Benj Aerospace Preliminary Design Review

Radio Controlled Golf Ball Transport Aircraft

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Executive Summary

This report details the preliminary design of a radio controlled aircraft by Benj Aerospace. The team has identified design requirements and selected target performance parameters for a competitive aircraft. To maximize the flight score, Benj Aero has selected a rather simple design that can be simply assembled and tested thoroughly. The philosophy driving the design is to build confidently towards a high, but not necessarily maximum score. Practically, meeting a score below the maximum is preferable to failure with a maximum score configuration.

The current approach is to construct a built up wood-monokote aircraft. Laser cut wood is very simple to manufacture and redesign, with low density. As the competition necessitates a high payload, minimizing empty weight is of the utmost concern. Through the scoring analysis, an optimum score of 54.6 can be achieved. The optimum score assumes a payload of 12 golf balls, and 14.5 m/s. Preliminary estimates say this can be achieved with the parts available, and perhaps surpassed in flight.

Preliminary Design	
Gross weight	1.3 kg
Empty Weight	0.75 kg
Payload Weight Ratio	0.4
Ball count	12
Max Cruise Speed	14.5 m/s
Ground Roll	21.2 m
Takeoff Speed	12.3 m/s

Conceptual Design

Mission requirements

The goal of the design project is to carry as large of a payload as possible, while achieving the highest possible flight speed. The maximum flight speed is set during a period of steady level flight. The payload will be golf balls, which can be considered as discrete mass increments of 46 grams or 0.45 newtons. The flight area is rather small. Therefore, banked turns must be completed multiple times during flight. Once flight is demonstrated, the aircraft must safely land with little to no damage to the vehicle to allow for another flight attempt if needed.

- Must be radio controlled
- Must be electric and propeller controlled
- Must use the standard motor, battery, speed controller, receiver, and transmitter
- Maximize cruise speed with largest possible payload
- Take off and land without structural damage
- Must be modular and transportable to the airfield

Design Requirements

The following design entry conditions must be met to attempt flight. Incorporation of working flight avionics that assist in stability must be designed. Testing and analysis must be done to confirm nominal operation of the aircraft. Testing will include ground roll, ground turning, control surface actuation, transmitter communication, and motor throttling.

- Takeoff distance of less than 100 m
- Stable ground roll
- No in-flight shifting of CG
- Roll, pitch, yaw control
- Static and dynamic stability in loaded flight
- Be maneuverable and intuitive to fly

Scoring Analysis

When designing the aircraft the most important thing is taking the given scoring function into consideration.

$$Flight\ Score\ =\ 7.5\ *\ \frac{W_p}{W_r}+f_p+\frac{V_{max}}{V_r}+\ 7.5\ *\ B$$

The first weighted variable is the payload weight (W_p) in Newtons. This variable is nondimensionalized by W_r = 1 N. Given that each golf ball weighs about 46g, or 0.45N, this would give about 3.4 points for each golf ball. When comparing that to the max velocity V_{max} around 15 to 20 m/s, the points granted from a high V_{max} would be the same for only about 6 golf balls. The payload weight fraction f is set 0.4, allowing for some flexibility in payload mass for any discrepancies that will come with prototyping and manufacturing. The empty flight completion factor B is either 1 or 0 depending on whether empty flight can be completed, so while this is an important design factor it is not one that is considered when looking at setting gross mass or max velocity for the aircraft.

The flight velocity is dependent on the gross weight, where the expected flight velocity can be found with the power to thrust ratio times the propeller efficiency. Since thrust equals drag in steady level flight, drag is substituted for thrust. The reference area can be expanded to the product of gross weight and wing loading. Solving for velocity obtains the scoring function as a function of gross weight.

$$\eta P/T = V$$

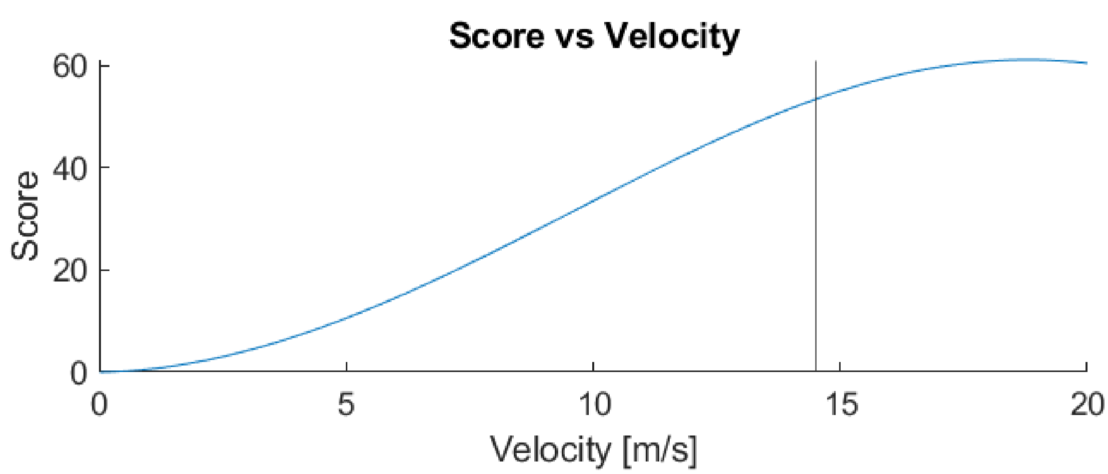
$$T = D = 1/2\rho V^2 C_D S = 1/2\rho V^2 C_D W/(W/S)$$

$$V = \sqrt{\frac{T}{W}\frac{W}{S}\frac{2}{C_D\rho}}$$

Since wing loading is a value that can be set, gross weight can also be given as a function of velocity. In doing so, while omitting the flight completion factor, the entire scoring function can also be plotted as a function of velocity.

$$W = \frac{2T}{\rho V^2 C_D}\frac{W}{S}$$

$$Flight\ Score = 7.5 * \frac{2T}{\rho V^2 C_D}\frac{W}{S} * \frac{1}{W_r} + f_p + \frac{V}{V_r}$$



This shows an anticipated score of about 55 given a max cruise velocity of 14.5 m/s.

Configuration Selection

A built up frame will be used to construct both the wings and the fuselage. A long and narrow fuselage was chosen to provide maximum strength and aerodynamics.

The empennage was designed taking into consideration the dimensions of the wing, an estimated distance between the quarter chord of the wing and the quarter chord of the vertical or horizontal stabilizer, and typical tail volume coefficients associated with homebuilt aircraft. These help provide the area of each stabilizer, allowing for flexibility depending on the shape of each stabilizer. For both vertical and horizontal components a trapezoid is used as a base, with the horizontal stabilizer specifically having a low to moderate taper ratio. The elevators and rudder are to be attached to the stabilizers with masking tape, with the total calculated area including the control surfaces.

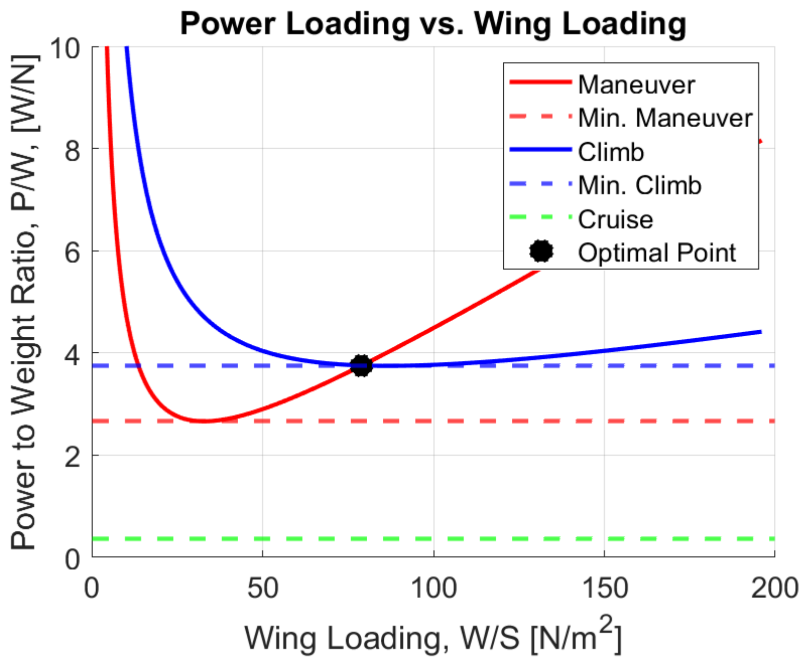
A tail dragger landing gear configuration has been chosen. The goal is to ensure a stable ground roll. In lighter RC aircraft like the present design, tricycle landing gear was feared to be uncontrollable if slightly perturbed. Successfully completing ground roll will reduce the probability of a catastrophic failure on the airfield when attempting takeoff or landing.

Component Configuration

Balsa wood ribs and spars support a thin skin of Monokote. The empennage is directly integrated with the fuselage. The wing is constructed separately from the fuselage and then attached using rubber bands or some other lightweight elastic fastener. The aircraft will use a tail dragger landing gear configuration and have ground steering through the rear wheel in linkage of the yaw control. A single font mounted 9x6E propeller and Cobra C-2217/16 provide the aircraft propulsion. All of the avionics are stored near the front of the fuselage, reserving the aft section to remain free for potential cargo. The wings are placed sufficiently far back that a cargo is not needed to meet stability requirements.

Initial Sizing

The driving sizing requirements are a 3g maneuvering load factor, and the climb requirement. The sizing plot shown considers a maneuver speed of 10 m/s, a 3g load factor. The climb requirement assumes a climb factor of G = 0.11 at the 12.3 m/s takeoff speed. Wing loading is set at 79 N/m^2. Power to weight ratio is set at 3.75 W/N. While conservative, the maneuver may alternatively be a 2g maneuver at 14 m/s, and still be adequately sized with the chosen wing loading and power to weight.



Preliminary Design

Propulsion

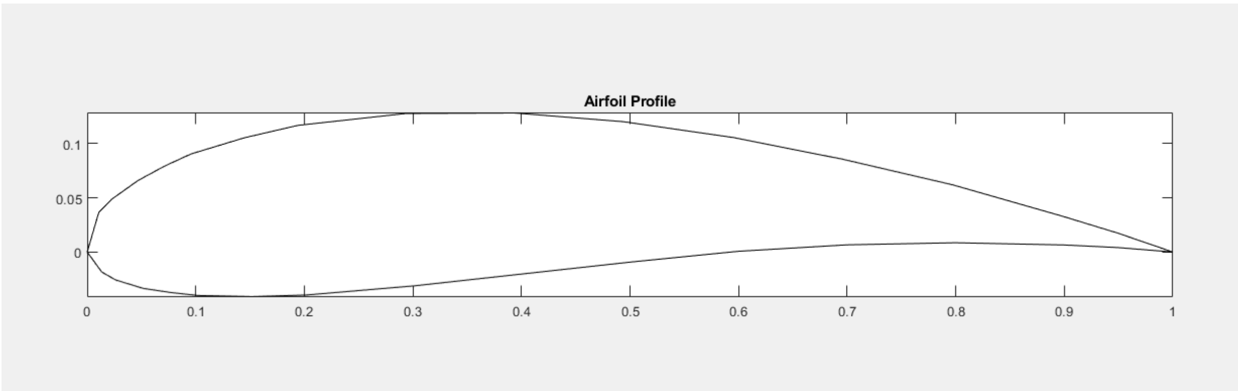
The motor and power supply are predetermined for the present design challenge. Thus, the aircraft will be constrained by the available motor power. A forward mounted propeller was chosen considering the static stability margin, and ease of manufacturing. The propeller is chosen based on the nominal operating conditions of the motor. Given the high voltage of the motor, and target gross weight, propeller selection was limited to only a few options.

The 9x6E propeller will be used. At low speeds, the propeller will be less efficient, and thus require more power to accelerate than a propeller with lower pitch. The power required for this target cruise condition is 77% that of the maximum available motor power.

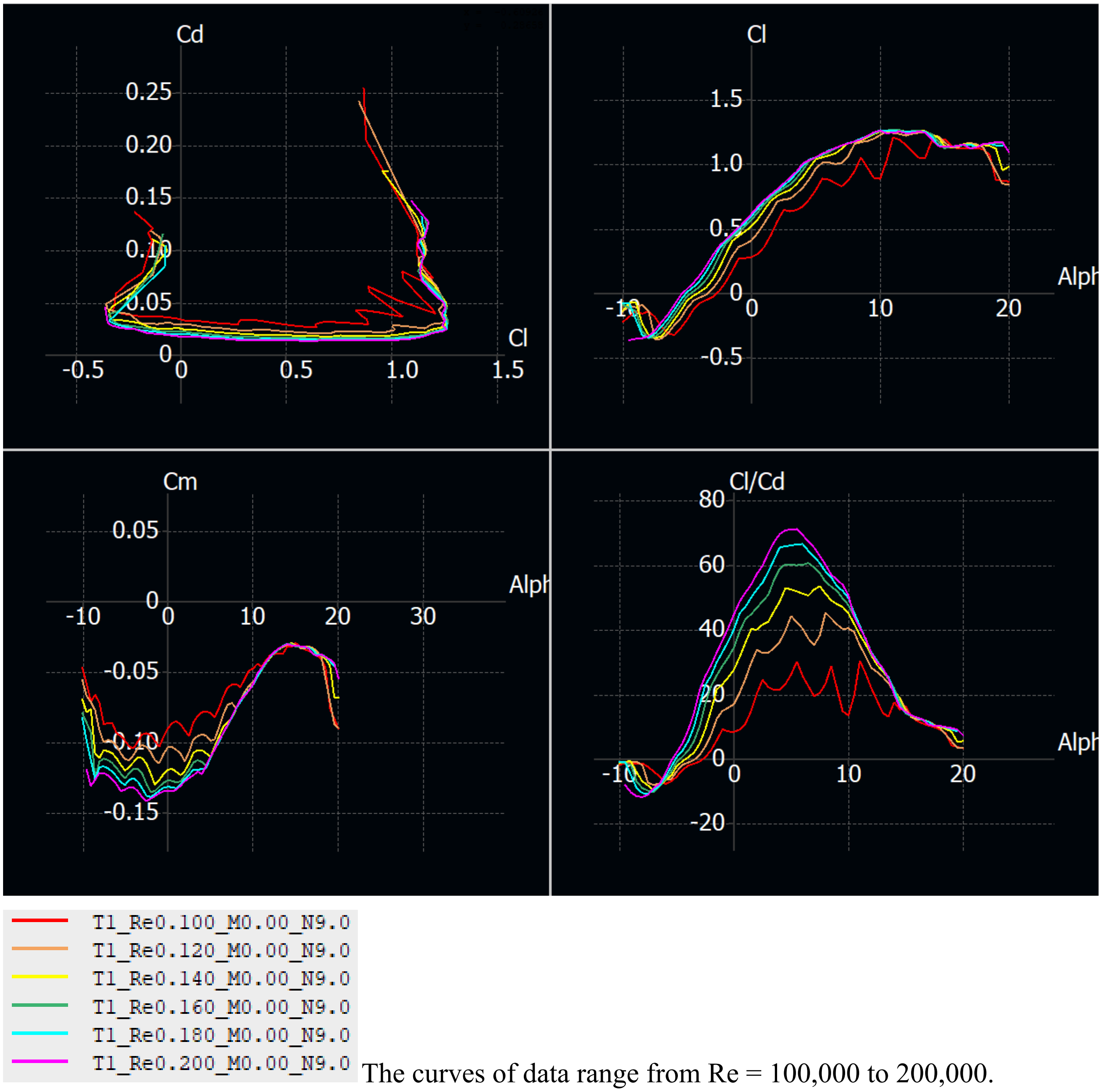
Efficiency	0.630
Thrust	8.28 N
Torque	0.19 N-m
Power Required	198.58 W
Advance Ratio	0.40
Rotational Speed	10000 RPM

Aerodynamics

The Gottingen 498 is the chosen airfoil for the aircraft. According to Daniel Raymer's historical trend data, small planes designed for low laminar speeds (close to Mach = 0) will have an optimal airfoil when the thickness to chord ratio is around 16%. The GOE 498 is chosen from a list of candidates with this characteristic because it provides a 0.45 cruising lift coefficient, which lies close to where our plane will be cruising, 0.4.



Below is a set of selected graphs that demonstrate the two-dimensional aerodynamic behavior of the airfoil.

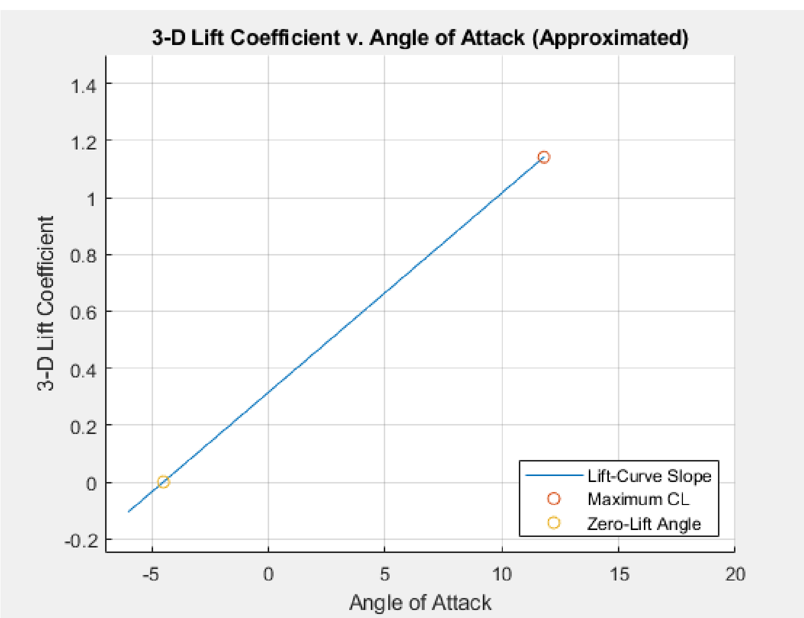


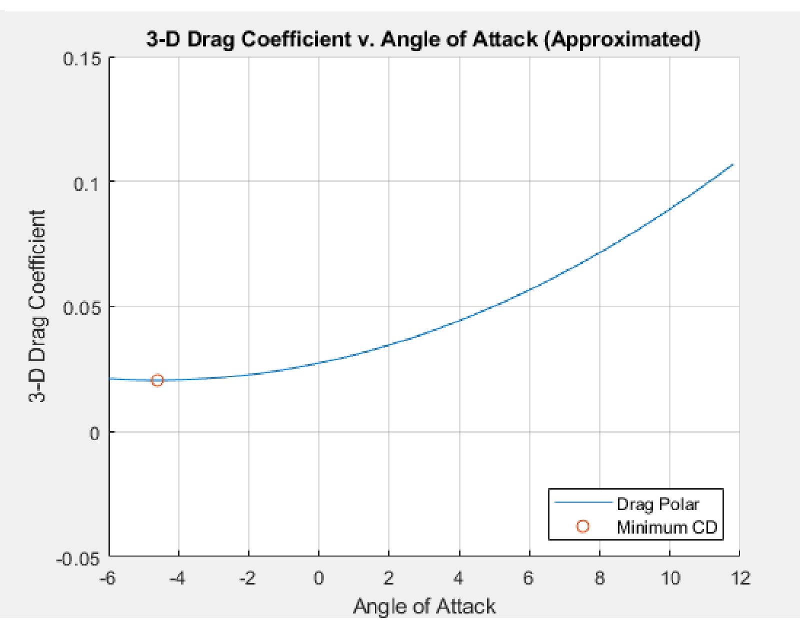
The curves of data range from Re = 100,000 to 200,000.

Using provided equations from the aerodynamics lecture from Professor Hwang, the 3D aerodynamic behavior of the plane can be approximated. Provided is a table of estimated values and required physical attributes of our wing profile.

Flight Reynold's Number	148,000
Flight Mach	0.05
Aspect Ratio	6.25
Span	0.97m
Area	$0.15m^2$
Cruise C_L	0.3152
Cruise C_D (subject to refinement)	0.052
L/D	6.062
Zero-Lift Angle	-4.5°
Sweep Angle	0°
Taper Ratio	0

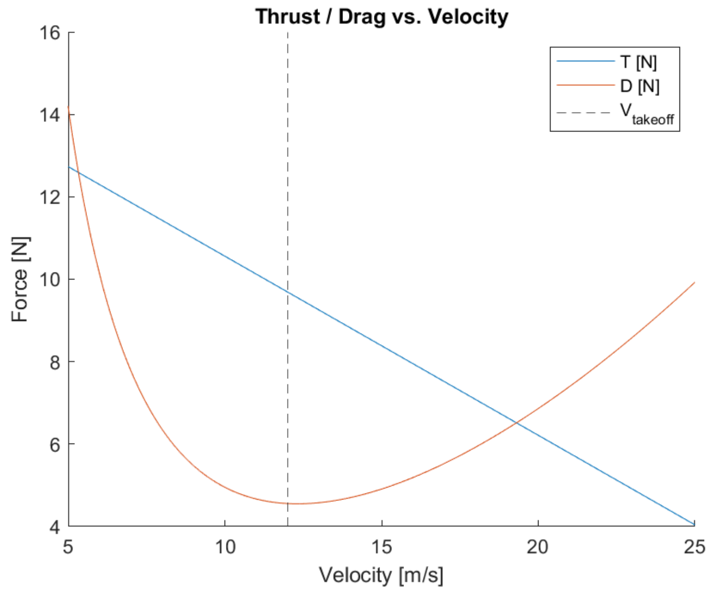
Below are graphs of CL and CD vs. Angle of Attack using the previously mentioned approximation method.





A high-wing configuration will be used as it provides a more stable roll. This allows the center of gravity to sit below the aerodynamic center, which will provide crucial stability to a plane carrying a payload that could possibly shift during flight. A rectangular wing profile is used for manufacturing ease. The benefits that are provided from perfecting a wing shape are marginal.

Takeoff Analysis



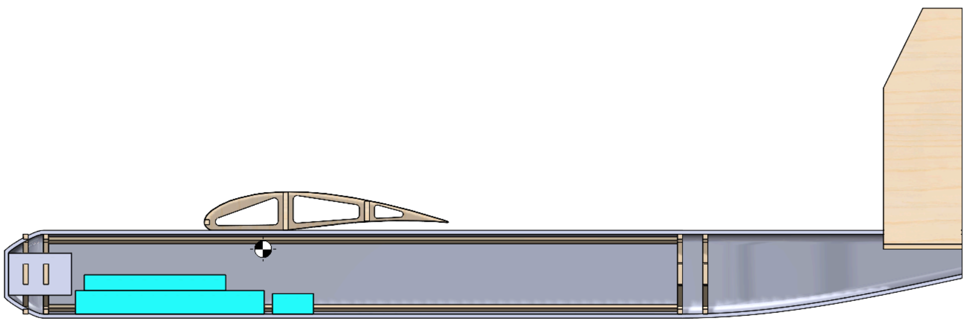
With the lift coefficient data provided for the given airfoil a takeoff lift coefficient can be estimated, which in turn helps estimate the takeoff speed of the aircraft at 12.3 m/s. At about 70% of this takeoff speed the mean acceleration is estimated by balancing thrust, drag, and rolling frictional forces considering the gross weight and lift. That is then used to calculate a takeoff ground roll distance of 21.2 m which is comfortably less than the 100 m runway provided for the competition.

Weights & balance

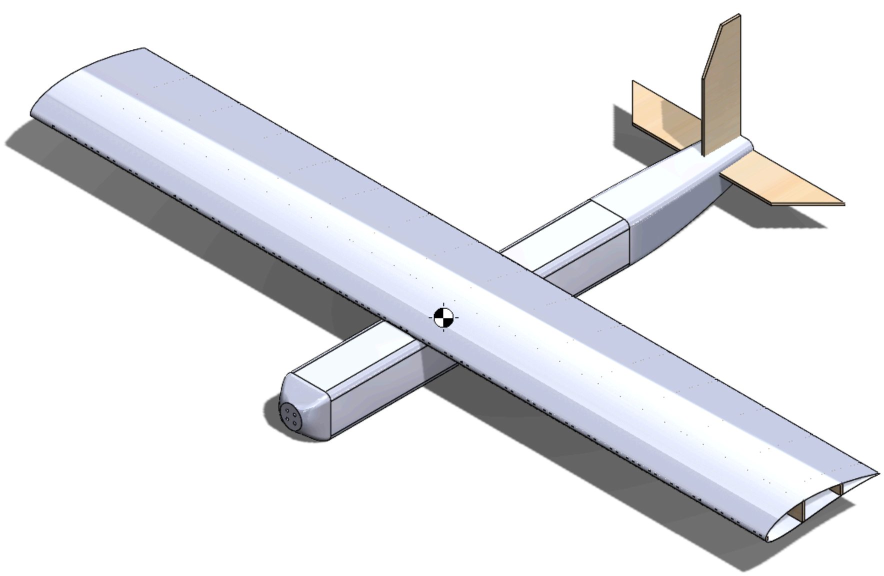
As materials have been selected, early weight estimates for the structure can be made. All off-the-shelf components have been weighed, modeled, and will be placed in an assembly of the aircraft. From the digital model, estimates for mass and inertias can be generated quickly with new weight placements. As of now, avionics have been placed as far forward on the aircraft as possible, as the CG is expected to shift backward.

Accurate modeling of the center of gravity is necessary for neutral point calculation. The wing geometry has been analyzed in XFLR5, and can generate estimates of the neutral point. As the design converges, analysis can be done in Open VSP to determine static and dynamic stability during nominal flight.

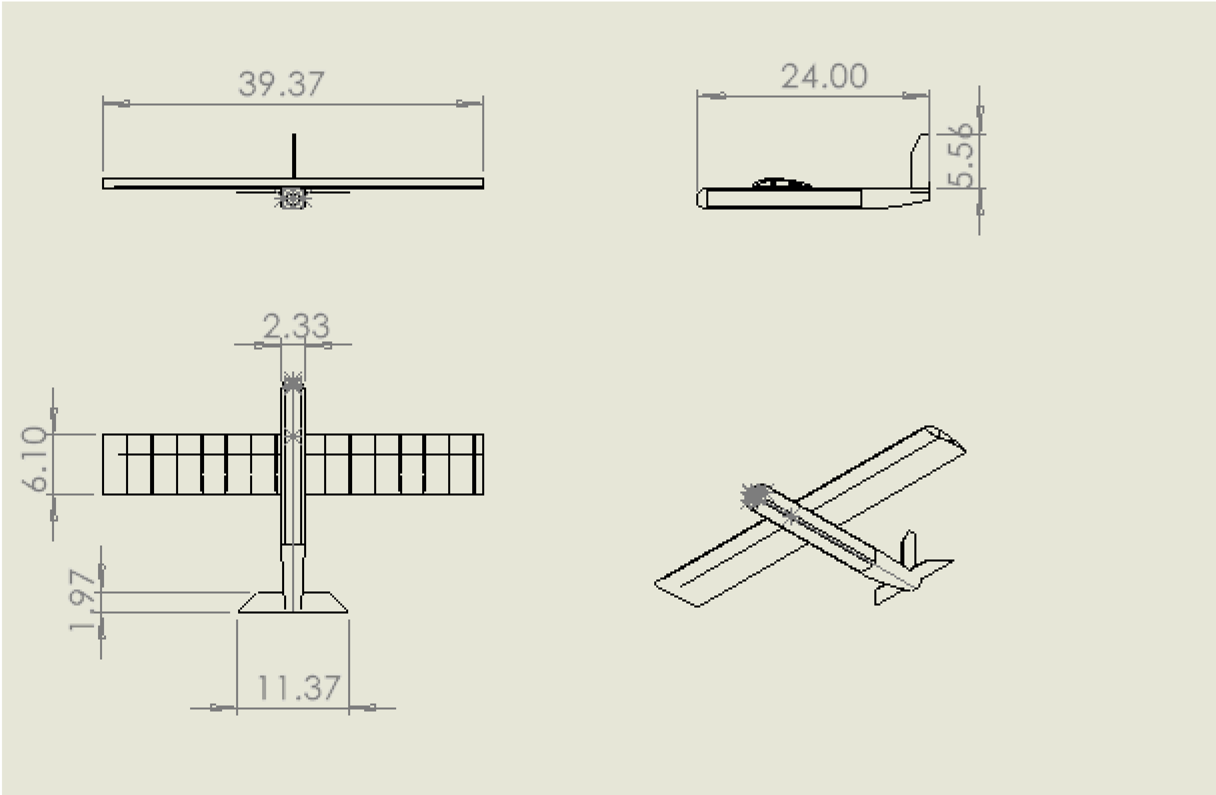
High-level CAD (isometric view + one-page three-view drawings)



Side View



Isometric View



3-View Drawings. Measurements shown in centimeters.