UCI Samueli School of Engineering

# Spring 2021 DBF Final Presentation

Team 2

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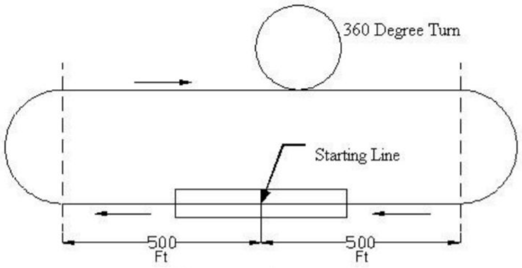
# DBF Problem Definition

- Design and Manufacture an aircraft to enter in the 2020-2021 AIAA Design/Build/Fly competition
- The competition will happen virtually, as decided by the AIAA
  - Will continue to make an aircraft capable of accomplishing competition requirements even though we will not be competing
- Aircraft is designed to achieve best score overall
- Aircraft will carry and tow a sensor package and complete all mission requirements
  - Mission 1: 3 laps with no payload in 5 min
  - Mission 2: 3 laps with payload (sensor in shipping containers) in 5 min
  - Mission 3: Deploy, tow and recover sensor and run as many laps as possible in 10 min
  - Ground Mission: Load and unload payload in the least time possible
- Design Constraints
  - 200 Whr battery capacity
  - 5 foot wingspan
  - Sensor must be fully contained in the shipping container during M2 and M3
  - Sensor must be at least 4 times longer than its diameter
  - Tow cable must be at least 10 times longer than the sensor length




Course layout shown to scale.

# Scoring Analysis

Two key conclusions

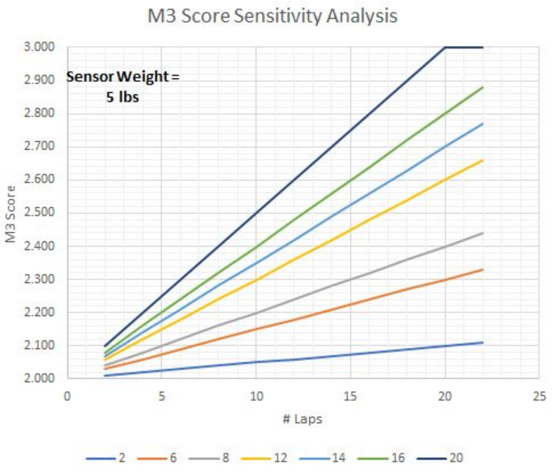
- Only having 1 sensor will yield high combination score of GM and M3
- Focus on finding max sensor length and sensor weight to maximize M3 score

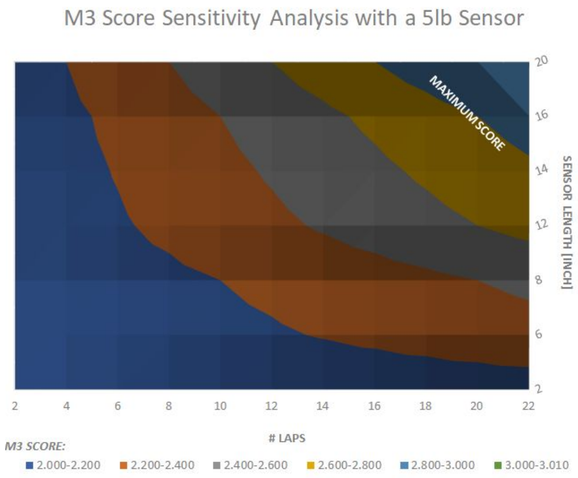
$$GM = \frac{Min\_(Time)}{N\_(Time)}$$

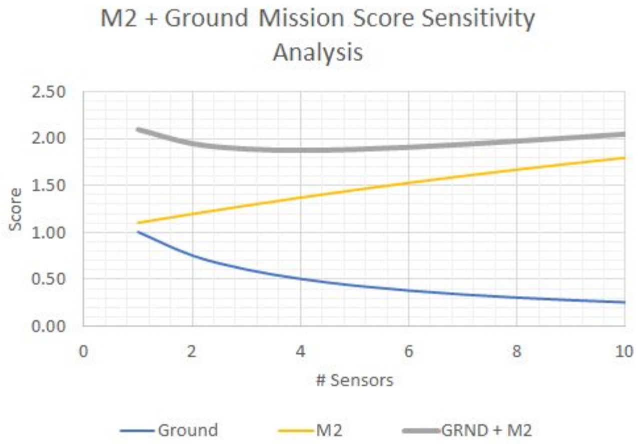
$$M1 = 1.0$$

$$M2 = 1 + \frac{N\_(\#Container/Time)}{Max\_(\#Container/Time)}$$

$$M3 = 2 + \frac{N\_(\#Laps * Sensor\ Length * Sensor\ Weight)}{Max\_(\#Laps * Sensor\ Length * Sensor\ Weight)}$$

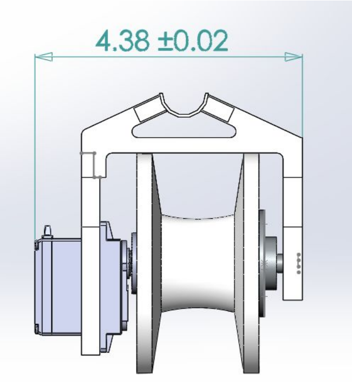


# Design Goal

Given the selection of focusing on mission 3. Our team is designing an airplane to carry the payload and deployment mechanism while completing as many laps as possible.





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# Wings Design

## In accordance with the design goal, the plane is being designed to fly as fast as possible.

Requirements:

- Takeoff in 100 ft
- 5 ft span
- 200 W hr Battery

Goals:

- Maximize aspect ratio (minimizes drag)
- Minimize weight
- Determine max cruise speed
- Select motor-propeller combo able to produce the thrust required

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# Limiting factors for wing sizing:

Takeoff Condition:

- Higher AR results in a higher wing loading.

$$S_g = \frac{1.44W^2}{g * \rho * s * C_{Lmax} * (T - D)_{0.7V_2}}$$

Reynolds Number:

- Higher Reynolds number, higher $C_{Lmax}$

Thickness of the Airfoil:

- Must be thick enough to cover the spar

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# Tail Design

Similar to the wing, the tails are designed to minimize drag.

Requirements:

- Falls within recommended tail volume range bounds
- Provides a large enough moment to allow for takeoff

Goals:

- Maximize aspect ratio
- Minimize weight

# Tail Design

Historical Tail Volume Ranges:

$AR_h$: 3-5 $AR_v$: 3-5

$V_h$: .48-.92 $V_v$: .24-.86

$$V_h = \frac{S_h l_h}{Sb}$$

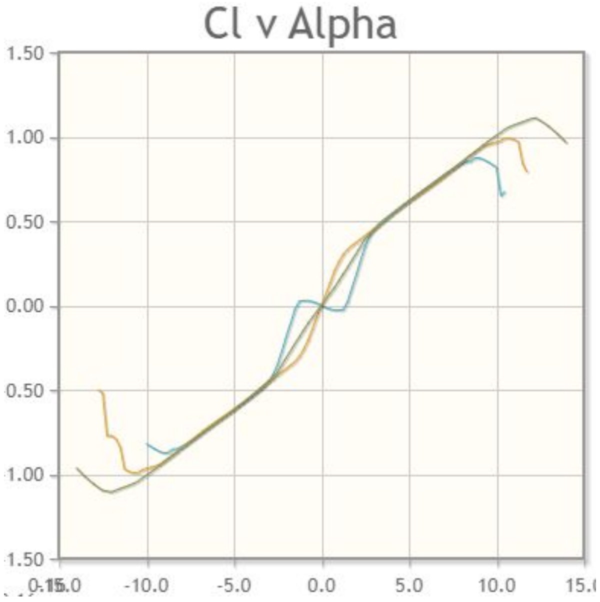
A chosen volume coefficient gave us the planform area. That area will be used with the chosen aspect ratio to solve for the chord.

# Tail Chord Limiting Factor

A chord that is too small will lead to a lower Reynolds number. This reduces the performance of the tails as shown to the right.

- Horizontal and Vertical Tail
  - Minimum chord length .5 ft

Minimum Reynolds number was set to 140,000 so the Cl max would match the assumptions made for takeoff calculations.




Blue - RN=50,000
Yellow - RN=100,000
Green - RN=200,000

| Wing and Tail Construction | Pros | Cons |
| --- | --- | --- |
| Foam | • Construction has very few steps<br>• Easy weight predictions | • Sourcing thick enough foam is very difficult<br>• Very easy to break or dent until coated<br>• Heavier (.634 lbs) |
| Balsa Structure | • Light weight (.45 lbs)<br>• Materials are currently available in lab<br>• Has empty space for wires and servos, making the aileron construction easier | • Construction requires more time in lab<br>• Coating can sag between ribs if spacing is not correct |

# Fuselage Sizing

Sensor length determines the overall length of the fuselage required. Sensor retraction method determines the height and width.

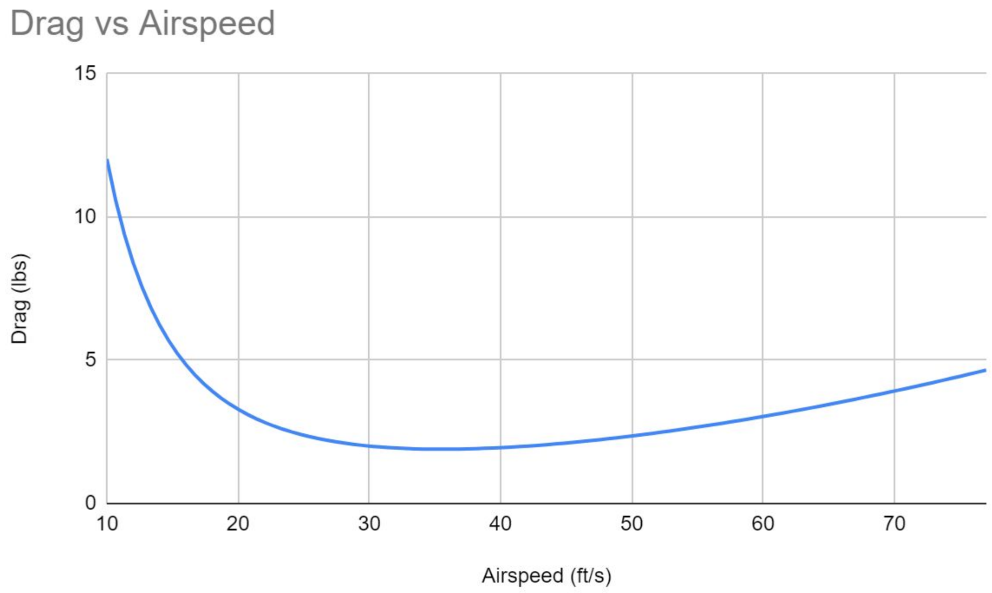
The goal for our design process is to minimize weight, while having a design that can result in a cg near the quarter chord of the wing.

| Fuselage Construction Method | Pros | Cons |
|---|---|---|
| Kevlar Shell | • Lightweight (.0217 lbs)<br>• Less Drag due to smaller outer diameter<br>• Easier construction for a circle | • Everything must be attached to tail boom which restricts the balancing of the center of gravity<br>• Team lacks experience making molds |
| Balsa Wood Structure | • Can provide additional support to the landing gear<br>• Has more attachment points which can help balance the center of gravity<br>• Easier to design different shapes.<br>• More rapid construction | • Higher weight (.0638 lbs)<br>• Outer dimensions will be larger due to rib thickness<br>• Sensor might have more difficulty entering fuselage. |

# Drag Calculations

Drag was calculating using the flat plate area. This drag was used to determine cruise velocity.

$$D_{total} = fq + \frac{1.33}{\pi q e}\left(\frac{W}{b}\right)^2$$

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# Determining Flight Condition

Drag buildup lets us determine the thrust for cruise, but the design goal is to fly as fast as possible, not minimum drag. To find this cruise condition the following mission requirements were used:

- Battery is 200 W hr
- 10 minutes of flight

The maximum continuous power for the duration of the mission was found to be 212 lb ft/s. This is the condition used to find the maximum cruise speed.

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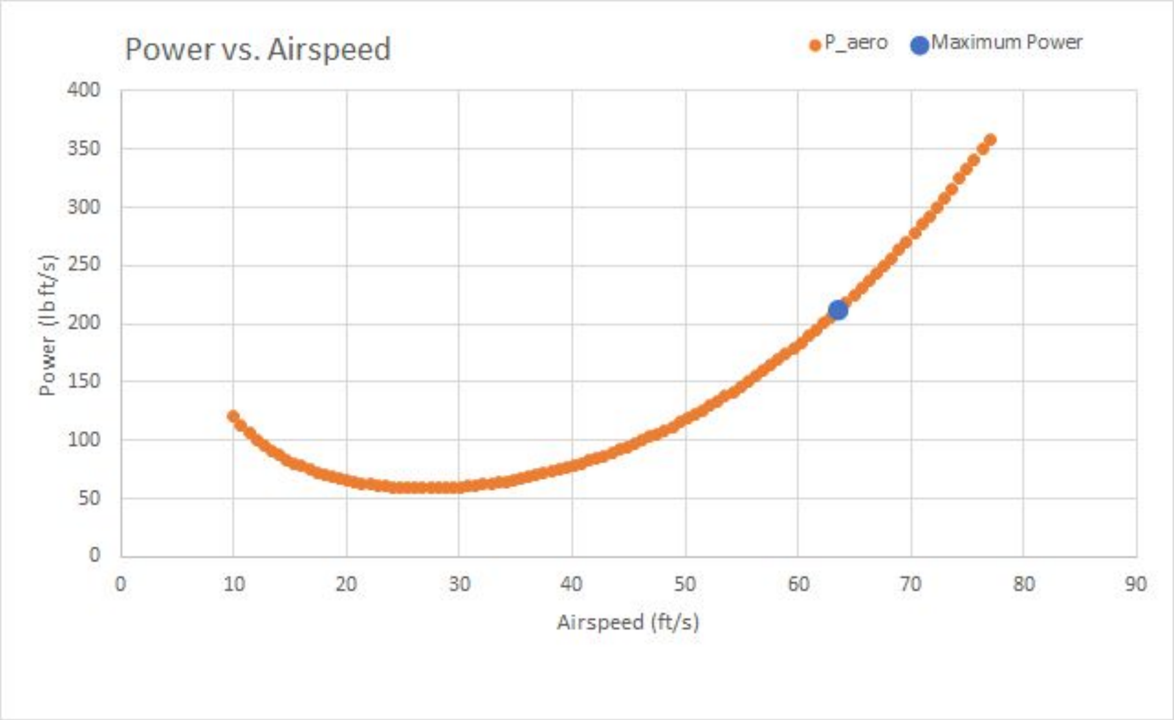
# Determining Flight Condition

Power was plotted for different airspeeds to determine our cruise condition. This was found to be 63 ft/s.

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# Motor-Propeller Sizing

Thrust has two requirements:

Takeoff Thrust: 7.5 lbs

Cruise Thrust: 3.28 lbs at 62.93 ft/s

Goal:

Select the lightest motor-propeller combination that is able to produce the required values above. From this the sunnysky x3520 motor was chosen with the 13x6.5 propeller.

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# Motor-Propeller Verification

## Takeoff Verification:

| Power (Watts) | Thrust (lbs) |
|---|---|
| 1000 | 8.21 |
| 900 | 7.72 |
| 800 | 7.1 |
| 700 | 6.64 |
| 600 | 6.24 |
| 500 | 5.45 |

## Cruise Verification:

For this test the motor was ran at the cruise thrust and the total duration of runtime was recorded.

Total Runtime: 13 minutes 7 seconds

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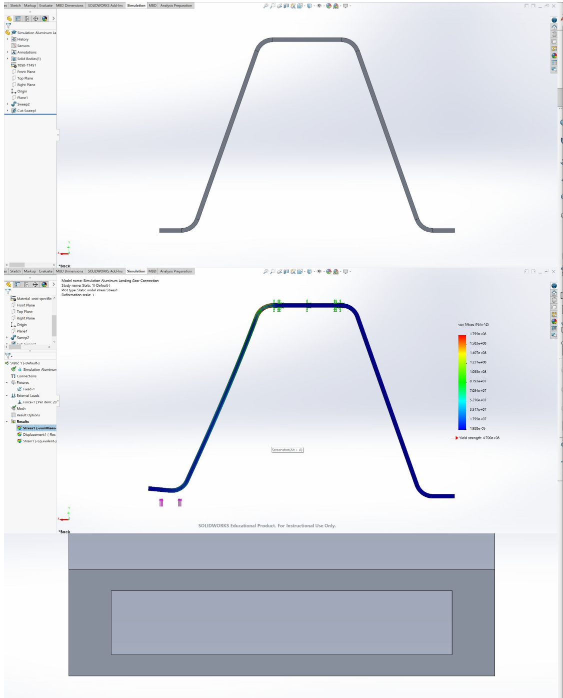
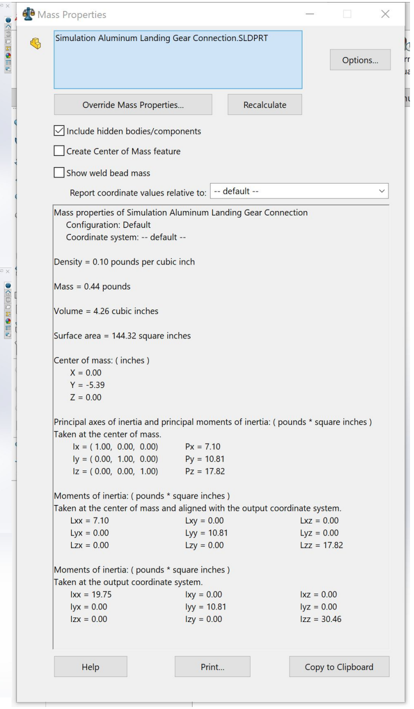
# Landing Gear Design




Hollow cross section
Thickness: 0.1 inch on sides
0.05 inch on top and bottom

| Property | Value | Units |
|---|---|---|
| Elastic Modulus | 10442717.11 | psi |
| Poisson's Ratio | 0.33 | N/A |
| Shear Modulus | 3901515.143 | psi |
| Mass Density | 0.1022402075 | lb/in^3 |
| Tensile Strength | 76144.81227 | psi |
| Compressive Strength | | psi |
| Yield Strength | 68167.7367 | psi |
| Thermal Expansion Coefficient | 1.311111111e-05 | /°F |
| Thermal Conductivity | 0.00209984 | Btu/(in·sec·°F) |

Material: Aluminum 7075(Conventional)
Mass: 0.44pounds

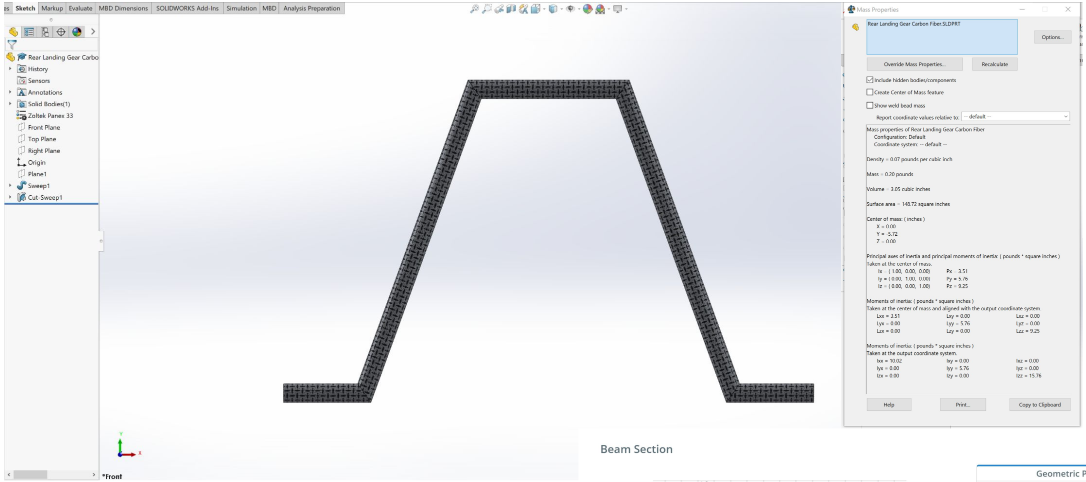
Simulation Assumption: 20 pounds force exerts on one wheel. (safety factor of 3)

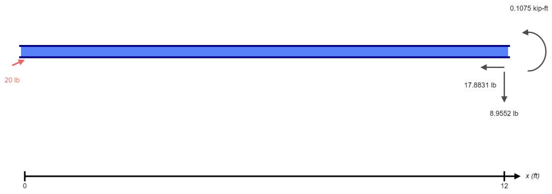
Result: Max Stress: 1.759*10^8 N/m^2
(Yield strength:4.8*10^8 N/m^2)
Maximum Displacement: 2.082mm

Discussion: Heavy in weight, but applicable from structural strength perspective.

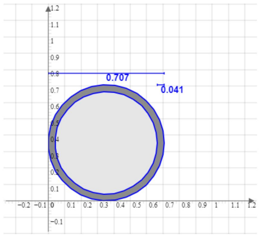
Weixiao Wang

# Landing Gear Design




Beam Section




| Geometric Properties | | |
|---|---|---|
| A | 0.0858 | $in^2$ |
| $C_z$ | 0.3535 | in |
| $C_y$ | 0.3535 | in |

| Bending Properties | | |
|---|---|---|
| $I_z$ | 0.0048 | $in^4$ |
| $I_y$ | 0.0048 | $in^4$ |

| Shear Properties | | |
|---|---|---|
| $A_z$ | 0.0403 | $in^2$ |
| $A_y$ | 0.0403 | $in^2$ |
| $Q_z$ | 0.009 | $in^3$ |
| $Q_y$ | 0.009 | $in^3$ |

| Torsion Properties | | |
|---|---|---|
| $A_z$ | 0.0095 | $in^4$ |
| $A_y$ | 0.3535 | in |

| Shape | Material | E (ksi) | ν | ρ (lb/ft³) |
|---|---|---|---|---|
| Hollow Circular | Carbon Fibre Reinforced Plastic | 21800 | 0.2 | 200 |

## Final Choice

A carbon fiber plate fabricated from standard modulus plain weave carbon fiber in a balanced and symmetric 0/90 layup has an elastic bending modulus of approx. 10 MSI. It has a volumetric density of about .050 lb/in3. Thus the stiffness to weight ratio or **Specific Stiffness** for this material is 200 MSI The Strength of this plate is approx. 90 KSI, so the **Specific Strength** for this material is 1800 KSI

By comparison, the bending modulus of 6061 aluminum is 10 MSI, the Strength is 35 KSI, and the volumetric of density is 0.10 lb. This yields a **Specific Stiffness** of 100 MSI and a **Specific Strength** of 350 KSI. 4130 steel has a stiffness of 30 MSI, a strength of 125 KSI and a density of .3 lb/in3 This yields a **Specific Stiffness** of 100 MSI and a **Specific Strength** of 417 KSI.

| Material | Specific Stiffness | Specific Strength |
|---|---|---|
| Carbon Fiber | 200 MSI | 1800 KSI |
| 6061 Aluminum | 100 MSI | 350 KSI |
| 4130 Steel | 100 MSI | 417 KSI |

Material: Carbon Fiber
Mass: 0.20pounds

Simulation Assumption: 20 pounds force exerts on one wheel. (safety factor of 3)

Result: Maximum Bending Moment 0.1075 kip·ft. (Far less than Maximum Bending Strength)

Discussion: Light in weight, and strong in Structural Strength

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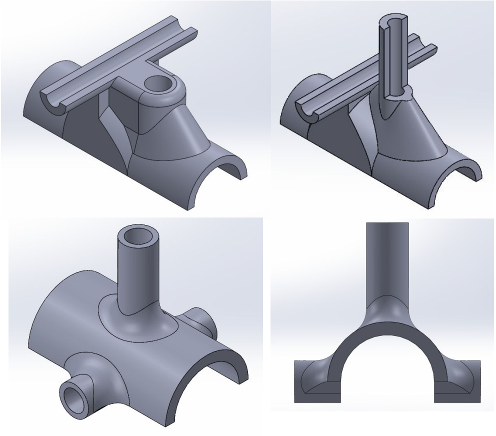
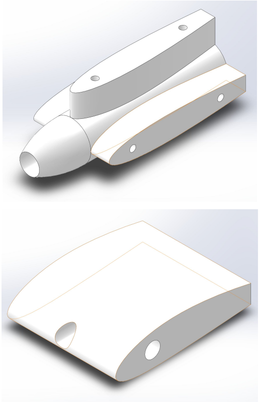
# Design of Connection between spars and tail boom

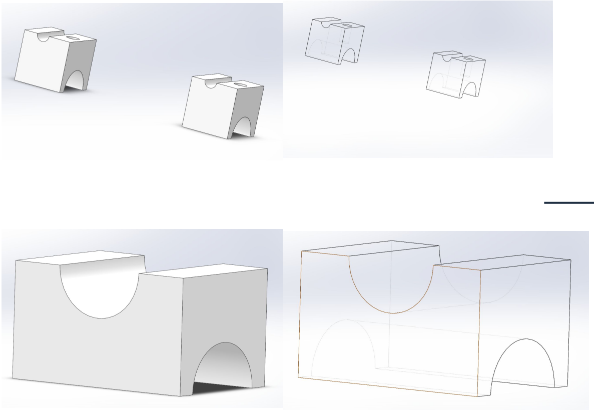


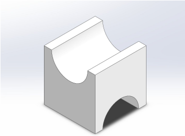
Design by Teagan



Design by Weixiao

Final Choice





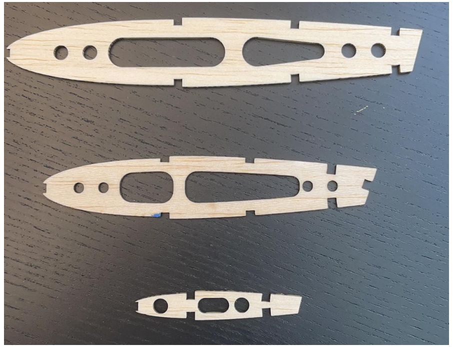
Further implement the design idea to landing gear connection

Advantage: Functional and easy to assembly.
Disadvantage: Hard to manufacture
(Hard to print layer by layer in 3D printed machine)

Advantage: Functional, easy to assembly, aerodynamic.
Disadvantage: Heavy weight causes potential for tail heavy in center of gravity.

Advantage: Lightweight, functional, easy manufactured, high structural strength.
Disadvantage: Have to use Carbon Tow to reinforce the joints.

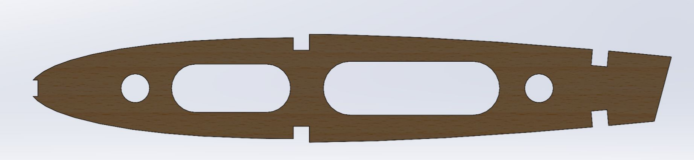
# Design and Manufacture of Cross Section of Wings and Tails



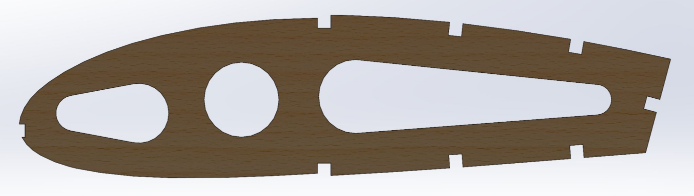
Second Prototype: Based on previous year aircraft dimensions.
Abandoned reasons: Different mission compared to previous aircraft.

Final Prototype: Chord length 6 inch.
Reason for choice: Based on tail volume calculation and Reasonable Reynolds number for Flight.

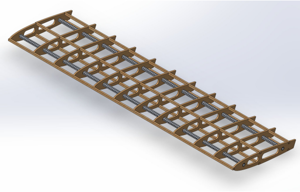
First Prototype: Based on theoretical calculations.
Abandoned reasons: Low Reynolds Number.



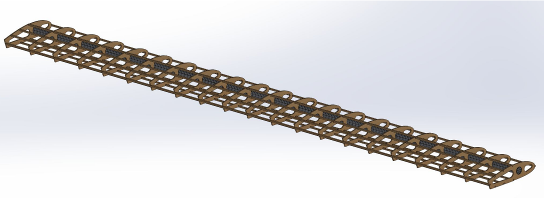
Tail: Chord length 6 inch.



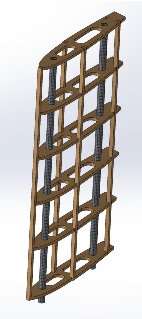
Wing: Chord length 8.5 inch.



Horizontal Tail Assembly



Wing Assembly



Vertical Tail Assembly

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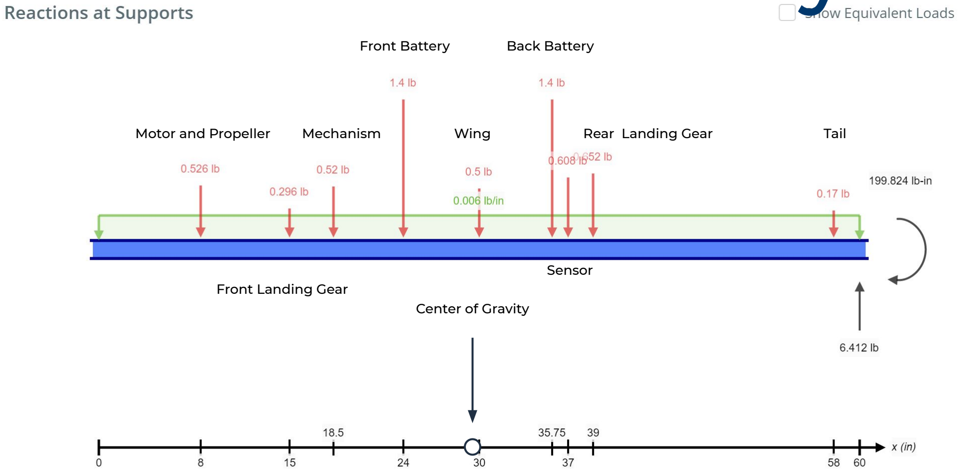
# Weight sheet

| | Parts Name | Weight(pounds) |
|---|---|---|
| 1 | Parts Name | Weight(pounds) |
| 2 | | |
| 3 | Propeller | 0.07 |
| 4 | Motor | 0.456 |
| 5 | Front Landing Gear | 0.196 |
| 6 | Front Landing Gear Connection(Carbon Fiber) | 0.07 |
| 7 | Landing Gear Connection(PLA) | 0.03 |
| 8 | Baterry Connection | 0.04 |
| 9 | Battery*2 | 2.77 |
| 10 | Mechanism | 0.52 |
| 11 | Aileron*2 | 0.02 |
| 12 | Wing | 0.45 |
| 13 | Wing Connection | 0.03 |
| 14 | Rear Landing Gear*2 | 0.392 |
| 15 | Rear Landing Gear Conneciton(Carbon Fiber) | 0.22 |
| 16 | Landing Gear Connection(PLA) | 0.04 |
| 17 | Sensor | 0.608 |
| 18 | Horizontal Tail | 0.06 |
| 19 | Vertical Tail | 0.03 |
| 20 | Landing Gear Connection*2 | 0.08 |
| 21 | Tail Boom | 0.34 |
| 22 | | |
| 23 | Total Weight | 6.422 |

Original Assumption of the Aircraft is approximately 6 pounds.

Current Calculation of Total Weight is approximately 6.4 pounds. (Reasonable Value)

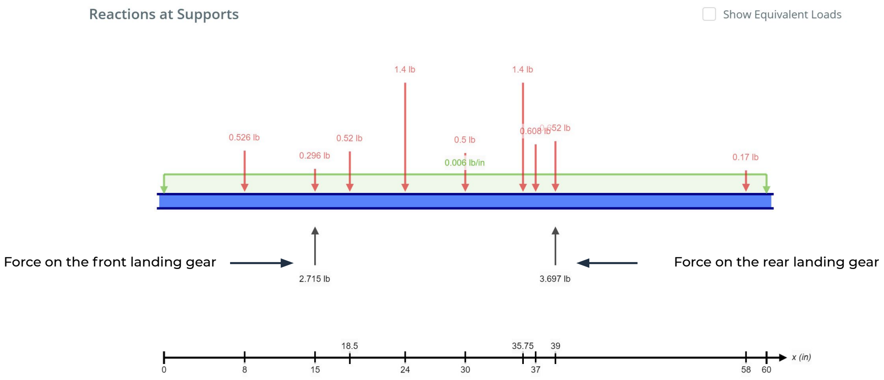
# Center of Gravity



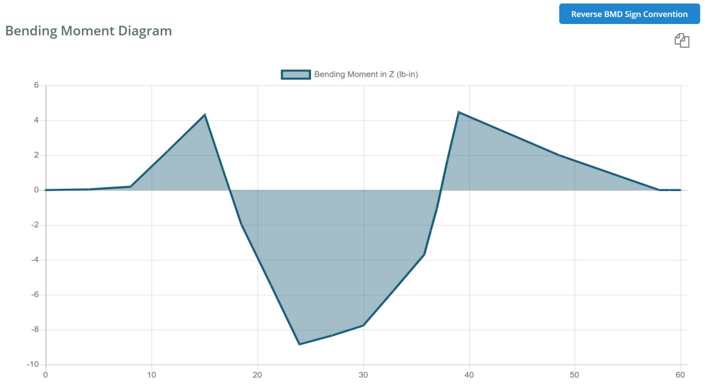

$$Location\ of\ Center\ of\ Gravity = \frac{\Sigma\ Total\ Moment\ related\ to\ one\ point}{Total\ Weight}$$

$$The\ Location\ of\ Center\ of\ Gravity\ related\ to\ the\ end\ of\ Tail\ Boom = \frac{199.824\ lb \cdot in}{6.412 in} = 31.164 inch$$

$$The\ location\ of\ Center\ of\ Gravity\ related\ to\ the\ front\ of\ Tail\ Boom = 52 - 31.164 = 20.836 inch$$




Force Diagram with two landing gear support




Moment Diagram with two landing gear support

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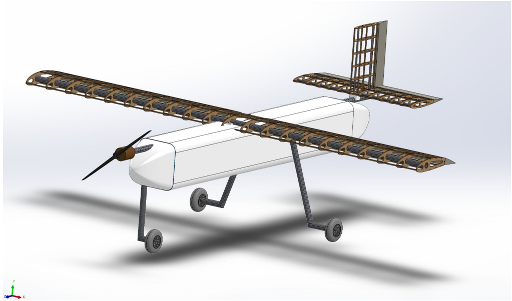
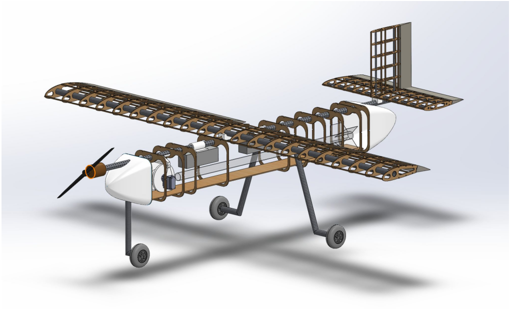
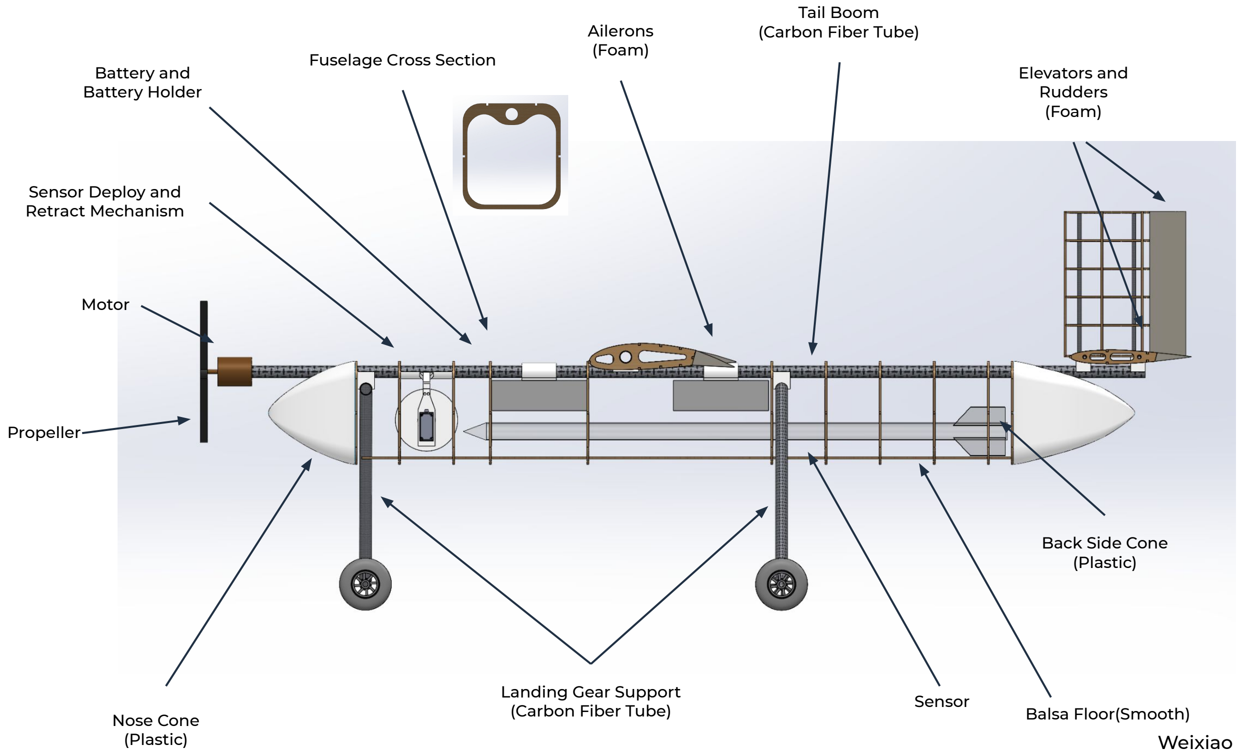
# Aircraft Configuration





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# Risk Assessment(Potential Problems)

- If the rib spacing is too short, the coating can sag between them which will ruin the part. We used values from previous airplanes and recommendations by Colin Sledge for these distances, but no prototypes were constructed.
- Sensor deployment and retraction has not been tested in actual flight, so more adjustments may be required.
  - Pitch up during deployment and retraction
  - Altering the hatch entrance

# Thank you for watching