DJO 1201

Design of a Micro Class Aircraft for the 2012 SAE Aero Design East Competition

Major Qualifying Project Report
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Abstract

The goal of this project was to design and construct a remote controlled aircraft as an entry in the Micro Class of the 2012 SAE Aero Design East Competition. To succeed at the competition, the plane had to be as light as possible, carry a high payload fraction, and fit in a box with a 24” x 18” x 8” interior dimension. The final design has a 50.2 inch wingspan, weighs 0.800 pounds, and is capable of carrying a payload of 2.2 pounds after being hand launched. Innovations such as modular assembly jigs in the fabrication process allow the aircraft to be constructed in less than eight hours. This report details the goals of the competition, design process, and final configuration of the aircraft. By completing aerodynamics, structures, stability, propulsion and selection analysis, the team was able to create a lightweight aircraft with a high payload fraction. By conducting flight testing and analysis, the team has been able to fine tune the aircraft and expects promising results at the competition, scheduled for late April, 2012.

Acknowledgements

The team would like to thank Professors David Olinger and Simon Evans for their guidance and support throughout the project. We would also like to thank our test pilots, Scott Annis and Mickey Callahan of the Millis Model Aircraft Club for their time, comments and enthusiasm, as well as our competition pilot, Eduardo Voloch for the volunteering of his time. The team would also like to thank The Wachusett Barnstormers, South Shore Radio Control Club, the Quinapoxet Flying Model Club and the WPI Student Chapter of the AIAA for providing audiences for practice presentations. We would like to acknowledge the WPI's Engineering Dean Office and Mechanical Engineering Department, the AIAA New England Chapter and the Mass Space Grant Consortium for their generous gifts which provided funding for the team's participation in the competition.

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1.0 Introduction

The goal of this project was to design and construct a remote controlled aircraft as an entry in the Micro Class of the 2012 SAE Aero Design East Competition. The SAE Aero Design East Competition provided several distinct advantages over a general design project. First, it provided explicit requirements in terms of weight, performance and other aspects, as would be expected from a real world customer. Second, it required the team to be able to effectively communicate and exhibit its creation to the competition judges in a real world scenario. Finally, the competitors from other schools provided motivation to the team to work as a cohesive unit to produce the best possible product.

The competition rules governed the design of the project. Table 1 summarizes the main constraints [1].

Table 1: Design Requirements

Sizing	All components must fit disassembled in a 24”x18”x8” carrying case (interior dimensions)
Payload Bay	Must have interior dimensions of at least 2”x2”x5”, be fully enclosed
Takeoff/landing	Must be hand or shuttle launched, landing on grass
Durability	Only the prop can break in order for the flight to be considered successful

The team’s score in competition was based on the aircraft’s empty weight, payload fraction and operational availability in addition to a technical report and presentation. Operational availability was defined as the percentage of successful flights the aircraft made around a simple circuit; Figure 1 shows possible layouts [1].

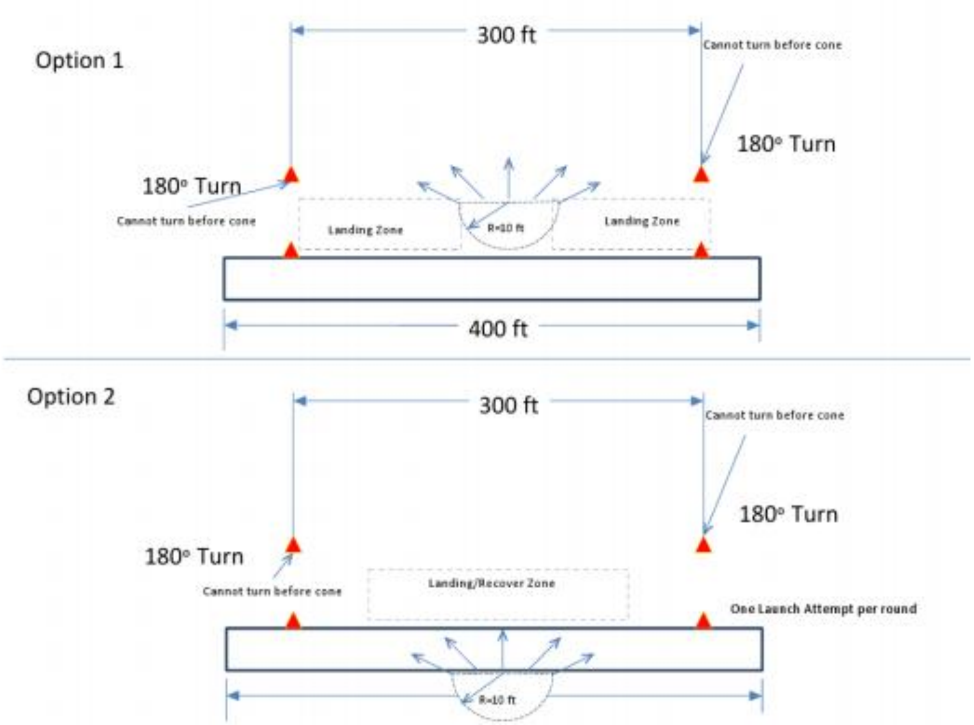

Figure 1: Possible Flight Circuit Layouts

The team's earlier efforts focused on researching the competition (including the aircraft designs of past winners) and the Remote Controlled (RC) aircraft hobby itself. The team then designed our own unique aircraft based upon this research and our own ideas, with decisions being shaped by additional research, experiments, calculations and flight testing. The remainder of this report aims to detail the steps taken by the team to achieve our final goal of a highly competitive aircraft in addition to explaining the final results.

2.0 Research

As WPI has not participated in the SAE Aero Design Competition in over a decade, the team began unaware of the event and with limited knowledge of the RC aircraft hobby. The team compensated for this inexperience with extensive research. Aircraft design textbooks and websites of official research organizations were referenced throughout the initial design process. Past designs from other schools were investigated to gain perspective on the competition. Individuals with experience in RC aircraft were interviewed to explore typical practices and skills involved with the hobby.

2.1 Past Competition Entries

The team examined three entries from past Micro Class competitions: Stevens Institute of Technology from 2006, the University of Minnesota Twin Falls from 2008, and the University of Cincinnati from 2011. The University of Cincinnati aircraft used both wood and composite materials to produce a lightweight, durable structure [2]. The University of Minnesota's design highlighted weight savings by means of a former and longeron configuration in the nose and cutouts in the tail [3]. Stevens Institute of Technology noted that their plane performed poorly in windy conditions because of the small wingspan [4]. The successful aircraft were light and resilient, but large enough to withstand adverse field conditions.

2.2 Hobby Aircraft

The team spoke with employees at RC Buyers Warehouse and members of the Millis Model Aircraft Club to gain insight on commercial products such as skin coat, glue and control systems [5,6]. From the RC shops we learned more on the availability and uses of certain products. Some key points we learned were the different grades of balsa wood, the differences between brushed and brushless motors, and the different types of skin coating material. The club also volunteered two pilots to fly the aircraft, offering comments on its in-flight responsiveness. The team considered this feedback when making design changes after initial flight tests. The feedback often proved very useful as we learned many new concepts such a p-factor, and the true effects of the center of gravity. We also learned a great deal on making on site repairs, which will be a very useful skill for the competition.

3.0 Experimentation and Calculations

This section presents the calculations and experiments used to develop the final aircraft.

3.1 Performance

The team used hand calculation, experimentation, and computer software to ensure the aircraft was capable of meeting the established goals.

3.1.1 Aerodynamic Data

The team performed wind tunnel testing in WPI's 2 foot square, closed-circuit subsonic wind tunnel on a one third-scale model of the aircraft's wing structure (Figure 2). To perform these tests, the team used the force balance created by a previous MQP group [7]. However, due to limitations with the set-up the team was only able to obtain reliable quantities for lift and drag at lower speeds.

Figure 2: One-Third Scale Wind Tunnel Wing

Figure 3 shows the lift coefficients obtained at different angles of attack (AoA), alongside the predicted two-dimensional values corrected for three-dimensional effects. The two-dimensional data was obtained by analyzing the Glenn Martin 4 airfoil in XFOIL at the cruise Reynolds and Mach Numbers (200531 and .027, respectively) [8]. Between -4 and 4 degrees, the team recorded similar lift coefficients for the speeds of 54.0 and 62.4 miles per hour respectively. As the AoA was increased, the values diverged, with a maximum difference of 0.84 at a 6-degree angle. The inability of the testing set-up to record lift forces greater than 2.5 pounds accounts for this discrepancy.

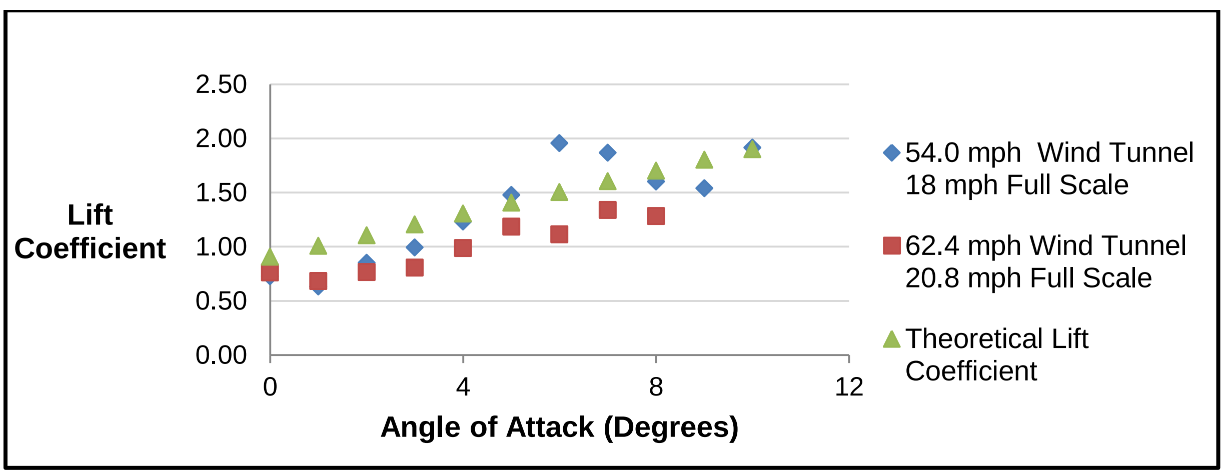

Figure 3: Lift Coefficient versus Angle of Attack

The actual lift coefficient values deviate from the theoretical ones for both speeds. This is because the wing is three-dimensional and a polyhedral. The polyhedral design reduces the upwards component of the lift in exchange for added roll stability; a choice the team made to save weight by reducing the need for ailerons. Using the lift coefficient data and Eq.1

$$L = C_L * \frac{1}{2} * \rho * V^2 * A \qquad (1)$$

(Where L is the lift, C_L is the lift coefficient, ρ is air's density, V is velocity, and A is cross-sectional area) an aircraft lift of three pounds was calculated. With an expected empty aircraft weight of 0.800 pounds, this yields an expected payload weight and payload fraction of 2.2 pounds and 0.733 respectively.

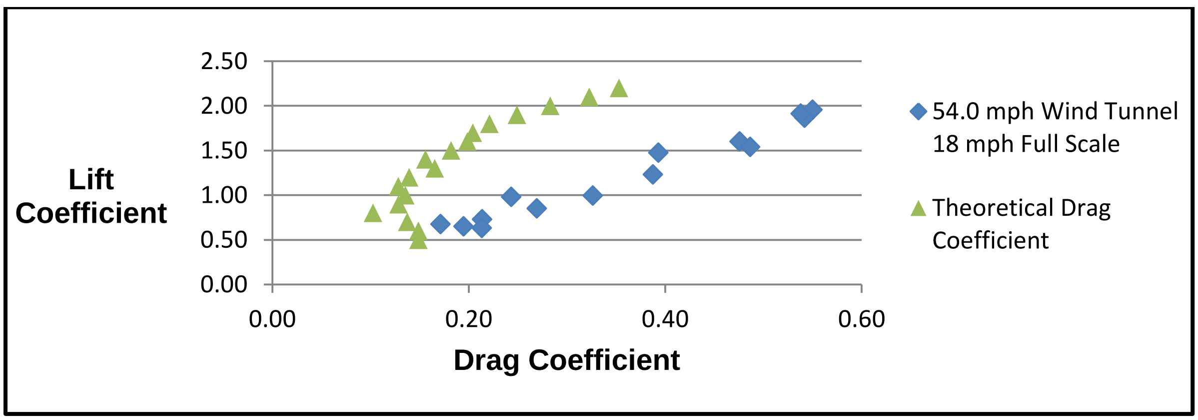

Figure 4: Drag Polar

Figure 4 shows an increased observed drag compared to the theoretical values for the airfoil. To develop these values, the team added the induced drag and parasitic drag to 2-D airfoil data [9]. The ridged surface of the test wing, caused by the rapid prototyper, caused an increase in drag. The remainder of the difference is assumed to be due to the polyhedral. However the motor is more than capable of overcoming the maximum drag found in testing.

3.1.2 Power Plant Performance

Based on the aerodynamic data from wind tunnel testing, the team was able to calculate the plane's power plant performance. In order to lift 3 pounds, the cruise speed of the aircraft must be 28 miles per hour. The equation to calculate the power output by the motor is:

$$P_M = v_p \tau = 154 \text{ W} \tag{2}$$

Where v_p is the pitch speed, and τ is the torque output by the motor. The equation for dynamic trust, T, is:

$$\mathrm{T} = T^3 + \left(2\rho A_p P_M v_p T\right) - \left(2\rho A_p P_M^2\right) \tag{3}$$

Where ρ=1.2 kg/m^2 (air density), A_p is the disc area swept out by the propeller, and v_p the velocity of the disc. Eq.3 yields a thrust of 24.2 ounces.   .

All other key parameters, such as stall speed, battery life and motor efficiency, were found using the *MotoCalc 8* software program [10]. The team entered key attributes of the aircraft, including wingspan, planform area, and the electronic components into the program which output the aircraft's flight envelope.

To measure static thrust, the team designed a high resolution digital thrust stand shown in Figure 5. It consists of a motor mounted to a wooden cone resting on a scale. The team ran the motor at full throttle to find a maximum static thrust value of 25.1 ounces. This data verified that the motor provides enough thrust for the desired flight conditions.

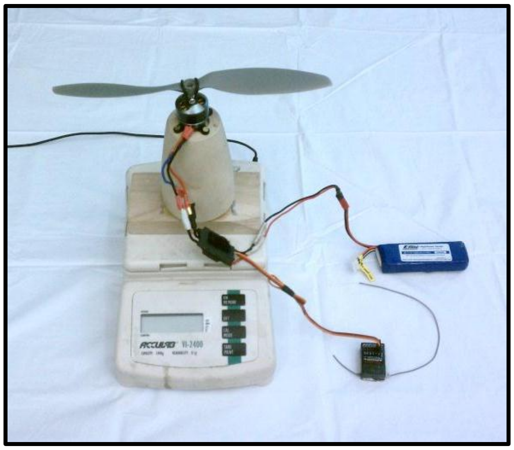

Figure 5: Thrust Stand

Figure 6 shows the thrust provided by the motor versus the drag experienced by the aircraft as a function of speed. The motor is capable of meeting and exceeding the drag for all reasonable cruise speeds.

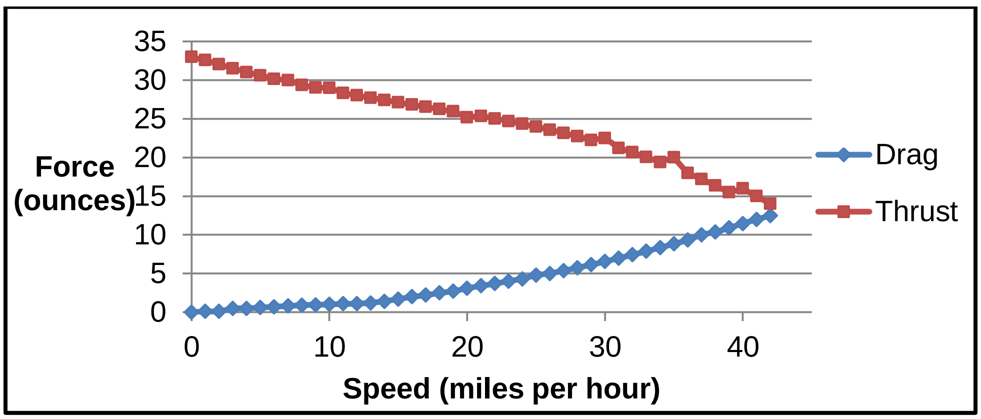

Figure 6: Thrust-Drag Plot

Another key characteristic of an R/C plane's propulsion is its power to weight ratio (P/W); the plane has a P/W ratio of 76 Watts per pound, which is acceptable for aircraft that do not require high maneuverability.

3.1.3 Competitive Performance

The main goal of the aircraft is to obtain as high a flight score as possible in the SAE Aero Design Competition, given by the equation below [1].

$$FS = (2 - EW)(PF)120 = 105.6 \quad (4)$$

Here FS is the flight score, EW the empty weight of the aircraft and PF the payload weight divided by the total weight of the loaded aircraft.

In addition to the explicitly stated rules, such as those shown in Table 1, this equation governed the design of the aircraft. With the current aircraft weight EW= 0.800 pounds and maximum payload of 2.18 pounds, the predicted flight score of the aircraft is 105.6, 7.5 points more than last that of year's winner [11].

3.2 Stability and Control

In order to have a statically stable aircraft in pitch, the center of gravity needs to lie between the most forward and neutral points of the aircraft. By having an up-to-date model of the plane in *SolidWorks* the team was able to specify the materials and densities for each part [12]. The team could then use *SolidWorks* to estimate the aircraft's center of gravity at any time. The team used historical data from full-size aircraft to determine initial dimensions for the elevators and rudders [13]. Results from initial flight testing led the team to decide to increase the size of the rudder, while decreasing that of the elevator for better response, while keeping in mind the effect of these changes on the stability envelope.

The team created an *Excel* spreadsheet programming tool containing the equations for the forward point, neutral point, static margin, size of the stability envelope, and the relevant parameters of the aircraft [14]. All distances were measured from the nose of the fuselage, and normalized by $\bar{C}$, the mean aerodynamic chord of the aircraft. This tool allowed the team to manipulate dimensions and determine the effect such changes had on the stability envelope.

To calculate the most forward point of the aircraft, $\bar{x}_{mf}$, the team used the equation:

$$\bar{x}_{mf} = \frac{x_{mf}}{\bar{C}} = \frac{-0.15 + \bar{x}_{ac_W} + A * \bar{x}_{ac_H}}{1 + A} = 1.064 \quad (5)$$

Where $\bar{x}_{ac_w}$ is the location of the wing aerodynamic center; $\bar{x}_{ac_H}$ is the location of the horizontal tail aerodynamic center and A (a stability coefficient) is given by:

$$A = \eta_H * \frac{S_H}{S_w} * \frac{C_{L\alpha_H}}{C_{L\alpha w}} * \frac{d\alpha_H}{d\alpha} = 0.0945 \quad (6)$$

Where η_H accounts for wake effects; S_H is the planform area of the horizontal tail, and S_w is the planform area of the wings. $C_{L\alpha_H}$ is the lift curve slope of the tail; $C_{L\alpha w}$ is the lift curve slope of the wings, and $\frac{d\alpha_H}{d\alpha}$ are the wing tip effects.

The equation to find the neutral point of the aircraft is:

$$\bar{x}_{np} = \frac{x_{np}}{\bar{C}} = \frac{C_{L\alpha_W} * \bar{x}_{ac_W} + \eta_H * \frac{S_H}{S_W} * C_{L\alpha_H} * \frac{d\alpha_H}{d\alpha} * \bar{x}_{ac_H}}{C_{L\alpha_W} + \eta_H * \frac{S_H}{S_W} * C_{L\alpha_W} * \frac{d\alpha_H}{d\alpha}} = 1.220 \quad (7)$$

The equation for the size of the stability envelope is:

$$SE = \bar{x}_{np} - \bar{\bar{x}}_{mf} = 1.060\ in \quad (8)$$

Using *SolidWorks*, the team calculated the normalized center of gravity without payload as 1.184, which falls within the stability envelope, which is visualized in Figure 7. The calculated normalized center of gravity with payload was 1.226, which is 0.006 inches aft of the neutral point. After a flight test under these conditions, the plane proved to be too sensitive to pitch and began to porpoise, causing the wings to snap in flight. Consequently, the payload was modified to maintain a constant center of gravity both when empty and with payload.

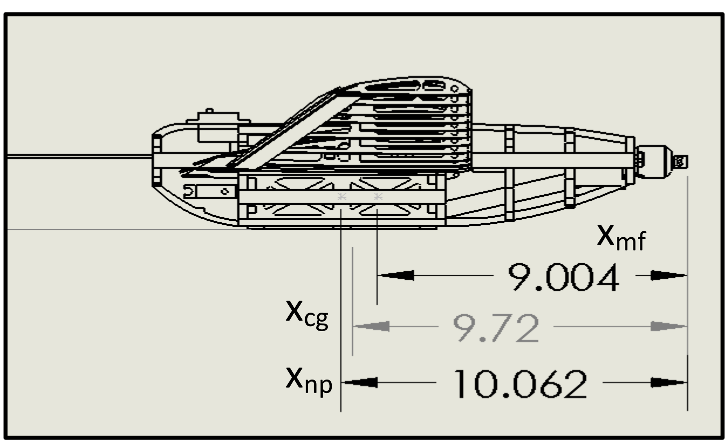

Figure 7: Stability Envelope

3.3 Weight Build-up

Table 2 shows the weight build up used by the team to track the weight of individual components. This table was used during the iteration process to identify potential sections of the aircraft for weight reduction.

Table 2: Weight Build up

Wing Assembly	Starboard	Balsa Wood	0.040	Tail Assembly	Balsa Wood	0.027
		Carbon Fiber Support	0.030		Carbon Fiber Boom	0.010
		Glue	0.018		Glue	0.004
		Skin Coat	0.018		Skin Coat	0.001
		Subtotal	0.106		Pull-Pull Control System	0.008
	Port	Balsa Wood	0.040		Subtotal	0.050
		Carbon Fiber Support	0.030	Electronics Assembly	Servos (x2)	0.050
		Glue	0.018		Battery	0.141
		Skin Coat	0.018		Receiver	0.012
		Subtotal	0.106		ESC	0.049
Misc.		Wing CF Spars (x2)	0.035		Motor (and shunt plug)	0.109
		Duct Tape	0.007		Propeller	0.012
		Subtotal	0.042		Subtotal	0.373
Fuselage		Balsa Wood	0.066	Payload Bay	Balsa Wood	0.015
		Glue	0.010		Skin Coat	0.010
		Skin Coat	0.018		Glue	0.004
		Subtotal	0.094		Subtotal	0.029
Total Assembly Weight [lbs]:					**0.800**	

The final weight was able to be reduced to 0.800 pounds by using even lighter balsa wood. A more detailed weight tracking document is uploaded as a separate file.

3.4 Structural Analysis

A structural integrity and durability analysis was critical due to the low density balsa utilized in the planes. The team selected contest grade balsa as the main material for the aircraft due to its low density of 4-7 pounds per cubic foot (compared to 10 pounds per cubic foot for regular balsa wood) [15]. While the yield strength also decreases with density, it did not vary enough to cause the team concern.

3.4.1 Finite Element Analysis

The team attempted to use ANSYS and SolidWorks Simulation Finite Element Analysis (FEA) software to estimate the stresses experienced by the wings and fuselage during flight [16, 12]. These attempts were unsuccessful because of the numerous interferences between parts found in the SolidWorks model. The team concluded that the time needed to fix the CAD model was excessive given the very limited schedule due to the competition deadline. With the assistance of Professor Olinger the team performed basic numerical calculations obtained from the ME 4770 Aircraft Design Class from C-term of 2011 [17].

3.4.2 Numerical Calculations

Because of the complexity of these calculations the team simplified the wings to two cantilever beams made out of a circular cross section, hollow tubes. The team approximated an elliptical lift distribution given by the equation:

$$L^{'}(z) = L^{'}_{o}\sqrt{1-\left(\frac{2z}{b}\right)^{2}} \quad (9)$$

Where L'(z) is the elliptical lift distribution along the wing span; z is the distance along the wing span between wing root and tip; b is the total wing span and $L^{'}_{0}$ is a constant determined by the equation:

$$\frac{L}{2} = L^{'}_{o} * \int_{0}^{\frac{b}{2}} \sqrt{1-(2*z/b)^\wedge 2}\ dz = 1.5\ lbf \quad (10)$$

Where L is the total lift experienced by the aircraft. The shear force distribution was found by using

$$V(z) = -L'_{o} * \int_{0}^{\frac{b}{2}} \sqrt{1*\left(2*\frac{z}{b}\right)^{2}}\ dz \quad (11)$$

The shear force distribution on one wing is shown in Figure 8. The distribution was calculated for half the wing span (from root to tip), and the negative sign is there because this force acts downward. The maximum value is 1.5 pounds, or roughly half the plane's total weigh, and it was found at z=0 (root).

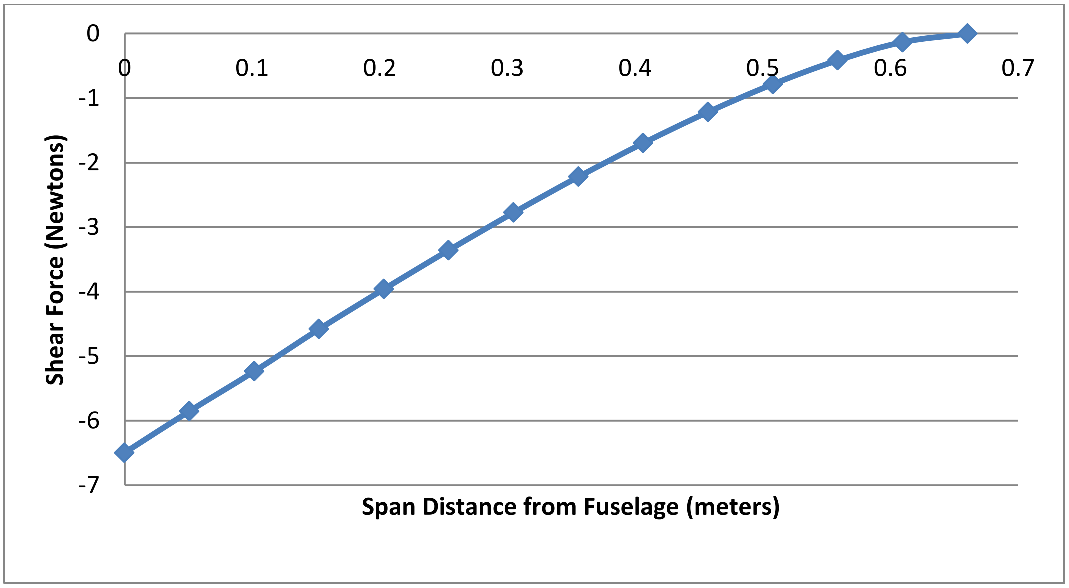

Figure 8: Shear Force Distribution

The team also calculated the bending stress distribution using

$$\sigma_{xx} = -(M * z)/I_{xx}$$

Where σ_{xx} is the bending stress along the x-axis, M is the bending moment as a function of z (from 0 to b/2) and I_{xx} is the area moment of inertia. These values were found to be very high for such low load conditions, with a maximum stress of over 1000 psi and the team concluded they were erroneous. These values were still below the carbon fiber's 80 ksi yield strength [18].

3.4.3 Wing Loading Testing

The group performed a static wing loading test to determine the maximum loading that the wings could experience. A series of weights were used to simulate the wing loading on the aircraft at cruise conditions assuming a total weight of 3 pounds.

The team performed a static wing loading test consisting of a pair of wings connected to the fuselage. The fuselage was then flipped over and weights were applied to simulate the lift forces experienced during cruise (Figure 9).

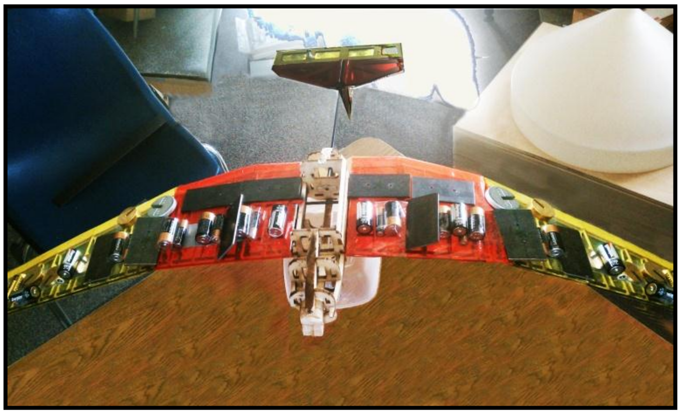

Figure 9: Static Wing Loading Test Set Up

The team added weights to simulate the elliptical lift distribution until failure occurred. The wings failed after experiencing 8.5 pounds of loading when the center rib closest to the dihedral fractured due to excessive bending forces in the left wing. This value was greater than the allowable expected 6 pounds, assuming a total weight of three pounds and a safety factor of two to account for additional forces experienced from maneuvering and wind gusts. The results of this along with the numerical results previously discussed suggested that the plane's wings should not fail during cruise conditions when flying with full payload. The wing tips deflected by approximately 0.5 inches (2.0 % of the wing span) when loaded with the maximum load of 8.5 pounds.

3.4.4 Wing Failure

On March 17, 2012, after three consecutive flights, the aircraft's right wing failed during flight when the pilot tried to gain control of the plane after it fell in a series of oscillations. Upon inspection of the remains, the team concluded that the failure was not due to the wing spars but because excessive bending stresses from the dihedral connectors fractured the center rib closest to the dihedral. After witnessing the same type of failure two times, the team decided to make several changes to the wing to increase its tensile strength.

The first change introduced was the thickening of the rib closest to the dihedral section on each wing to prevent the same type of failure experienced. All the ribs were modified to allow for a narrower top balsa spar and a new bottom spar to run all the way from the root to the dihedral. Finally, a “shear web” was implemented by cutting thin pieces of 1/16 inch thick balsa and gluing them between the top and bottom spars in between ribs. These pieces greatly increased the bending strength of the wing. This was backed up by the results of a second static wing loading test. The new wings were capable of supporting 14.8 pounds, nearly two times as much as the previous design.

3.5 Flight Testing

Starting in February the team went to Medfield for flight testing of the aircraft. Over the course of two and a half months, the team tested four different design iterations of the aircraft. The changes made were in direct response to problems observed during flight testing.

The first design flown had a test-set of landing gear attached to the bottom of the payload bay. For the first trial, the team tried taking off from the ground as it was a windy day. As the plane started to move forward, the tail lifted enough that the propeller hit and dug into the ground, and the resulting torque broke the aircraft. The team was able to made enough field repairs for a second trial, this time hand-launched. This trial also ended in failure, as the plane crashed into the ground after about ten seconds of flight time. The joysticks on the transmitter were wired backwards, so that the thrust and control surfaces were controlled opposite to the industry standard. The pilot was unable to account for this in time, and lost control of the aircraft. At the pilot’s recommendation, the team re-wired the transmitter for all future uses, and also adjusted the sensitivity of the transmitter as the pilot said it was too responsive.

The second iteration flown addressed the issues with the transmitter, and did not have landing gear, instead having a reinforced belly for landing. On this day, the plane flew successfully, while also bringing other things to the team's attention. First, the torque of the motor had not been accounted for, and so the pilot had to constantly give it right-stick to account for the aircraft's tendency to fly left. Second, the first former was strengthened to withstand more force and torque from the motor. Finally, blast plates were added to further reinforce the nose. These changes were all reflected in the third iteration flown.

After flying the third iteration of the plane, wing warping and inconsistencies of the leading edge led the team to put a smaller diameter carbon fiber rod at the leading edge. The team also refined its skin-coating technique, and took more care in the manufacturing process to look for warping earlier on.

The fourth iteration handled better, but the wings were damaged during flight. This led to the team adding shear webbing to the center wings to resist the shear forces induced during flight. This necessitated the addition of a bottom spar to the center wings for the shear webbing to connect to. These changes were the last changes made, and the fifth iteration flew and landed successfully, and is the final design.

In total, the team accumulated 22 flights over the course of the flight testing period, 16 of those being flown with the fifth iteration. Out of these 16 there were only two crashes because of wood grain misalignment in some of the wing components. This flight record yields an 87.5% availability record that is well above the 40%, or four out of 6 successful flights, required by the SAE rules [1].

4.0 Design

This chapter describes the processes followed to create the final assemblies of the aircraft.

4.1 Design Evolution

This section aims to provide a timeline of the team's design process, starting with initial drawings up through the design entered in competition. In doing this, we aim to present major choices made by the team and to provide our justifications for such decisions.

4.1.1 Initial Gliders and Early Sketches

The team started its design process with simple sketches (Appendix D). After reviewing the pertinent literature each team member developed several drawings for the possible aircraft. Two main ideas immediately presented themselves: a conventional aircraft and a flying wing.

The team built a glider of each design to test these ideas. The gliders were constructed mainly from housing insulation, balsa wood, glue and duct tape. These models were built approximately the same size as the final intended aircraft. While visually pleasing, the gliders ultimately failed due to the team's oversight of approximating airfoils on the wings, rather than fitting the wings to the profile of an actual airfoil. The team was able to determine that a flying wing would be more difficult to fit in the case (and, as we would later learn, more difficult to control in flight) and abandoned the idea at this point.

4.1.2 Airfoil Selection

Having settled upon a conventional aircraft design (and knowing that an airfoil would be needed) the team set about establishing a reasonable goal for the aircraft's weight and payload capacity. Based on past entries and analysis of the flight score equation (the team decided the aircraft should weigh no more than one pound and be capable of lifting a total weight of three pounds. This decision combined with the box dimensions, which limited the planform area, and knowledge of typical RC aircraft speeds allowed the team to determine the needed lift coefficient for a given combination of the aforementioned parameters (Figure 10). The team then compared multiple airfoils which would provide lift coefficients in the needed range, at reasonable angles of attack (Table 3) [19].

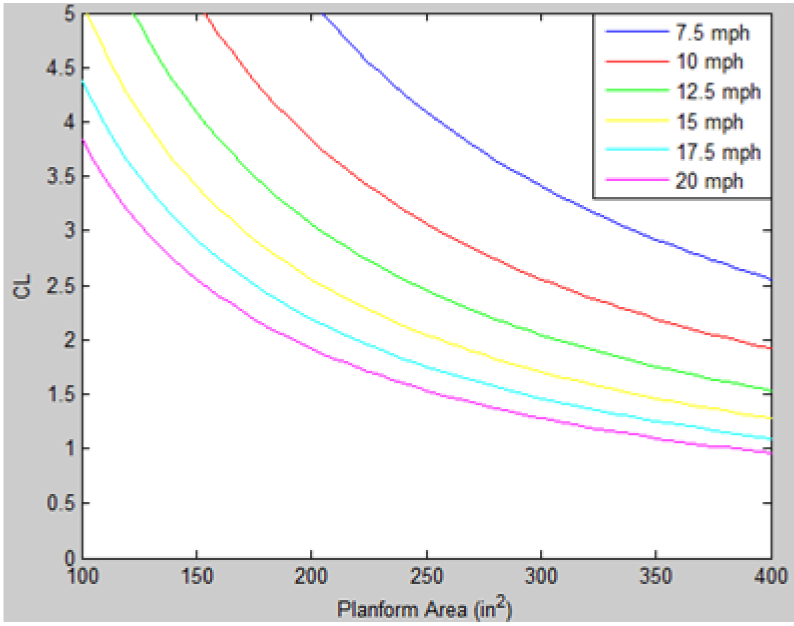

Figure 10: Lift Coefficient vs. Planform Area

Table 3: Airfoil Comparison Chart

	CH10 (smoothed)	EPPLER 421	Glenn Martin 4	GOE 462	S1223
Thickness (%)	12.84	14.57	15.49	10.95	12.14
Camber (%)	10.20	8.72	7.675	13.37	8.67
Trailing Edge Angle (%)	10.33	15.05	18.28	3.71	12.11
Lower Surface Flatness	24.46	58.51	95.42	4.24	17.62
Leading Edge Radius (%)	1.95	5.97	3.72	3.00	3.10
Maximum Lift (C_L)	2.31	2.17	2.42	2.54	2.43
Stall Angle-of-Attack (degrees)	11.5	15	11	10	8
Maximum Lift-to-drag (L/D)	58.74	43.20	70.59	426.30	71.86
Lift at Maximum Lift-to-drag	1.57	0.85	1.87	1.27	2.19
Angle-of-Attack for Maximum Lift-to-drag (L/D)	3	-2	6	0	5.5

The team examined these airfoils based on maximum lift coefficient, stall characteristics, ease of manufacturability and drag properties. We ultimately decided on the Glenn Martin 4

(Figure 11) due to its two-dimensional lift to drag ratio of 70.6, and its maximum lift coefficient of 2.42 that occurs five degrees before stall [16]. Its relatively flat bottom and low camber of 7.7% ensured reliable and replicable manufacturing. The thicker airfoil is also more resistant to breaking during construction.

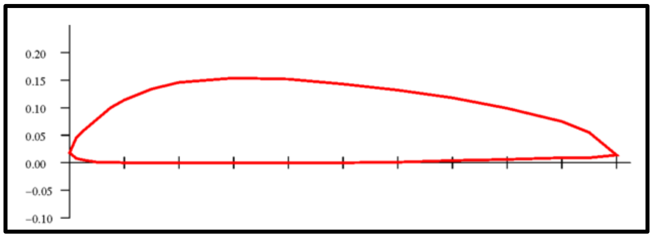

Figure 11: Glenn Martin 4

4.1.3 Second Glider

With the airfoil selected, the team built another, more accurate glider again on the same scale as the final plane. This glider consisted of housing insulation, wood and packing tape (Figure 12). The team performed multiple glide tests with the aircraft, noting good performance. At this point the team tested the notion of using a thin airfoil. This would be achieved by only applying skin coat to the upper surface of the wing, leaving the bottom portion exposed. While lighter and consuming less material, the thin airfoil version of the glider performed less favorably. The team believes this was due to poor weight distribution more than any aerodynamic effects of the wings. However, due to fear of issues created by the exposed ribs on the bottom surface causing a step in the airflow along with the greater possibility of the skin coming detached from the wing the team abandoned this idea.

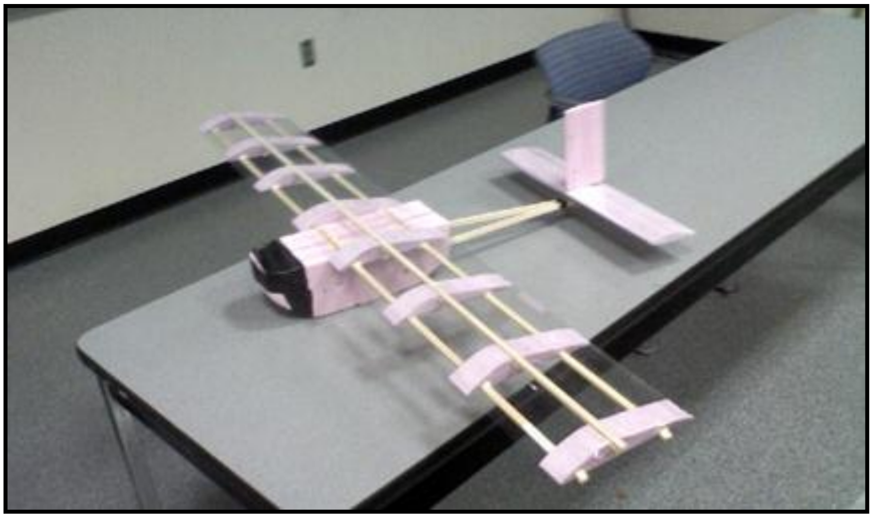

Figure 12: Second Glider

4.1.3 SolidWorks Models

After the second glider, the team developed a more detailed model in SolidWorks. This allowed for easier customization and development of individual components and prevented the team from wasting material. Figure 13 shows screenshots of the model progressing from initial design to the competition entry.

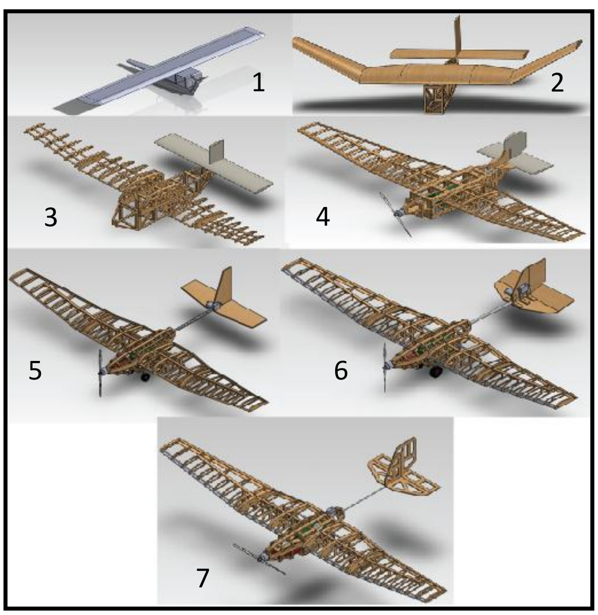

Figure 13: Design Progression

At this stage the team made several key decisions. No planform area that would produce the desired lift would be capable of fitting in the box, with the 24” x 18” x 8” dimensions as a single piece, so the wings had to be split into multiple pieces. While the team originally considered having the wings permanently attached to the fuselage and hinged, no suitable lightweight hinge could be found or devised so we decided to split the wings into two pieces which would be very close to the maximum box length of 24 inches.

After reviewing the course requirements, the team decided to forego the use of ailerons. This decision was made due to the low maneuverability required by the course and the added weight required in both structure and servos. It was also later noted that the introduction of ailerons would create disturbances in the airfoil and the aircraft would need constant trim adjustment [20]. To compensate for the lack of roll control, the wings incorporate a polyhedral design. The angled wings create a non-zero slide slip angle which in turn creates a restoring rolling moment if the plane is disturbed from equilibrium. The wings are polyhedral rather than the typical dihedral for a easier connection to the fuselage. The polyhedral angle was selected as ten degrees based on historical trends.

Originally, the team designed the aircraft to have landing gear. The team felt that landing would otherwise damage the aircraft and present an unnecessary risk to operational availability at competition. Different configurations of landing gear were evaluated, with weight, placement, and wheel size varying. When the team was unable to come up with a set of landing gear that was light-weight and sized correctly to give the propeller enough clearance to not hit the ground on landing, the decision was made to try a belly landing. Flight testing proved that a belly landing was not only possible, but feasible and easily incorporated into the final design.

The team also struggled with designing the payload to meet the rules of the competition. Early ideas included moveable doors or coverings which would allow access to a portion of the fuselage meant to store the payload. Eventually it was decided to create a removable enclosure which could be placed in the fuselage and secured by the same means as the wings. While it most likely added unnecessary weight, the team felt it the best option when compared to other alternatives.

The final problem encountered by the team was the tail. In order for the aircraft to be pitch stable, the distance required between the wings and tail would cause the plane's length to exceed the maximum dimension of the box. The team originally thought this would mean a removable tail but was concerned with the weight and assembly time added by this connection.

4.2 Final Design

This section describes the final layout of the aircraft, its method of assembly and the carrying case which keeps it secure during transport and storage. Figure 14 Full planeFigure 14 shows the final design, dubbed *Tina*, and Table 4 summarizes the key parameters.

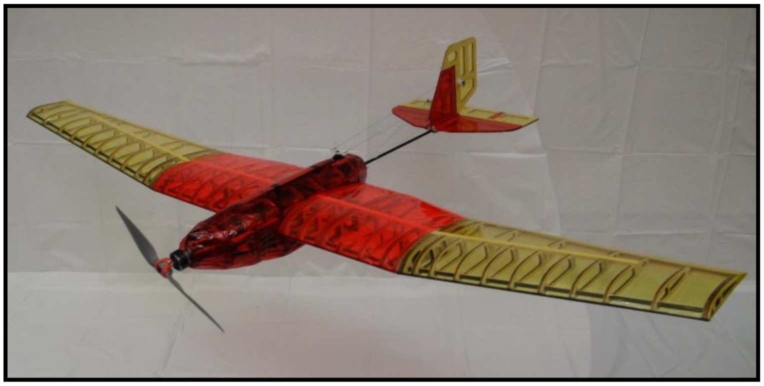

Figure 14 Full plane

Table 4: Key Parameters

Characteristic	Value
Wingspan	50.20 inches
Length	29.74 inches
Height	7.75 inches
Wing Area	292.38 square inches
Empty Weight	0.800 pounds
Max Payload Fraction	0.71
Cruise Speed	28 miles per hour
Aspect Ratio	8.98
Wing Loading at Maximum Payload	0.010 psi
Power to Weight Ratio	76 Watts per pound

4.2.1 Wings

The wing assembly consists of a port and starboard wing (Figure 15) which are mirrors of each other.

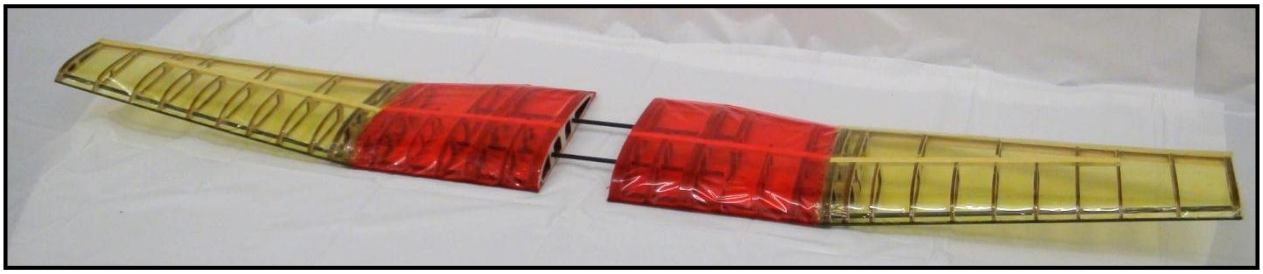

Figure 15: Wing Assembly

The wingspan was determined with respect to the maximum dimension of the carrying case, permitting a span of 23.6 inches. The team tapered the wings to create a more elliptical lift distribution. The taper starts 3.5 inches from the root of each wing in order to provide room for the spars that connect the wings to the fuselage. This gave a chord of 8 inches at the root and 4 inches at the tip. The dihedral angle is set at 10 degrees and occurs 8.5 inches from the root of the wing, allowing for a sizable polyhedral wing and additional roll stability in flight. These values provide an aspect ratio of 8.98 and planform area of 292.38 square inches.

Each wing consists of 18 ribs of various thicknesses arranged to provide structural support and surface area for skin covering. Figure 16 shows the anatomy of two ribs; one has the shape of the full airfoil and the other is a half rib. Holes were cut in the ribs to allow for a leading edge guide (**A**), a main spar (**B**), top and bottom support (**C**), trailing edges (**D**) and reduce weight (**E**). The three wings closest to the fuselage have additional holes (**F**) to allow the support struts to pass through. The half rib maintains the shape of the airfoil while providing surface area to apply the skin coat and reduce weight.

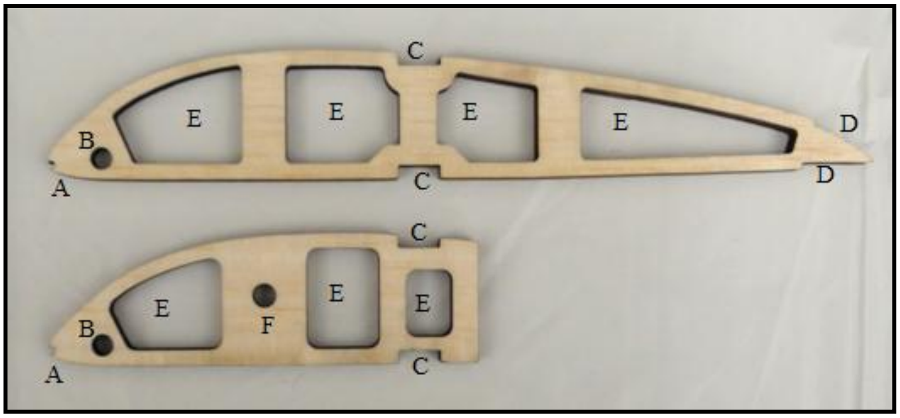

Figure 16: Full and Half Ribs

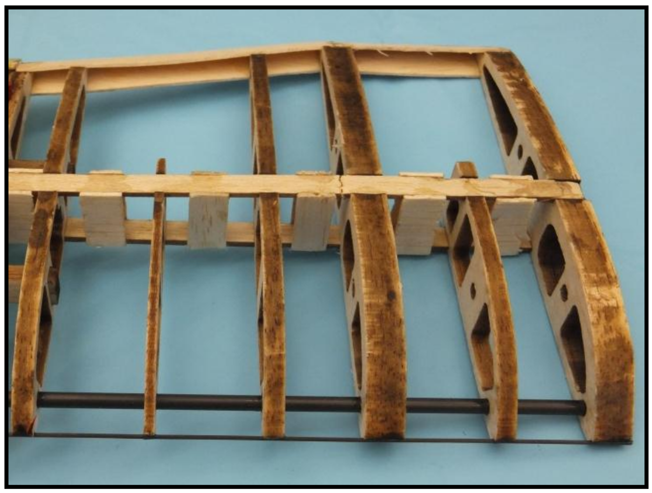

Figure 17: Center Wing with Shear Webbing

The main spar and top and bottom supports provide the majority of the structural rigidity. In between the two spars the team has placed sixteenth inch balsa strips to act as shear webbing (Figure 17). The addition of this shear webbing (and the change from a top spar to a top and bottom spar) increased the maximum static wing loading from 8.5 pounds to 14.8 pounds. The leading edge guide maintains the airfoil's shape, while trailing edges supply additional surface area for skin coat application. This design allows the wings to be both structurally sound and lightweight.

4.2.2 Fuselage

The fuselage (Figure 18) serves as the central hub for all other assemblies. It must enclose the payload bay, support the wing and tail assemblies, and contain the electronic components. The fuselage is made of formers and longerons, providing an aerodynamic profile while limiting weight. A former is the vertical piece which makes up the cross section of the fuselage at a given point, and the longerons run along the length of the fuselage to hold the formers together and provide additional surface area for skin coat.

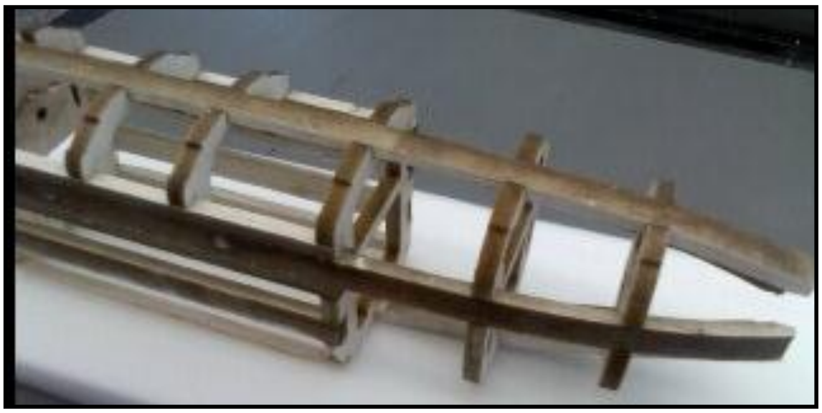

Figure 18: Fuselage

The team customized each former to meet the needs at each point in the aircraft. The nose houses the electronics; the center is open for the payload bay; the aft contains the servos and supports the tail. The ability to modify the internal cross section of each former independent of the others simplified the design process.

The longerons hold the formers together and provide the outline for the aircraft's aerodynamic profile. They attach to notches in the formers to ensure proper fitting during construction. Similar to the formers, the longerons vary from the nose to tail of the aircraft to provide the overall desired shape and allow for attachment of the wings. The longerons also offer the main surface for the application of skin coat.

4.2.3 Tail

The team designed a lightweight tail (Figure 19) that provides adequate control surfaces. The team removed excess material in order to reduce weight, covering the holes with skin coat. The boom tail reduces the weight while providing a rigid surface on which to mount the tail.

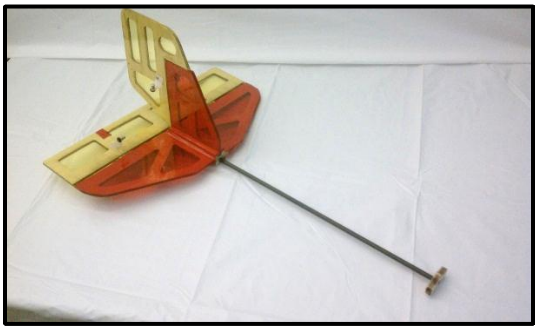

Figure 19: Tail

During storage, the tail collapses into the fuselage, allowing the two to fit within the case as a single unit. Prior to flight, the tail extends and a plate on the rear of the payload bay prevents it from sliding towards the aircraft's nose. Figure 20 shows a computer-generated model of this mechanism. A key-piece attached to the end of the boom interlocks with the back former to prevent rotation, fixing the control surfaces relative to the airframe.

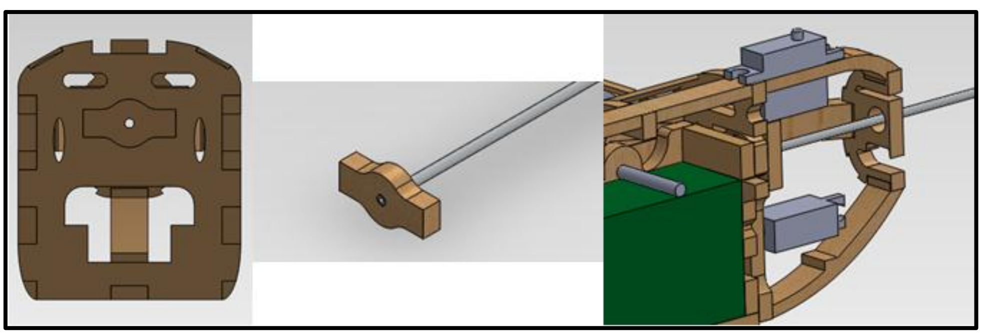

Figure 20: Tail-Locking Mechanism

Each control surface attaches to a servo located in the fuselage by means of a pull-pull system. This prevents the need to adjust or reconnect the controls system between storage and flight, expediting the assembly process.

4.2.4 Electronics

The team focused on finding lightweight electronic components that would still provide the necessary power and performance characteristics. Table 5 summarizes the electronic components selected by the team.

Table 5: Electronic Components

Part	Make/Model
Motor	E-flight Park Flyer, 1360KV
Prop	10x5 with Prop Saver
Servos	Hi-tec MG-65
ESC	Erc 25A programmable
Battery	Tenergy 11.1V 900 mAh 25C
Receiver/TX	Spectrum DX5e TX with Spectrum AR600 with Matching Five-Channel Receiver

The motor is a lightweight model designed for high thrust applications. The team used *MotoCalc* to identify appropriate propellers based on the motor [10]. The team then tested the propellers on the thrust stand and selected a 10x5 propeller since it produced 2.42 ounces more thrust than that of the 9x6. The propeller attaches to the motor using a Prop Saver, ensuring the propeller fails before the nose on landing. The motor has a maximum voltage input of ten volts. The Electronic Speed Controller (ESC) governs this input to prevent overloading.

The battery has a 900 mAh rating to remain lightweight and provide adequate flight time. The battery life ranges between three to five minutes at a cruise speed of 28 miles per hour, with exact time depending on throttle position and servo use. However, at cruise the aircraft can travel over 2400 feet in one minute, giving it sufficient time to complete the circuit even at maximum power consumption.

The servos are lightweight with metal gears to prevent stripping, which can occur with nylon gears. The transmitter is a simple five-channel model, with a matching receiver. Velcro holds all the electronics in place during flight so that they can be easily removed in the event of a crash.

4.2.5 Payload and Payload Bay

The payload bay (Figure 21) resembles a simple basket, yet serves several functions. A raised rear plate prevents the tail assembly from sliding forwards during flight. The bottom surface of the payload bay also serves as a skid to protect the plane during landing. The payload bay connects to the fuselage via the same spars that connect the wings.

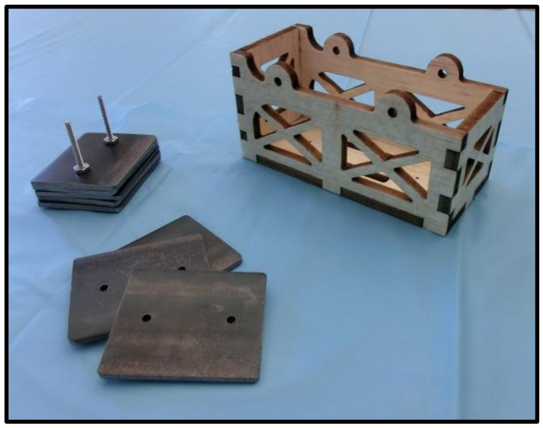

Figure 21: Payload Bay

The payload consists of steel plates, which can be added or removed to produce different weights. The support assembly is two screws attached to a similar plate that holds the payload such that the center of gravity of the plane does not vary with payload weight.

4.2.6 Carrying Case

As an SAE requirement, the plane has to be transported in a 24" x 18" x 8" box with interior foam linings and cut outs matching the shape and size of all components [1] inside the box. The team's box is a pine box with a double hinged side and side handles for easy transport (Figure 22). Its interior dimensions are slightly greater than the required dimensions to accommodate a one-inch layer of rigid pink insulation foam.

Figure 22: Carrying Case

To accommodate all the components in the most efficient way, the team created a quarter-inch thick wooden tray located four inches from the bottom of the case. The upper compartment was reserved for the smaller components such as propellers, wing spars, payload bay and radio transmitter. On the bottom section of the case the team placed the fuselage with the collapsed tail and the wings.

During the first half of the project the team experimented with liquid rigid and foam polyurethane foam to practice making molds for the different components (Figure 23). Even though the soft foam proved suitable for this application, this idea was abandoned because of the excessive time required to make all the molds and cure the mixture of chemicals.

Figure 23: Liquid Polyurethane Rigid Foam

The team decided to purchase a variety pack of foams from supplier McMaster-Carr to test different foam firmness ratings and the ability of the laser cutter to cut foam. All types of foam proved to be possible to cut with high speeds and low power settings after several runs. The final order was a 4608 cubic inch, firmness rating 2, “Super-Cushioning” polyurethane foam purchase. Using SolidWorks the team modeled the cut out shapes for all the different layers of foam surrounding the aircraft components. These files were then converted to AutoCAD drawings to be used with the school’s laser cutter. Once all the foam layers were cut to match the desired cut outs, the team used spray adhesive to glue them together, and then super glue to adhere the foam to the rigid foam and the wooden tray.

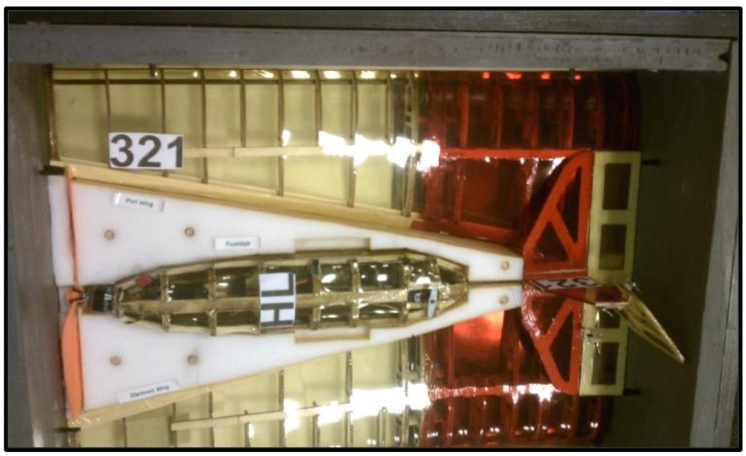

Figure 24: Wings and Fuselage in Foam Cut Outs

The foam proved to be rigid enough to hold its shape while soft enough to provide cushioning to protect all the parts. The team added labels next to all cut outs as a competition requirement [1]. The case was further protected by placing bubble wrap and packing peanuts in the cardboard box used to ship it.

4.2.7 Final Assembly

Throughout the project, the team designed the various sub-assemblies to allow the aircraft to go from in storage to flight ready status in less than three minutes. This translated to limiting the number of connections, and those used needed to serve multiple roles. Figure 25 shows a montage of the assembly of the aircraft to flight ready status.

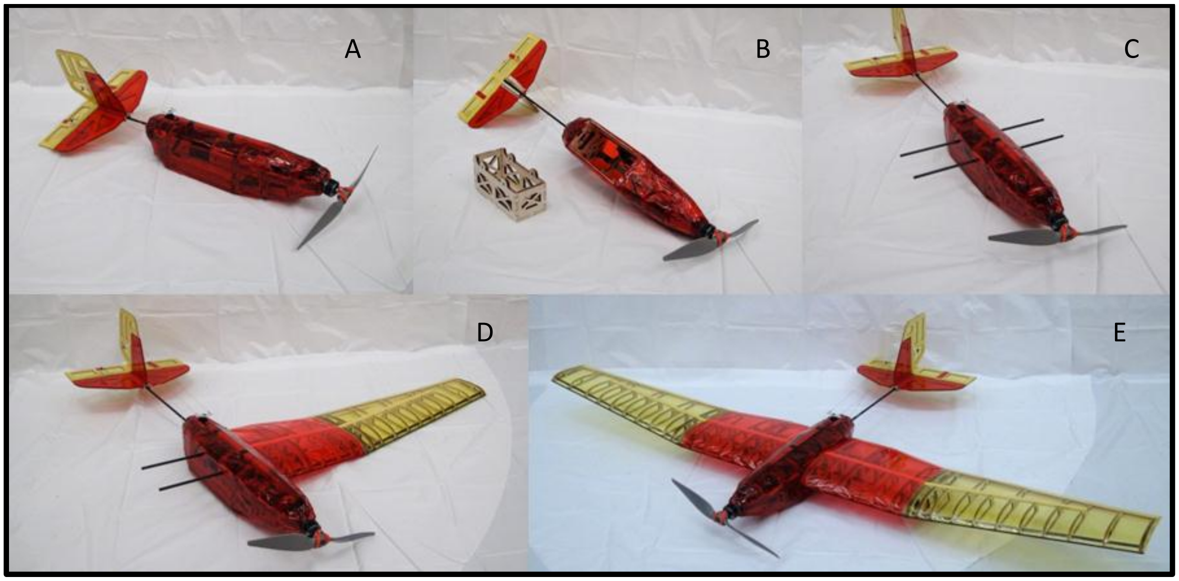

Figure 25: Final Assembly Montage

To prepare the aircraft for flight, the assembler first attaches the battery to the ESC, both of which are located in the nose of the aircraft. The assembler then extends the tail and rotates it until the horizontal fin is level and the tail locked into place. The payload bay is then installed in the open fuselage, securing the tail. Two carbon fiber spars then join the payload bay and fuselage together through a pair of holes in both components. Both wings are then slid over the spars. Duct tape is placed around the bottom of the fuselage and onto the lower wing surfaces to hold them in place during flight. The final step is the connection of the shunt plug near the nose of the aircraft, providing power to the motor.

5.0 Manufacturing

The team placed high importance on a design that could be reliably and easily manufactured. Shown below in Figure 26 are the fleet of aircraft the team sent to the

SAE competition, identical in all but the color of the skin coat and the presence of stickers on one of the planes.

Figure 26: Competition Fleet

5.1 Construction Materials

The team’s search for lightweight, durable materials led to the use of wood and composites for the structure of the aircraft. The team also investigated skin coat materials to enclose the tail, fuselage, and wings as well as various glues to join all the components.

While balsa constitutes 68.0 % of the structural mass of the plane, it is not capable of withstanding all the loads experienced in the airframe. In these places, the plane uses carbon fiber tubes because they have a yield strength three orders of magnitude larger than that of balsa. Carbon fiber has a larger density of 93.6 pounds per cubic foot, limiting its use to reinforcing critical areas [18].

The team coated the aircraft with UltraCote Lite. It adheres through the application of heat, preventing the need of additional glue. UltraCote Lite shrinks at higher temperatures, which allowed the team to create a smooth, tensioned finish to the aircraft. This taut surface reduced potential drag and increased the structural rigidity of coated components.

The team used both super glue and thin cyanoacrylate (CA) glue to join the parts into the final subassemblies. CA glue was used for the majority of the aircraft for its 1-3 second cure times, reducing the amount of manufacturing time for the aircraft. The cure time of the CA glue was not enough to make the minor adjustments associated with placing the trailing edge of the wing. For this reason, super glue was used because of its thirty second cure time.

5.2 Tools Utilized

The team constructed a jig (Figure 27) out of acrylic to ensure accurate construction of the wings with each build. The box has slots for a set of three reversible trays. Turning the trays around changes the side being built (starboard or port); flipping the trays over alternates the section of the wing (center or dihedral). The openings offer a snug fit for each rib and are spaced accordingly. The ribs are slid onto the main support and inserted into the tray openings. The support rod and spars are then glued to the ribs while the structure remains fixed in the jig. Once dry, the wing was removed and the remaining elements can be added without deforming the wing.

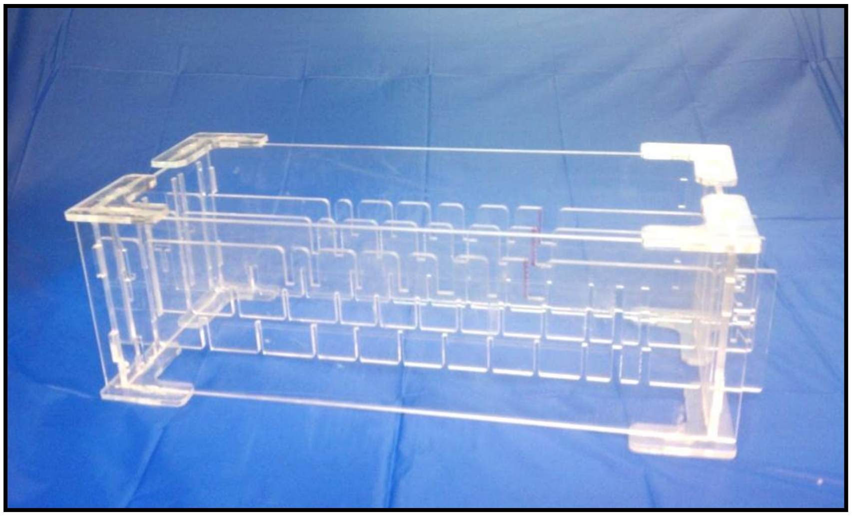

Figure 27: Assembly Jig

To join the dihedral and center wing sections, a modified rib is needed to create the relative angle and maximize the contact surface between the two. This is done by sanding away a portion of a half inch rib using the jig in Figure 28. The interior depression of the jig places the rib at a ten degree angle in relation to the horizontal tracks on the sides of the device. By running a block sander over the tracks, one side of the rib is faced to a ten degree angle with respect to the other. By accurately reproducing the angle, aerodynamic symmetry between the two wings is established.

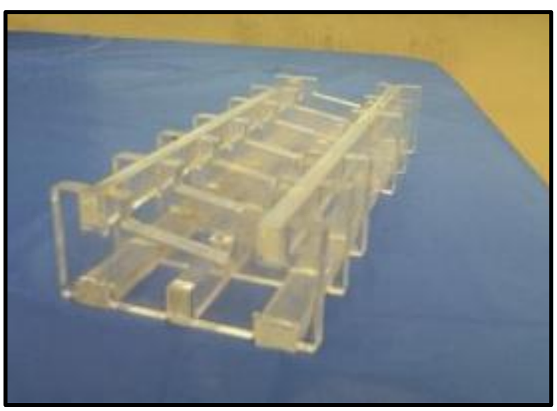

Figure 28: Dihedral Sanding Jig

The interlocking method of the fuselage and payload bay allowed for the parts to be reliably assembled by hand. The tail was a simple design; the orientation of the control surfaces was guaranteed by the structural supports. The construction of these components would have been overcomplicated if a jig was used.

The team used the laser cutter in WPI's Mechanical Engineering Department, machine shops to cut the balsa components for the aircraft and the acrylic used for the assembly boxes (Figure 29). The laser cutter is a Universal Laser Systems VLS 4.60, using Universal Control Panel (UCP) software with the Laser Interface+ materials-based print driver. The laser cutter was able to cut the parts within 0.005 inches of the specified dimensions. In order to prevent loose fits during construction, the team offset all profiles by the width of the laser before cutting. The laser cutter allowed the team to manufacture any wooden component accurately in a matter of minutes.

Figure 29: Laser Cutter

Included in the software for the laser cutter is a materials database with settings built in, allowing the user to optimize cuts or engraving. However, the team found that these settings were unreliable for balsa; the default settings for power were too high, and the setting for speed too low, causing the wood to burn initially (Figure 30). After much trial and error, the team eventually determined appropriate settings to cut the balsa at varying thicknesses. These settings are shown in Table 6.

Figure 30: Burnt Balsa Wood

Cutting the acrylic for the assembly jig was considerably easier. The team had to make sure to cut slowly enough to actually penetrate the entire depth of the sheet, but quickly enough that the heat would not re-seal the acrylic after the laser passed.

Table 6: Laser Cutter Settings

	Power	Speed	PPI	Depth	Passes
1/16” balsa	85%	75%	150	0.08”	1
1/8” balsa	85%	60%	150	0.14”	2
1/4" balsa	85%	55%	200	0.26”	3
1/2" balsa	75%	50%	300	0.53”	6
1/4" acrylic	100%	3%	300	0.26”	1

6.0 Required SAE Deliverables

This section describes the design report and technical presentation produced by the team in accordance with the competition rules.

6.1 SAE Design Report

Similar to the aircraft itself, the design report had its own set of rules and regulations and was due approximately one month before competition [1]. The report was limited to no more than 30 pages (all inclusive). It had to be less than one megabyte when electronically submitted as a PDF. As a whole, the report had to summarize the design process and describe the final product and highlight the unique features of the aircraft. Any variations between what was presented in the report and the competition aircraft would result in a penalty. The team's final design report is included as a separate file for the benefit of future teams or interested readers.

In addition to the guidelines provide by SAE, the team found three design reports from past competitors of other schools publicly available. These, along with their final scores allowed the team to better understand what sort of information and style the judges were looking for in the design report [21]. The high scoring reports focused on brief, informative statements with many visual aids. Lower scoring reports contained excessive explanations or tangents on the process of general aircraft design, rather than the specifics of the given plane.

The team developed our design report in conjunction with the final design, starting four months before the deadline. While this required the rewriting of several sections, it allowed ample time for review and evaluation. The team made the decision to start earlier in order to ensure that the best possible product would be submitted to the competition.

6.2 SAE Technical Presentation

The technical presentation consists of three stages: a timed three minute assembly of the aircraft, a ten minute oral presentation and a five minute question and answer session [1].

Aware of that the aircraft needed to be assembled by two people in less than three minutes, the team designed the aircraft to meet this goal, as stated before. Currently, two members of the team can assemble the plane in less than two minutes, well below the maximum time.

The team created a PowerPoint presentation for the SAE Aero East Competition [22]. This presentation will be given by two suited up team members the day prior to the competition flights. The presentation covers the same material as the design report and has been specifically divided into:

- Introduction (Competition Overview/Design Requirements)
- Engineering Process
- Research
- Calculations
- Experimentation
- Final Design
- Manufacturing Cycle
- Conclusion (Predicted Competition Performance)

To prepare for the question and answer session, the two presenters made sure to familiarize themselves with all aspects of the plane's design, construction and configuration. The team travelled to model aircraft clubs in the area to gain experience in fielding unexpected questions from those with experience in the field. Presentations were also made to groups on campus who had interest in the project, such as the student chapter of the AIAA.

7.0 Conclusion and Expected Results

Over the past four terms, this team started with no experience in designing an aircraft. The team had never heard of a laser cutter, or knew one existed on the WPI campus. The team had no experience with RC aircraft. Despite all of this, the team worked hard for eight months straight, never losing focus or drive, Mistakes were made, lessons learned, and over the four terms, the team evolved from a group of college seniors into a cohesive unit. Each member's strengths were capitalized upon, and work delegated accordingly, making the design and manufacturing process seamless and efficient. The dynamics of the team developed to reflect what the ideal dynamics of a project group in industry would be.

The final aircraft weighs 0.800 pounds and is capable of lifting a payload of 2.17 pounds. The aircraft's design revolved around the application of aerodynamics, structural mechanics and other engineering principles, careful material selection, and simple, repeatable production. By using contest-grade balsa and carbon fiber to construct a rib and spar style structure, the group minimized the plane's empty weight while maintaining a durable aircraft. A collapsible tail and removable wings allowed for storage in the transport case, while maintaining aerodynamic surfaces large enough to generate the necessary lift and provide proper control of the aircraft. The few, multipurpose connections allow for quick assembly. The use of the laser cutter and the self-developed assembly jig guaranteed prompt manufacturing with reproducible results. These factors combined to allow the team to generate a highly competitive Micro Class aircraft for the 2012 SAE Aero Design East Competition. The competition will be held on April 27-29, 2012 in Marietta, GA after the MQP report submission deadline, so final results from the competition are not presented in this report.

8.0 Future Improvements

The goal of this section is to help future teams, by noted improvements our team could not complete due to restrictions (time, costs and deadlines). The areas included are: electronics, stability, and manufacturing.

From an electronics standpoint, this portion of the plane was a difficult one as no one had previous RC or electrical engineering experience, for example the integration of the components with soldering the correct pieces.   The key to having successful electronic would be to do plenty of research prior, including on-line research, and especially talking to experts, the weighting their opinions in the deciding factor for the final plane. Also keep in mind that not many people build planes for heavy lift competitions, and think that a powerful motor is a must, while not considering the consequences of the added weight. This idea of balanced out the added weight versus the performance advantage was the main consideration in the decision process not only for the electronics but the plane as a whole.

The stability analysis used a CG calculated by the team using SolidWorks to the model based off of the materials and densities assigned. Unfortunately, the revisions made throughout the project were not always reflected in the SolidWorks model, or it would just be updated at a later date. This resulted in the center of gravity not being where it theoretically should have been, which became obvious during flight testing at Medfield. Towards the end of the project, as we were building the final iterations, we measured the center of gravity of the physical, fully-constructed plane with payload by balancing the plane on two points. In the future, make sure to keep the CAD model completely up-to-date, regardless of the number of changes made, to minimize this. Additionally, measure the center of gravity physically earlier on in the project to compare to the theoretical value, as this would help with knowing if design changes to the plane or payload need to be made.

From a design standpoint, future teams should investigate shortening the fuselage and placing the electronics beneath the payload bay. This should alleviate the issues we experienced with the CG changing based on the amount of payload. As the electronics constitute 47% of the aircraft's empty weight, this will make it easier to align the empty weight center of gravity and that of the payload.

Future teams should also focus on lightening the aircraft as opposed to carrying more. As the flight score is more heavily dependent on empty weight than payload fraction removing weight even at the cost of lift capacity can be a wise decision.

For materials, we recommend the team explore a more variety of materials. Lite ply and birch ply are two materials that can be used in place of areas such as the half inch balsa ribs on the wings. According to Daniel-Webster College, birch ply has a better strength to weight ratio. Other materials include denser balsa (12 pound density). 1/32 balsa that has a 12 pound density is equal in weight to the 1/16 contest grade balsa, however it is much harder and less likely to dent. For carbon fiber tubes, the team should explore tubing that may have a larger outer diameter but thinner walls. This will reduce the weight while still maintaining rigidity.

While lab testing is good for understanding the aircraft, nothing compares to flight testing. For this reason, we suggest that the team attempt to flight test starting by the early part of C term if possible.

Our team ran into several issues with shipping. It is usually better to order domestically, and buying parts in local stores or selecting in store pickup is a great way to prevent holdups in assembly. At the same time, some online components are lighter and worth waiting on. We ordered some parts from Hong Kong and despite rush shipping, It took us over 3 weeks to get the necessary receiver in.

Don't be afraid to try and learn something new. Your team will need a decent number of people to be capable of Solidworks modeling, AutoCad tolerancing, and any other necessary programs. Do what you can to get as many teammates helping with the modeling, or even watching over someone’s shoulder to discuss ideas and try and pick up some tips. The best way to learn something is by doing it.

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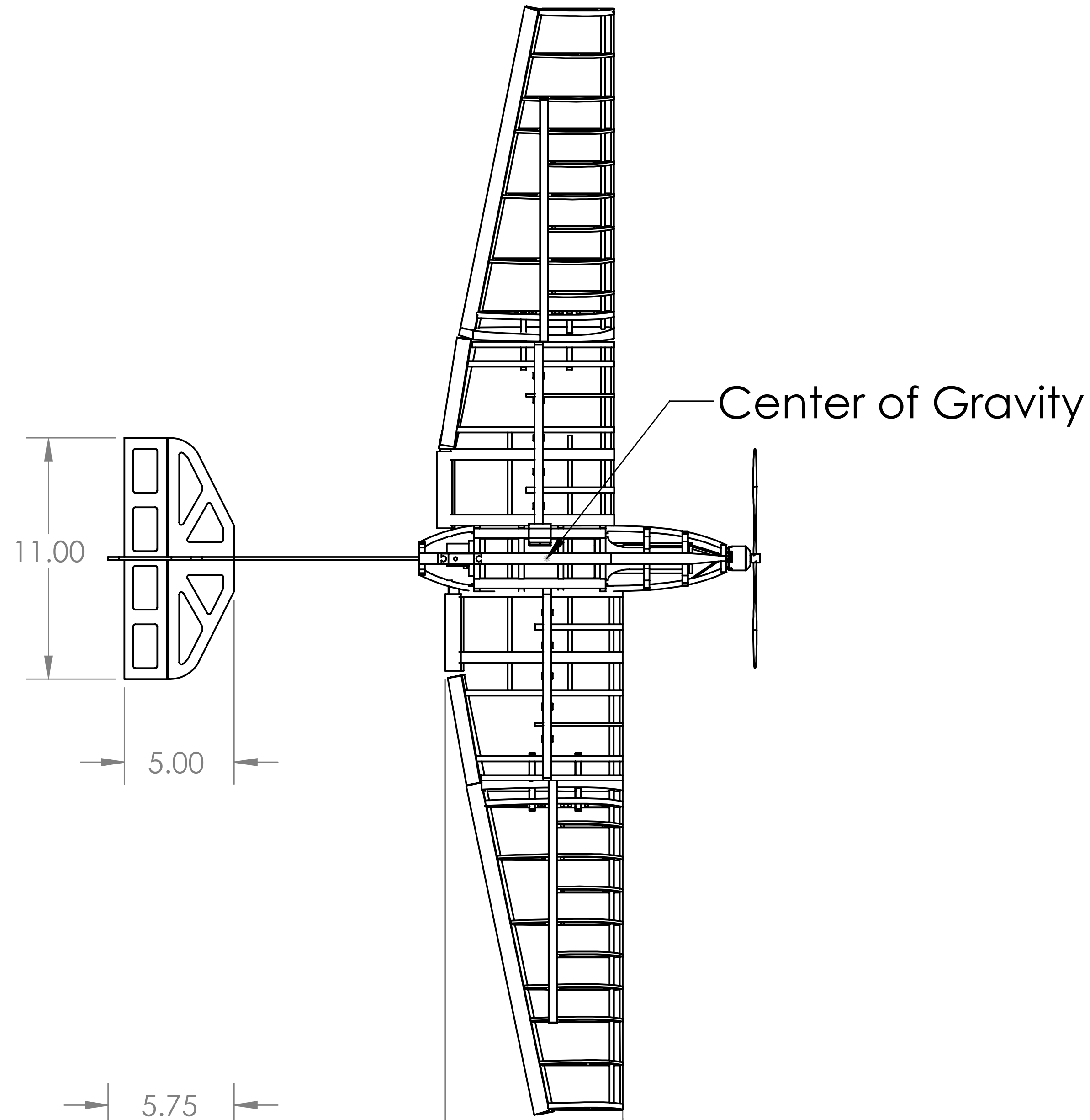

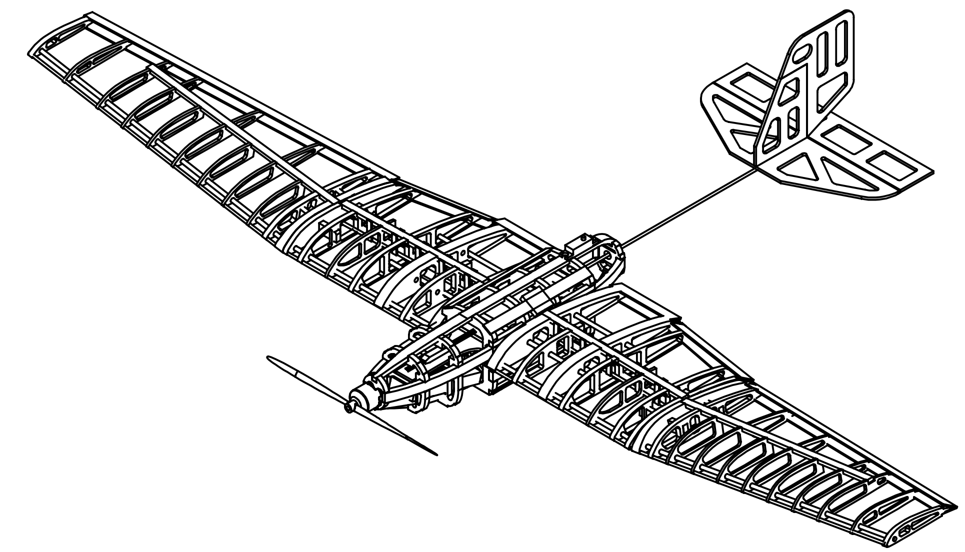

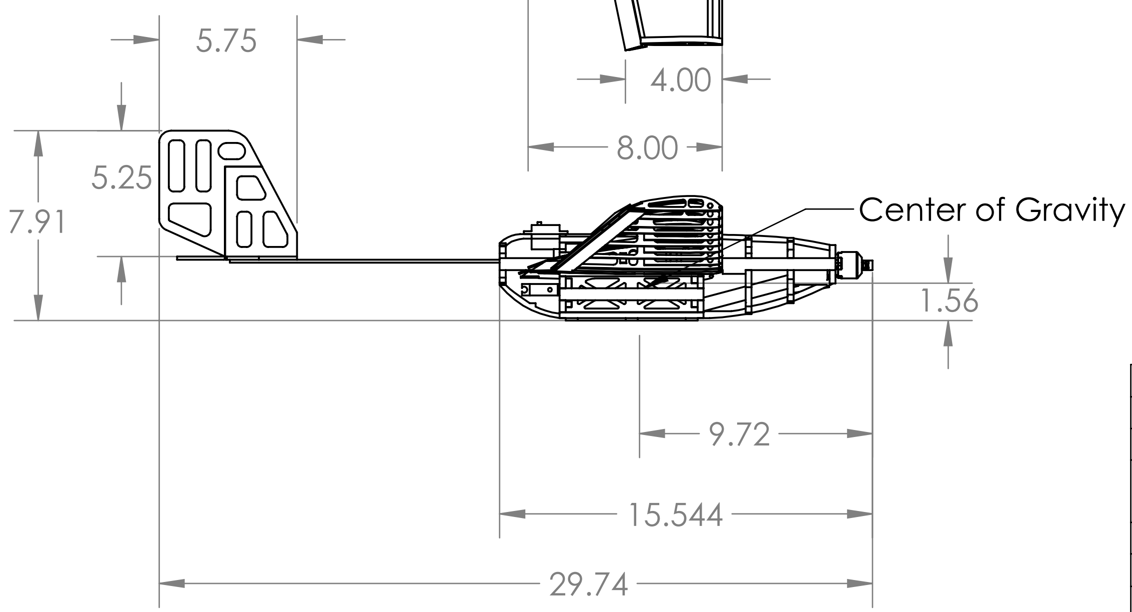

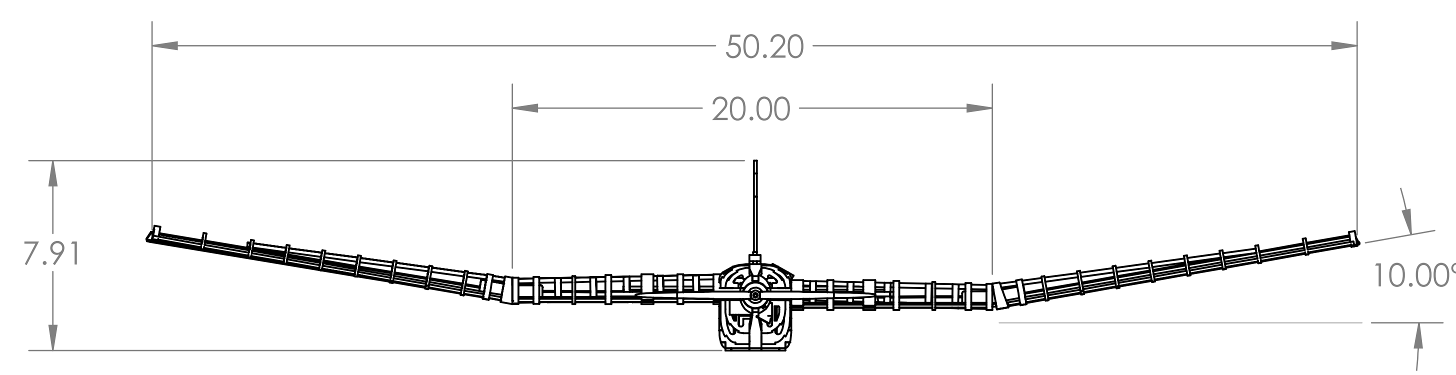

Wing Span	50.20 inches
Height	7.75 inches
Length	29.74 inches
Wing Area	292.38 square inches
Aspect Ratio	8.98
Empty Weight	0.825 pounds
Maximum Payload Fraction	.73
Engine Make	Eflite
Engine Model	Park 370
Max. Payload Wing Loading	0.01 psi

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
LINEAR: +/- 0.25
ANGULAR: +/- 2 DEGREES

	NAME	DATE
DRAWN	Keegan Mehrtens	3/17/2012
CHECKED	Ethan Connors	3/17/2012

COMMENTS:

Team Name:	Goat Works
Team Number:	321
School Name:	Worcester Polytechnic Institute

SIZE B | DWG. NAME Appendix A | REV 1

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

Appendix B – Cost per Plane

Based on WPI's project funding structure, the team had an initial budget of $960. The team kept a detailed record of the costs incurred for materials and the amount of material used to build each aircraft in order to provide pertinent data to the school for future entries and evaluate its financial efforts. Table 7 itemizes the cost for one plane by material.

Table 7: Cost per Plane

Material	Price
Balsa wood	$21.28
Carbon fiber	$18.47
Electronics	$262.23
Skin Coat	$11.99
Miscellaneous	$19.67
Total	$333.64

These costs do not reflect tax, shipping or expenses incurred by travelling to a store. The miscellaneous costs include things such as glue and control systems. As electronics constitute 78.6% of the cost for one aircraft, only one set was purchased. The same electronics were placed in every build of the aircraft in order to avoid higher costs.

Appendix C. Design and Manufacturing Instructions and Tips

This section provides advice on various tasks learned by the team throughout the project to better prepare future teams for the SAE Aero Design Competition.

Creating Airfoils in Solidworks – As Solidworks is the 3D modeling software most students are familiar with, the team assume future teams will also use it to model their aircraft throughout the design stage. As such, we feel it important to explain how to import airfoil profiles to the program. The first step is to obtain the coordinates for an airfoil. This can be obtained many ways, such as an output from Xfoil or the website used by the team, worldofkrauss.com.

Once one has the coordinates they need to be put into an Excel spreadsheet with columns ordered as X, Y and Z coordinates respectively. This file can then be imported into Solidworks through the Insert curve option, shown below in Figure 31.

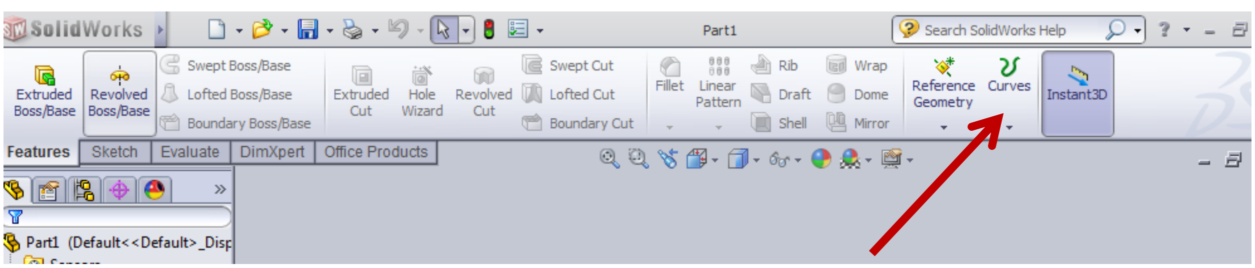

Figure 31: Location of Insert Curve Feature

Having the airfoil coordinates in Excel also allows for easy scaling, which is convenient for building ribs on a tapered wing.

Grain Orientation – The grain of the balsa wood is a key factor in determining how the part should be cut. For the dihedral connectors, the grain should run from the root towards the tip of the wing. This greatly increased the strength of the wing. However, for the top and bottom support connectors (1/16th inch balsa), the grain should be oriented from top to bottom, to optimize the compression strength between the two.

CA Glue– Cyanoacrylate (CA) glue is a very common glue for the hobby. The thin CA glue works very fast and creates a very strong bond. One advantage is the ability to apply the glue after two parts have been put together. When applying CA glue, it may seep through the surface. This means that when gluing thin wood on a table, you run the risk of gluing the part to the table.

CA Hinges – CA Hinges consist of a small piece of fabric which is inserted into a slot made in the wood. The team chose to use these hinges because they are lightweight and do not need a common rotation axis. As the hinges are fabric, they bend wherever a crease is made, as opposed to metal hinges whose pins need to be meticulously aligned. To use a CA hinge, one simply needs to make a slit in the middle of each piece of wood where the hinge is to be located. The hinge is then slid into each piece of wood, typically with spacers placed in between to guarantee the desired distance. A drop of CA glue is then placed on the hinge which then seeps into the wood, securing the pieces together after a few seconds.

Jigs – Jigs and templates are very helpful in reducing the manufacturing process. While care and precision are necessary for the entire build process, any tooling that can be developed to reduce the chance of human error will greatly assist with the final product.

Design to manufacture, don't design then manufacture – Parts should be designed with some sense of how the design will be produced. If you need help with this process, talk with professors and people in the machine shop on campus. You can also look up youtube solutions and how current RC aircraft do this.

Skin Coat – When using heat applicable/shrinking skin coat, the team found the following method to work best. Adhere the skin coat to a (reasonably) flat surface then stretch it tight and adhere to the edges of the area you intend to coat, so that it is as taught and wrinkle free as possible but not stuck to most of the surface. A heat gun can then be used to shrink the area in between where it has been sealed, creating a smooth, tight surface. The iron can then be used again to apply the coat directly to any surface after it has been shrunk.

To provide a detailed example, consider the center wing portion of our aircraft. It was skin-coated started at the trailing edge. The UltraCote Lite was placed so that there was some overflow on all edges of the underside of the wing and that it could be wrapped from trailing edge to leading edge and back to trailing edge from bottom to top in one piece. The skin was adhered (using pressure to get a good seal) to the bottom of trailing edge. The overlapping skin was then trimmed and adhered to the upper trailing edge surface. Next, the skin was pulled tight by one team member while another ironed the skin to the bottom most surfaces of the outer ribs. The skin was then wrapped around the leading edge, pulled tight and sealed to the upper trailing edge of the wing. The skin was then trimmed down and sealed to the upper surfaces of the outer ribs, again using pressure to get a good seal. The edges of the skin were also folded on to the outside rib to ensure it could not pull up when the heat gun was used. The heat gun was then used to shrink and tighten the skin. Finally the iron was applied to seal the skin to each individual rib.

Some final tips:

- Having a heat gun makes a large difference
- Use smaller pieces of skin coat to fit more complex geometries
- If the seal is not sufficient, shrinking the material with the heat gun can cause it to pull and break these seals

- Be careful not to put holes in the material by applying the heat gun for too long, but small holes or tears are easily patched with the iron, just cut a small piece and apply it directly to the skin
- Shrinking the skin can induce warping in the wings, if this happens, bend the wing opposite the warp (past where you want it) and continue shrinking for a while
- Use small pieces of tape on either side to pull the skin coat apart from the bottom layer
- When using the heat gun, go slow and pause to check your work often
- Sometimes heating one area can remove wrinkles in another
- Even large folds/wrinkles can be removed from the skin with the iron if used properly, but more material means more weight, even if shrunk
- Take the time to do it right, if it is wrong, start again

Appendix D. Initial Sketches

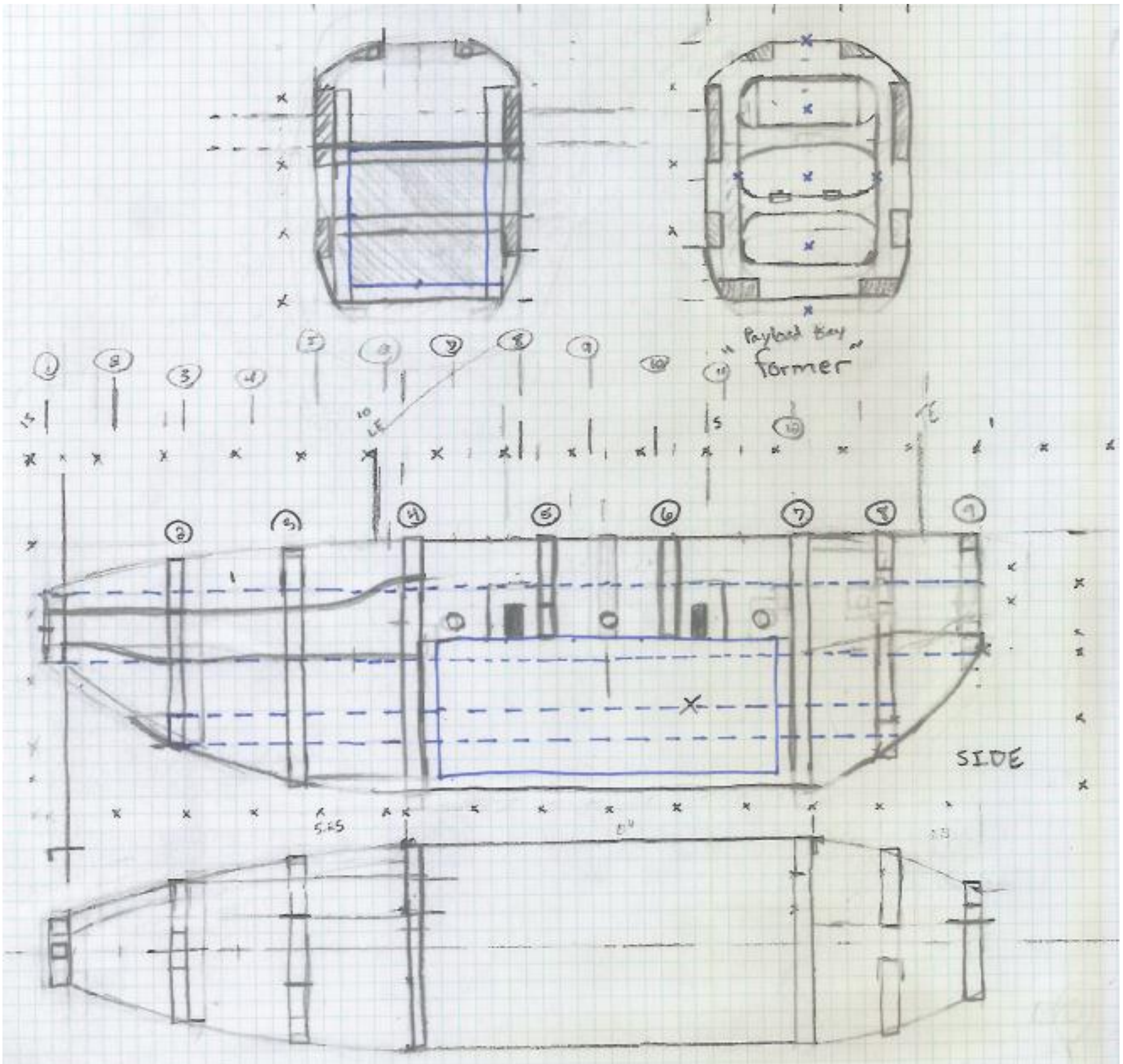

Figure 32: Fuselage Layout

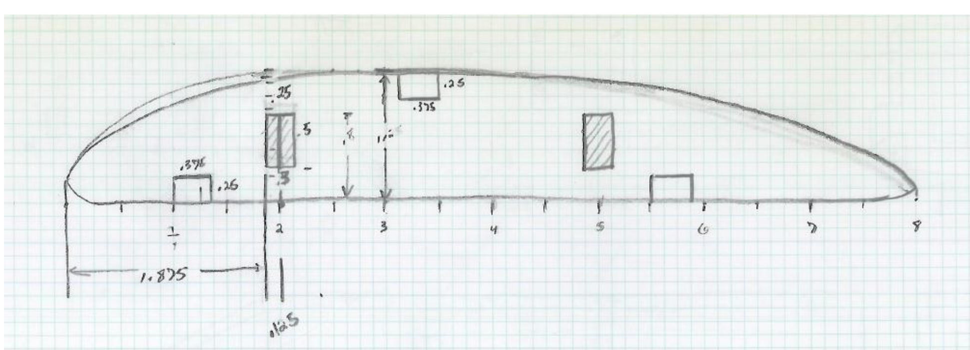

Figure 33: Early Wing Rib Layout

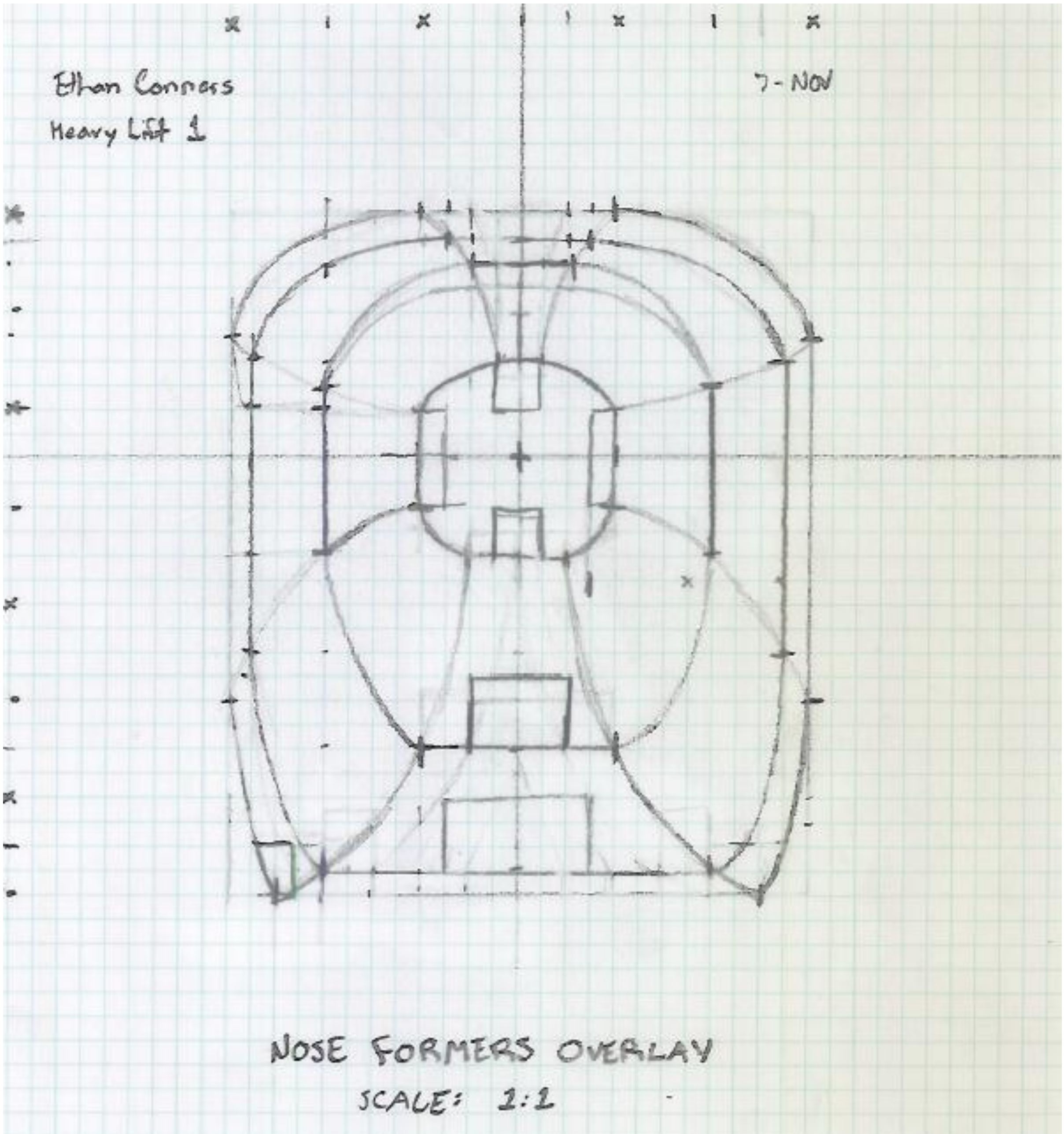

Figure 34: Front View of Fuselage

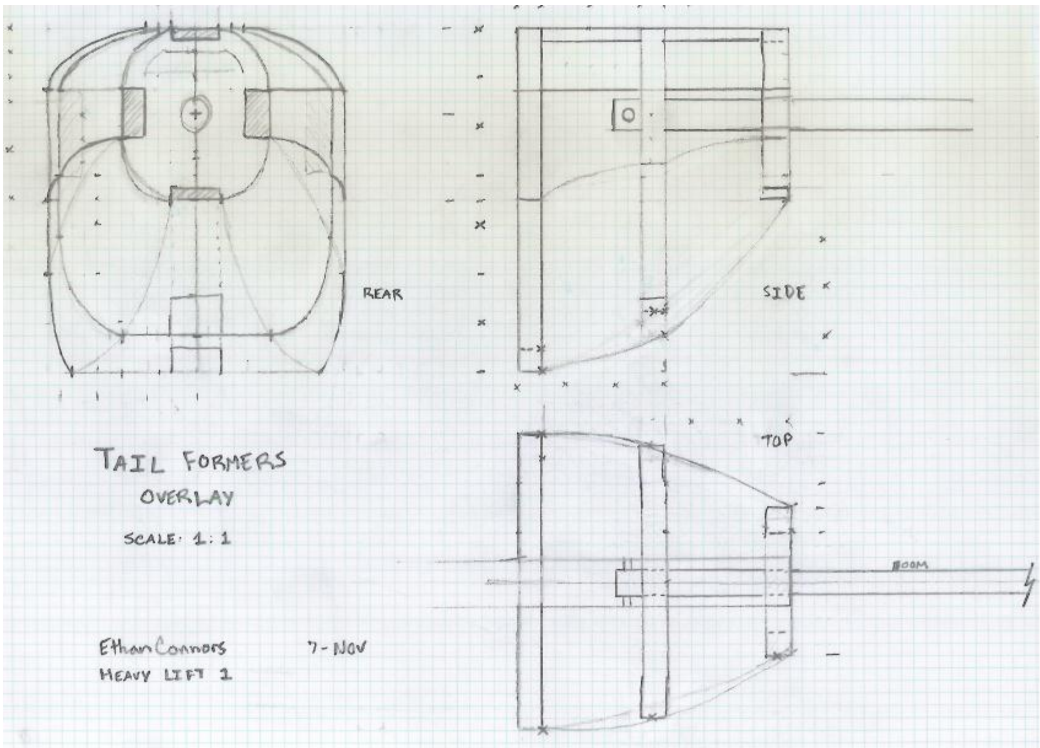

Figure 35: Front View of Fuselage

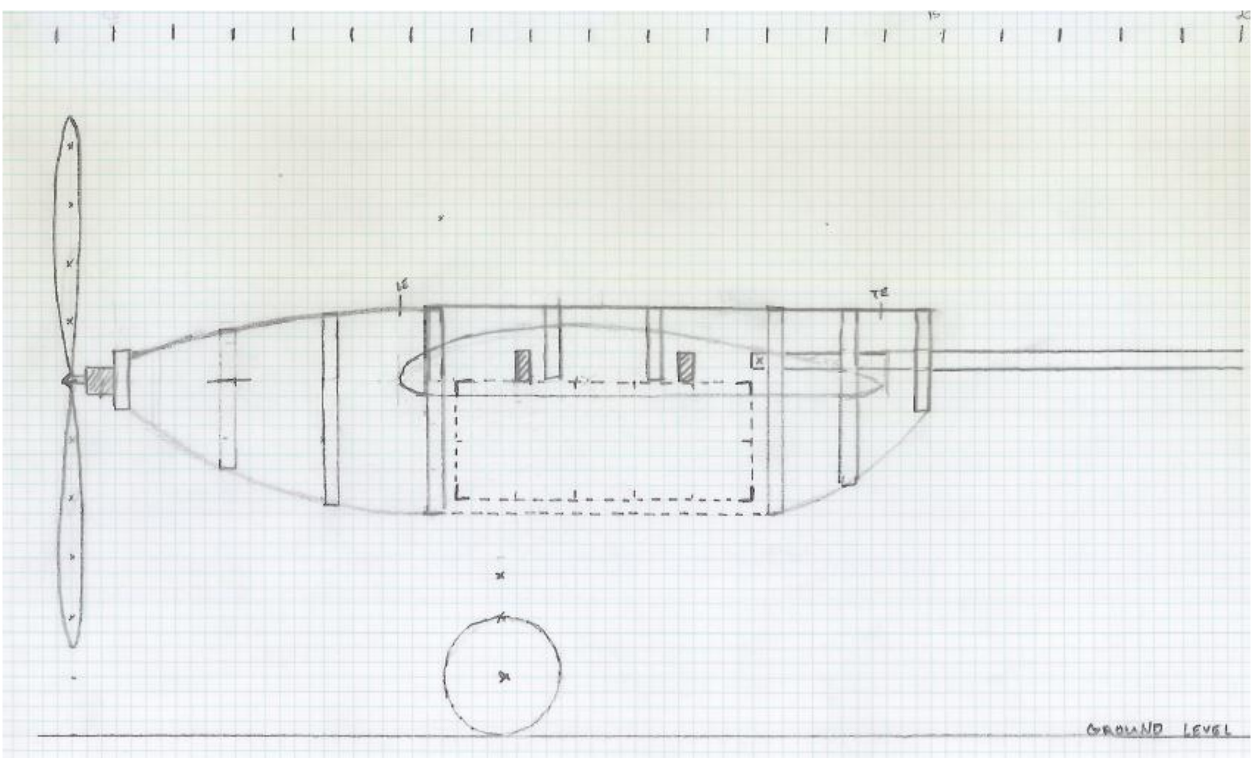

Figure 36:Side View of Fuselage

Appendix E. Contact Information

This section lists the contacts and facilities used by the team which we believe will help future groups.

Suppliers:

RC Buyers Warehouse: 95 Northeastern Boulevard Nashua, NH 03062

http://www.rcbuyers.com/

Used by the team for most hobby supplies, largest RC store in the area. The best place to see parts and components for planes, and they solely focus on RC aircraft. Also, mention you are from WPI and you will get a student discount (anywhere from 15-25% off of your final order). Well worth the drive.

Hog Heaven: 494 Main St. Sturbridge, MA http://www.hogheavenhobbies.com/

Closer than RC Buyers, and very well stocked. More focused on broader hobby realm (trains, cars, etc). They have a lot of plane components, but some items (such as UltraCote Lite) are not stocked. They also do not have a school discount.

National Balsa: http://www.nationalbalsa.com/

Supplier for all the wood used by the team. Can select from regular balsa (~10lb/ft^3), contest grade (~4-7 lb/ft^3), or hand-picked at no more than 5 lb/ft^3. Need to call to order hand-picked/see if they have it in stock

Goodwinds: www.goodwinds.com

Good supplier for carbon fiber. Be sure to order the right kind and ship through USPS (faster). Wrap duct tape or gorilla tape around the cutting section (so there is about a half inch of duct tape wrapped around the tube on either side of the cutting line) to prevent splintering of the rod.

McMaster Carr:

Supplies directly to WPI, used for case foam as well as motor mount screws.

Piedmont Plastics (formerly Plastics Unlimited): 55 Millbrook Road, Worcester, MA.

Good for all acrylic needs. Need a minimum of 10 lbs for an order, so either use scrap from Washburn for small needs or buy a few 24"x18" for projects

Neil Whitehouse: Basement of Higgins

Manufacturing consultant for robotics, etc. Good person to talk to about how to get through the manufacturing process.

And of course, Lowe's, Home Depot and Amazon.com, don't be afraid to repurpose tools, materials or ideas from other disciplines!

RC Aircraft Clubs:

While the team wishes we had contacted RC groups sooner to discuss the hobby and begin test flying, ourselves, our advisors and the members of the clubs we spoke with feel there is something to be said for not doing so until a (near) final product has been built. This is to keep the design original and team developed, as required by SAE rules. While the members of the club are very knowledgeable on the hobby, ALL decisions must be made and justified by the team. It is ok to ask for opinions and answers to questions, but in the end, the team must decide what the best step is to take.

Millis Model Aircraft Club: http://www.millismodelaircraftclub.com/

This is the club with which the team conducted all of its practice flights, and we would like to once again thank Scott Annis and Mickey Callahan for all the help they provided, along with the rest of the club. However, they have asked that future teams contact the club president so that other members may have a chance to be involved if they would like.

Quinapoxet Model Flying Club: http://www.qmfc.org/

A closer club (located in Holden) than that in Millis. Also seemed very willing to set-up test flights and assist in any way possible, but contact had already been established with the Millis Model Aircraft Club for sometime at this point. The team gave a practice SAE presentation to this group, which was the initial reasoning for contacting outside organizations.

South Shore Radio Control Club: http://ssrccsite.homestead.com/HOME.html

One of the largest RC Clubs in the area, located in Bridgewater, MA. The team also gave a practice SAE presentation here.

Wachusett Barnstormers: http://www.wachusettbarnstormers.org/

Another group the team gave a practice presentation to, based in Gardner, MA.

Past Group Members:

All members of the team have been greatly impressed with the hobby and intend to continue with it after leaving WPI. As such, we would like to extend the sense of community we found among other hobby enthusiasts to future teams, and offer up our permanent contact information in cases anything in the report is left unclear, our future advice is sought.

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Paul Crosby: Pcrosby67@gmail.com

David “Dirwin” Irwin: daveirwin857@gmail.com

Keegan Mehrtens: knmehrtens@gmail.com

Carlos Sarria: Carlossarria91@gmail.com