well as positional tolerances that restrict the possible methods of attachment within the fuselage’s interior space. While the maximum amount of internal stores carried will achieve a higher score in competition, it is important to consider the amount of space required for such capacities and how that added size will affect the weight and maneuverability of the aircraft. After observing footage of past competitions and the frequency with which previous team’s crash, due to poor flight conditions or overloading, the team collectively decided to ensure a safe and stable aircraft by carrying only the minimal amount of internal stores. While this may prove a sacrifice in single mission scoring, it should ensure the completion of the competition without catastrophic failure.





Figures 22 and 23 show the internal stores mount without and with rockets inside respectively.

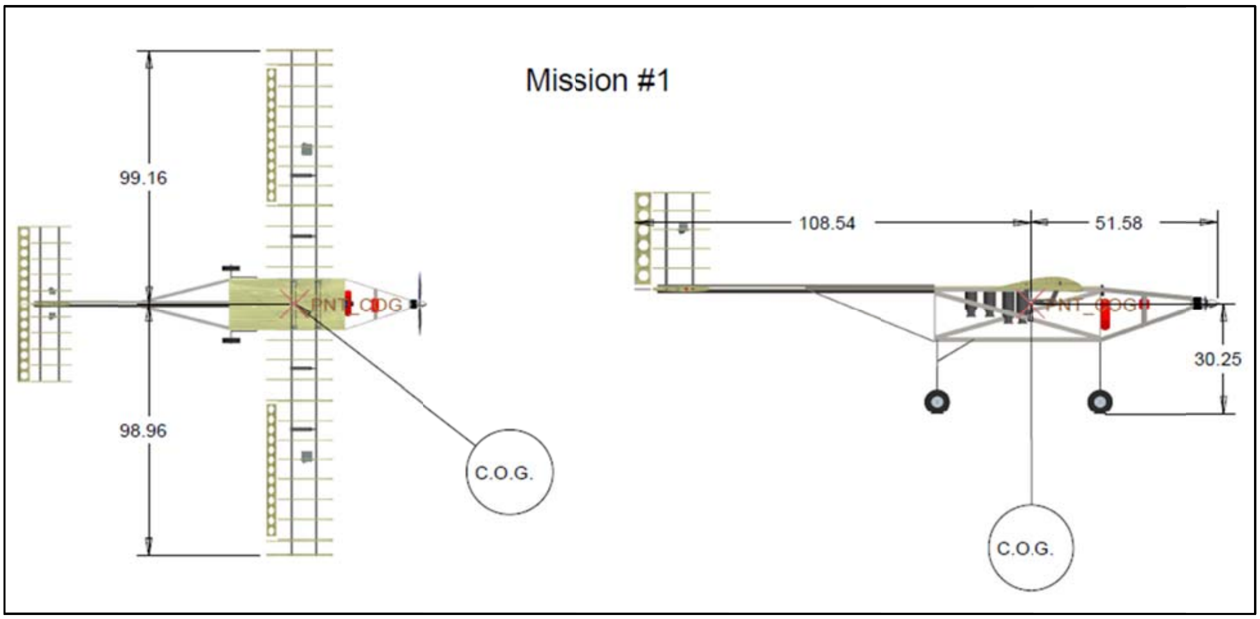
The internal stores are held in place inside the fuselage by four thin-wall plastic tubes with an inner diameter of one inch, matching the external diameter of the “MiniMax” rocket. This clamps the rocket around a large portion of its circumference while also spreading the contact patch over a large surface area which prevents any movement during flight. The other end of the tubes are attached to the basswood plate acting as the ceiling of the fuselage, yielding a very stable attachment point thanks to the comparably large footprint provided by the 1 ¼” outer diameter plastic tubing.

5.5 Weight and Balance

Upon completion of modeling our final design, an estimate of total empty weight was determined to be 2.334 kg (5.14 lbs). This is within the proposed boundaries the team set out with preliminary design factors, however more mass efficiency is hoped to be achieved during fabrication.

5.5.1 Center of Gravity

Throughout the three mission profile, the current aircraft design provides a well-balanced center of gravity in both horizontal and vertical reference frames. The C.G. is within 1mm of centerline from wingtip to wingtip, and sits firmly under the wing's secondary spar near the center of the fuselage. The vertical position of the C.G. is also within 1 mm of the propeller's center during all three mission scenarios.



Units – (cm)

Figure 24 shows a weight and balance diagram for mission 1

The CG position for missions two and three are shown below, the orientation of external rockets shown provides equal weight balance for each side of the wing yielding an identical CG location for mission three and mission two. While this may not always be the case, depending on the external arrangement prescribed at competition, it is known that an uneven arrangement of rockets will result in the CG moving slightly off center.

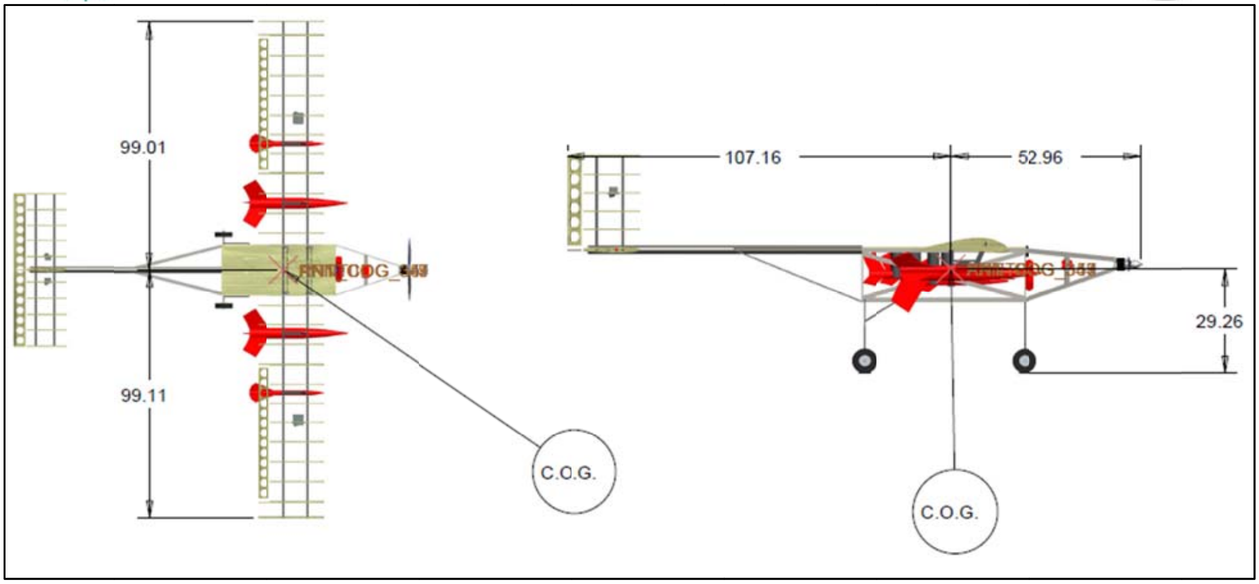
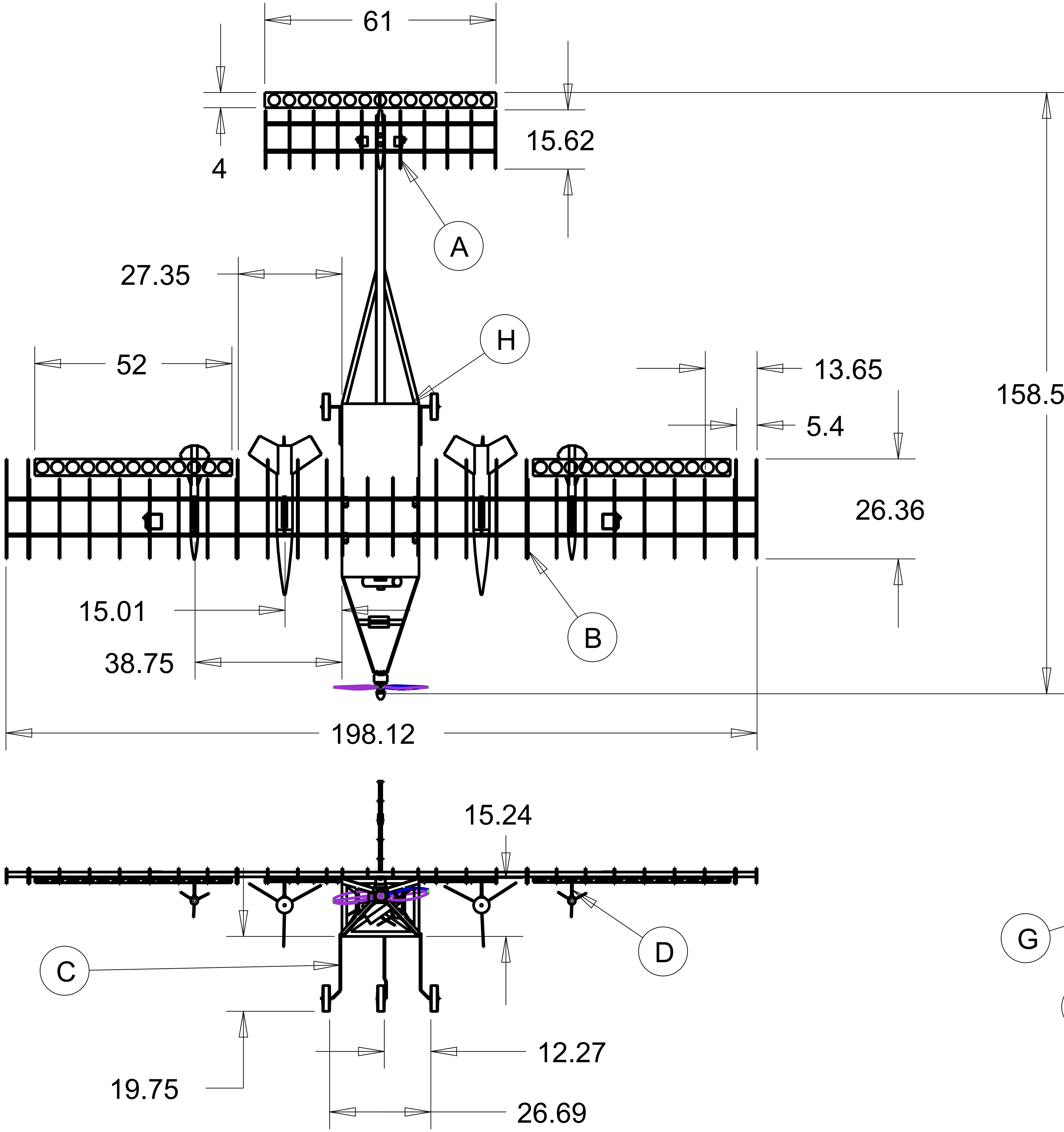
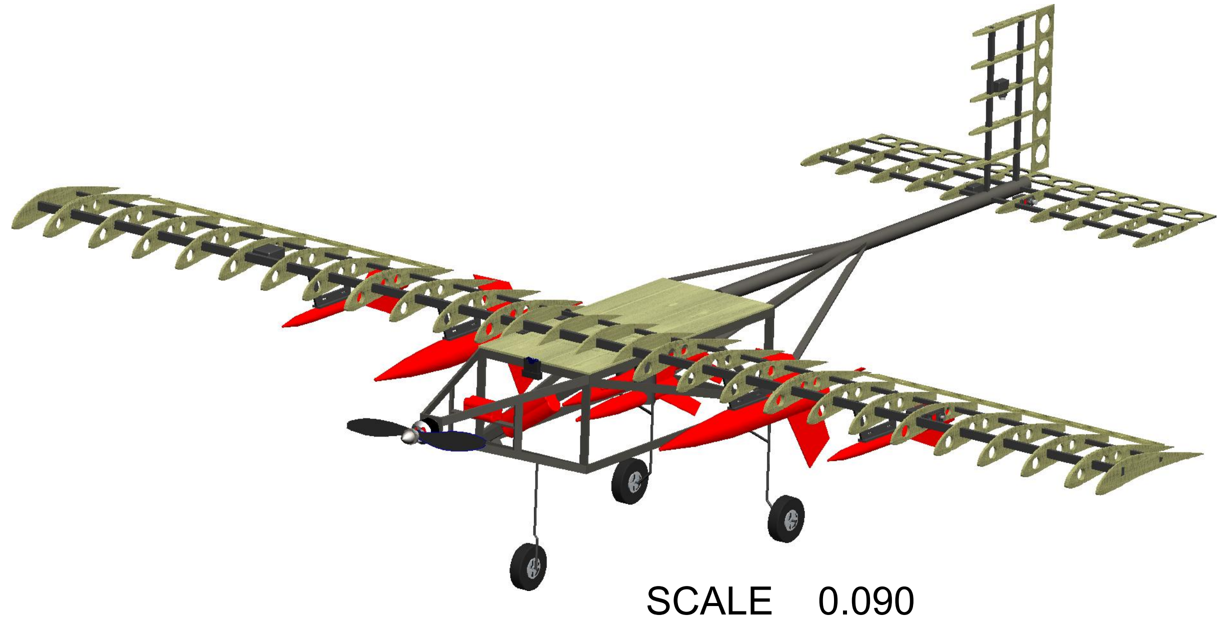
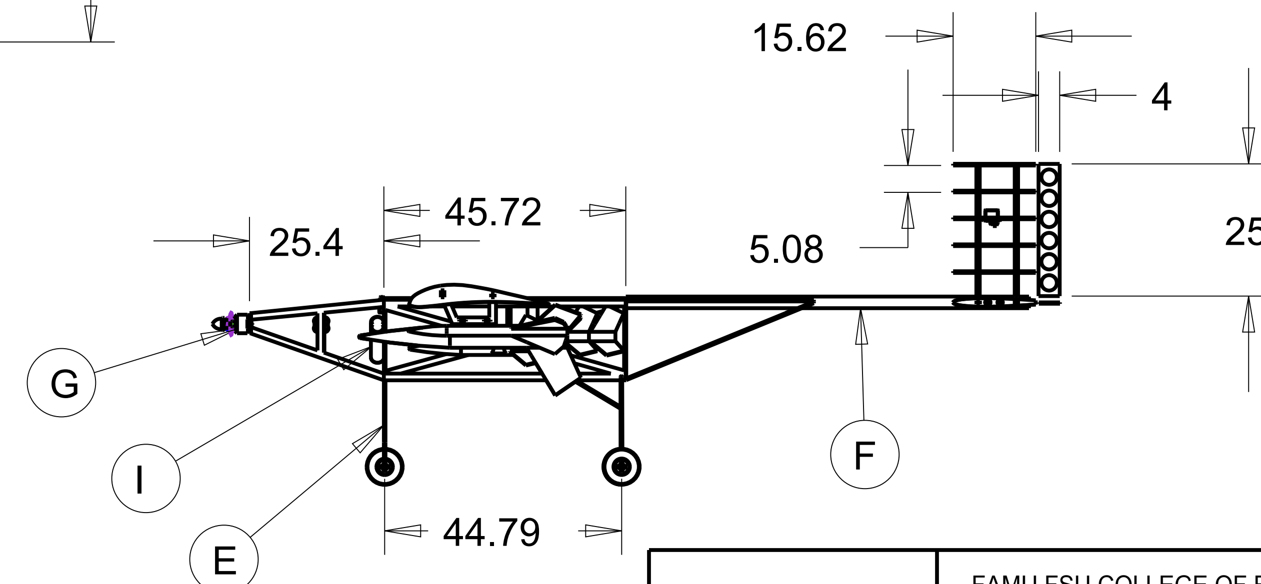


Figure 24 shows a weight and balance diagram for missions 2 and 3







Primary Componants

A	Tail Section	D	External Store Mount	G	Propulsions System
B	Main Wing	E	Nose Gear	H	Fuselage
C	Main Landing Gear	F	Fuselage/Tail Connector	I	Battery Compartment

NOTE:
ALL DIMENSIONS
IN CENTIMETERS

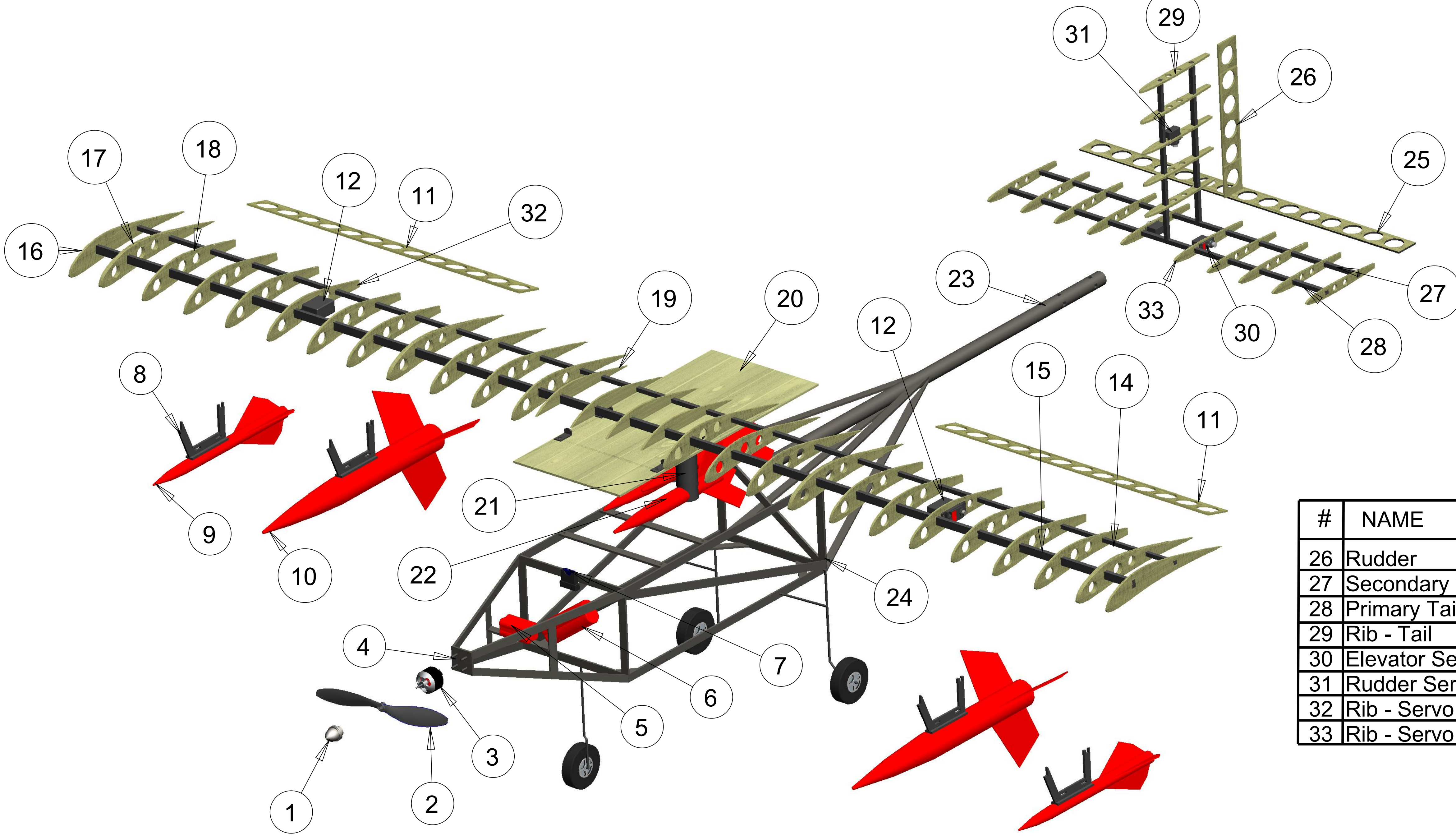
FAMU FSU COLLEGE OF ENGINEERING
CESSNA-RAYTHEON-AIAA DESIGN/BUILD/FLY 2013

DOCUMENT TITLE

Three View

TEAM NAME	DATE APPROVED	REPORT TITLE	SIZE
PEGASUS	02/19/2013	DRAWING PACKAGE	B

DRAWN BY	SCALE	SHEET NUMBER
Lee Becker	0.07	1 of 4



#	NAME	MATERIAL	QTY.
26	Rudder	Balsa	1
27	Secondary Tail Spar	Carbon Composite	1
28	Primary Tail Spar	Carbon Composite	1
29	Rib - Tail	Balsa	12
30	Elevator Servo	n/a	2
31	Rudder Servo	n/a	1
32	Rib - Servo (Wing)	Balsa	2
33	Rib - Servo (Tail)	Balsa	3

#	NAME	MATERIAL	QTY.	#	NAME	MATERIAL	QTY.
1	Propeller Chuck	Aluminum	1	14	Secondary Spar	Carbon Composite	1
2	Propeller	Plastic	1	15	Primary Spar	Carbon Composite	1
3	Electric Motor	n/a	1	16	Rib - Wing End	Balsa	2
4	Motor Mount	Carbon Composite	1	17	Rib - Regular	Balsa	12
5	Battery Pack (Servo)	n/a	1	18	Rib - Aileron	Balsa	14
6	Battery Pack (Motor)	n/a	1	19	Rib - Fuselage	Balsa	4
7	20 Amp Fuse Holder	n/a	1	20	Fuselage Top	Basswood	1
8	External Store Att.	Carbon Composite	4	21	Internal Store Att.	Plastic	4
9	HiFlyer Rocket	n/a	2	22	MiniMax Rocket	n/a	4
10	DerRedMax Rocket	n/a	2	23	Tail Tube	Carbon Fiber	1
11	Aileron	Balsa	2	24	Fuselage	Carbon Composite	1
12	Aileron Servo	n/a	2	25	Elevator	Balsa	1

NOTE:
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CESSNA-RAYTHEON-AIAA DESIGN/BUILD/FLY 2013

DOCUMENT TITLE

STRUCTURAL ARRANGEMENT

TEAM NAME	DATE APPROVED	REPORT TITLE	SIZE
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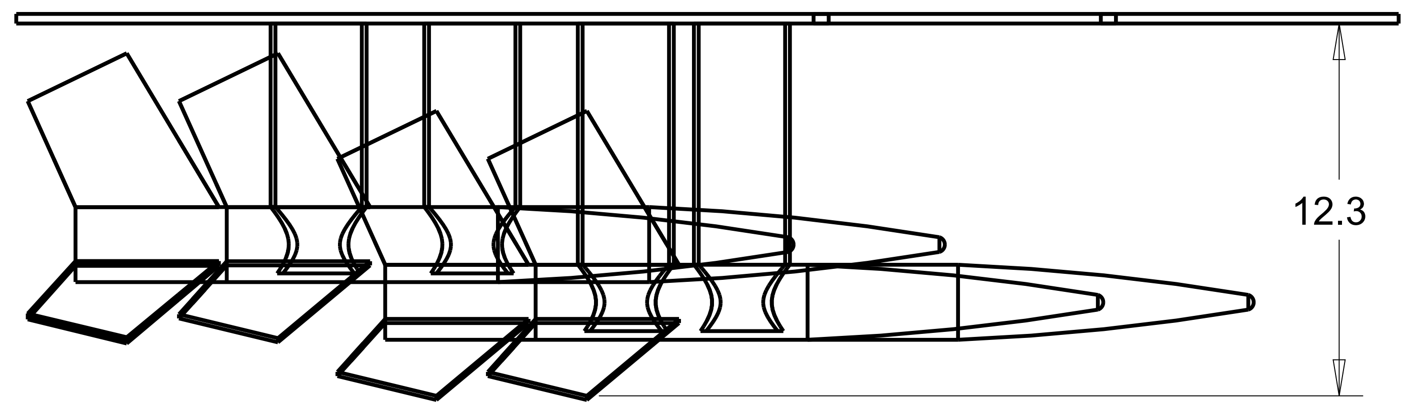
WILL WATTS	0.100	2 of 4



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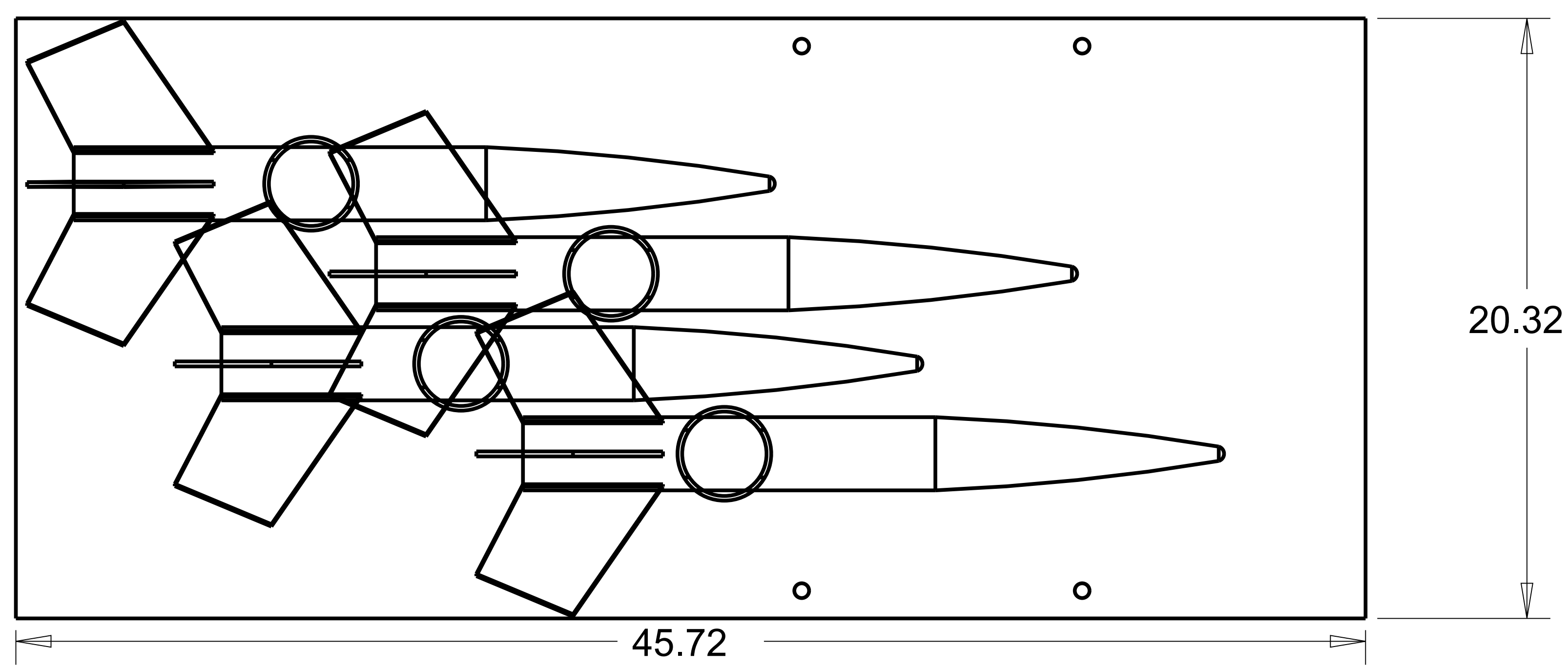

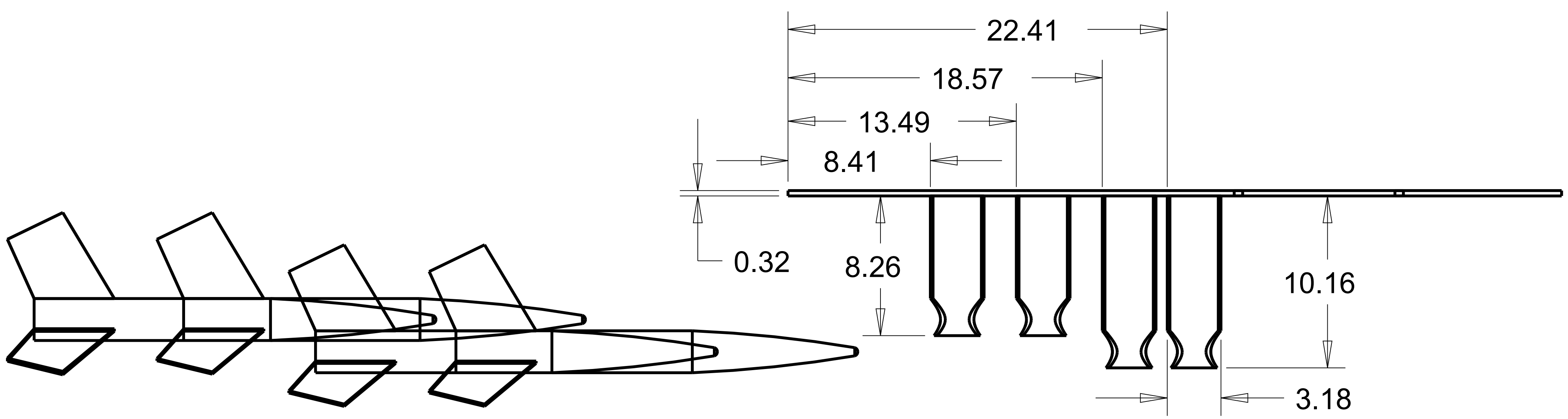

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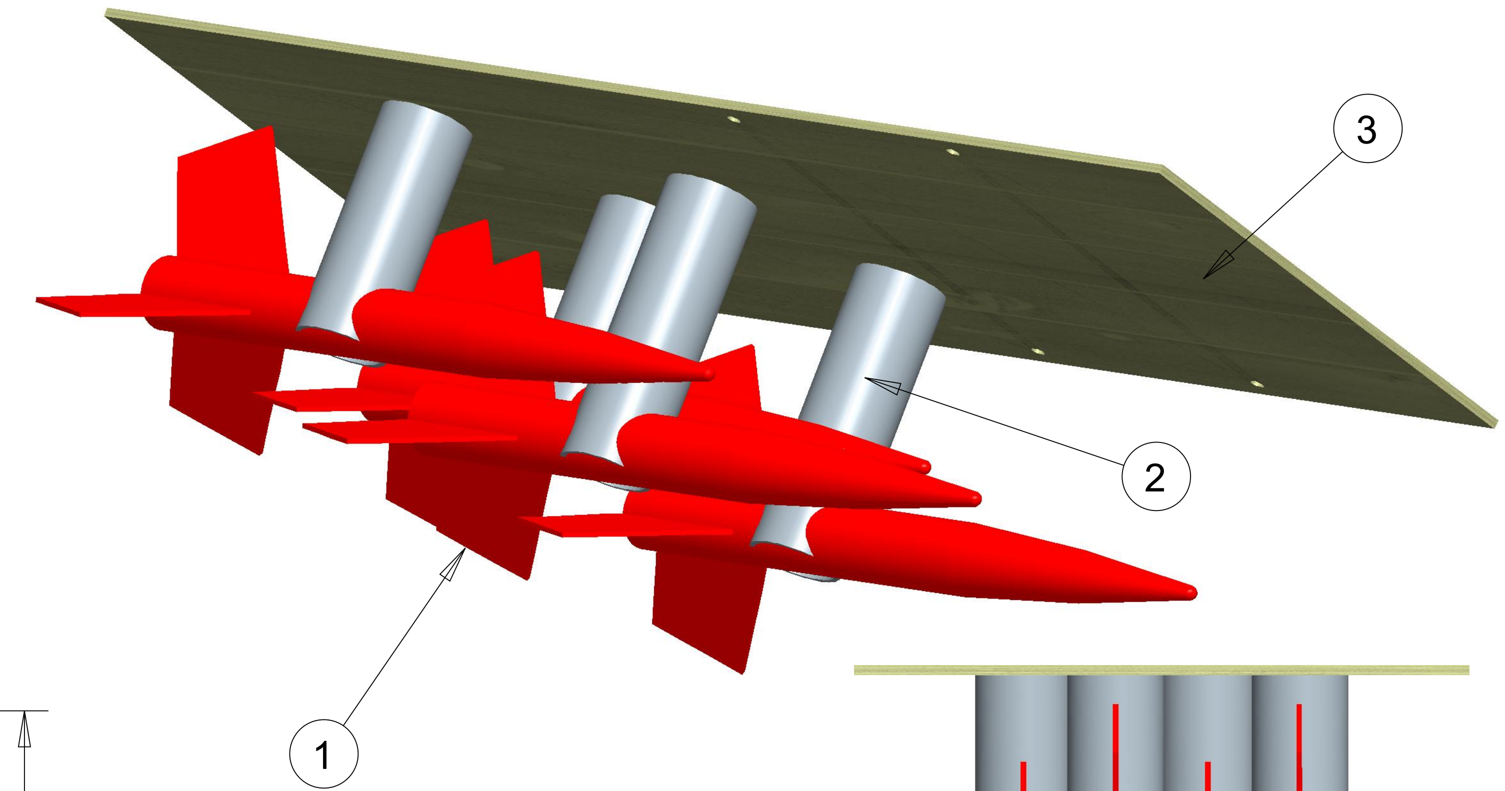

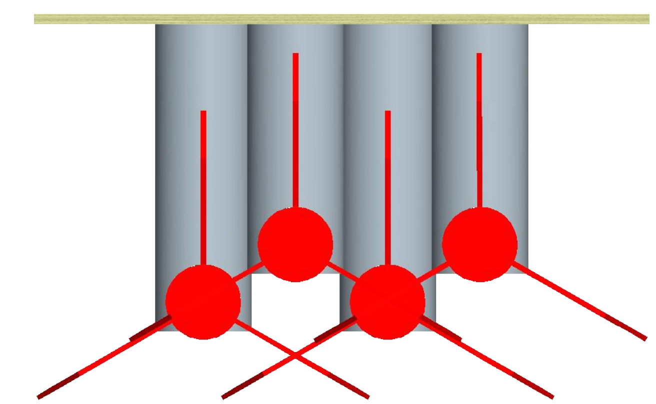

	ITEM
1	MiniMax Rocket
2	Attachment Tube
3	Upper Fuselage

NOTE:
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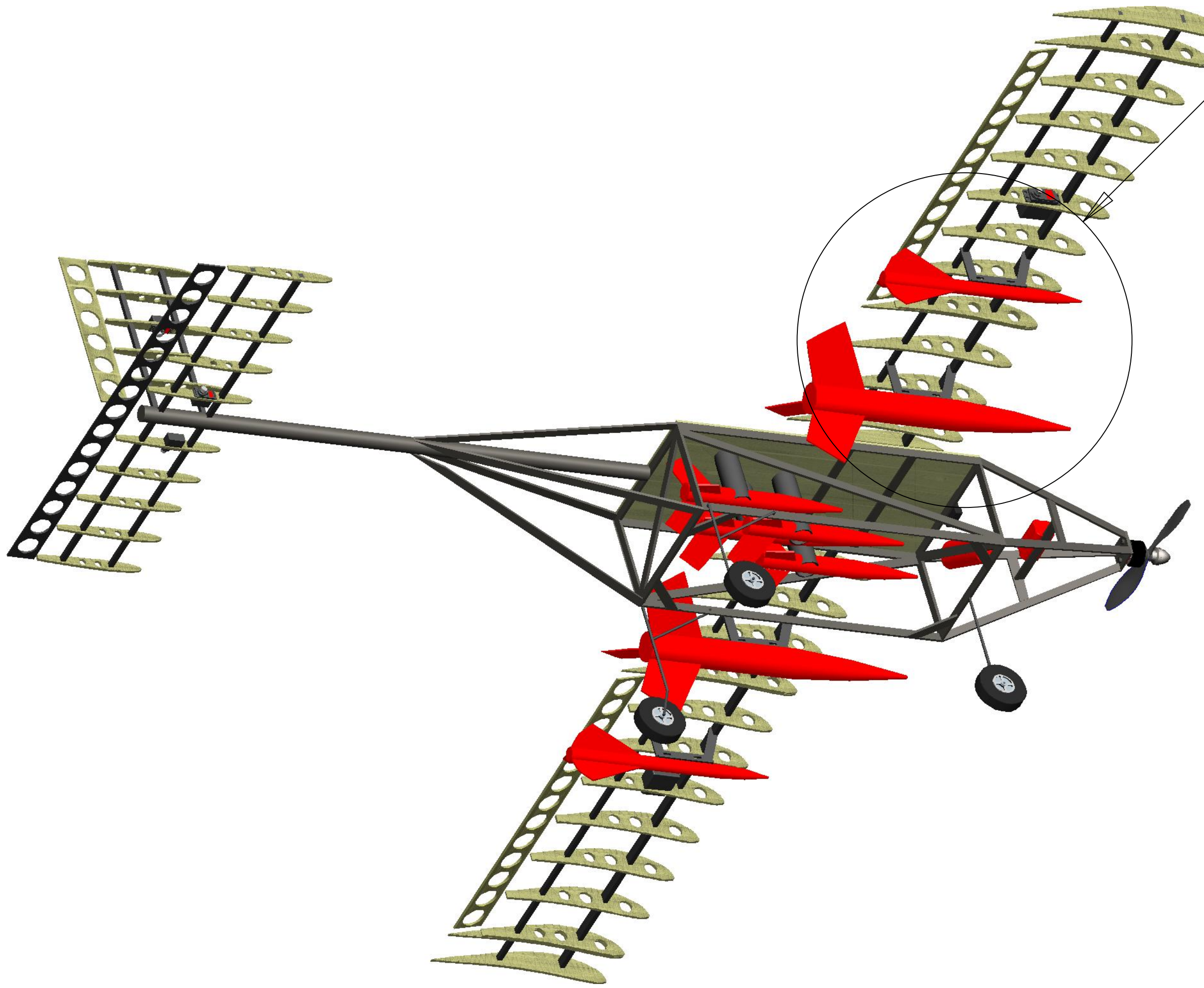
DOCUMENT TITLE

Internal Store Configuration

TEAM NAME	DATE APPROVED	REPORT TITLE	SIZE
PEGASUS	02/19/2013	DRAWING PACKAGE	B

DRAWN BY	SCALE	SHEET NUMBER
WILL WATTS	0.400	3 of 4



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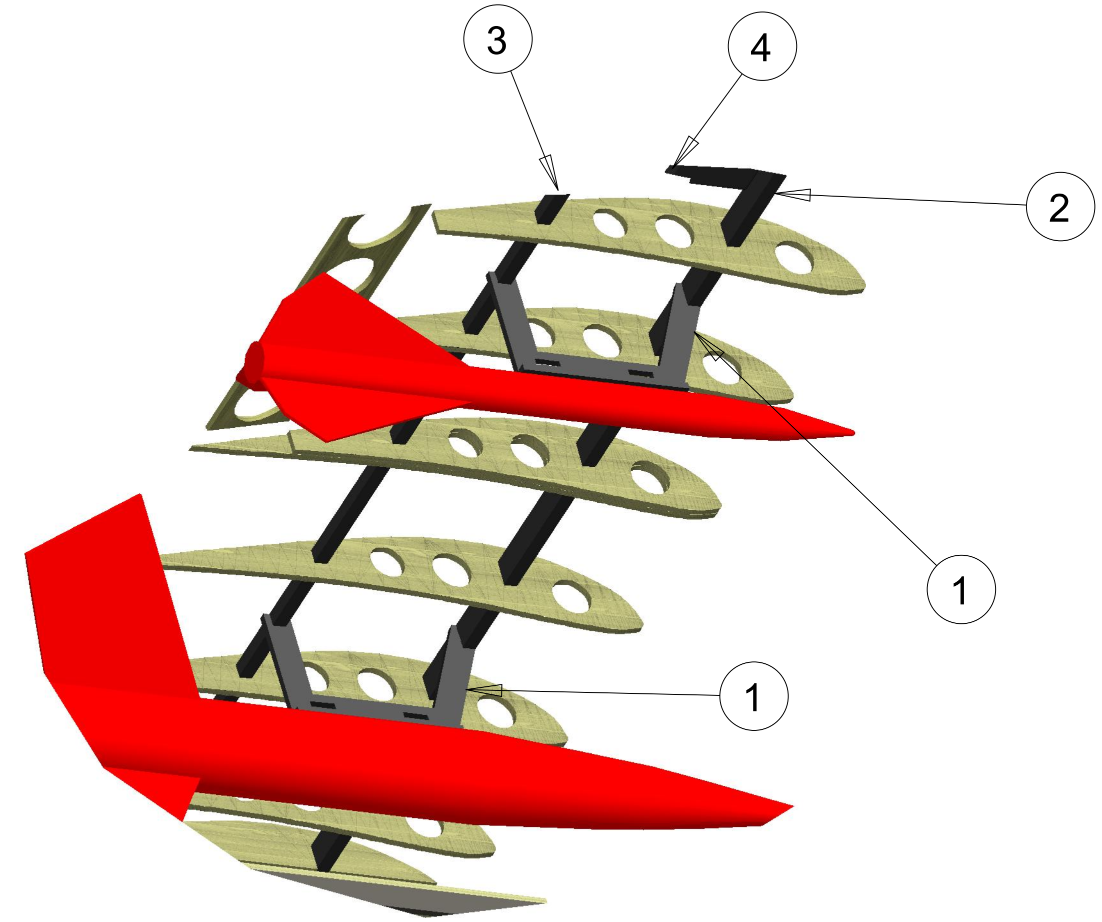

DETAIL A
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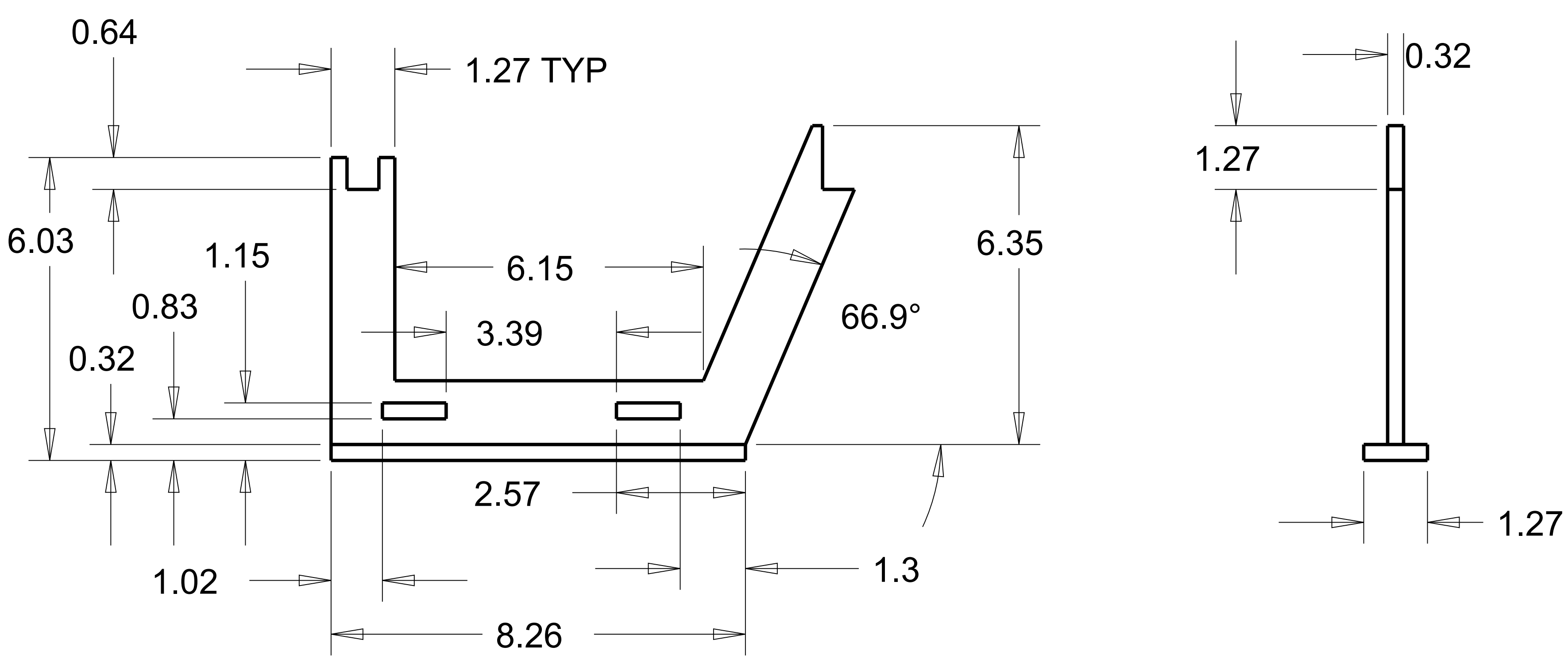

	Item
1	External Store Bracket
2	Main Spar
3	Secondary Spar
4	Alerion Servo

NOTE:
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DOCUMENT TITLE

External Store Attachment Method

TEAM NAME	DATE APPROVED	REPORT TITLE	SIZE
PEGASUS	02/19/2013	DRAWING PACKAGE	B

DRAWN BY	SCALE	SHEET NUMBER
Lee Becker	0.75	4 of 4

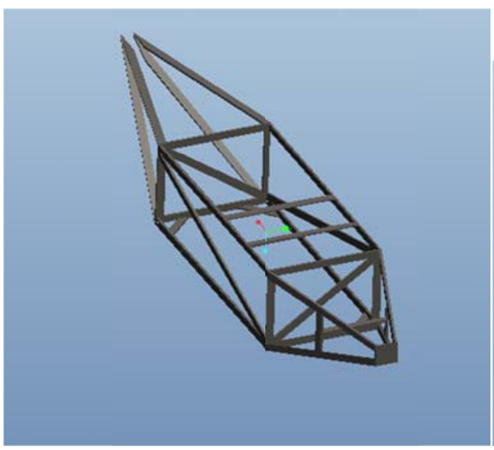
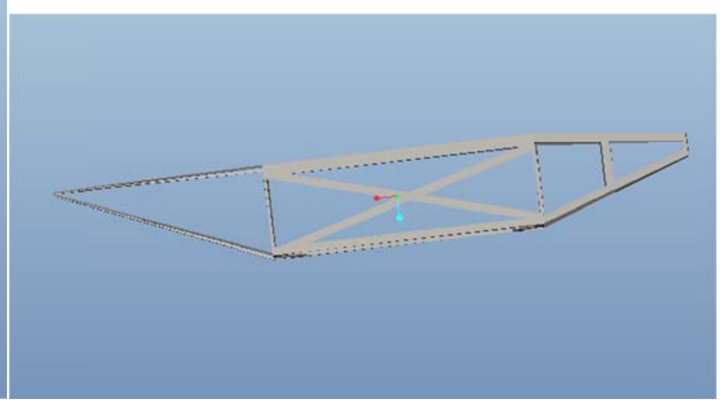
6.0 Manufacturing Plan and Processes

6.1 Materials Selected

The primary goal in materials selection is to minimize cost and meet all product specification goals that are outlined. For optimal performance, it has been decided to select materials that have a high Young's modulus, while maintaining relatively low weight properties. It was also considered to choose materials that could be manufactured easily, due to limited resources. Composite materials and natural materials are the optimal choices to complete the job. Balsa wood is a primary choice for its strength and low weight. It has also proven effective for past competitions. Carbon fiber composite shares these characteristics, but is stronger.

6.2 Fuselage

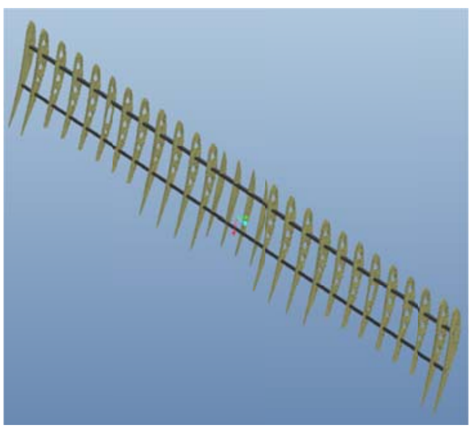
The fuselage is made of a carbon fiber frame, topped off by a sheet of basswood in order for the internal stores to have an attachment point. The frame will be covered with Monokote, further aiding in keeping the weight low. The fuselage will be accessible from the bottom, per contest rules.

Figures 25 and 26 show the basic frame for the fuselage, designed primarily to secure 4 rockets.

6.3 Wing

The main wing was composed of two principal materials. The wing ribs were laser cut from balsa sheets. The spars were hand cut from a longer square profile .25 inch by .25 inch carbon fiber tube. The forward spar was made by epoxying two carbon fiber tubes together in order to create one ultra-rigid spar that is double the height of the other. The wings were constructed by creating (34) EPPLER 422 ribs, while truncating some ribs to lie over top the fuselage, and truncating others to make space for the ailerons. After all of the ribs were cut with holes to reduce weight and to make room for the spars, the system was bound together using standard small aircraft adhesive. In order to properly apply the shrink-wrap cover more effectively, a sheet of 1/32 inch balsa was steamed and form fitted to the leading edge of the wing. This helps in adding damage resistance to the wing in transport and helps reduce shear that could tear the shrink wrap in the event of the wing flexing too hard. Next, the external stores attachment pieces were attached spars and the structure of the wing was complete. Finally, the shrink wrap was applied to the wing, thereby completing its fabrication.



Figures 25 and 26 show our Preliminary wing model and a photo of its construction (with control surfaces included)

6.4 Tail

The tail, which is made up of the rudder and elevator, is made up of the same materials as the Fuselage. In this case the Balsa wood ribs were formed into a NACA (SOMETHING) symmetric airfoil instead. Elevator is made up of two equal sized carbon fiber tubes, and the rudder is made up of one carbon fiber tube. The manufacturing is a similar process. The ribs were cut to reduce weight, and to leave space for the tubes

.

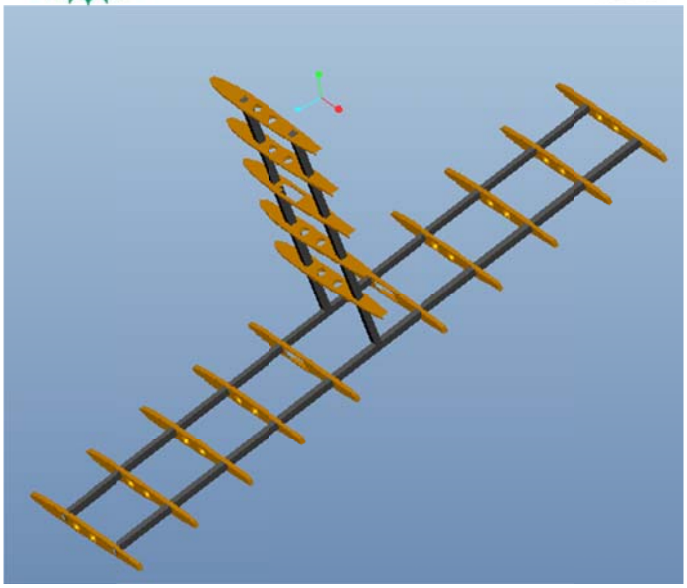


Figure 27 shows a 3-d rendering of our tail section.

6.5 Landing Gear

The landing gear is composed of a small quantity of steel piano wire. The reason this material was selected was for its high elastic modulus. A steel bar is capable of absorbing adequate energy in its deflection at landing such that it is reliable for multiple landings before it begins to show signs of strain and needs to be replaced (like all aircraft components). The landing gear was fabricated by taking a single thin steel bar and bending it to fit the eight-inch base of our fuselage, and the bending it once more to house the ultra-light wheels which sit in their place plainly on the non-rolling steel axle.

Figure 28 shows a 3-d model of our landing gear, which shows a toe of zero and a camber of zero to minimize taxi roll resistance at take-off.

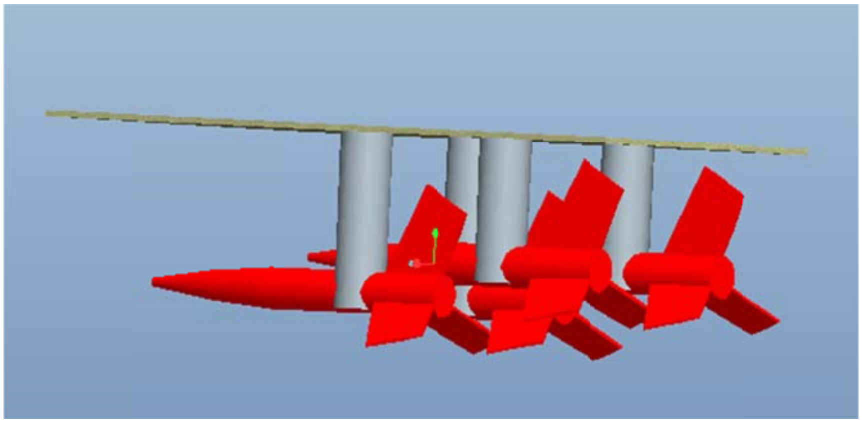


Figure 29

6.6 Internal Stores Attachment

The internal stores will be attached to the plane by fitting into a plastic tube which is attached to the inner roof of the aircraft and can be loaded from the bottom bay door of the aircraft. The internal stores attachment fabrication method was simple. To create the internal stores attachment, we took several pieces of 1-1/4" inner diameter tubing, and drilled a 1" hole through the center profile of the cylinder near the base. This allows for the rocket to be pushed into place by lightly displacing the elastic composite material, which will snap back into place when the rocket has crossed its threshold.

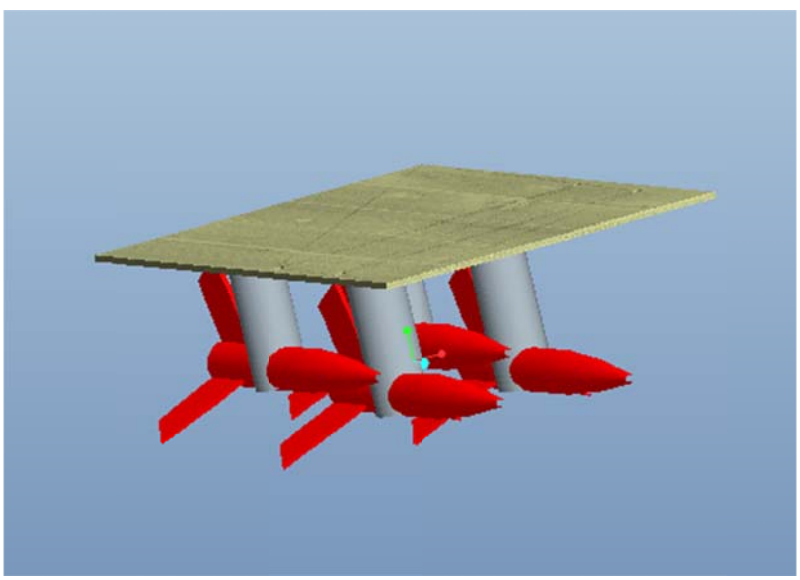
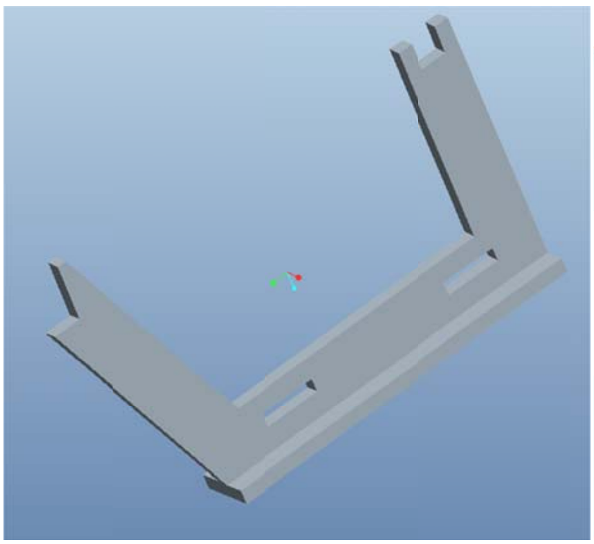


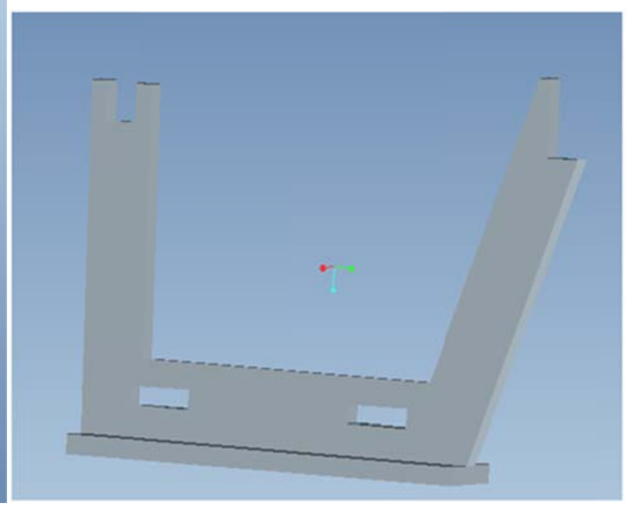
Figure 30

Figures 29 and 30 show the internal stores sitting in their intended configuration which has been designed to minimize the square profile of the housing for them.

6.7 External Store Attachment

The external stores will be attached to the underside of the main wing by the use of a “U-shaped’ bracket that is connected to the main and secondary spars. The bracket will be made of carbon fiber composite strips. It will be composed of three separate strip segments, each cut at the proper angle in order to form the desired shape, so that they can be put together using an epoxy resin. There will be two small holes placed in them so that the rockets can be zip tied to the bracket. This will reduce the time it takes to attach the stores.

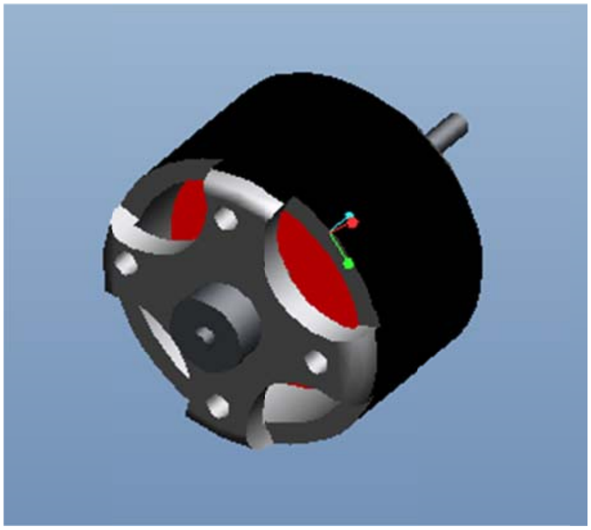


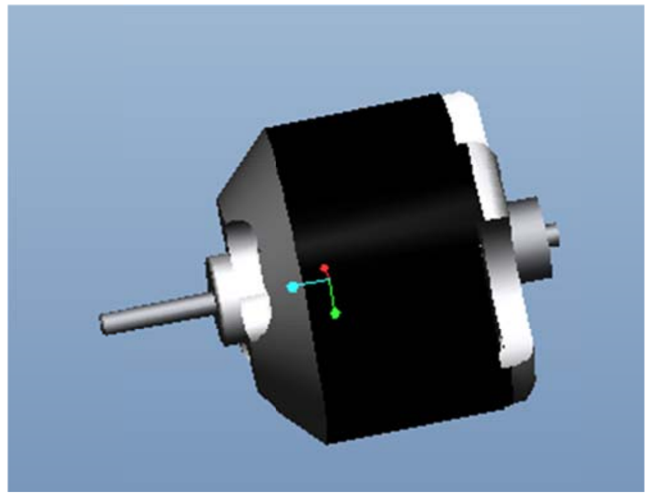


Figures 31 and 32 respectively show the external store attachment devices, which will adhere to the spars at the top, and allow for a zip tie to the rocket through the holes at the bottom.

7.0 Component Testing

7.1 Propulsion Testing





Figures 33 and 34 respectively show two angles of the motor that we have chosen (Turnigy 1320 Kv)

In order to ensure that the system is capable of successfully taking off in a 30’x30’ square, there is a considerable amount of optimization that must be completed in order to minimize risk of overstepping the boundary in our full weight take-off. Safe and controlled taxiing is also tested in this phase.

The testing for the propulsion system began with purchasing a small array of motors and propellers. The motors were chosen for their rated static thrust when combined with a range of manufacturer tested propellers. Our testing method was to assemble the propulsion system via a test rig, and rather than ordering an array of batteries, a BK Precision brand power supply rated for over twenty amps was used.

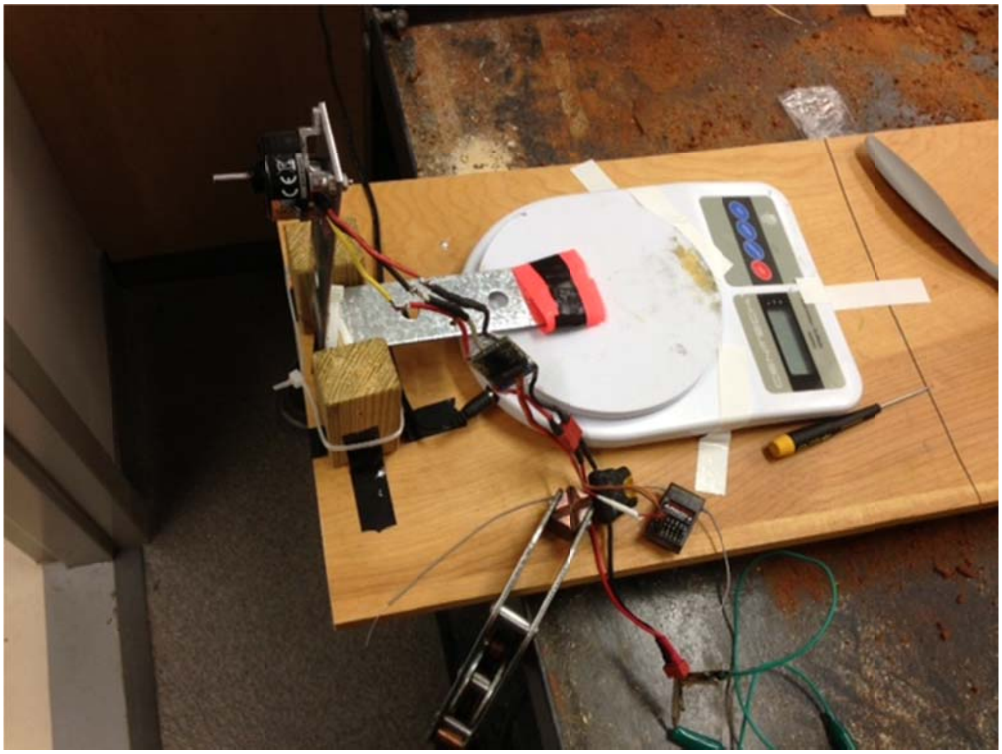
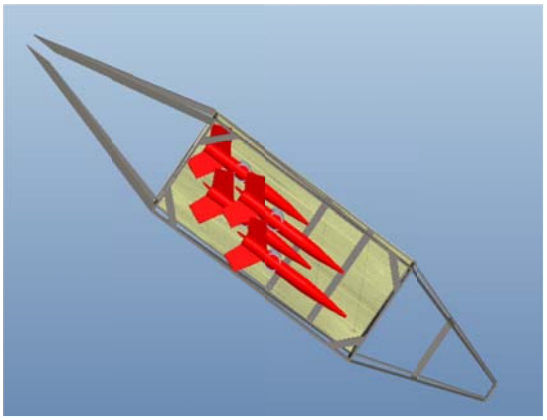
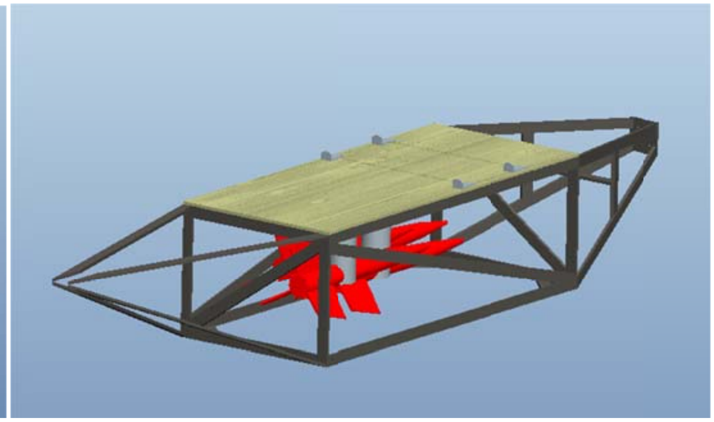


Figure 35 shows a photo of our propulsion test rig with the propeller removed.

In the test depicted in the photo above, thrust was measured on a digital scale due to a reversed propeller on a fixed motor. In this test, the propulsion was hooked up to a power supply box (rather than a battery) and the system was tested in order to measure static thrust and amperage draw due to various propeller dimensions and two motors. The test was done by using an equal length moment arm to transfer a force through 1:1 mechanical advantage from aero thrust to vertical weight pressing onto the digital scale shown.

7.2 Internal Stores Securement Testing





Figures 36 and 37 show the internals stores and fuselage, illustrating how the two fit together in a secure unit.

In order to partake in the competition, we must be 100% confident that our aircraft can hold the internal and external stores securely. This testing will ensure that what takes off with of the aircraft will land with the aircraft.

This testing was done by inspection. After inserting the rockets into their attachment device, it could be determined that they would come loose from any force that flight or a hard landing could subject.

Safety Testing

This is a simple inspection that will determine that all battery packs are shrink-wrapped. The propulsion electronics system must be limited by a 20-Amp fuse. This testing was done by inspection and it was determined by multiple witnesses that there were no tears in any shrink wrap seams for any electrical components.

7.3 Wing Load Testing

Given the load the wing will be subjected to, our wing was equipped with two very strong carbon fiber spars. These spars will minimize wing deflection, ensuring that the materials that make up the wing will remain intact and will not crack due to acrobatic loading in flight.

The wing was tested by taking the spar itself and subjecting a static load to the center point, while measuring the deflection (in centimeters), and analyzing the gram load at center's effect on the angle of deflection of the square profile carbon fiber tube.

8.0 Testing Results

8.1 Propulsion Testing

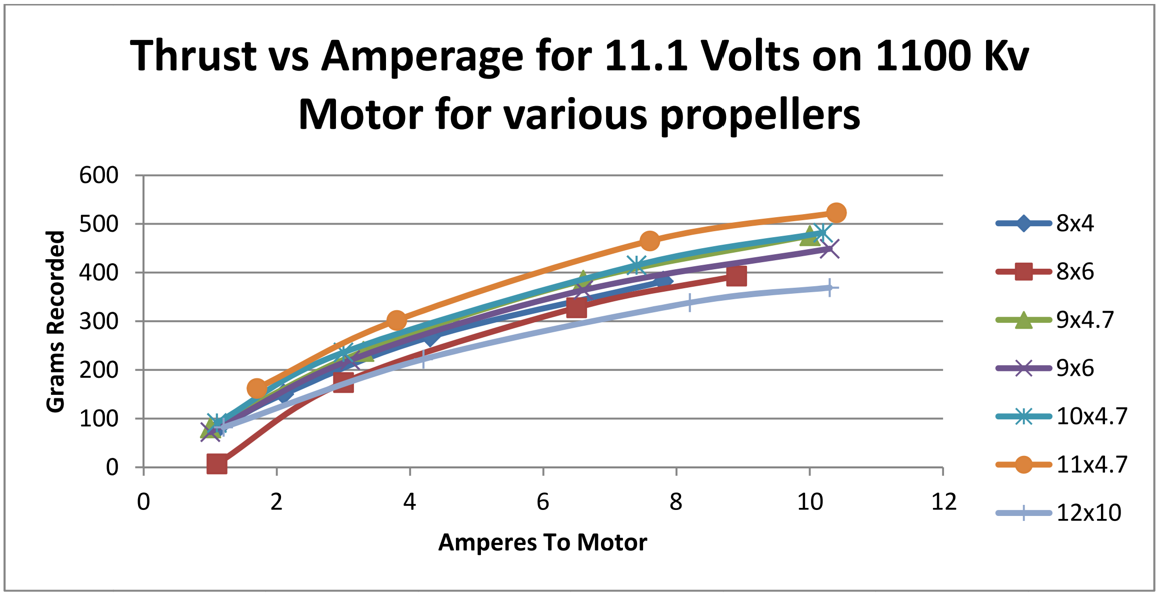


Figure 37 shows the relationship between thrust generated and the amperes pulled by the motor for an 1100 Kv motor by an array of propellers.

For each propeller tested on the 1100 Kv motor, the amount of thrust increased as the amount of amperage increased. It is safe to say that as the amperage approaches the maximum of 20A, the thrust will continue to rise. The propeller with the 11 inch diameter and 4.7 inch pitch performed the best out of the 7 propellers tested, maxing out at 524g of thrust while running on 10.4A. The smaller propellers (those with a small diameter) did not fare as well as the larger propellers. Another noticeable trend is that the propellers with the lower pitch performed better overall, than the other propellers. This is attributed to the fact that these propellers have a shorter distance to complete a 360° turn. Therefore, the propeller with a higher diameter and low pitch is desirable

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
Kv:	1100	1100	1100	1100	1100	1100	1100	1100
Voltage:	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Prop Length:	8	8	9	9	10	10	11	12
Prop Pitch:	4	6	4.7	6	4.7	7	4.7	10
Amperage 1:	1.1	1.1	1	1	1.1	1.3	1.7	1.2
Static Thrust 1:	78	6.9	81	72	91	92	162	82
Amperage 2:	2.1	3	3.3	3.1	3	3.9	3.8	4.2
Static Thrust 2:	150	174	238	220	236	237	302	222
Amperage 3:	4.3	6.5	6.6	6.6	7.4	7.7	7.6	8.2
Static Thrust 3:	268	328	384	364	415	360	465	338
Amperage 4:	7.8	8.9	10	10.3	10.2	10.4	10.4	10.3
Static Thrust 4:	382	393	476	449	482	409	523	369

Table 12 shows the data that has been truncated before the point where the equipment could not provide consistent results. The trend is generally logarithmic.

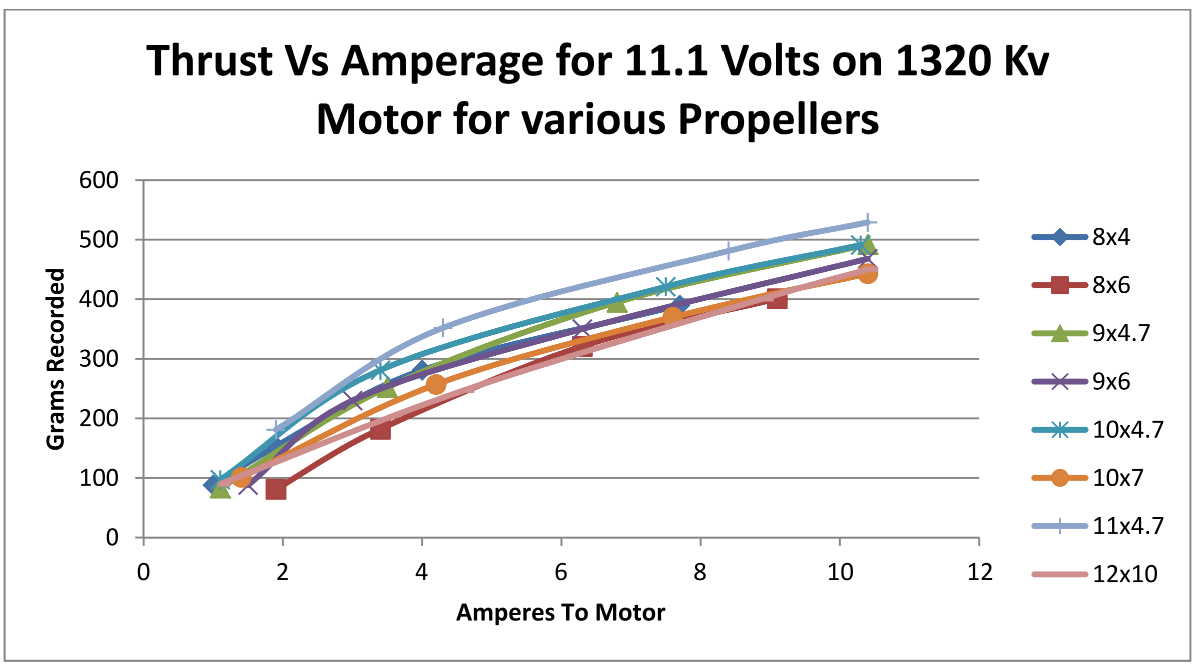


Figure 38 shows the relationship between thrust generated and the amperes pulled by the motor for an 1320 Kv motor by an array of propellers.

For each propeller tested on the 1320 Kv motor, there was a similar trend as the 1100 Kv motor: the amount of thrust increased as the amount of amperage increased. The propeller with the 11 inch diameter and 4.7 inch pitch again performed the best out of the 7 propellers tested, maxing out at 529g of thrust while running on 10.4A. Across the entire sample, this motor allowed the static thrust to increase for all of the propellers. Since the competition requires that takeoff happens within a small area, it is desired to have a motor that will allow a high thrust. The smaller propellers showed the same trend as the 100 Kv motor. Since the trends are much of the same and we need the most thrust that our aircraft can handle, the 1320 Kv motor has been chosen over the former.

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
Kv:	1100	1100	1100	1100	1100	1100	1100	1100
Voltage:	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
Prop Length:	8	8	9	9	10	10	11	12
Prop Pitch:	4	6	4.7	6	4.7	7	4.7	10
Amperage 1:	1	1.9	1.1	1.5	1.1	1.4	1.9	1.1
Static Thrust 1:	88	81	83	88	97	101	181	90
Amperage 2:	1.9	3.4	3.5	3	3.4	4.2	4.3	4.6
Static Thrust 2:	153	182	252	230	281	257	352	247
Amperage 3:	4	6.3	6.8	6.3	7.5	7.6	8.4	8.9
Static Thrust 3:	281	321	395	350	421	370	481	401
Amperage 4:	7.7	9.1	10.4	10.4	10.3	10.4	10.4	10.4
Static Thrust 4:	390	401	492	468	491	443	529	450

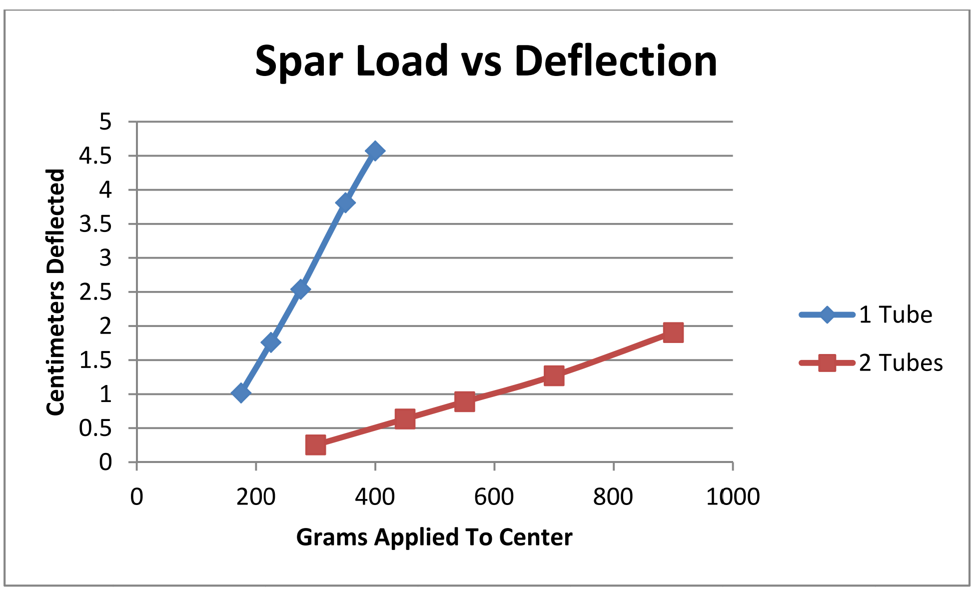
Table 13 the data that has been truncated before the point where the equipment could not provide consistent results. The trend is generally logarithmic.

8.2 Spar Load Testing

The single spar and double spar were tested using various weights at the center of the spar. This was done in order for the team to simulate how the wing would respond under bending. These spars are made of a carbon fiber, and were predicted to respond fairly well to applied loads. As expected, the double spar displayed less elasticity with the applied forces, with the single spar displaying 4 times the deflection as the double spar in most cases. With this being the case, the main wing will contain the double spar running through the ribs. Since the aircraft can experience the most forces during turns, it is desired to use the configuration that is best suited to sustain these forces during flight.

1 Tube		2 Tubes	
g	cm	g	Cm
175	1.016	300	0.254
225	1.76	450	0.635
275	2.54	550	0.889
350	3.81	700	1.27
400	4.572	900	1.905

Table 14 shows a small set of data that indicated the relationship between load applied at the center of our spar and the linear deflection from the zero point of the spar.



Below in Figure 39 are the deflections of the spars shown in centimeters

1 Tube		2 Tubes	
g	degrees	g	degrees
175	0.006441	300	0.003221
225	0.011158	450	0.005767
275	0.016103	550	0.008051
350	0.024154	700	0.011449
400	0.028984	900	0.014492

Table 14 shows a small set of data that indicated the relationship between load applied at the center of our spar and the angular deflection from the zero point of the spar.

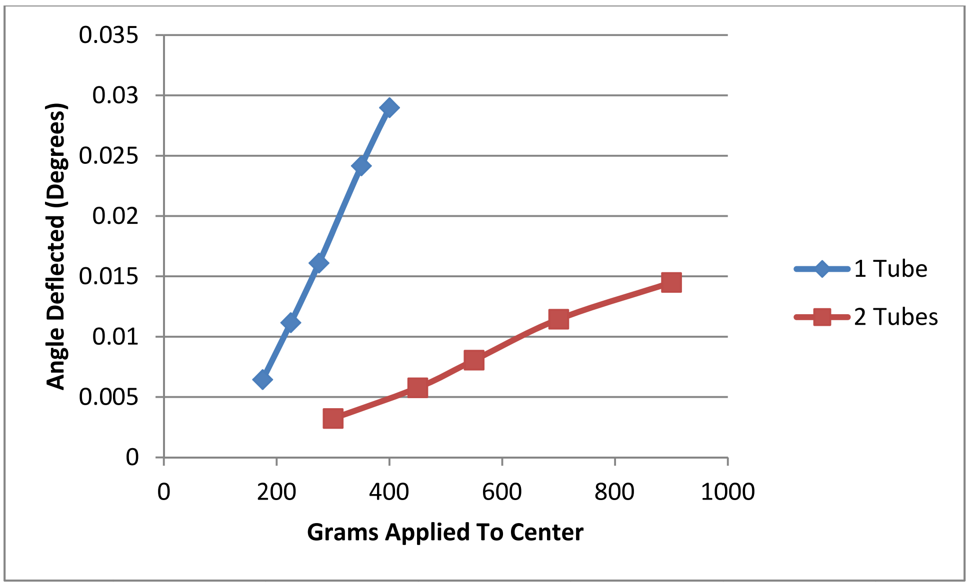


Figure 40 shows the relationship between force applied at the center of our spar and the angle of deflection from the (fixed) endpoint under static loading.

The resulting graphs above are principally linear. This is to be expected due to the fact that the spars were not loaded to their respective limits.

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