Goat Works

Team # 321

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SAE Aero Design East 2012 Micro Class Design Report

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Appendix
2012 SAE AERO DESIGN

STATEMENT OF COMPLIANCE

Certification of Qualification

Team Name	Goat Works	Team Number	321
School	Worcester Polytechnic Institute		
Faculty Advisor	Prof. Simon W. Evans		
Faculty Advisor's Email	sevans@wpi.edu		

Statement of Compliance

As Faculty Advisor, I certify that the registered team members are enrolled in collegiate courses. This team has designed, constructed and/or modified the radio controlled airplane they will use for the SAE Aero Design 2012 competition, without direct assistance from professional engineers, R/C model experts or pilots, or related professionals.

Signature of Faculty Advisor

Team Captain Information:

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Note: A copy of this statement needs to be included in your Design Report as page 2 (see 6.1).

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A: Coefficient used to simplify Stability Equations
AoA: Angle of Attack
A_p: Disc Area Swept by Propeller
b: Wingspan
$\bar{C}$: Mean Aerodynamic Chord
CA: Cyanoacrylate
$C_{L\alpha_H}$: Slope of the Lift Curve for the Tail
$C_{L\alpha w}$: Slope of the Lift Curve for the Wing
$\frac{d\alpha_H}{d\alpha}$: Wingtip Effects
ESC: Electronic Speed Controller
EW: Empty Weight
FS: Flight Score
L: Lift
L'_0: Constant for Lift Distribution Equation
$L'(z)$: Lift Distribution
mAh: milliAmp hours
P/W: Power to Weight Ratio
PF: Payload Fraction
P_M: Power output by motor
R/C: Remote Control
SAE: Society of Automotive Engineers
SE: Stability Envelope
S_H: Horizontal Planform Tail Area
S_w: Wing Planform Area
T: Thrust
TX: Transmitter
V_{in}: Motor input Voltage
V_p: Pitch speed of the propeller
WPI: Worcester Polytechnic Institute
$\bar{x}_{ac_H}$: Location of the Aerodynamic Center of the Horizontal Tail along the Length of the Aircraft
$\bar{x}_{ac_w}$: Location of the Aerodynamic Center of the Wings along the Length of the Aircraft
$\bar{x}_{mf}$: Most Forward Point as percent of Mean Aerodynamic Chord
$\bar{x}_{np}$: Neutral Point as percent of Mean Aerodynamic Chord
x_{mf}: Most Forward Point
x_{np}: Neutral Point
z: Distance Coordinate along Wing
η_H: Wake Effects
ρ: Air Density

1.0 Introduction

The SAE Aero Design Competition affords students the opportunity to design an aircraft with real world considerations. Success in the competition depends upon the application of aerodynamics, structural mechanics, and other engineering principles in designing and fabricating a heavy lift aircraft. Added to these challenges are the necessary concerns of time management, financial constraints, and the utilization of each team member's unique strengths.

The team's primary objective was to produce a highly competitive aircraft, requiring a low empty weight and a high payload fraction. Figure 1 shows the final design, dubbed *Tina*, and Table 1 summarizes the key parameters.

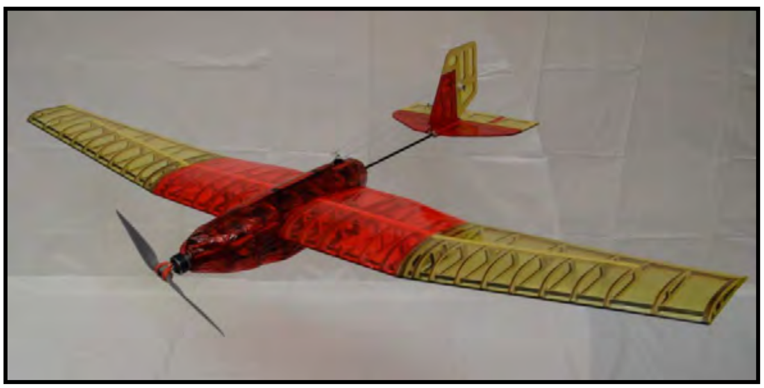


Figure 1: *Tina*

Table 1: Key Parameters

Characteristic	Value
Wingspan	50.20 inches
Length	29.74 inches
Height	7.75 inches
Wing Area	292.38 square inches
Empty Weight	0.881 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

To meet the primary goal, the team aimed to design an aircraft weighing under one pound and capable of lifting a combined weight of three pounds. In addition, the aircraft had to comply with the competition rules [1]. Table 2 summarizes the main constraints.

Table 2: 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 secondary team goal was to establish a repeatable manufacturing process to prevent variations in weight and size between each build of the aircraft. This would reduce errors in fabrication, lower production time, and ensure the competition aircraft would accurately reflect the design documents.

Governed by these central goals, the aircraft design evolved due to the team’s extensive research, discussion and calculations. Understanding these efforts in detail is crucial to evaluating the aircraft. This insight provides justification for the final design and speaks to why *Tina* is a serious Micro Class contender in the 2012 SAE Aero East Design Competition.

2.0 Design Process

This section outlines the engineering process followed by the team in pursuit of its two main objectives and the research behind its decisions.

2.1 Literature Review

As WPI has not participated in this 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. 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.

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.

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]. 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.

2.2 Decision Process

Throughout the design process, the team sought to make decisions in line with its primary objectives: a sturdy lightweight aircraft and simple manufacturing. The team first developed a basic airframe fulfilling all the competition rules. This airframe was then continuously modified to reduce weight, increase strength and simplify manufacturing.

The team systematically and repeatedly analyzed each component of the initial airframe to identify areas for weight reduction and those that were structurally unsound or complex to manufacture. Upon encountering a problem area, the team researched existing solutions, conducted tests, performed calculations and discussed amongst themselves to devise possible solutions.

The implementation of a solution depended on its effectiveness at solving the original issue and its interaction with the rest of the aircraft. More often than not, the solution caused negative side effects, such as increased weight or more complex geometries. The team evaluated and ranked the consequences of the new design and the original problem by their impact on the team's ability to accomplish the primary goals. The team then rethought both the solution and the affected components to see if the adverse aspects could be lessened or removed. When a problem could not be resolved, the team chose options that had the least impact on the achievement of said goals.

Once the team felt it had found the best possible solution, they applied it to the current design. At this point the team finalized minor details, such as dimensional tolerances and grain orientation. These considerations were not critical to devising and evaluating a solution, but were necessary to build the final product.

3.0 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). Due to limitations with and the availability of WPI's testing facilities, 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) [7]. 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.

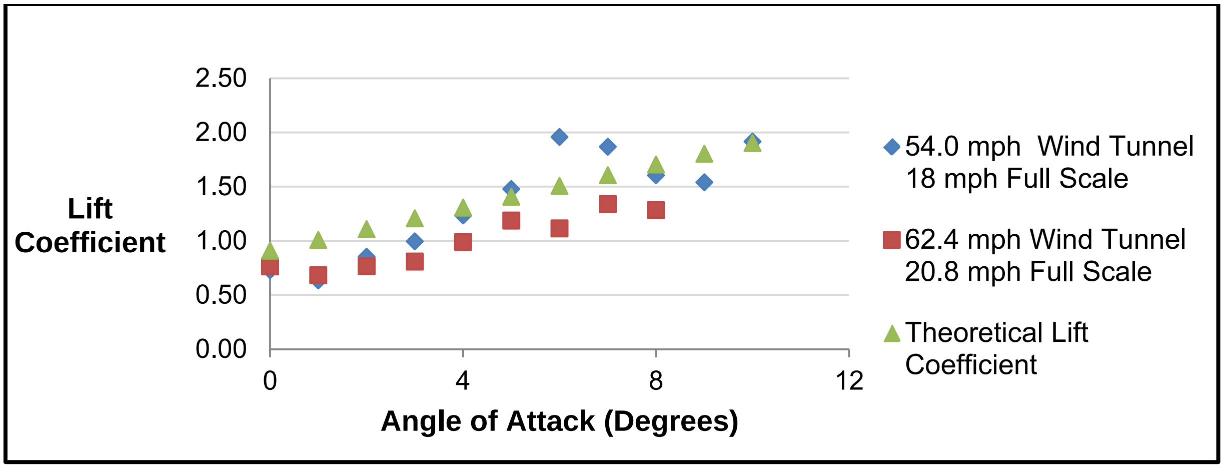


Figure 3: Lift Coefficient versus Angle of Attack

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.

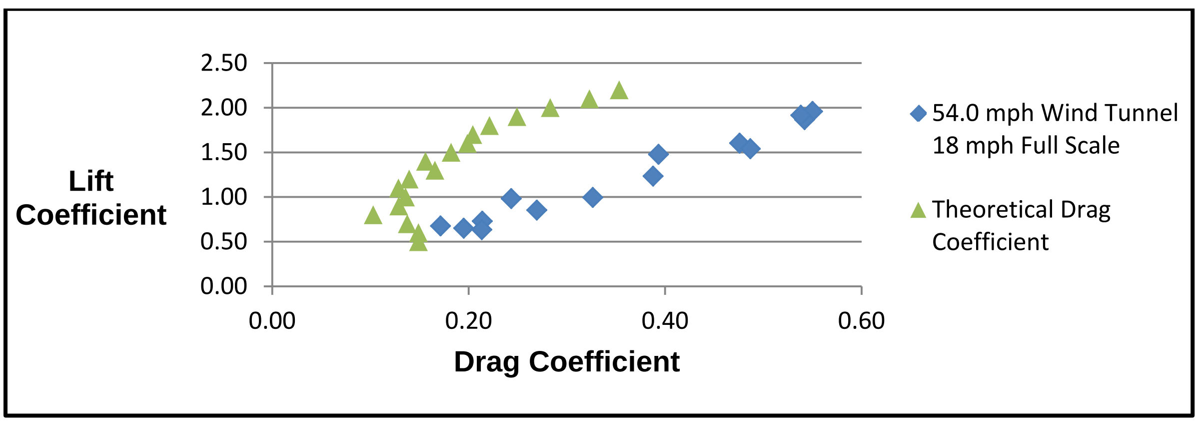


Figure 4: Drag Polar

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 [8]. 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:

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

Equation 1: Motor Power

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

$$\mathrm{T} = T^3 + \left(2\rho A_p P_M v_p T\right) - \left(2\rho A_p P_M^2\right) = 24.16 \text{ ounces}$$

Equation 2: Dynamic Thrust

Here, ρ is the air density and A_p is the disc area swept out by the propeller.

All other key parameters, such as stall speed, battery life and motor efficiency, were found using the *MotoCalc 8* software program [9]. 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 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.

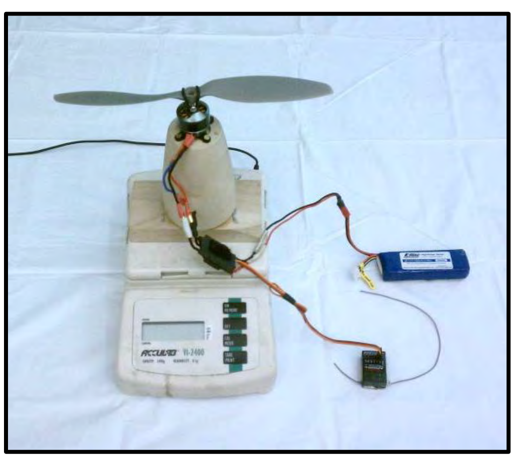


Figure 5: Thrust Stand

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.

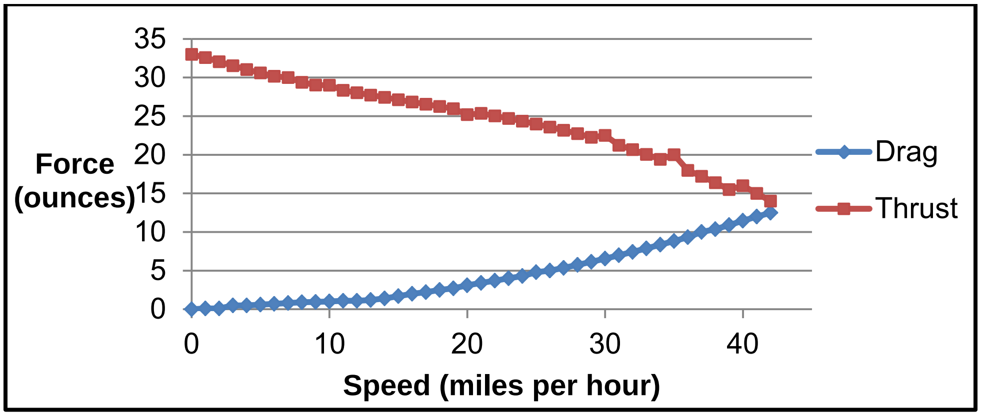


Figure 6: Thrust-Drag Plot

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].

$$FS = (2 - EW)(PF)120 = 102.23$$

Equation 3: Flight Score

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 of 0.825 pounds and maximum payload of 2.18 pounds, the predicted flight score of the aircraft is 102.23, 4.05 points more than last that of year's winner [10].

3.2 Stability and Control

In order to have a statically stable aircraft in pitch, the center of gravity needs to lie between the 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 [11]. The team could then use *SolidWorks* to estimate the aircraft's center of gravity at any time.

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 [12]. 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:

$$\bar{x}_{mf} = \frac{x_{mf}}{\bar{C}} = \frac{-0.15 + \bar{x}_{ac_w} + A * \bar{x}_{ac_H}}{1 + A} = 1.08$$

Equation 4: Most Forward Point

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:

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

Equation 5: Stability Coefficient (*A*)

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:

$$\bar{x}_{np} = \frac{x_{np}}{\bar{C}} = \frac{C_{L\alpha_w} * \bar{x}_{ac_w} + \eta_H * \frac{S_H}{S_w} * C_{L\alpha_H} * \frac{d\alpha_H}{d\alpha} * \bar{x}_{ac_H}}{C_{L\alpha_w} + \eta_H * \frac{S_H}{S_w} * C_{L\alpha_w} * \frac{d\alpha_H}{d\alpha}} = 1.24$$

Equation 6: Neutral Point

The equation for the size of the stability envelope is:

$$SE = \bar{x}_{np} - \bar{\bar{x}}_{mf} = .16$$

Equation 7: Stability Envelope

Using *SolidWorks*, the team calculated the normalized center of gravity as 1.18, which falls within the stability envelope.

The team used historical data from full-size aircraft to determine dimensions for the elevators and rudders [8]. 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.

3.3 Wing Sizing

The team selected the Glenn Martin 4 airfoil (Figure 7) 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 [13]. 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.

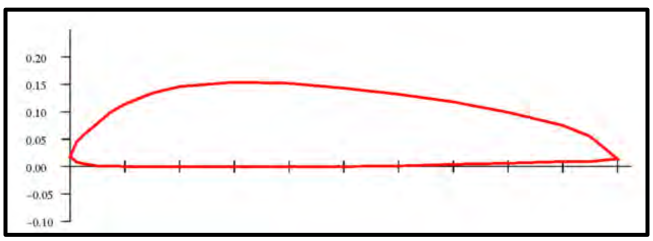


Figure 7: Glenn Martin 4

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.

3.4 Weight Build-up

Table 3 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 3: Weight Build up

Wing Assembly	Starboard	Balsa Wood	0.048	Tail Assembly	Balsa Wood	0.033
		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	0.114		Pull-Pull Control System	0.008
	Port	Balsa Wood	0.048		Subtotal	0.056
		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	0.114		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	0.074	Payload Bay	Balsa Wood	0.020
		Glue	0.010		Skin Coat	0.010
		Skin Coat	0.018		Glue	0.004
		Subtotal	0.092		Subtotal	0.034
Total Assembly Weight [lbs]:						**0.825**

3.5 Structural Analysis

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

The team approximated an elliptical lift distribution given by the equation:

$$L'(z) = L'_o\sqrt{1-\left(\frac{2z}{b}\right)^2}$$

Equation 8: Wing Loading Distribution

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:

$$\frac{L}{2} = L'_o * \int_0^{\frac{b}{2}} \sqrt{1 -* (2 * z/b)^\wedge 2}\ dz = 1.5\ lbf$$

Equation 9: Equation for Determining L'_0

Where L is the total lift experienced by the aircraft.

The team performed a static wing loading test consisting of a pair of wings connected to the fuselage. The fuselage is then flipped over and weights are applied to simulate the lift forces experienced during cruise (Figure 8).

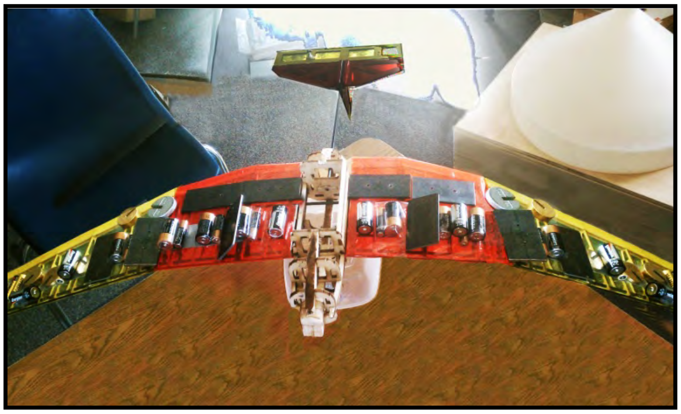


Figure 8: Static Wing Loading Test Set Up

The team added weights to simulate the elliptical lift distribution until failure occurred. The wings failed after experiencing 8.5 pounds of loading when a center rib closest to the dihedral fractured due to excessive bending forces. 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.

4.0 Specifications

This section breaks down the various components of the airplane to highlight their specific characteristics and how they interact with the aircraft.

4.1 Wings

The wing assembly consists of a port and starboard wing (Figure 9) which are mirrors of each other.

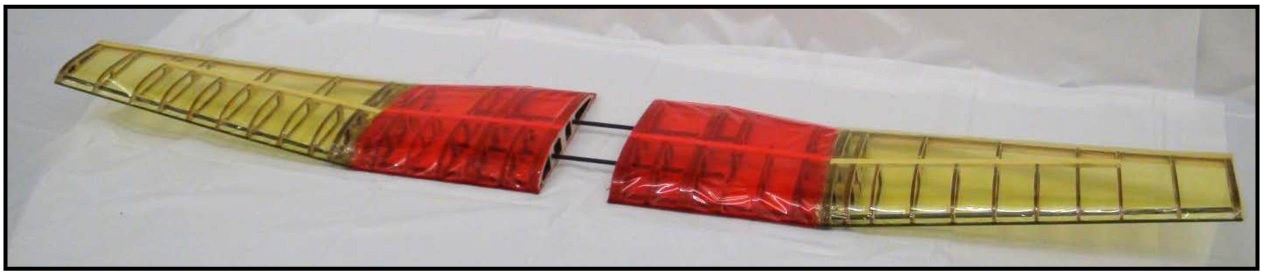


Figure 9: Wing Assembly

Each wing consists of 18 ribs of various thicknesses arranged to provide structural support and surface area for skin covering. Figure 10 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.

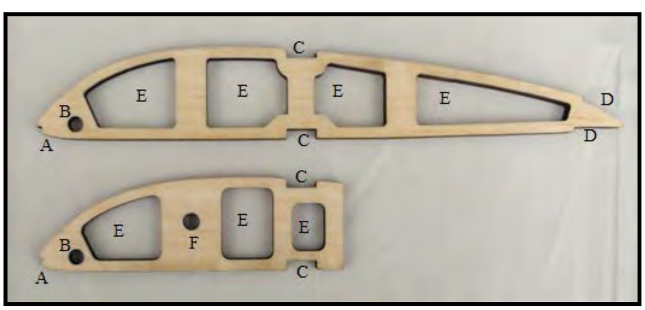


Figure 10: Full and Half Ribs

The main spar and top and bottom supports provide the majority of the structural rigidity. 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 Fuselage

The fuselage (Figure 11) 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.

Figure 11: 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.

4.3 Tail

The team designed a lightweight tail (Figure 12) 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.

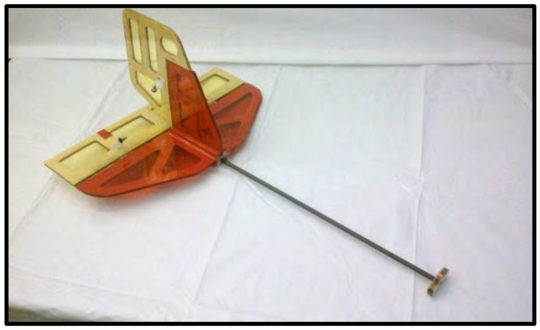


Figure 12: Tail

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 13 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.

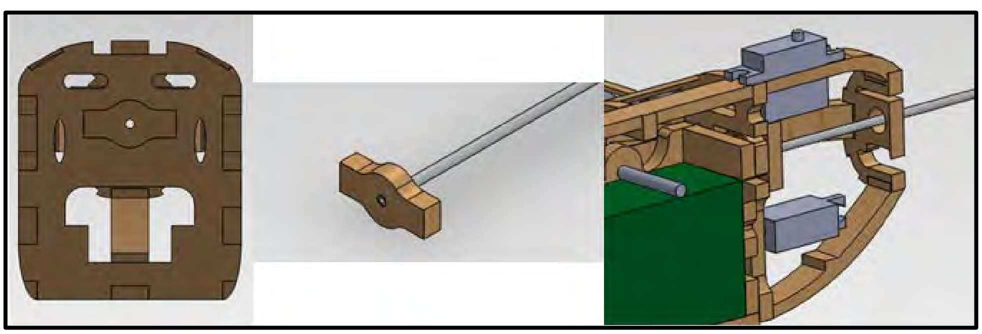


Figure 13: Tail-Locking Mechanism

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.

4.4 Electronics

The team focused on finding lightweight electronic components that would still provide the necessary power and performance characteristics. Table 4 summarizes the electronic components selected by the team.

Table 4: 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 [9]. 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 10 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 3 to 5 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.

4.5 Payload and Payload Bay

The payload bay (Figure 14) 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.

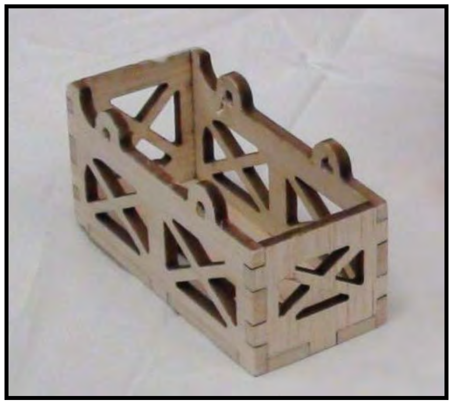


Figure 14: Payload Bay

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.

4.6 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 15 shows a montage of the assembly of the aircraft to flight ready status.

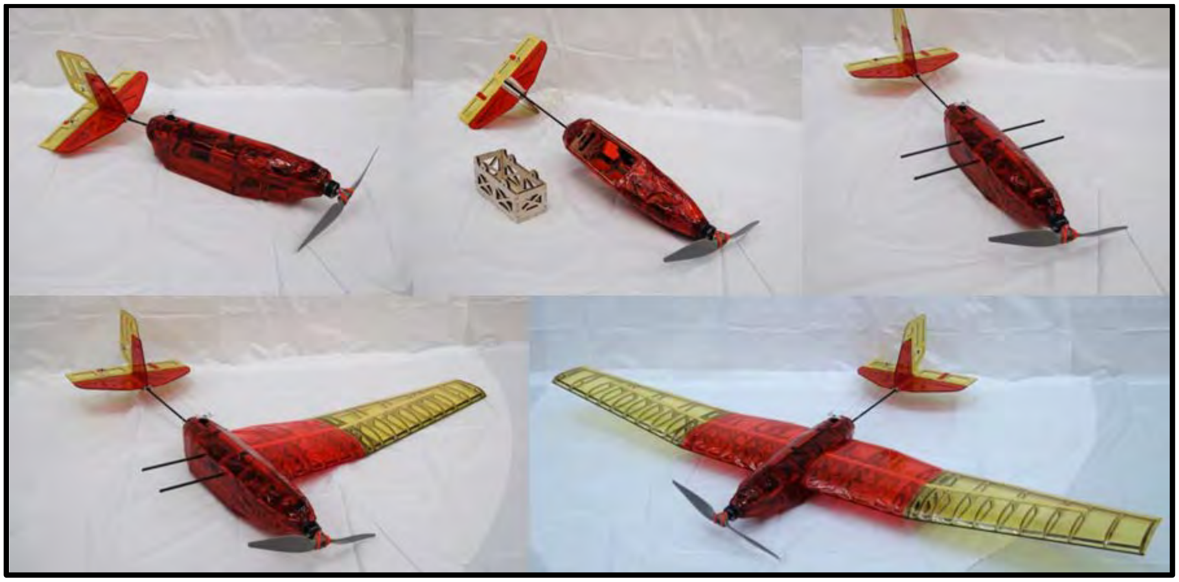


Figure 15: Final Assembly Montage

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 Fabrication

The team placed high importance on a design that could be reliably and easily manufactured.

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.

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) [14]. While the yield strength also decreases with density, it did not vary enough to cause the team concern.

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 [14].

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 16) 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.

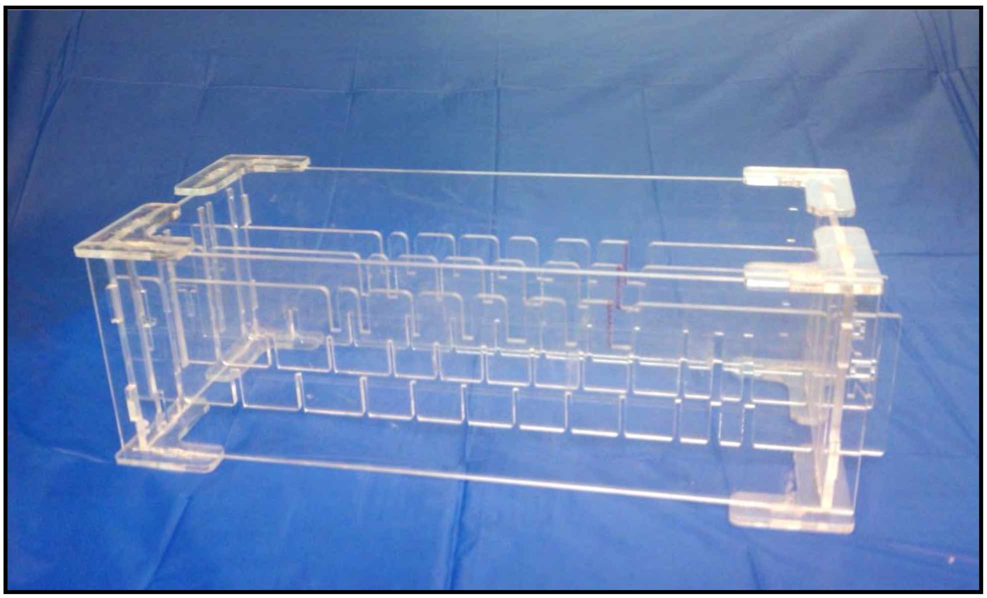


Figure 16: Assembly Jig

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 17. 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.

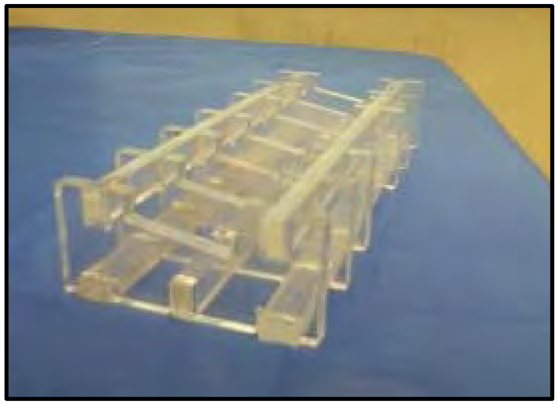


Figure 17: Dihedral Sanding Jig

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 at WPI's machine shops to cut the balsa components for the aircraft and the acrylic used for the assembly boxes. 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 accurately manufacture any wooden component in a matter of minutes.

6.0 Summary

This section highlights the features that make the aircraft unique and evaluates the final product against the team's stated goals.

6.1 Innovations

Several features distinguish *Tina* from similar aircraft. The collapsible tail facilitates the plane's storage while decreasing the time needed to prepare the aircraft for flight. The two spars that join the wings, fuselage and payload bay together provide a simple way to assemble the aircraft. The dihedral joints provide a precise angle while contributing to the structural strength of the wing. The assembly jig reduced manufacturing errors by providing proper positioning for the ribs during wing fabrication. These differentiate the team's aircraft from the rest of the field.

6.2 Conclusion

The final aircraft weighs 0.825 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.

References

[1] SAE Rules Committee, First. "SAE International 2012 Collegiate Design Series Aero Desig East and West Rules." : 1-51. http://students.sae.org/competitions/aerodesign/rules/rules.pdf (accessed December 15, 2011).

[2] LasUjvaryt, Kelley. "UC Teams Fly High at SAE Aero Design East." *University of Cincinnati*. University of Cincinnati, 04 May 2011. Web. 2 Sep 2011. <http://www.uc.edu/news/NR.aspx?id=13588>.

[3] "Micro Air Vehicle." Stevens Institute of Technology. Web. 02 Sept. 2011. <http://www.stevens.edu/ses/me/fileadmin/me/senior_design/2006/group05/design.html>

[4] TJ Coffey. SAE Heavy Lift Micro Class 2008. 2008. Photograph. flickr.comWeb. 2 Mar 2012. <http://www.flickr.com/photos/aero_gopher/sets/72157607475906103/>.

[5] “Employees of RC Buyers Warehouse, Nashua NH." Personal interview. 16 Feb. 2012.

[6] “Annis, Scott and Mickey Callahan of the Millis Model Aircraft Club.” Personal Interview. 27 Feb. 2012

[7] *XFOIL*. Vers. 6.97. Drela, Mike and Youngren, Harold. 2008, Computer Software.

[8] Raymer, Daniel. *Aircraft Design: A Conceptual Approach*. 2nd ed. Dayton, OH: AIAA, 1992. Print.

[9] *MotoCalc8.* Vers. 8. Capable Computing, Inc. 2011. Computer Software

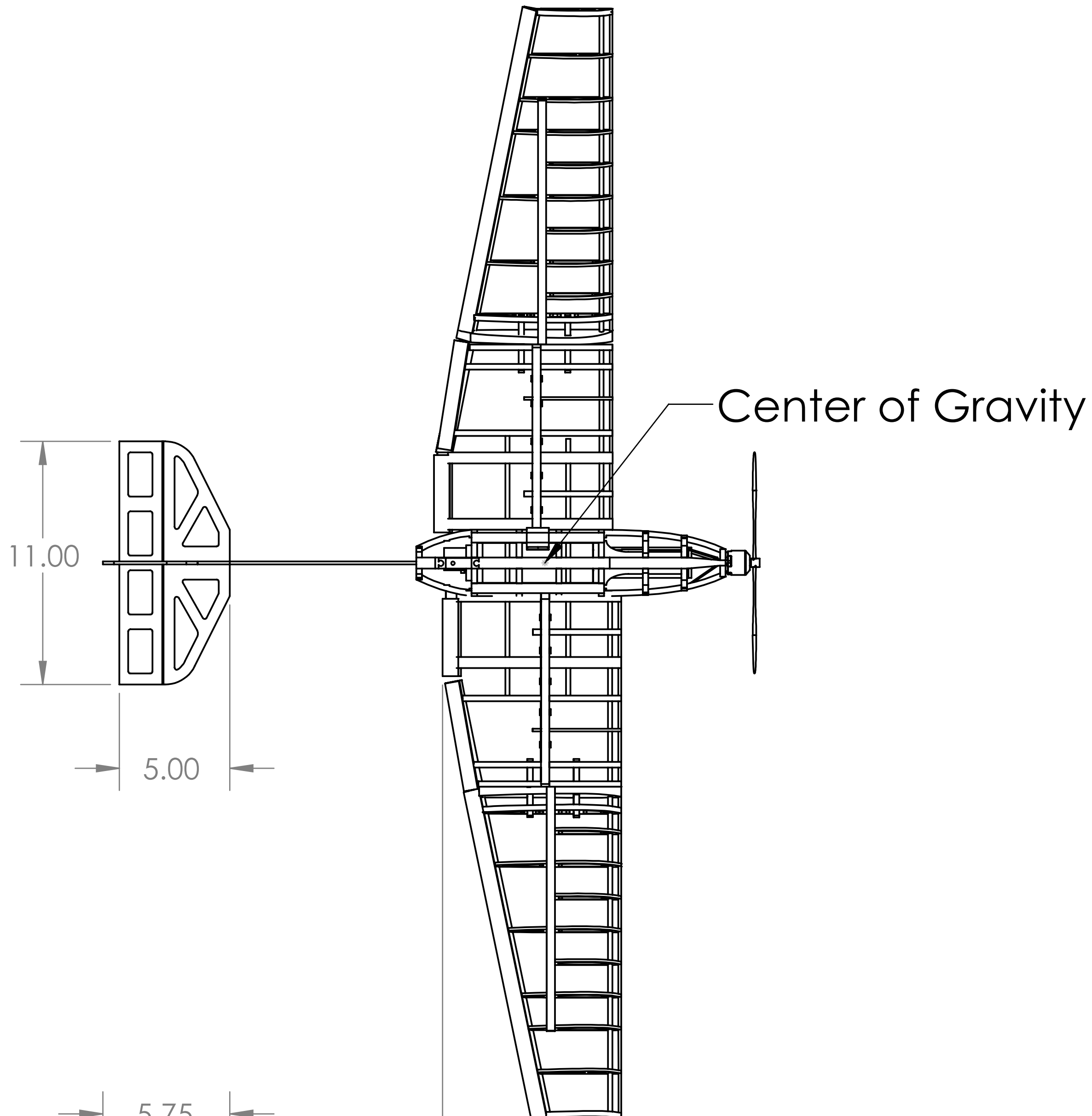
[10] “Lockheed Martin/ SAE Aero-Design in Marietta Results” SAE. Web. 02 Sept. 2011. <http://students.sae.org/competitions/aerodesign/east/results/2011micro.pdf>.

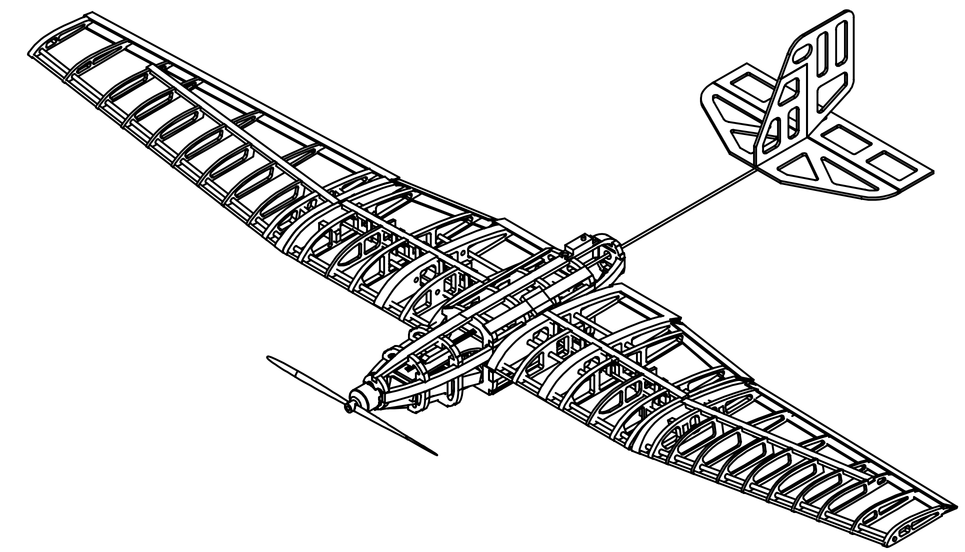
[10] *Solidworks*. Vers. 2012. Dassault Systemes, 2012. Computer Software.

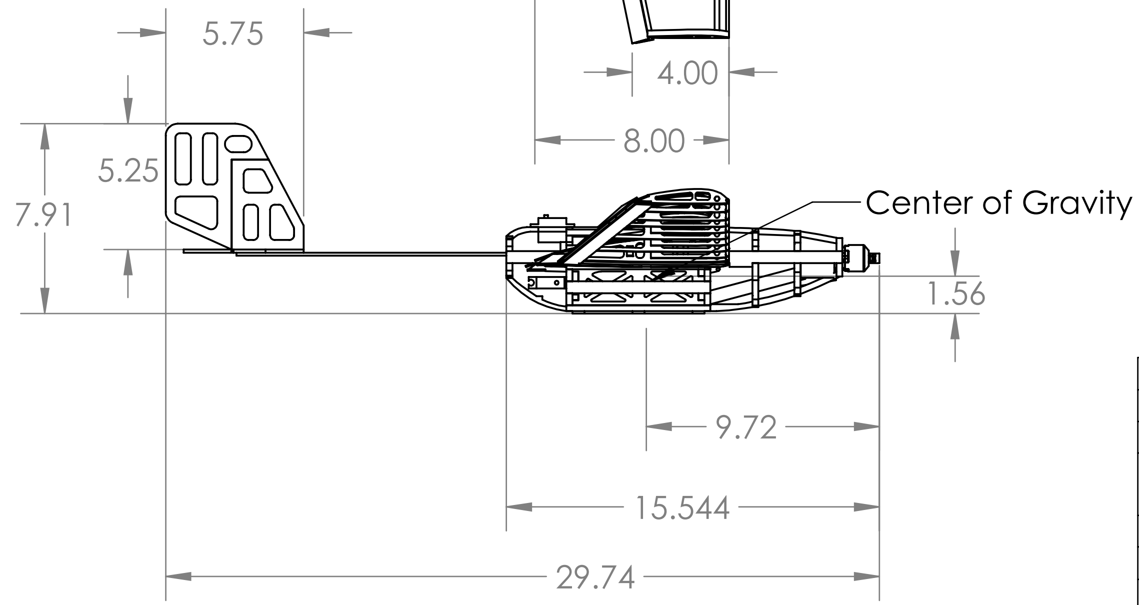
[12] *Microsoft Excel*. Vers. 2010. Microsoft, 2010. Computer Software

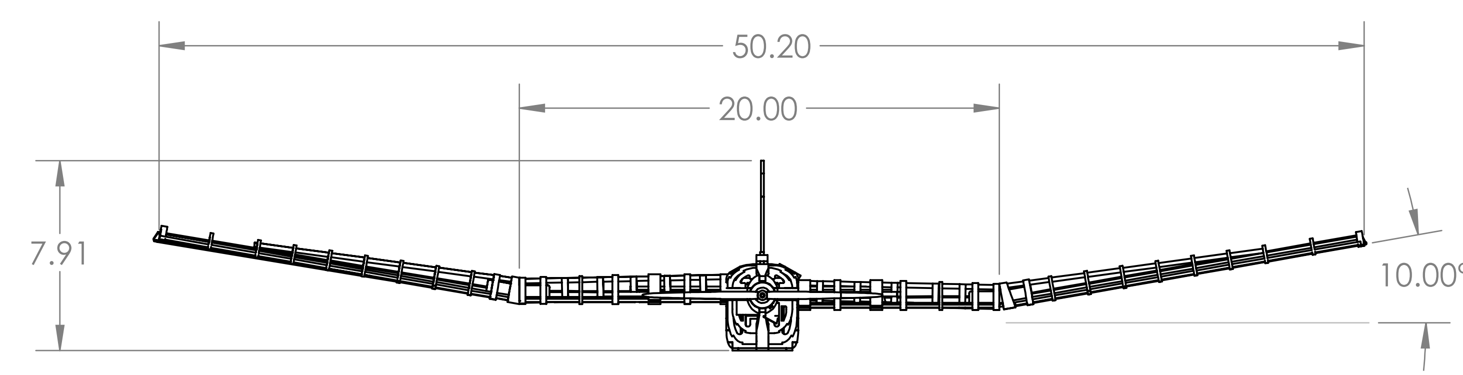
[13] "Glenn Martin 4." *Airfoil Investiagtion Database*. N.p., 22 Jan 2011. Web. 7 Oct 2011. <http://www.worldofkrauss.com/foils/255>.

[14] *CES EduPack* 2012. Granta 2012. Computer Software.









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 – Payload Prediction Curve

Figure 3: Payload Prediction