Northrop Grumman Collaboration Project

Multi-role Aircraft (MAC)

Sponsored by:

NORTHROP GRUMMAN

MAC Chief Engineer

Alexander Koukourikos

April 7, 2023

Preliminary Design Review (PDR)

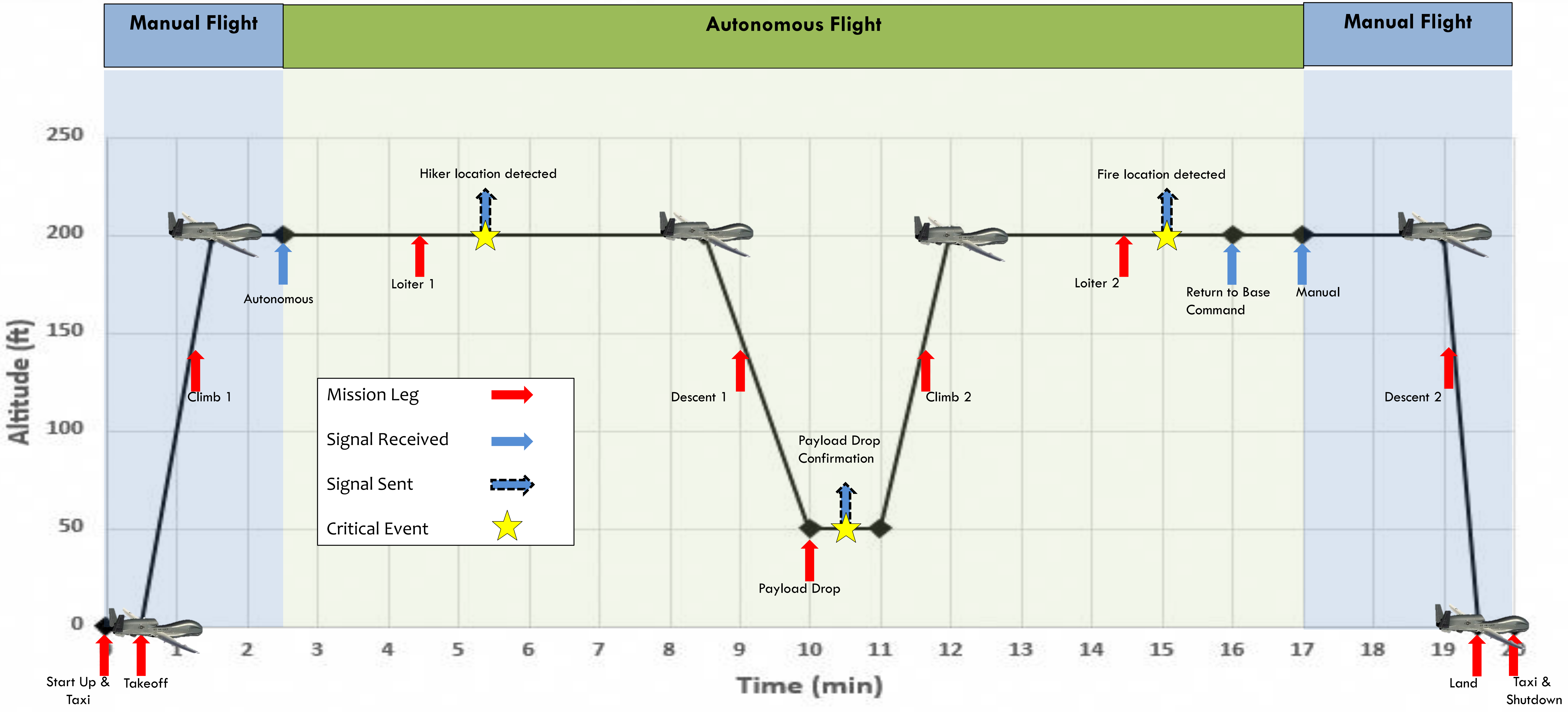
MAC Overview

- List of Abbreviations
- Concept of Operations and Mission Profile
- Preliminary Design Summary
- Technical Subsystems' Breakdown
  - Aerodynamics
  - Stability & Controls
  - Propulsion
  - Payload Integration
  - Structures
  - Manufacturing
  - Electrical and Hardware
  - Software
- Questions and Comments

List of Abbreviations

- MAC – Multi-role Aircraft
- MAC – Mean Aerodynamic Chord (Stability & Controls)
- FOM – Figure of Merit
- W&B Analysis – Weight and Balance Analysis
- P/W – Power to Weight
- W/S – Wing Loading
- CFD – Computational Fluid Dynamics
- CL – Lift Coefficient
- CD – Drag Coefficient
- Cm0 – Pitching moment coefficient at zero degrees angle of attack
- Cmα – Slope of pitching moment coefficient versus angle of attack
- Cm – Pitching moment coefficient

ConOps/Mission Profile



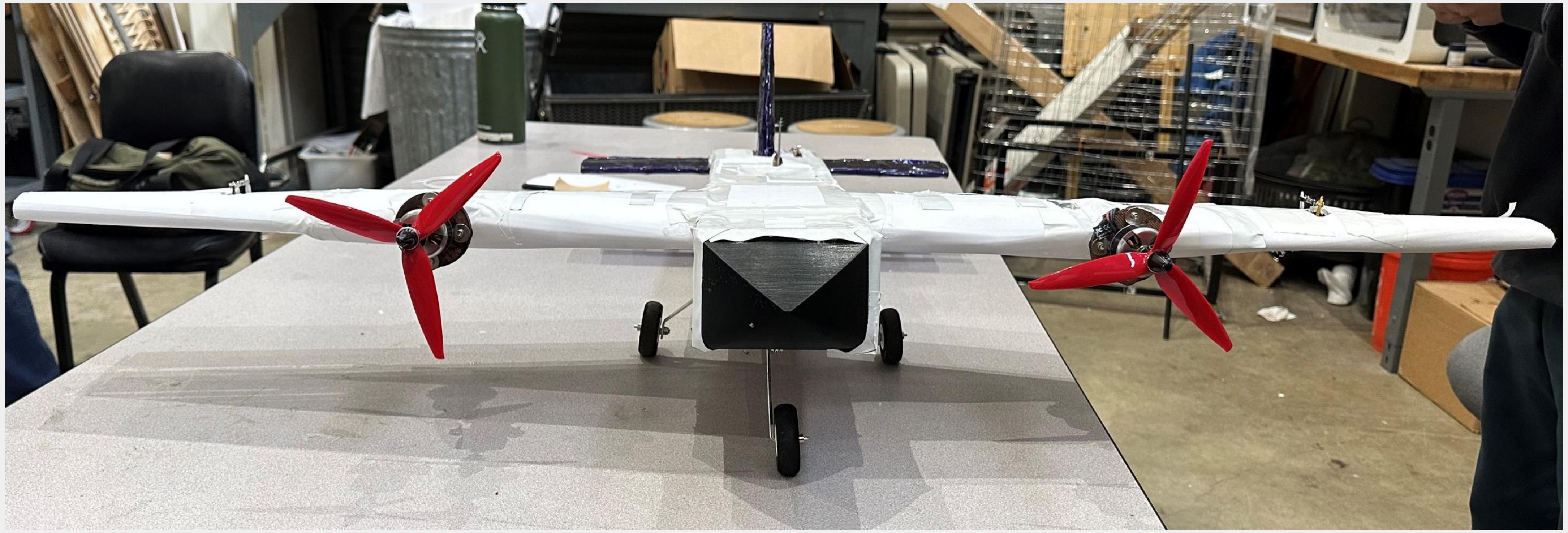
Compliance Matrix at PDR

ID Number	Description	Verification Method	Status
[MAC_01]	The vehicle shall autonomously drop the relief package within a 250ft radius of the hiker's geolocation	Flight Test	In Progress
[MAC_02]	The vehicle shall have a minimum, fully loaded, endurance flight time of 20 minutes	Power Budget Analysis	Yes
[MAC_03]	The vehicle shall be stable in all axes	Stability Analysis	Yes
[MAC_04]	The vehicle navigation should be fully autonomous during flight operations	Flight Test	In Progress
[MAC_05]	The vehicle shall be capable of taking off and landing from asphalt runways	Flight Test	In Progress
[MAC_06]	The vehicle shall perform manual takeoff and landing for safety constraints	Flight Test	In Progress
[MAC_07]	The vehicle shall autonomously obey geofence boundaries provided by the GCS	Flight Test	In Progress
[MAC_08]	The vehicle shall meet all FAA Part 107 requirements.	W&B Analysis, CFD Simulation	Yes
[MAC_09]	The vehicle shall have all core electronic components on a removable tray*	Visual Inspection, Ground Test	Yes
[MAC_10]	The MAC shall be able to geolocate a target area, which represents a thermal hotspot or fire, to an accuracy of 10ft	Flight Test, Ground Test	In Progress

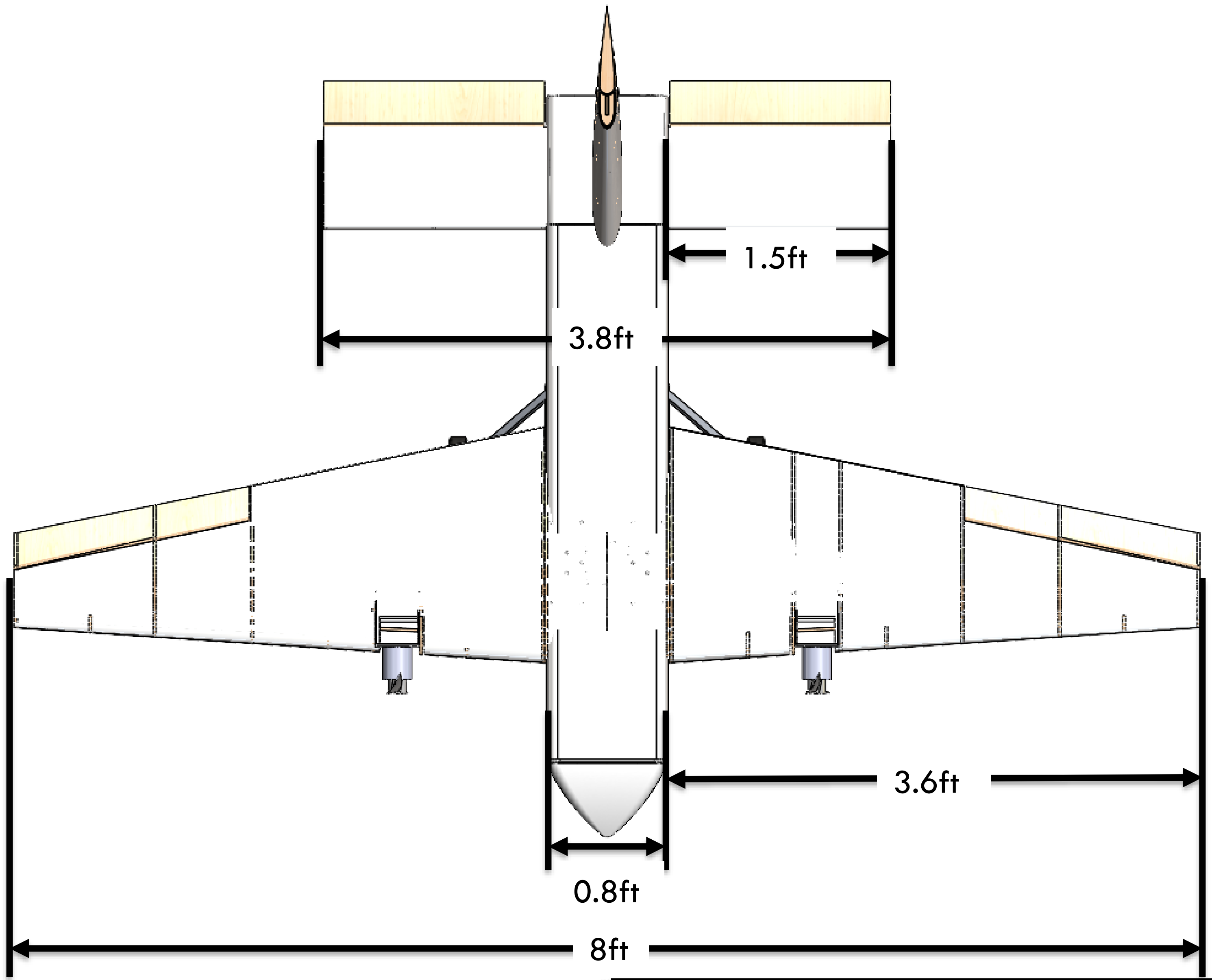
Compliance Matrix at PDR

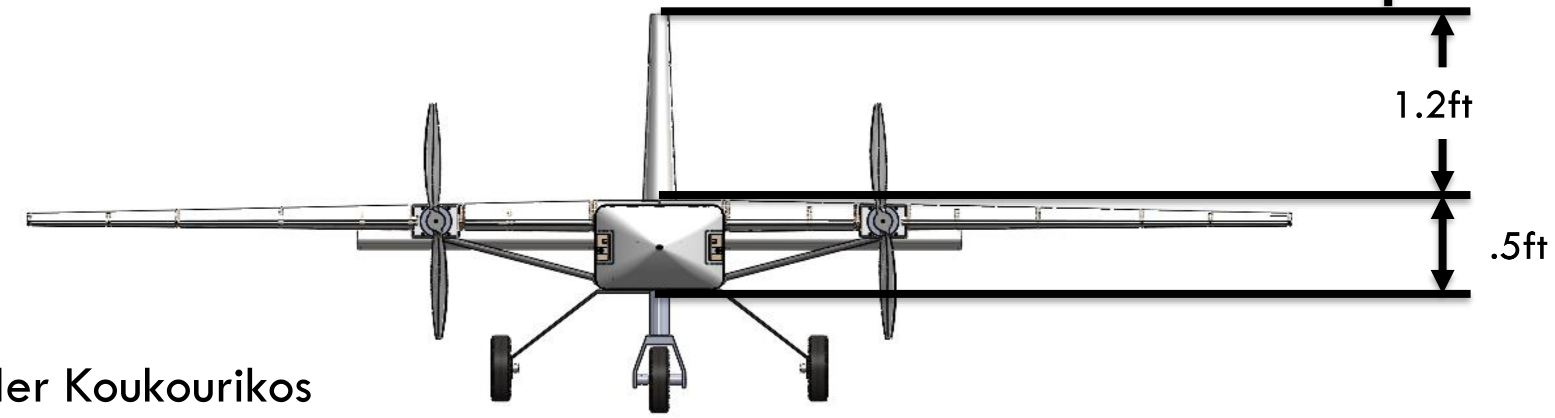
ID Number	Description	Verification Method	Status
[MAC_11]	The MAC shall be capable of detecting a target area with the dimensions no smaller then 3ft x 3ft (L x W)	Flight Test, Ground Test	In Progress
[MAC_12]	All mission critical components shall be able to be repaired and running within 10 minutes of component failure.	Ground Test	In Progress
[MAC_13]	The MAC shall be able to geolocate a walkie talkie broadcasting on Family Radio Service (FRS) channels to an accuracy of 10 ft (TBR).	Flight Test, Ground Test	In Progress
[MAC_14]	The vehicle shall support manual flight controls during any flight phases.	Flight Test	In Progress
[MAC_15]	The MAC shall be capable of taking off from and landing on a runway with a minimum length of 500 ft.	Flight Test	In Progress
[MAC_16]	The MAC shall provide a payload mechanism system for the relief package.	Visual Inspection	Yes
[MAC_17]	The MAC shall initiate payload drop sequence within 15 minutes (TBR) of mission start.	Flight Test	In Progress
[MAC_18]	The vehicle shall transmit health and status information to GCS at a minimum rate of 1 Hz.	Communication Test	In Progress
[MAC_19]	The MAC shall be capable of executing and recovering from an emergency loiter pattern upon GCS command.	Communication Test	In Progress
[MAC_20]	The MAC shall be commanded and controlled from a single ground control station using one standardized communication network.	Communication Test	In Progress

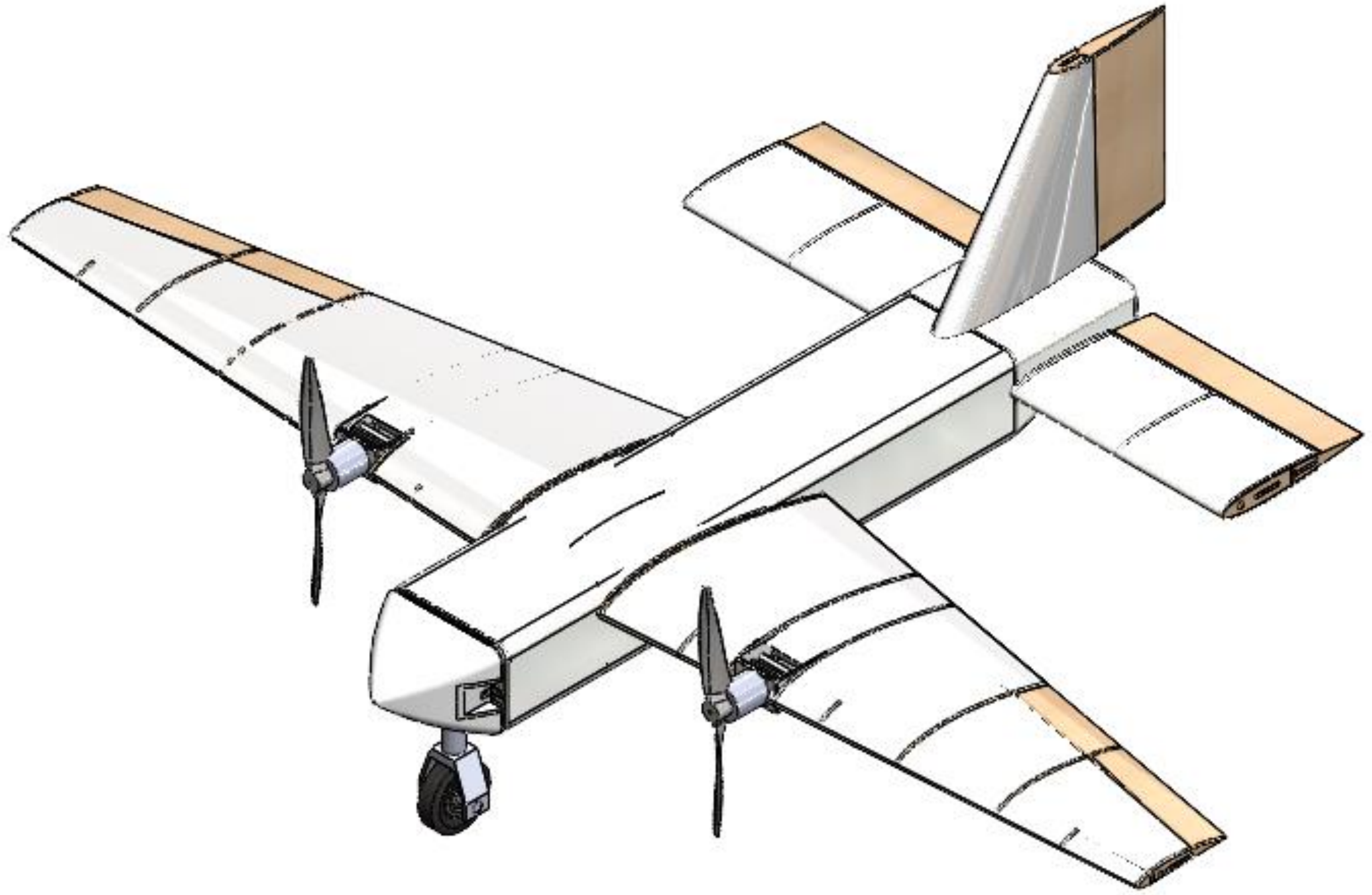
Chosen Design – T-Hawk

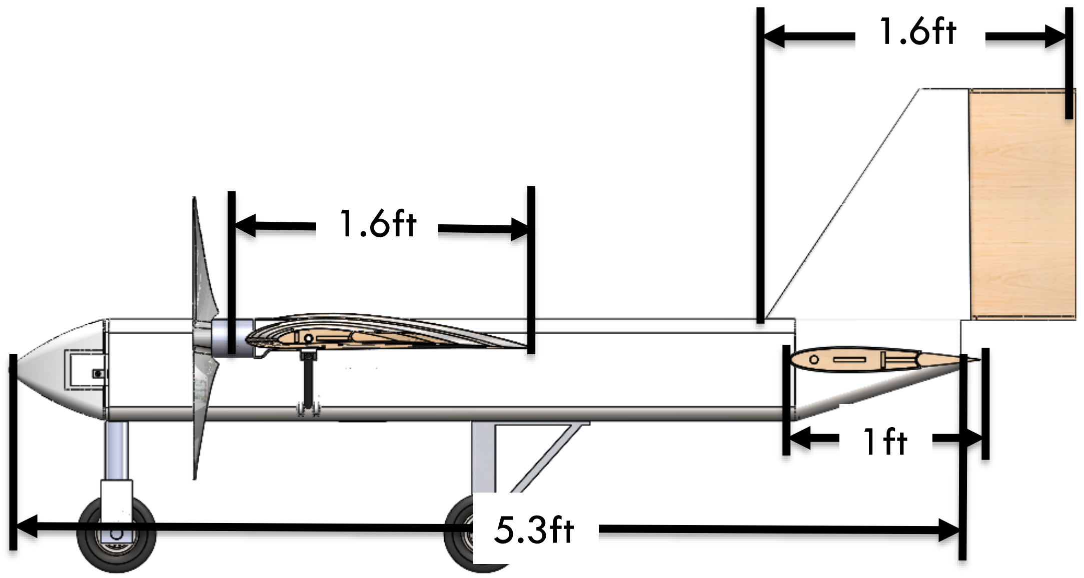


Dimensions

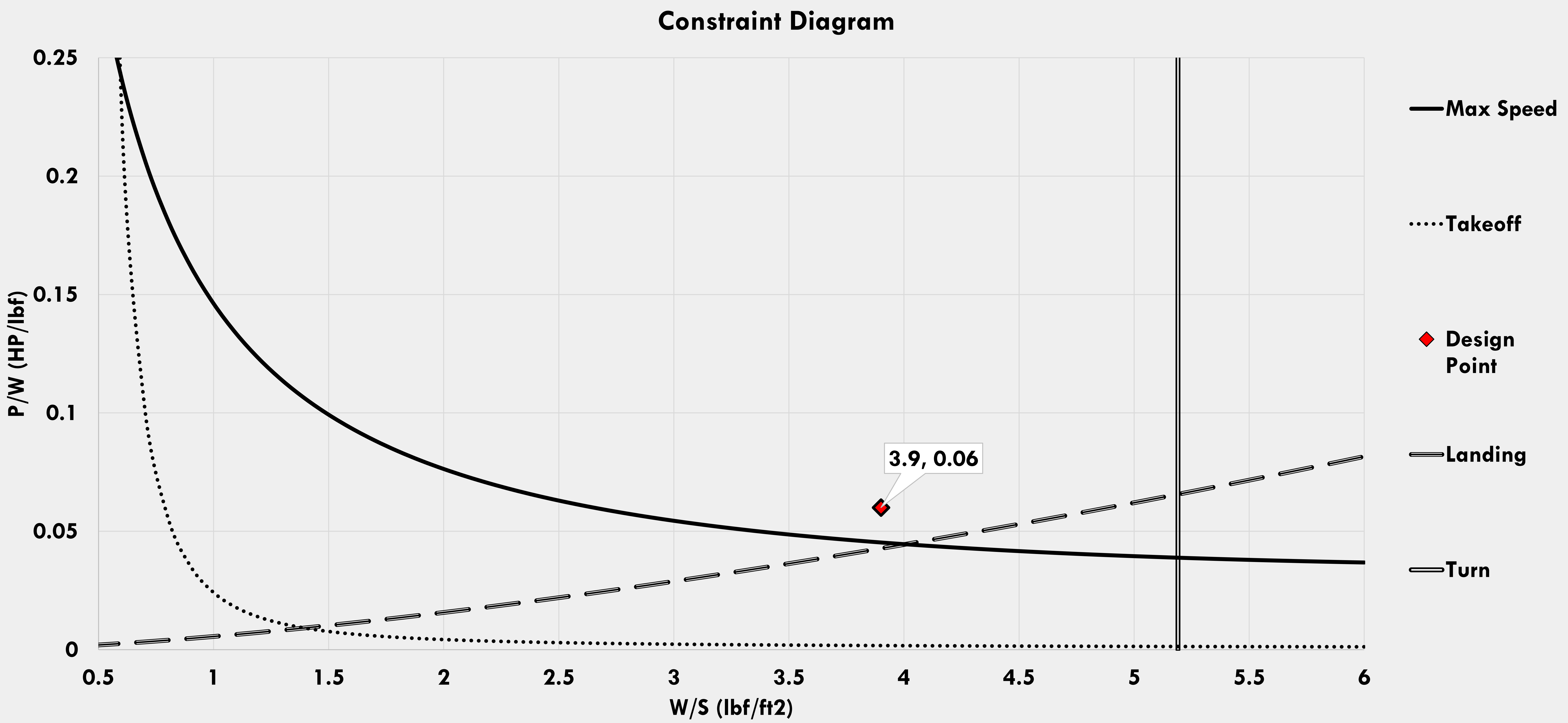




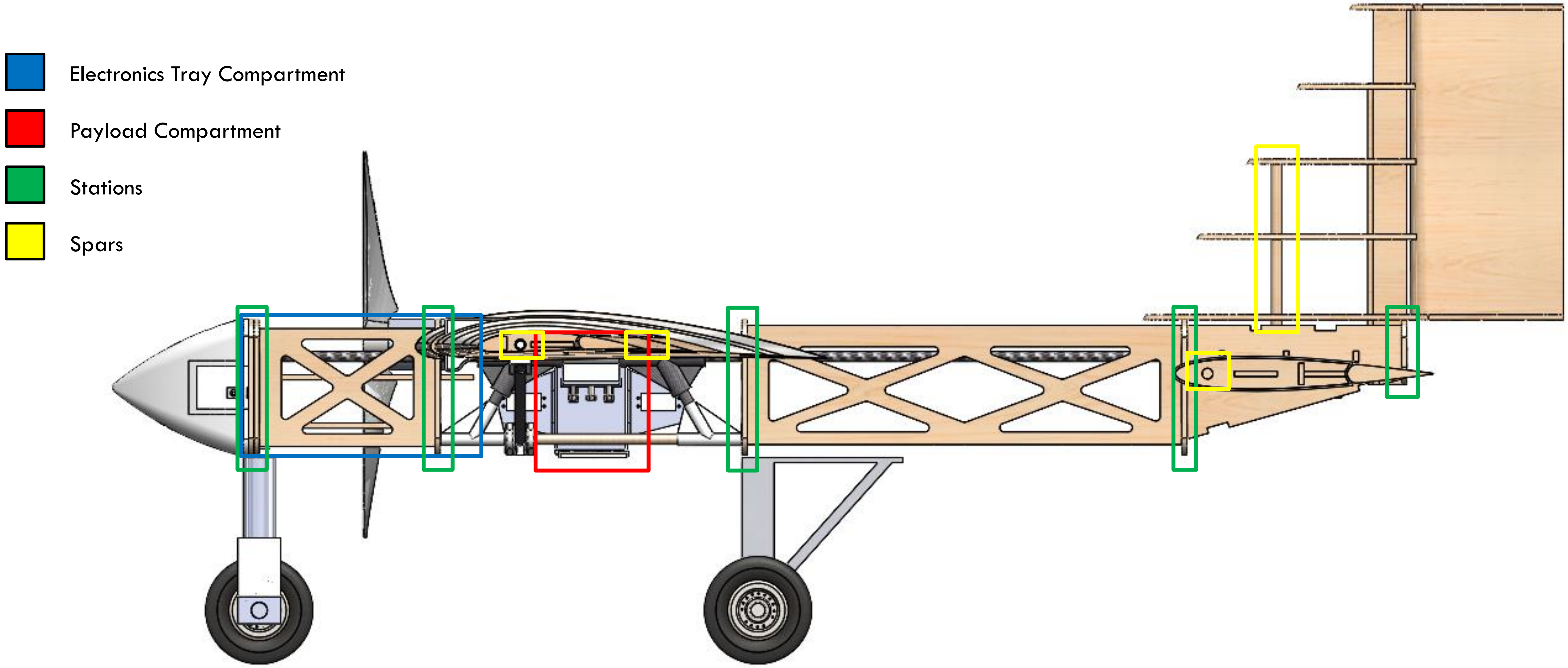




Constraint Diagram

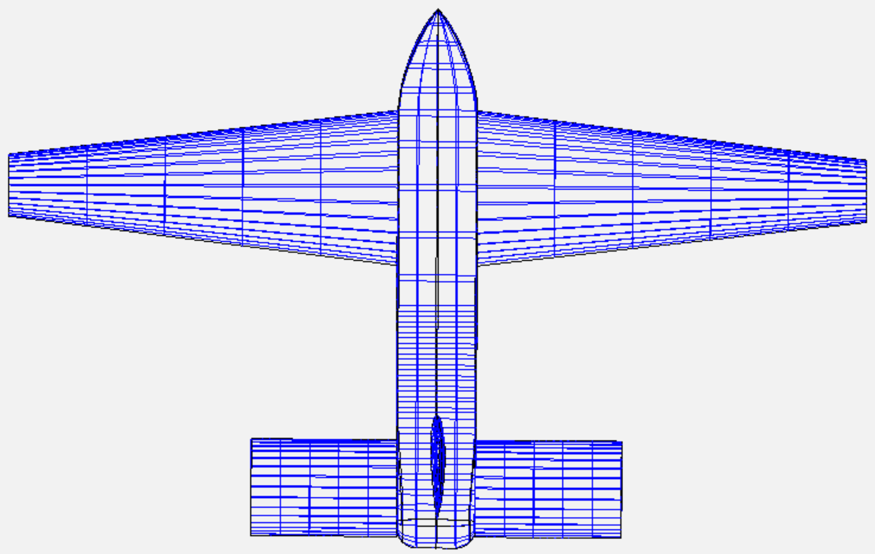


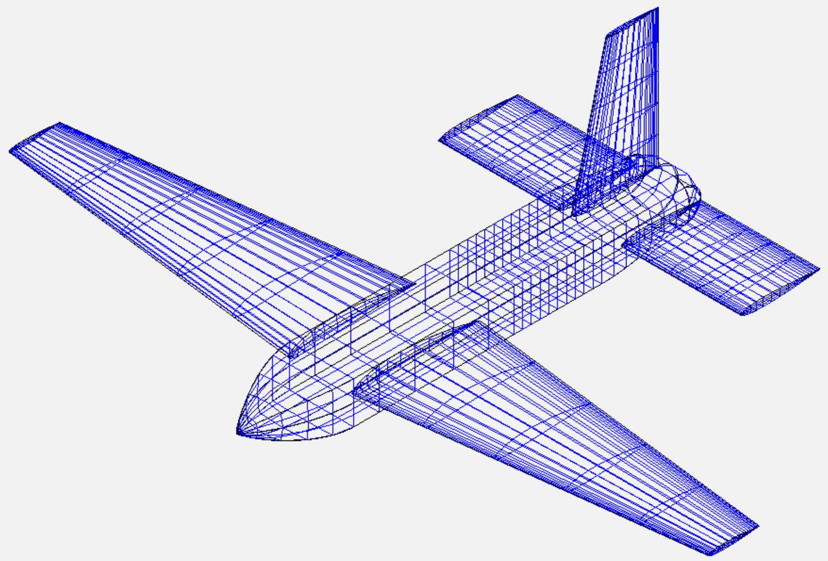
Fuselage Layout



Planform Dimensions

	Dimension	Value	Justification
Fuselage and Nose	**Total Length**	5.3 ft	Nose and pod dimensions together, 66% of wingspan
	Height	0.525 ft	10% of Total Length
	Width	0.805 ft	15% of Total Length
Wings	**Wingspan**	8 ft	Gives enough room for the payload and all the internal components without being unnecessarily large
	Wing Area	8.974 ft^2	Constraint Diagram
	Aspect Ratio	7.132	Provides more stability for the aircraft with high AR
	Taper Ratio	0.4	From Raymer's textbook, 0.4 gives best CL value
	Root Chord	1.603 ft	Based on wing area
	Root Height	2.31 in	Thickness at the Root Chord



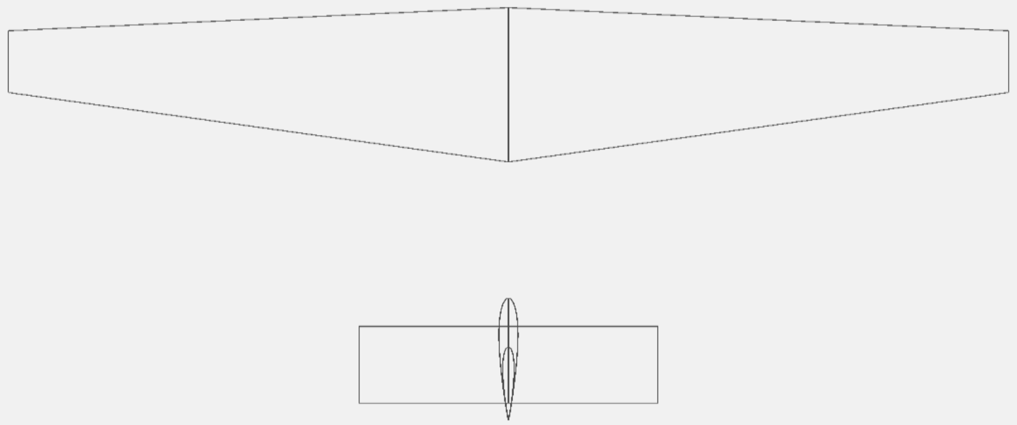


Wing and Tail Airfoil Selection Criteria

Attributes	Reasoning	Wing Priority	Tail Priority
High $C_L/C_{D\ Max}$	Higher efficiency at flight & low drag	1	5
Low α at $C_L/C_{D\ Max}$	Less Trim Needed for Efficient Flight	3	7
High $C_{L\ Max}$	Better Aircraft Performance Characteristics	2	6
High $\alpha_{\ Stall}$	Better Aircraft Performance Characteristics	4	8
Low $dC_M/d\alpha$	Encourages Longitudinal Stability	5	1
High C_{Mo}	Favorable for Longitudinal Stability	6	2
High t_{max}	Accounts for Internal Wing Components, Manufacturability for Tail	7	3
Low % Chord at t_{max}	Ensure the Center of Gravity is Located Toward the Front	8	4

1 = Highest Priority , 8 = Lowest Priority

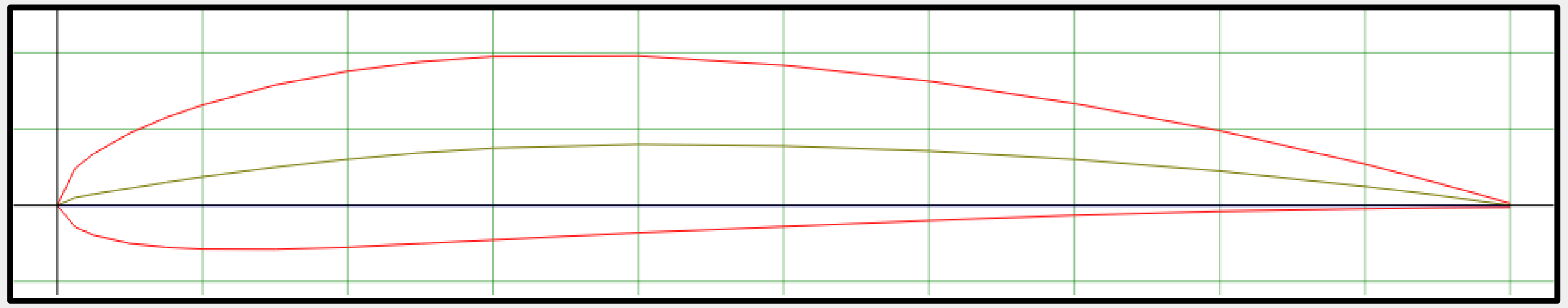
XFLR5 Assumptions for Airfoil Analysis



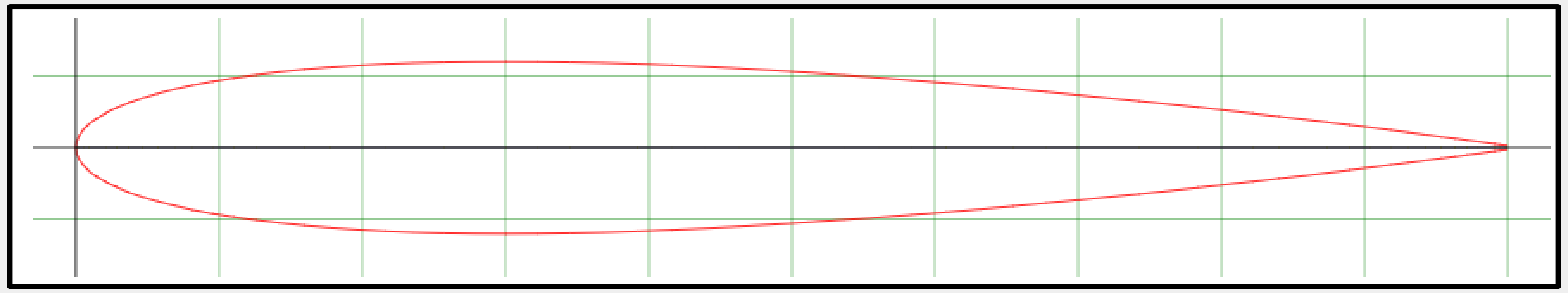
- Fixed Lift Analysis
- Analyzed at Sea Level Conditions

Airfoil Finalists

Selected Wing Airfoil: NACA 4412



Selected Tail Airfoil: NACA 0012



Figures of Merit	$C_L/C_{D\ max}$		$C_{L\ max}$		α_{stall}		
	1.7207		1.6387		0.8929		Weighted total = Sum (W)
	U	W	U	W	U	W	
NACA 6412	3	5.162	9	14.748	5	4.465	24.375
NACA 4412	7	12.045	5	8.193	5	4.465	24.703
S3010	5	8.604	3	4.916	7	6.250	19.77
CLARK Y	7	12.045	3	4.916	3	2.679	19.64
NACA 2412	5	8.604	1	1.639	5	4.465	14.708

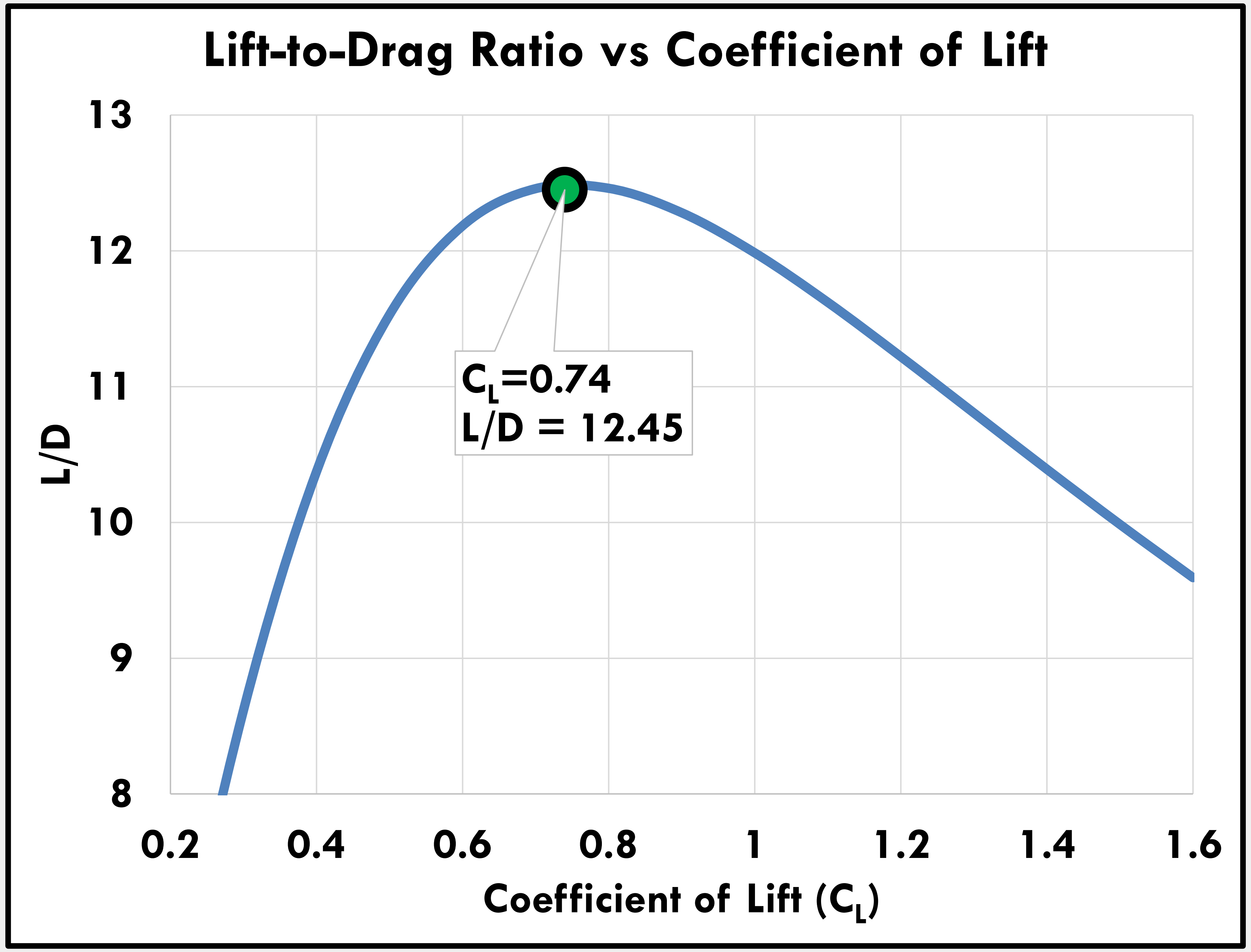
Figures of Merit	$C_L/C_{D\ max}$	α at $C_L/C_{D\ max}$	$T_{max\ (\%)}$	% Chord at $T_{max\ (\%)}$
E168-il	87.1	6.0	12.45	26.7
N0012-il	75.64	7.5	12	30
N0009sm-il	75.623	7.5	9	30.9
B540ols-il	74.8	8	9.7	22.1
FX76120-il	78.608	9	12.1	27.9

Drag Build-Up Calculations

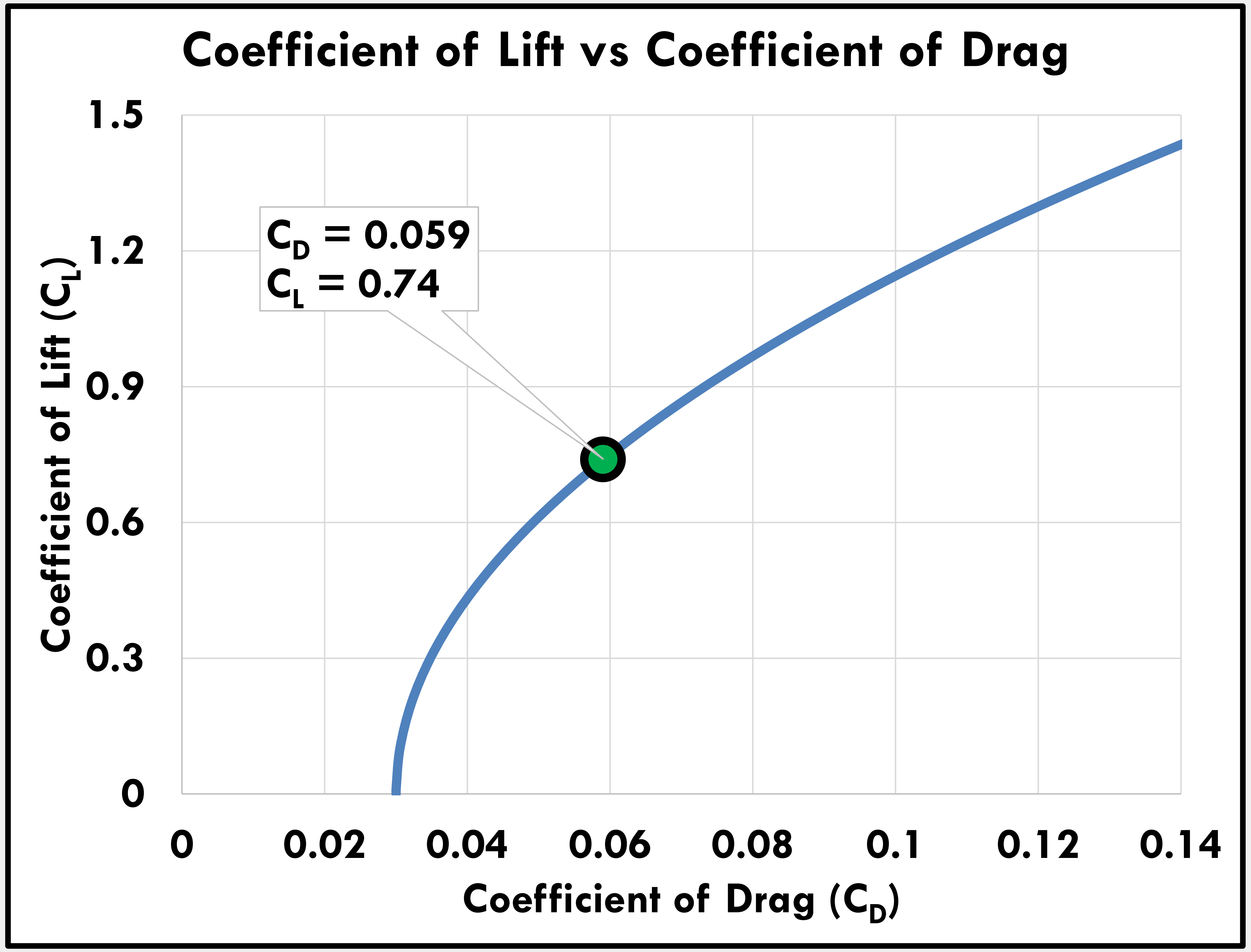
Area	Assumption
Wing	Wetted Area from CAD
Fuselage	Wetted Area from CAD
Horizontal Tail	Wetted Area from CAD
Vertical Tail	Wetted Area from CAD
Engine	Treated as Fuselage Form Factor
Landing Gears	Favorable for Longitudinal Stability
Equation and Procedures were adapted from Chapter 12 of Roger D. Schaufele's "The Element of Aircraft Preliminary Design"	

Parasitic Drag Build up for 67 ft/s	
Component	C_{Dp}
Wing	0.0145
Fuselage	0.0081
Horizontal Tail	0.0024
Vertical Tail	0.0015
Main Gear	0.00085
Nose Gear	0.00095
Induced Drag Build Up for 67 ft/s	
C_L	0.74
C_{Di}	0.0320
Total Drag Build Up	
Total (C_{di} + C_{Dp})	0.0609
Total Drag Force	2.7556

Drag Polars

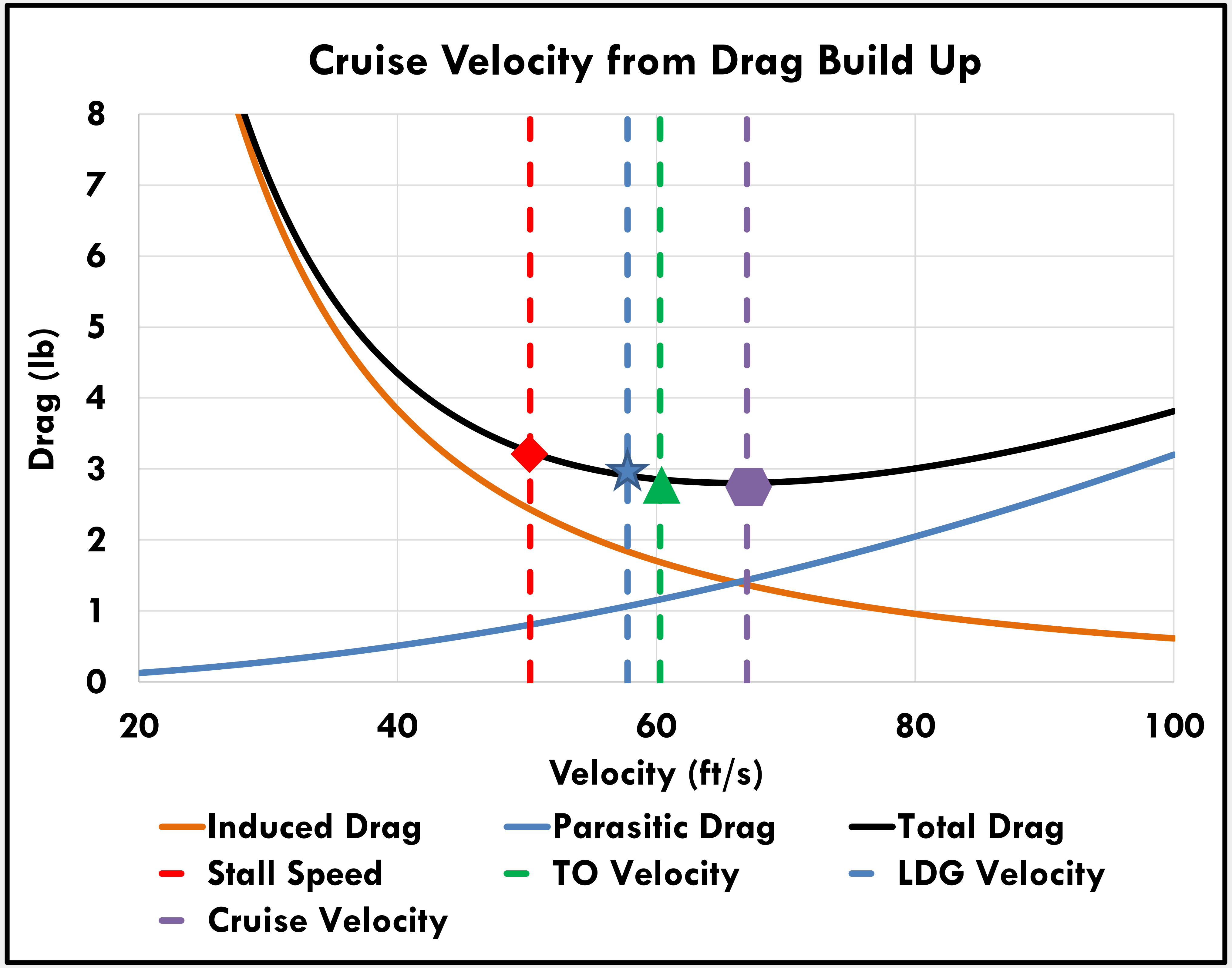


Lift-to-Drag Ratio vs Coefficient of Lift
13
12
11
10
9
8
L/D
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Coefficient of Lift (C_L)
C_L=0.74
L/D = 12.45



Coefficient of Lift vs Coefficient of Drag
1.5
1.2
0.9
0.6
0.3
0
Coefficient of Lift (C_L)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Coefficient of Drag (C_D)
C_D = 0.059
C_L = 0.74

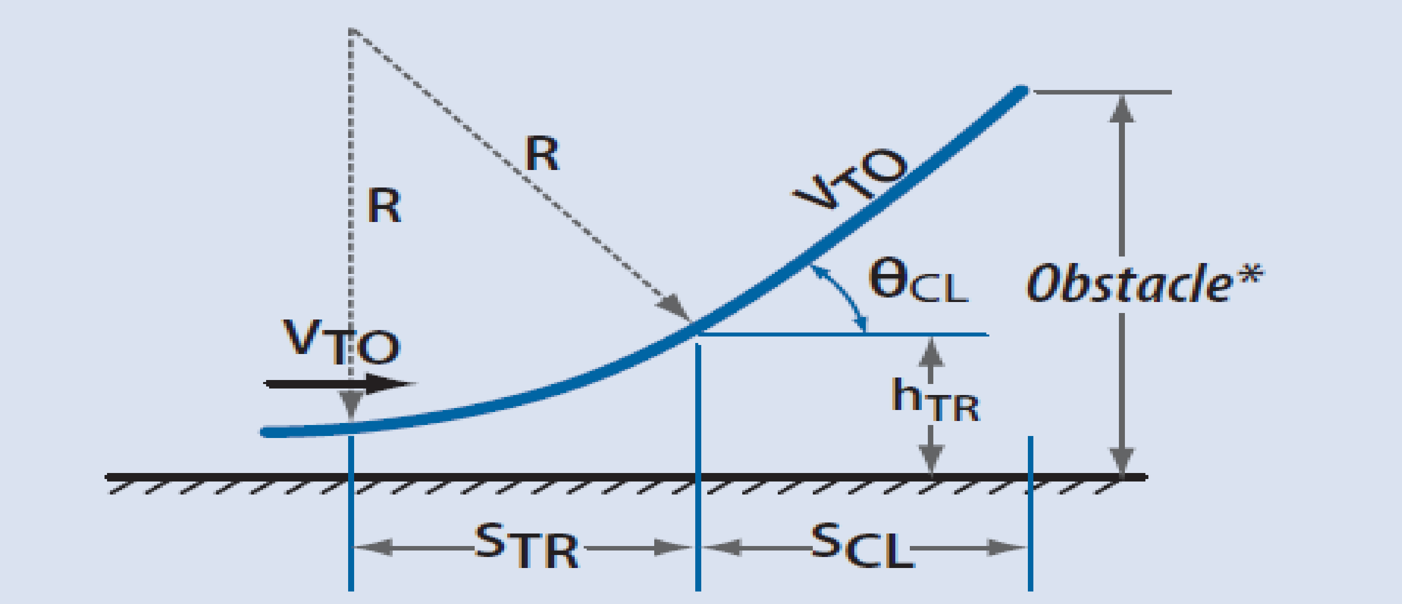
Optimum Cruise Velocity



Optimal Velocities			
Velocities	Speed (ft/s)	Drag (lbs)	Symbol
Stall	52	3.30	◆
Takeoff	60	2.93	▲
Landing	58	2.97	★
Cruise	67	2.89	⬢

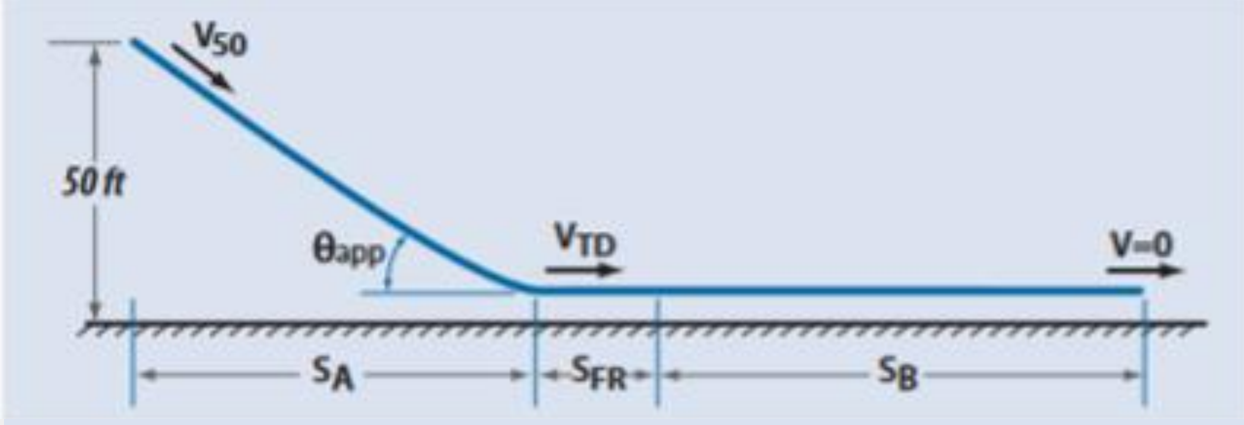
Takeoff and Landing Distances

Takeoff Distance		
Parameter	**Value**	**Units**
Ground Distance	53	ft
Rotation Distance	121	ft
Transition Distance	129	ft
Climb Distance	0	ft
Takeoff Distance	**174**	**ft**
Takeoff Distance*	**303**	**ft**



*Obstacle height=35ft for commercial and 50ft for the military.

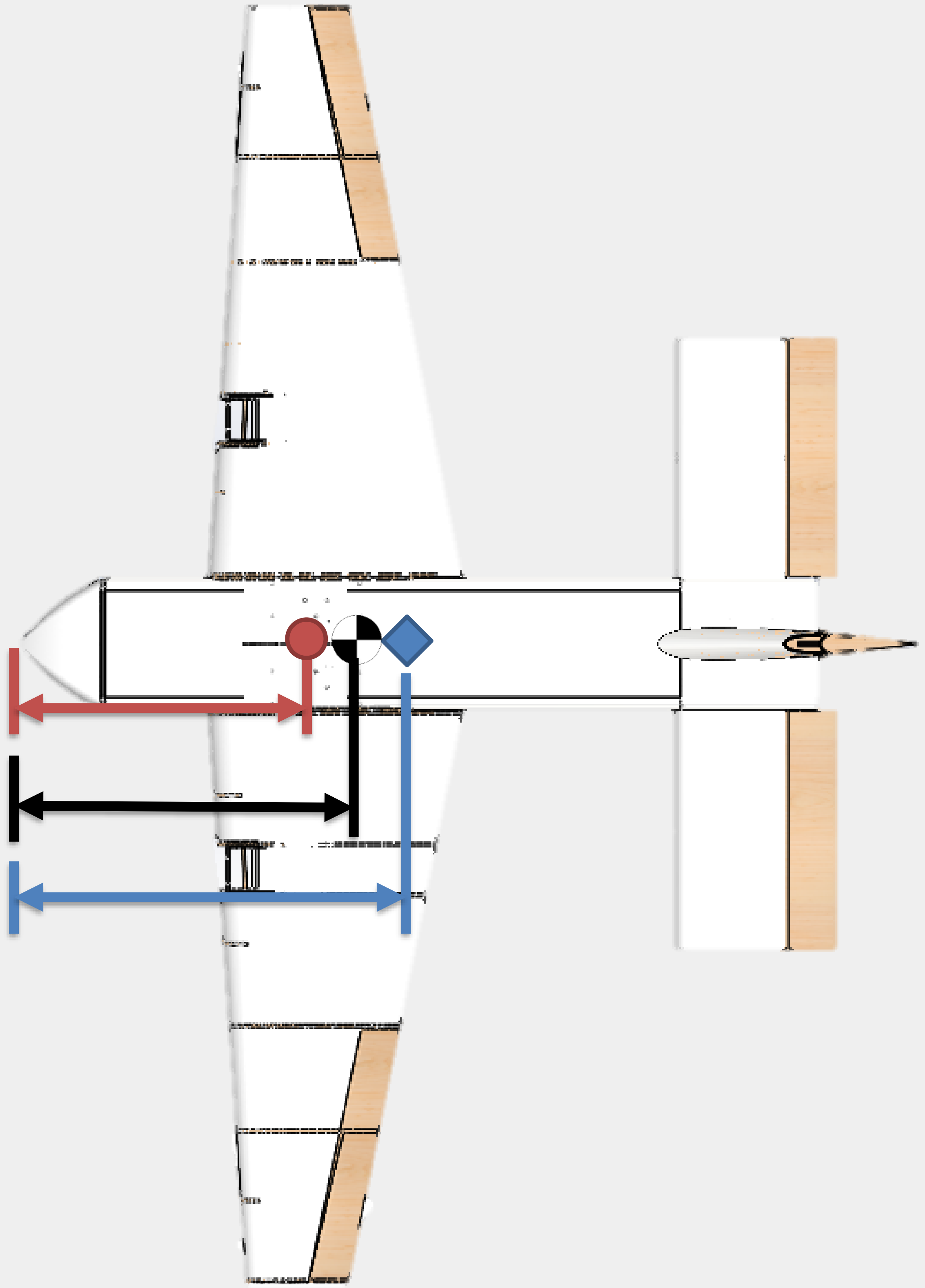
Landing Distance		
Parameter	**Value**	**Units**
Braking Distance	53	ft
Air Distance	121	ft
Free-Roll Distance	129	ft
Landing Distance	**285**	**ft**
Landing Distance*	**440**	**ft**



*Obstacle height=35ft for commercial and 50ft for the military.

Calculation methods courtesy of Nicolai and Carichner

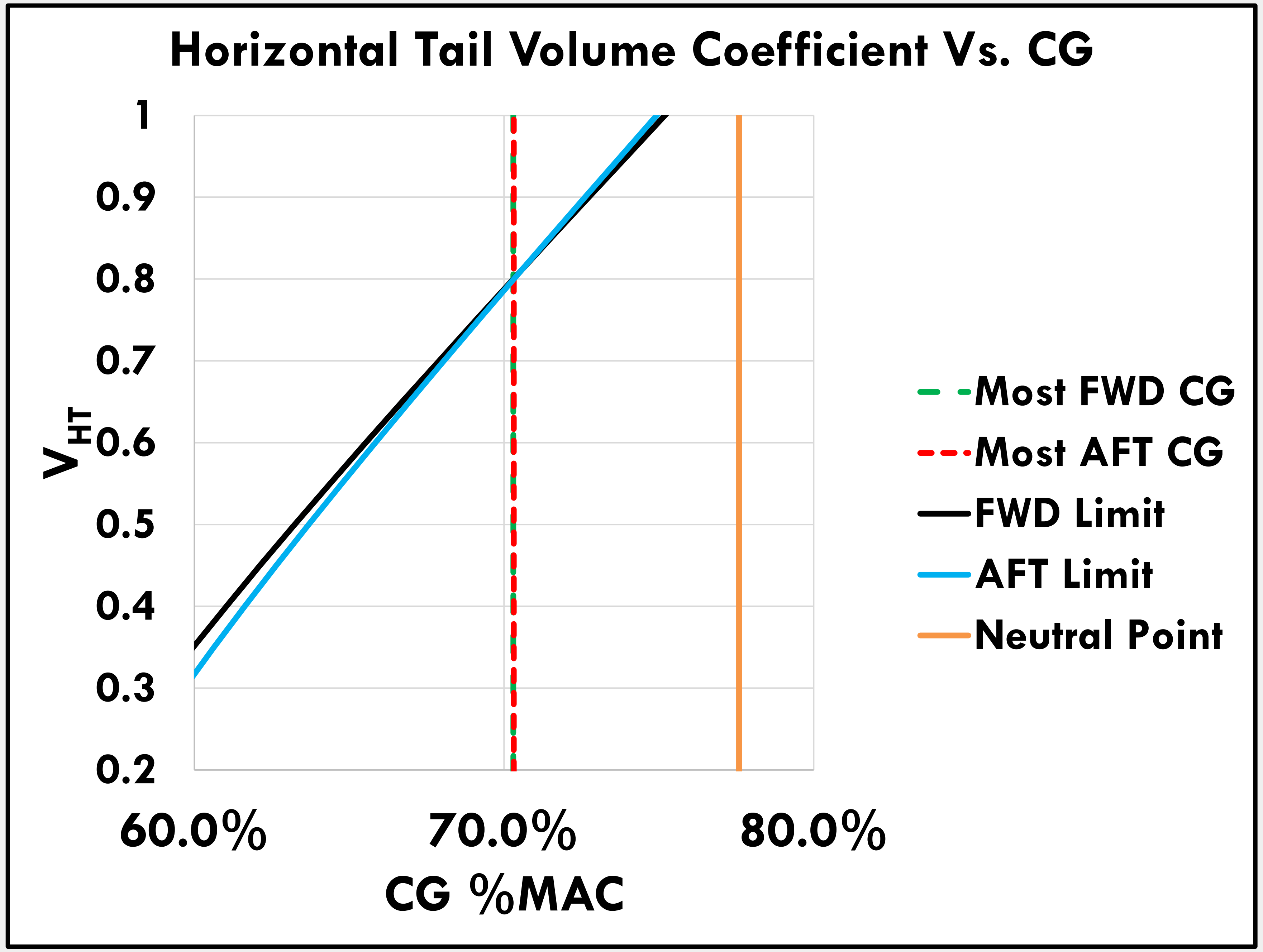
Neutral Point & Static Margin



Locations		
Symbols	**Variable**	**Distance From Nose**
●	Wing Aerodynamic Center	1.5 ft
◐	CG	1.9 ft
◆	Neutral Point	2.1 ft
	Static Margin	8%

Neutral point developed from Nelson, *Flight Stability and Automatic Controls*

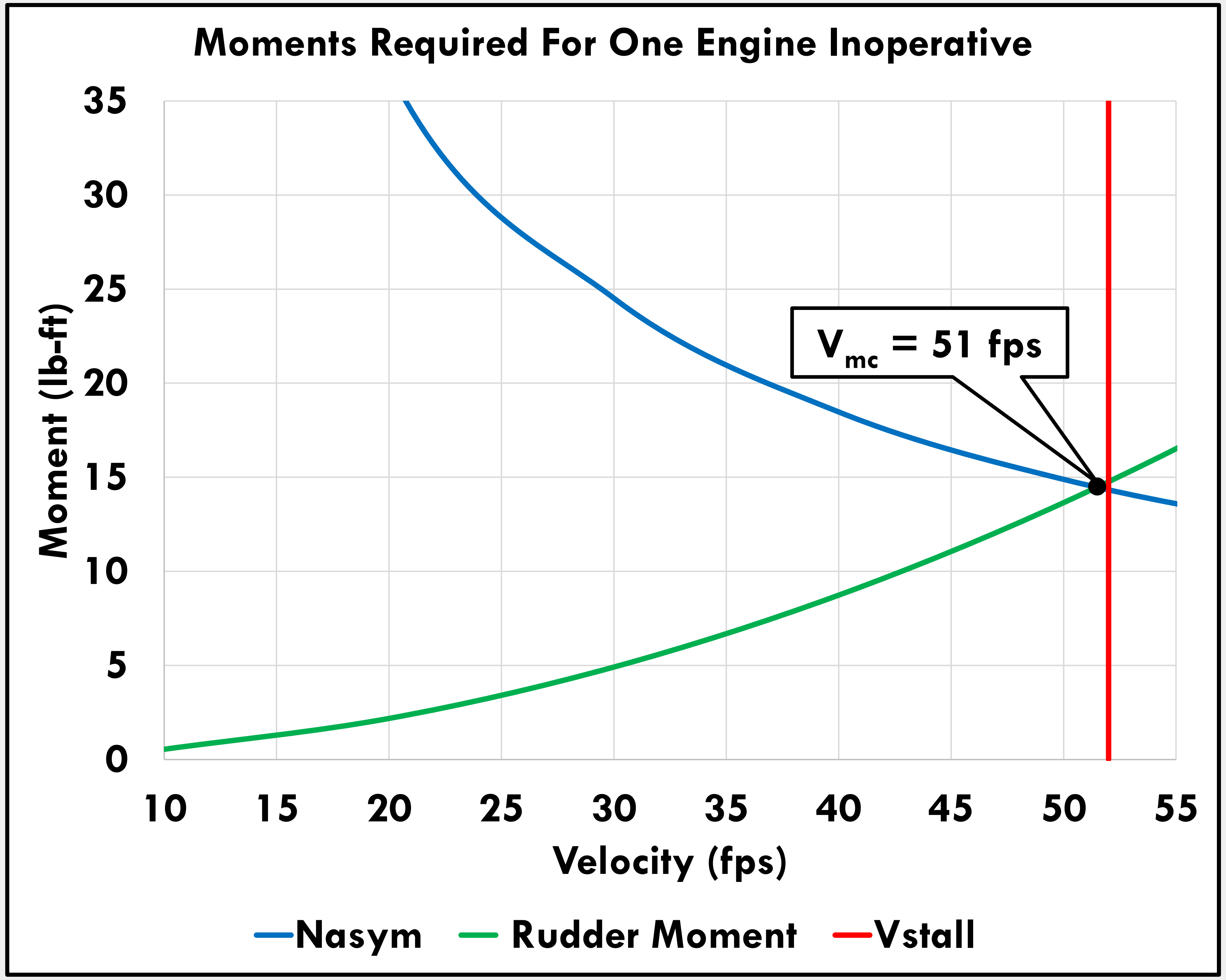
Horizontal Tail



Horizontal Tail Dimensions	
Variable	**Value**
Horizontal Moment Arm (L_{HT})	2.8 ft
Horizontal Tail Volume Coefficient (V_{HT})	0.8
$Span_{HT}$	3 ft
Aspect Ratio	3
Taper Ratio	1
Root Chord/Tip Chord	1 ft
Horizontal Surface Area (S_{HT})	3 ft^2
S_{HT}/S_W	0.34

Horizontal tail sizing developed from Sadraey, *Aircraft Design*

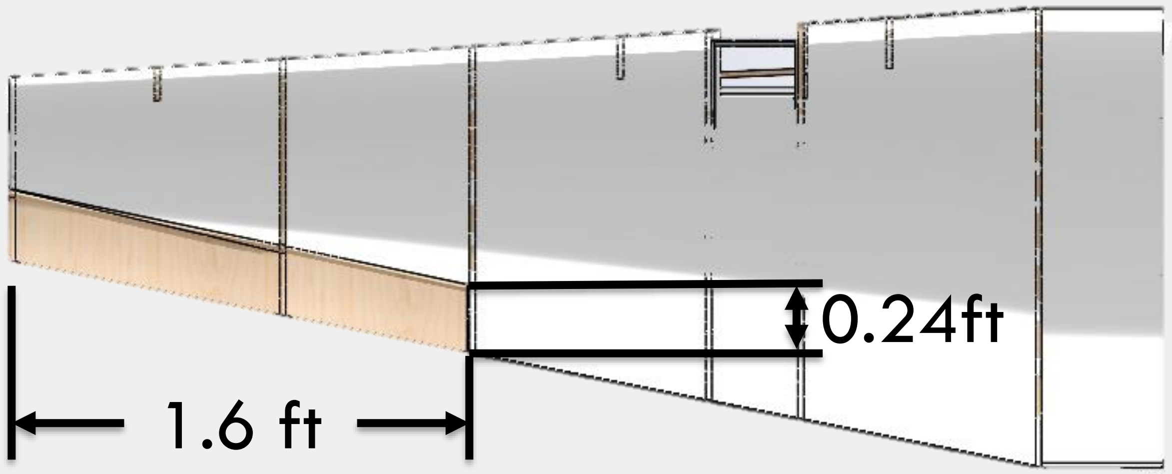
Vertical Tail

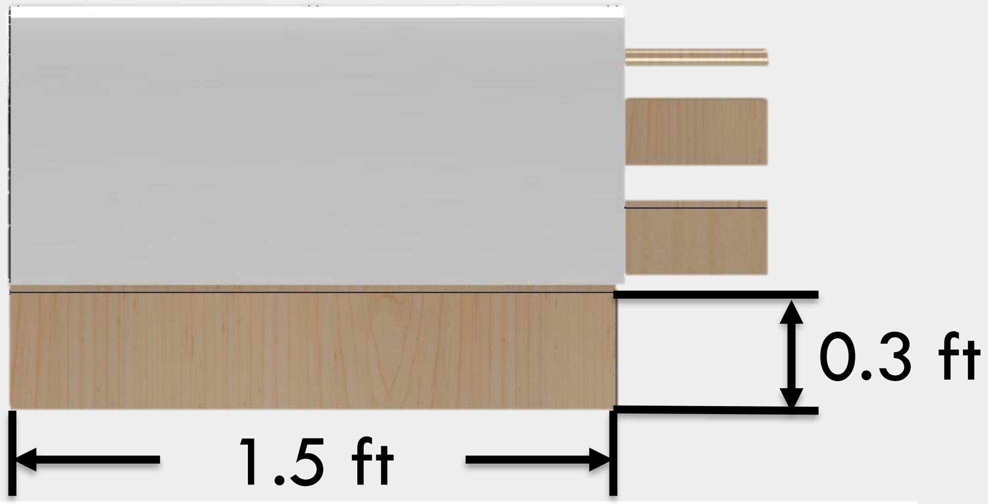


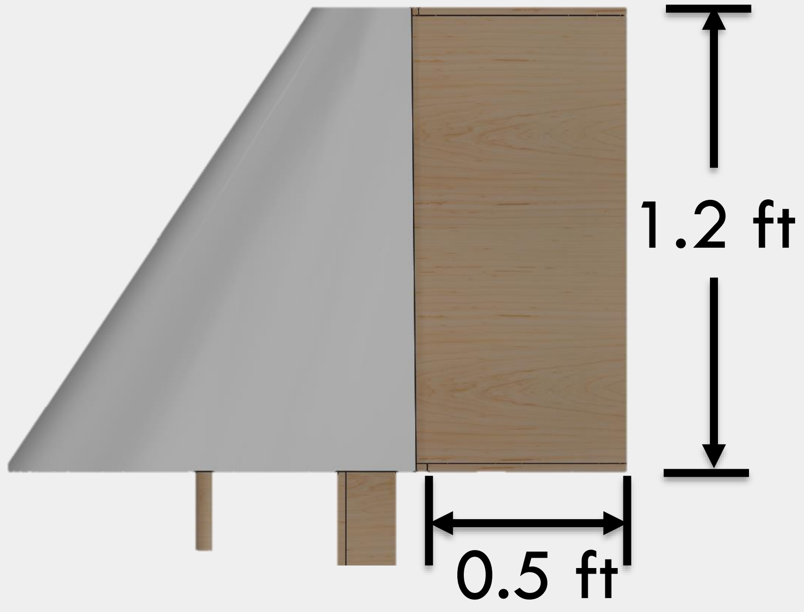
Vertical tail sizing developed from Sadraey, *Aircraft Design*

Vertical Tail Dimensions	
Variable	**Value**
Vertical Moment Arm (L_{VT})	3.3 ft
Vertical Tail Volume Coefficient (V_V)	0.07
Vertical Surface Area (S_{VT})	1.6 ft^2
Aspect Ratio	1
Taper Ratio	0.5
$Span_{VT}$	1.2 ft
Root Chord	1.6 ft
Tip Chord	0.8 ft
MAC	1.3 ft
S_{VT}/S_W	0.17

Control Surfaces







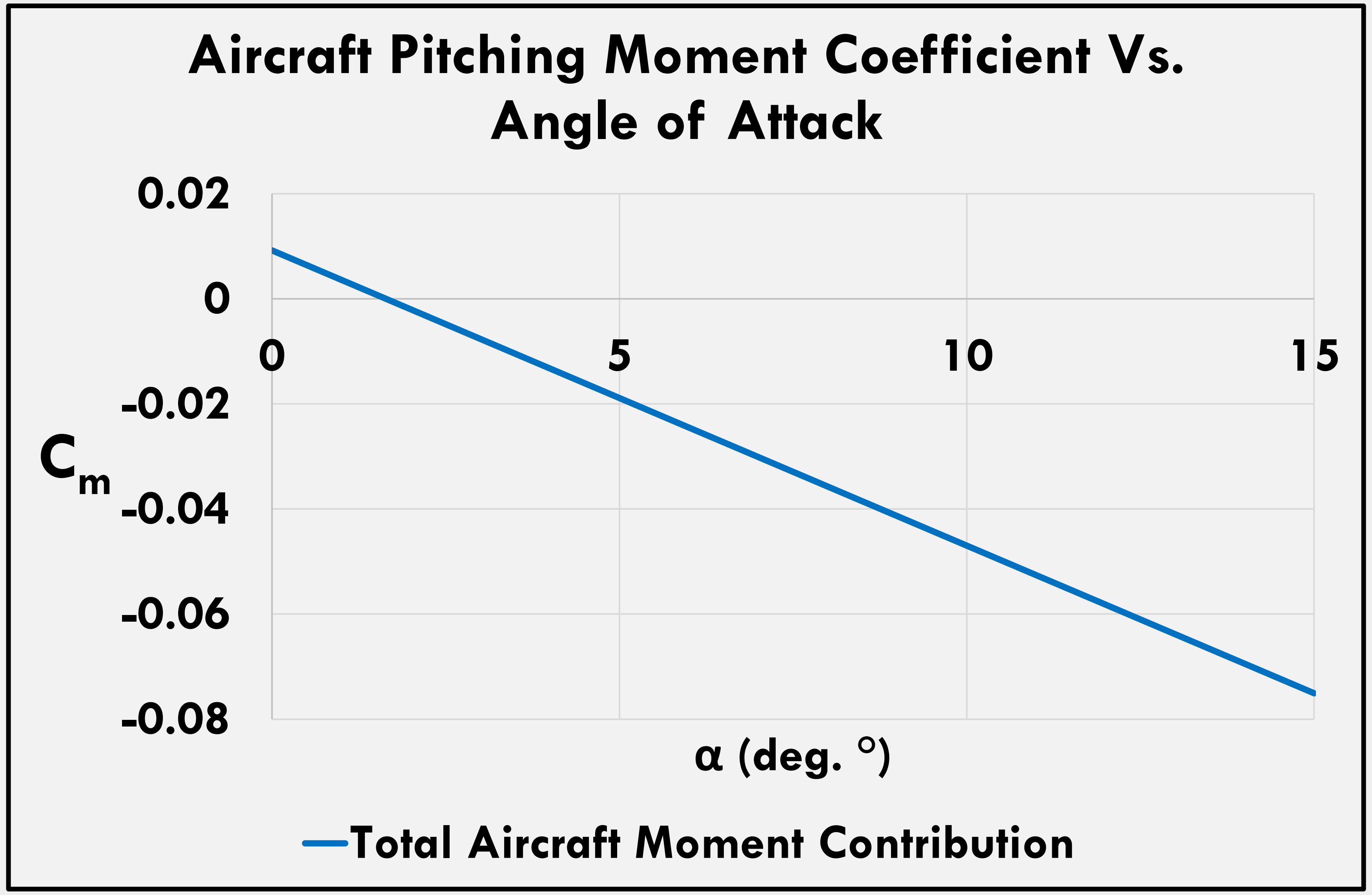
Aileron	
Variable	**Value**
Effectiveness ($\tau_{aileron}$)	0.4
Chord Ratio	0.2
$Span_{Aileron}$	1.6 ft
Time To Bank 30°	1.02 s
$S_{Aileron}/S_W$	0.085

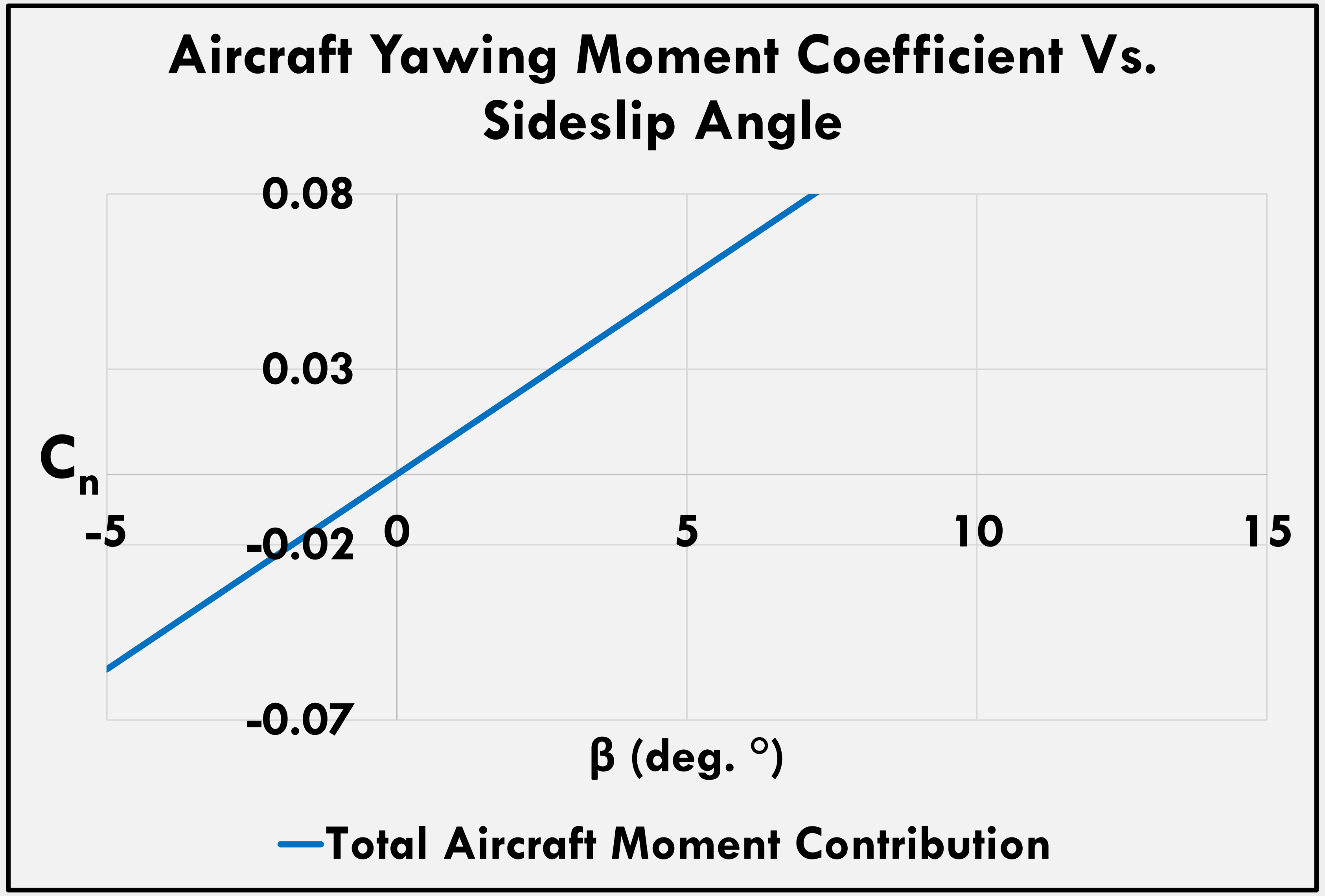
Elevator	
Variable	**Value**
Effectiveness ($\tau_{elevator}$)	0.5
Chord Ratio	0.3
*$Span_{Elevator}$	1.5 ft
Deflection For Trim (δ_E)	-1.2°
$S_{Elevator}/S_{HT}$	0.29

* *For each elevator*

Rudder	
Variable	**Value**
Effectiveness (τ_{rudder})	0.6
Chord Ratio	0.38
$Span_{Rudder}$	1.2 ft
Deflection For Asymmetric Thrust (δ_R)	19.2°
S_{Rudder}/S_{VT}	0.38

Static Stability





Static stability analysis developed from Nelson, *Flight Stability and Automatic Controls*

- Rolling Moment vs. Angle of Sideslip: $C_{\ell\beta} = -0.0115 \text{ deg}^{-1}$
- **Aircraft is longitudinally, directionally, and laterally stable**

Dynamic Stability

Longitudinal Flying Qualities		
Mode	**Value**	**Level**
Phugoid (Damping Ratio)	0.0089	2
Short-Period (Damping Ratio)	0.915	1

Lateral Flying Qualities		
Mode	**Value**	**Level**
Spiral Mode (Time To Double)	20 s	1
Roll Mode (Time Constant)	0.13 s	1
Dutch Roll (Damping Ratio)	0.231	1

- **Level 1** - Flying qualities clearly adequate for the mission flight phase.
- **Level 2** - Flying qualities adequate to accomplish the mission flight phase but with some increase in pilot workload and/or degradation in mission effectiveness or both.

Dynamic stability analysis and flying qualities developed from Nelson, *Flight Stability and Automatic Controls*

Propulsion System Design Logic Flow

Calculate Power Required from constraint diagram

→ Size Motors

→ Size Propellers

→ Size ESC

→ Size Batteries

Trade Study: Engine Type

	FOM's	Cost		Safety		Maintenance		Energy/Fuel type		Weight		Performance		Weighted total = Sum (W)
		0.20789002		0.40798381		0.49213853		0.626042544		1.616367468		2.649577628		
Alternative Configurations		U	W	U	W	U	W	U	W	U	W	U	W	
Electric motor		5	1.03945	5	2.039919	5	2.460693	7	4.382298	5	8.081837	7	18.54704	36.55124
Combustion Gas		5	1.03945	1	0.407984	1	0.492139	1	0.626043	1	1.616367	3	7.948733	12.13072
Ducted fans		1	0.20789	5	2.039919	3	1.476416	5	3.130213	5	8.081837	1	2.649578	17.58585

Final Selection: **Electric Motors**

- Cost and weight efficiency for power output
- Low Upkeep
- Smaller size

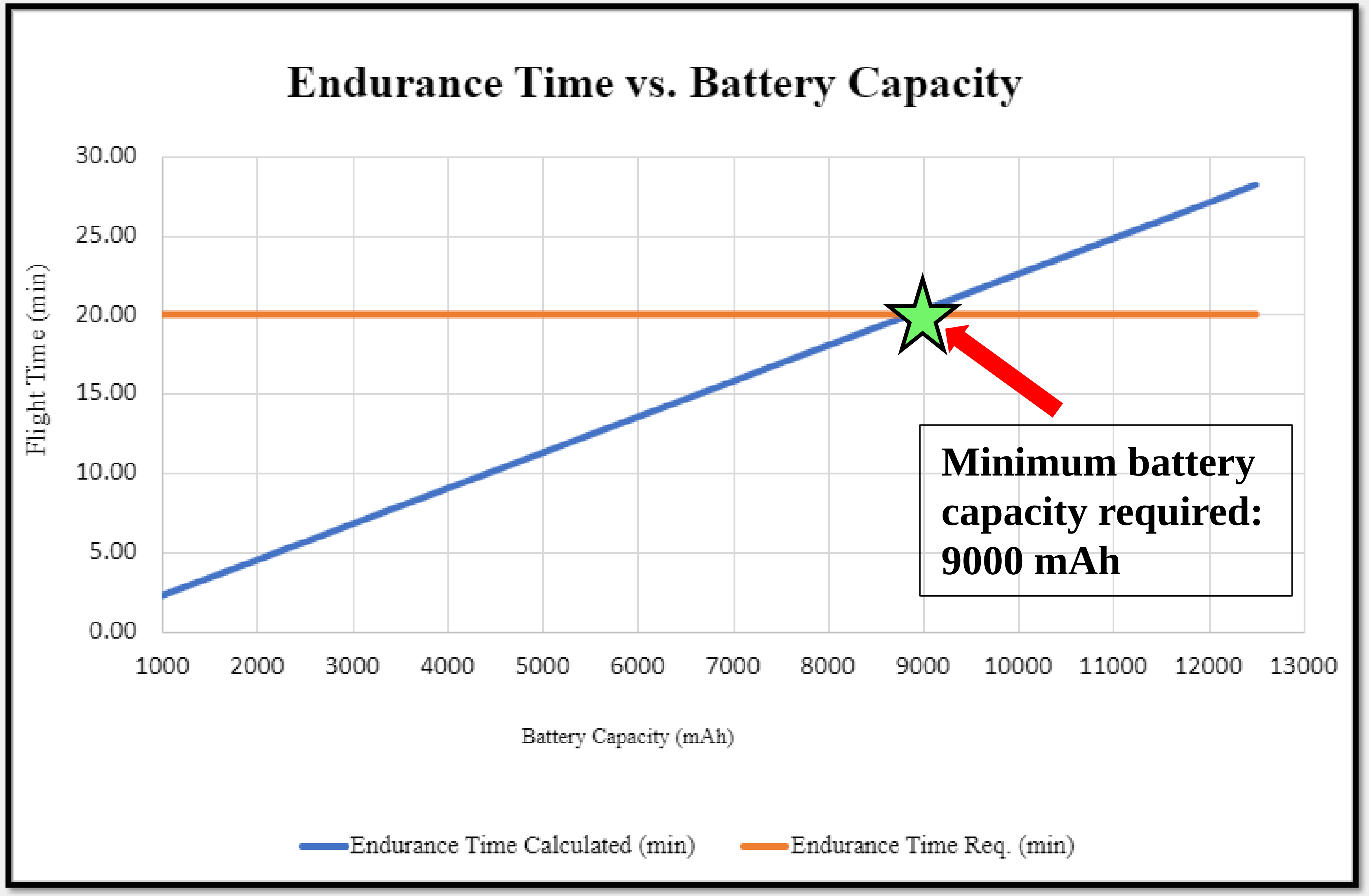
Trade Study: Number of Motors

FOM's	Cost		Maintenance		Safety		Efficiency		Weight		Performance		Weighted total = Sum (W)
	0.22		0.26		0.75		1.14		1.24		2.38		
Alternative Configurations	U	W	U	W	U	W	U	W	U	W	U	W	
2 motor	7	1.54	5	1.3	5	3.75	5	5.7	5	6.2	5	11.9	30.39
4 motor	3	0.66	7	1.82	1	0.75	1	1.14	3	3.7	3	7.14	15.23
6 motor	1	0.22	3	0.78	7	5.25	3	3.42	1	1.24	7	16.66	27.57

Final Selection: **2 Motors**

- Most weight efficient
- Simple setup
- Best reliability for maintenance and control

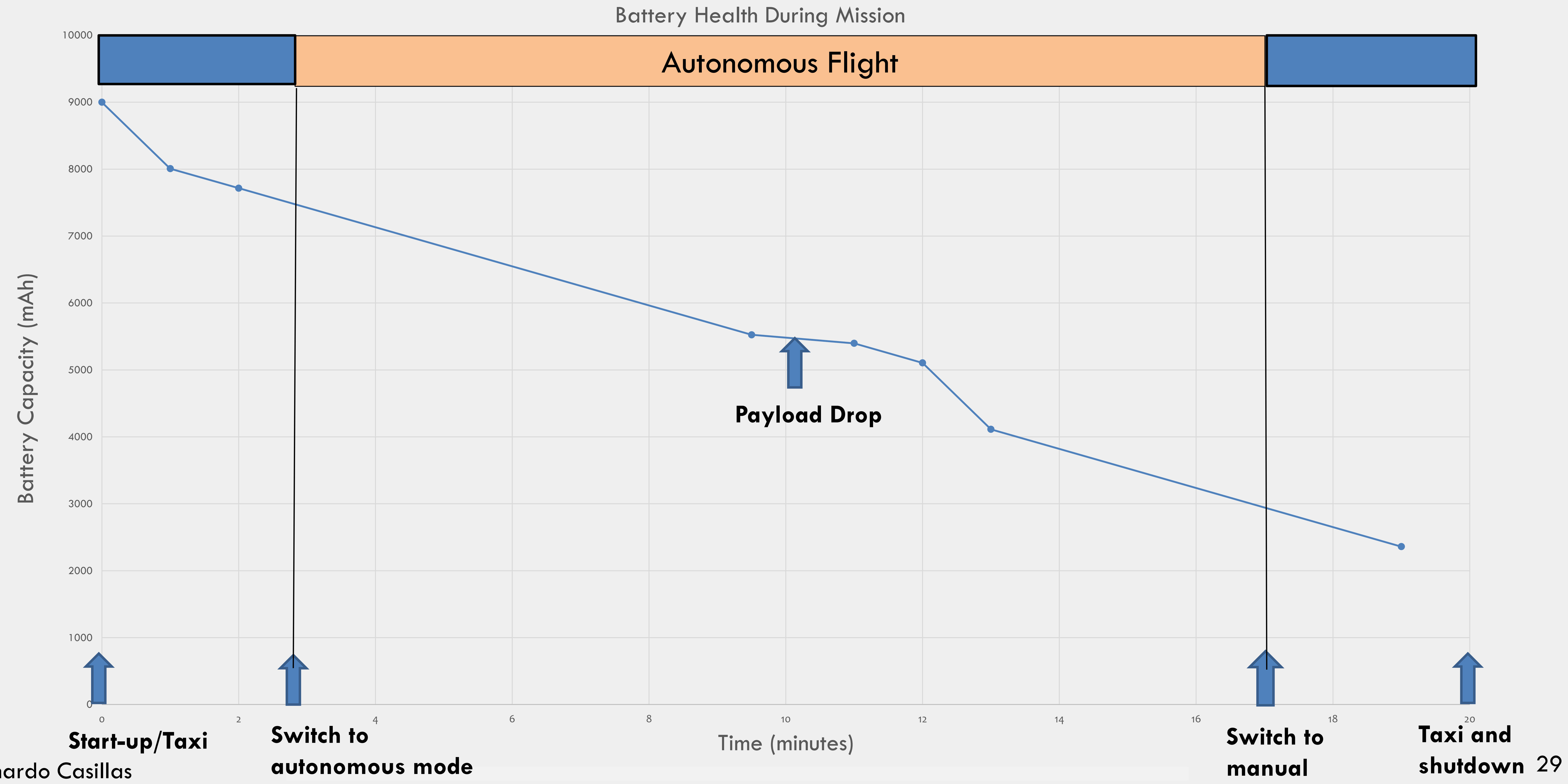
Battery Analysis



Parameter	Value
MTOW	35 lbs
P/W ratio	0.06hp/lbs
Effective Battery Capacity	80%
Avg Amp Draw	21.31 Amps
Cruise Throttle	50-60%
Takeoff Climb Throttle	100%
Endurance Time Required	20 minutes

*For single motor with 19x10in propeller

Mission Profile by Battery Capacity



Leonardo Casillas

Propulsion System Final Hardware Selection

- Motor & Prop: T Motor AT 5220-A KV 220
  - Max Power: 2700 W
  - S-rating: 6-12S (44.4 V)
  - 19 by 10 in. Propellers
- ESC: Cobra 80A High Voltage
  - Rated Amperage: 80 A
- Batteries: Zeee 6S Lipo Battery (tentative selection)
  - Sized for endurance time of 20 minutes
  - Cell count: 6 Cells (22.2V)
  - C-rating: 100C
  - Capacity: 9000mAh

Propulsion System Testing

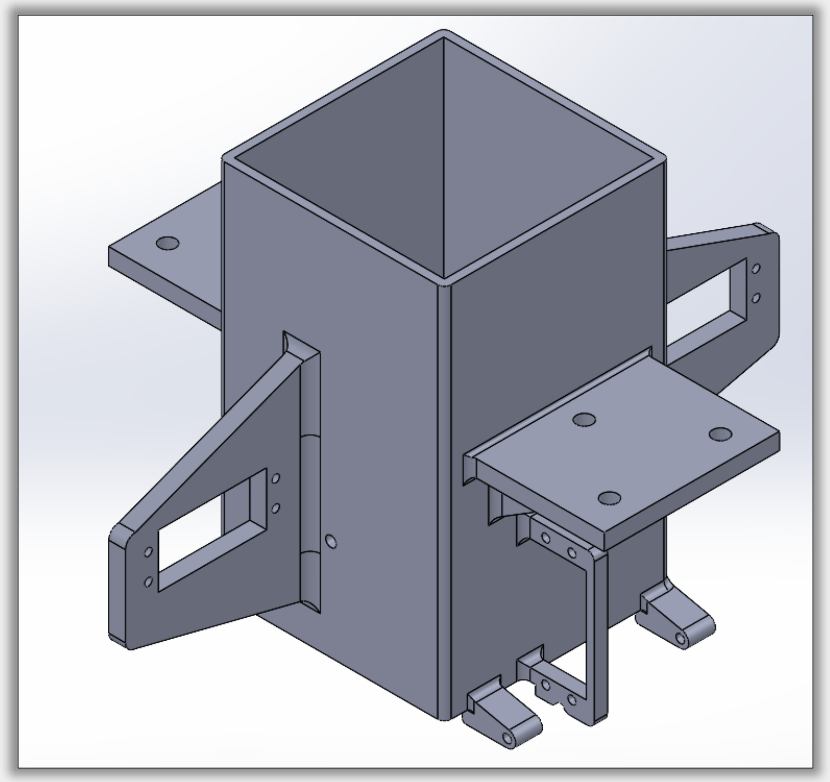
- Load cell-based testing stand
  - Measure motor force output for use in required throttle calculations
  - Measure current draw during throttle procedures to test battery life sustainment for mission

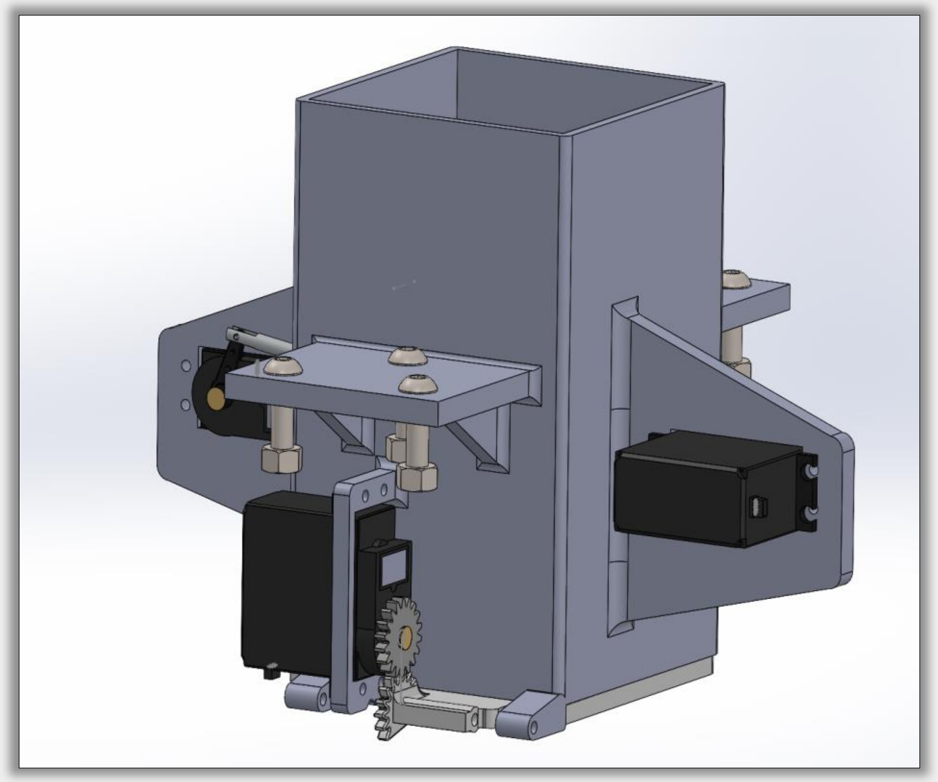
Current Model:

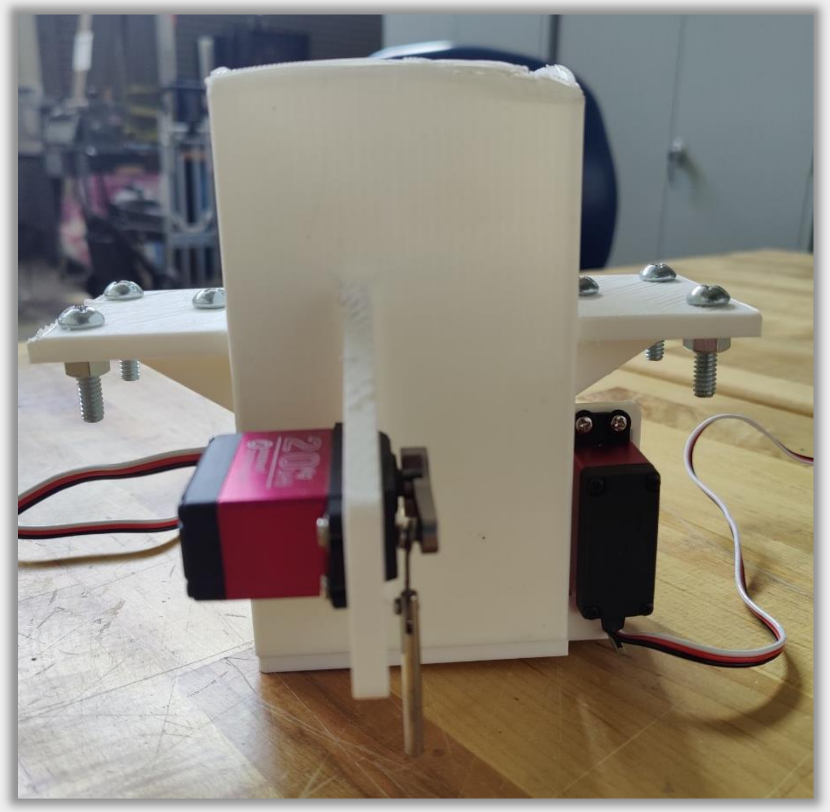
Test Footage

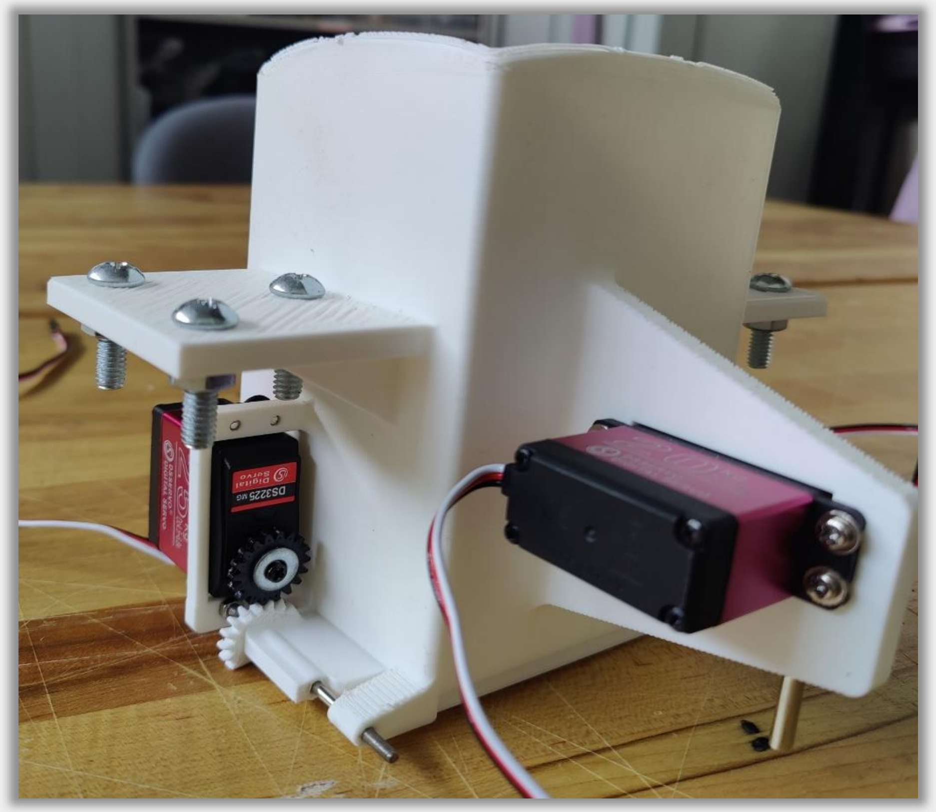
Payload Bay Structure

- Mount for door and servos incorporated into the structure
- Flanges incorporated with bolt holes for mounting structure to UAV
- Assembly Components:
  - Servos
  - Servo Pins
  - Gears
  - Bolts and nuts
  - Door

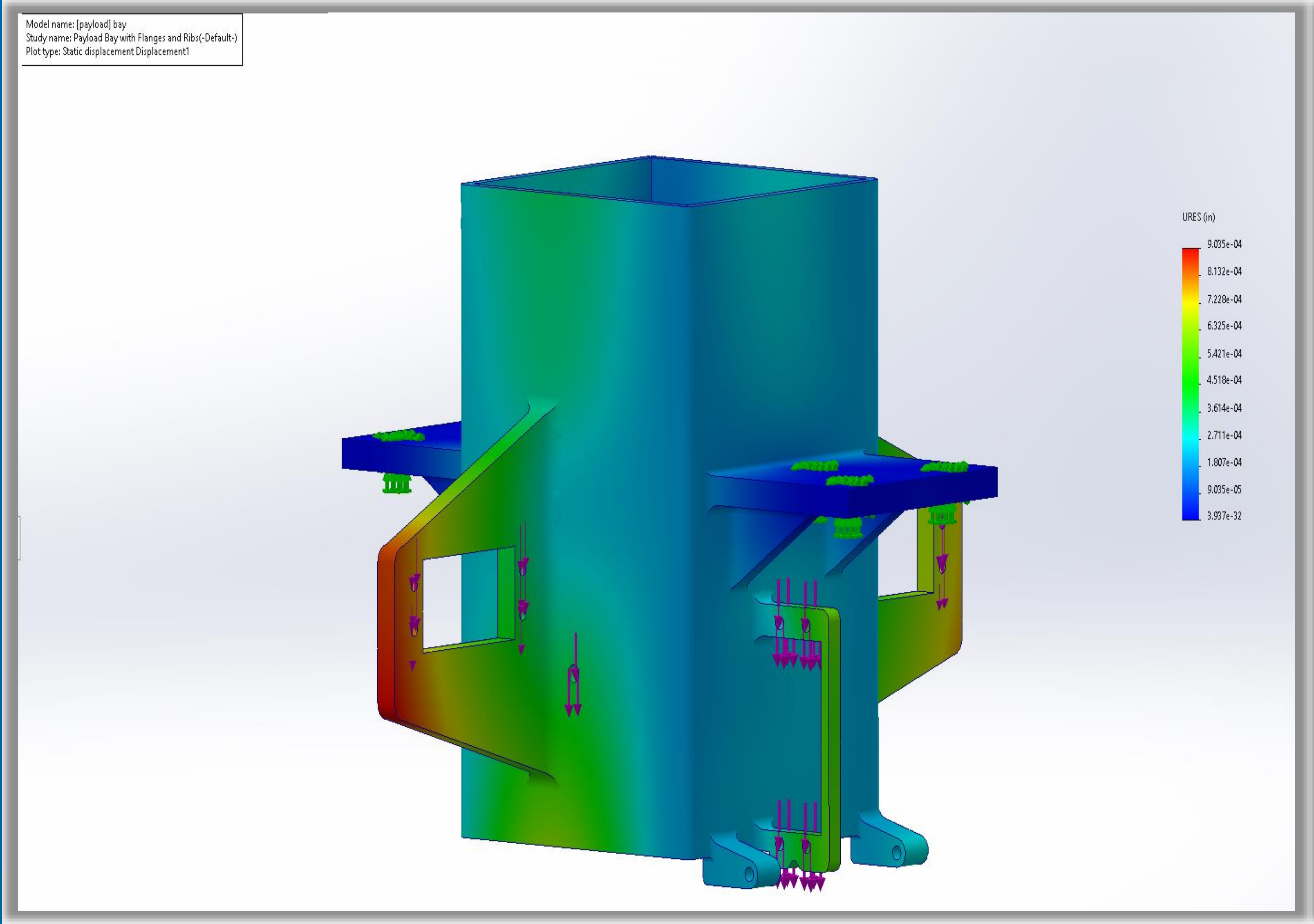


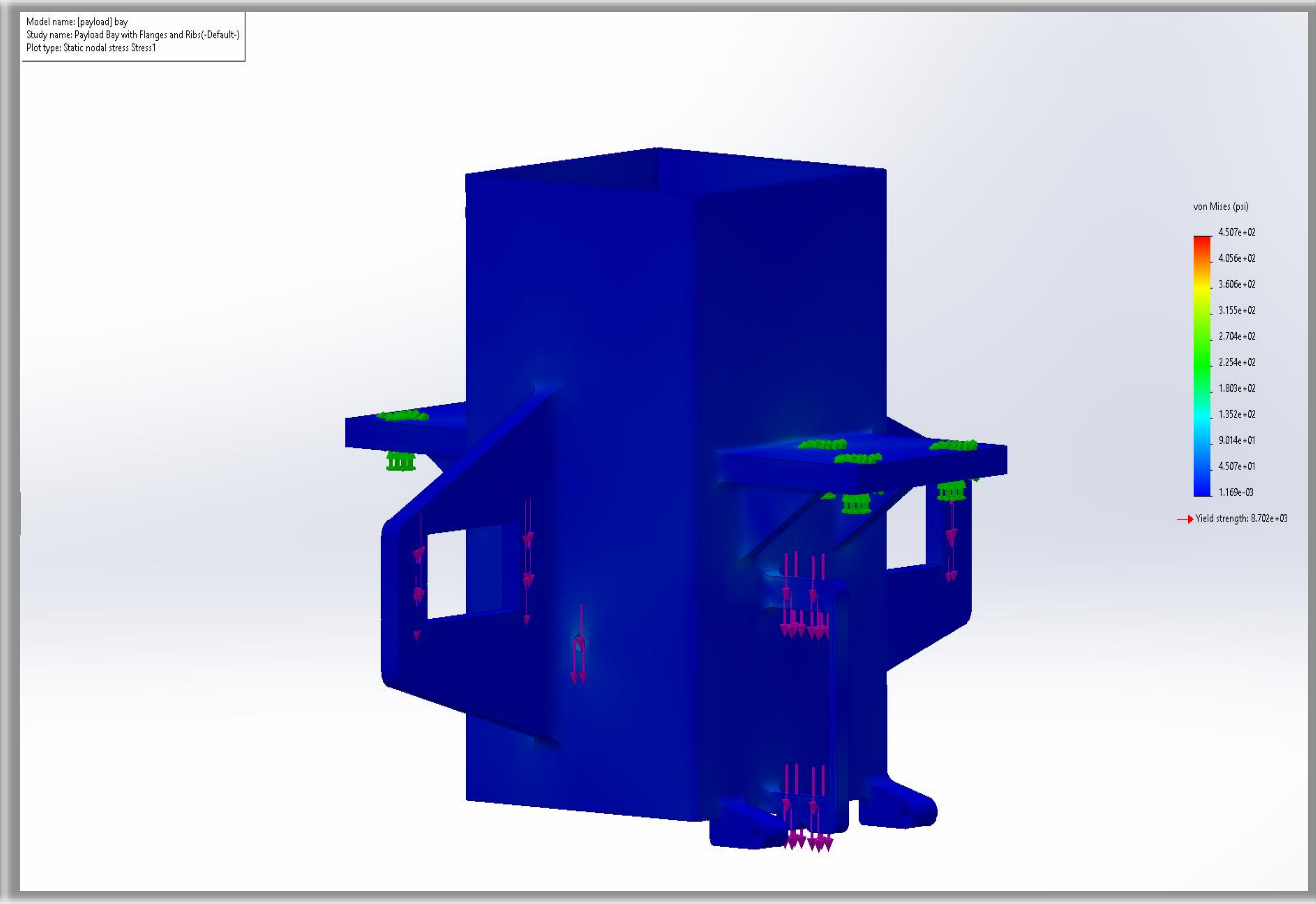






Payload Bay Structure FEA





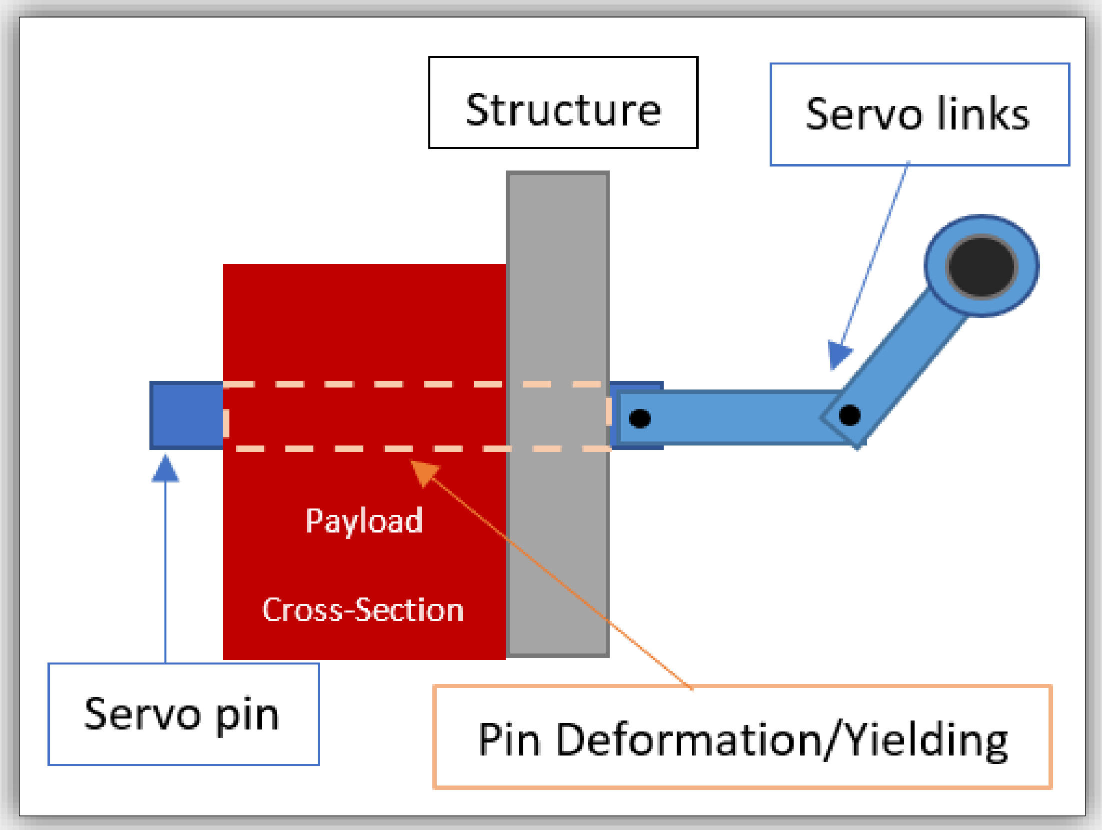
- Max Displacement: 9.08E-4 in
- FOS = 19.31

Updated Release Method

- Both pins inserted into the survival kit which hold it in place
- Pins are released, leading to freefall of the kit

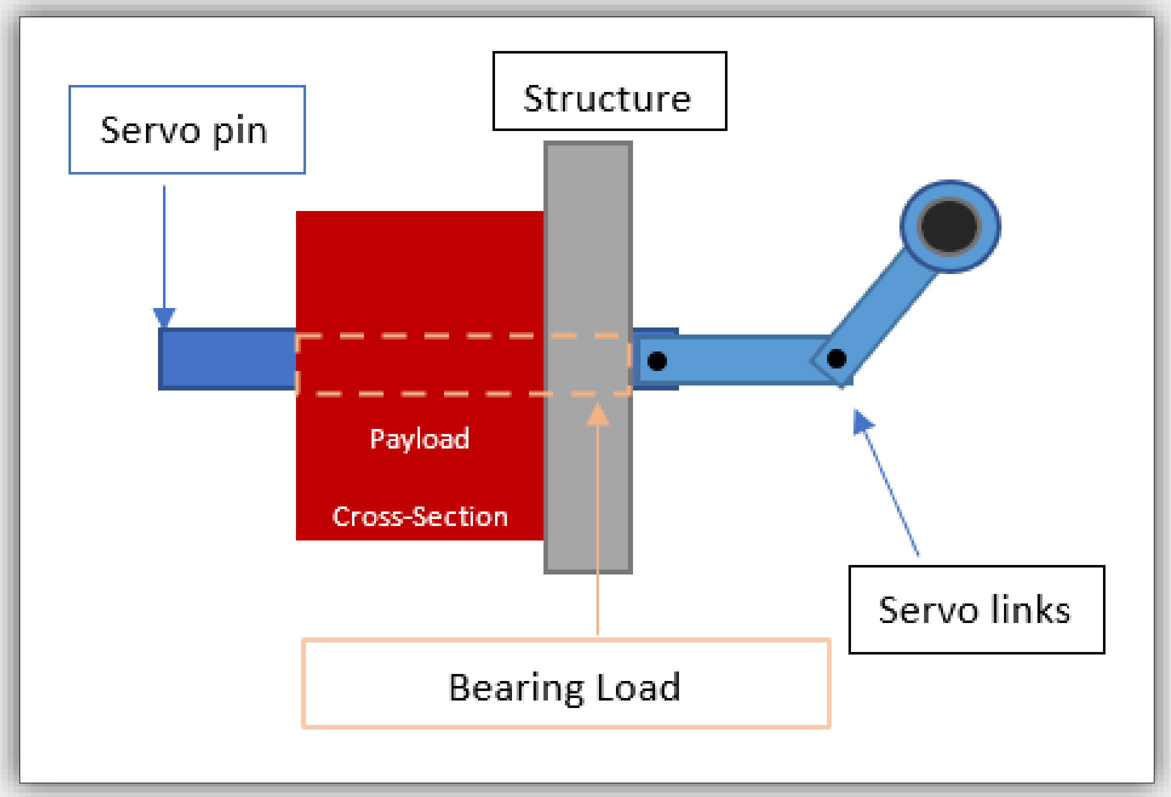
Servo Pin Stress Calculations

- Servo Pin Stress Calculations
  - Bending and shear stress calculated for servo pin based on weight experienced by pin
  - The servo pin is made of 7075-T6 Aluminum
- Results
  - Von-Mises Stress: 1.76 ksi
  - Bending Factor of Safety: 41.6



Pin Bearing Load Calculations

- Bearing Load
  - Calculated for servo pin in contact with the payload bay structure and the kit
  - The payload bay structure is made of PLA
- Results
  - Von Mises Stress: 495.32 psi
  - Factor of Safety: 10.14

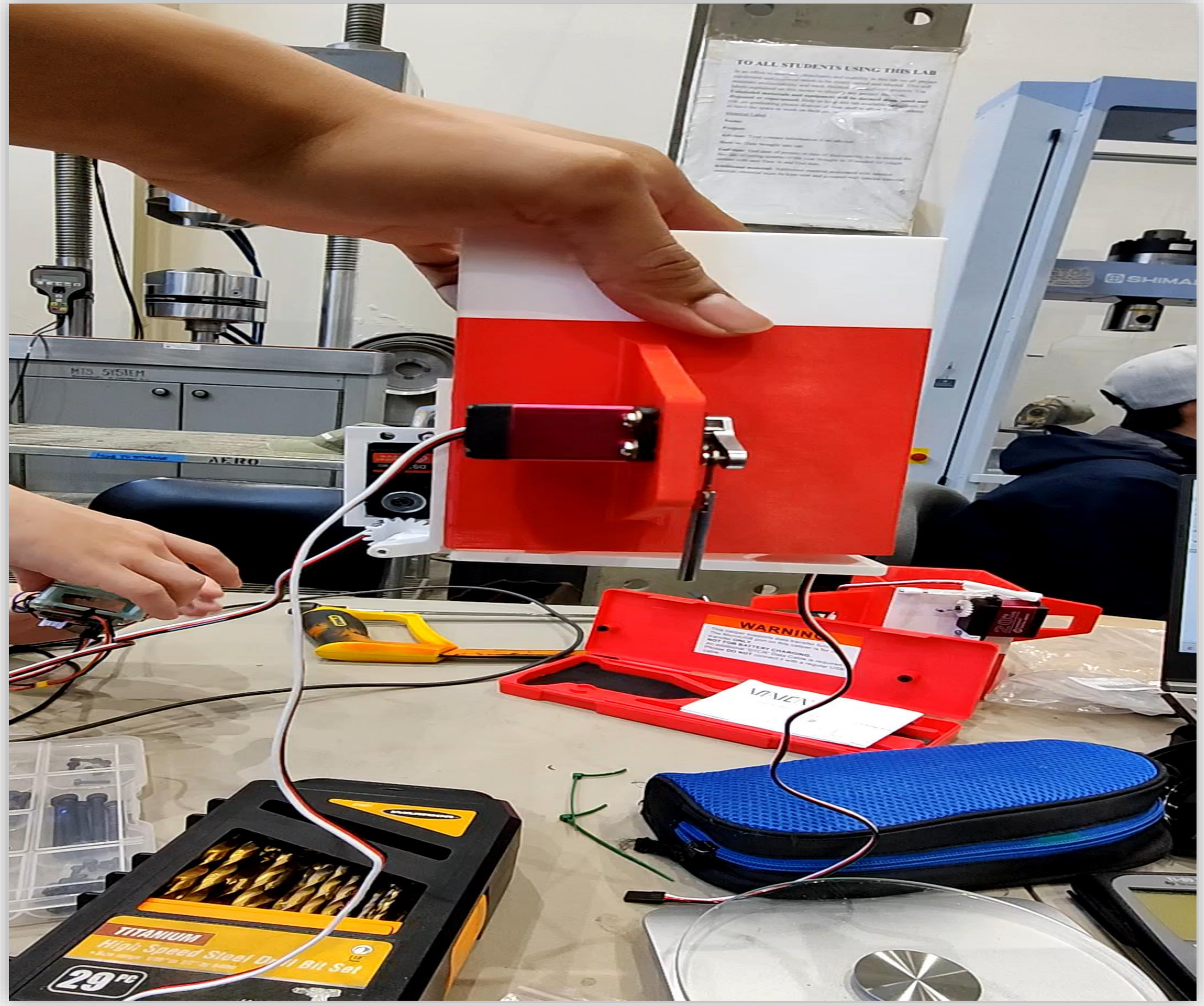


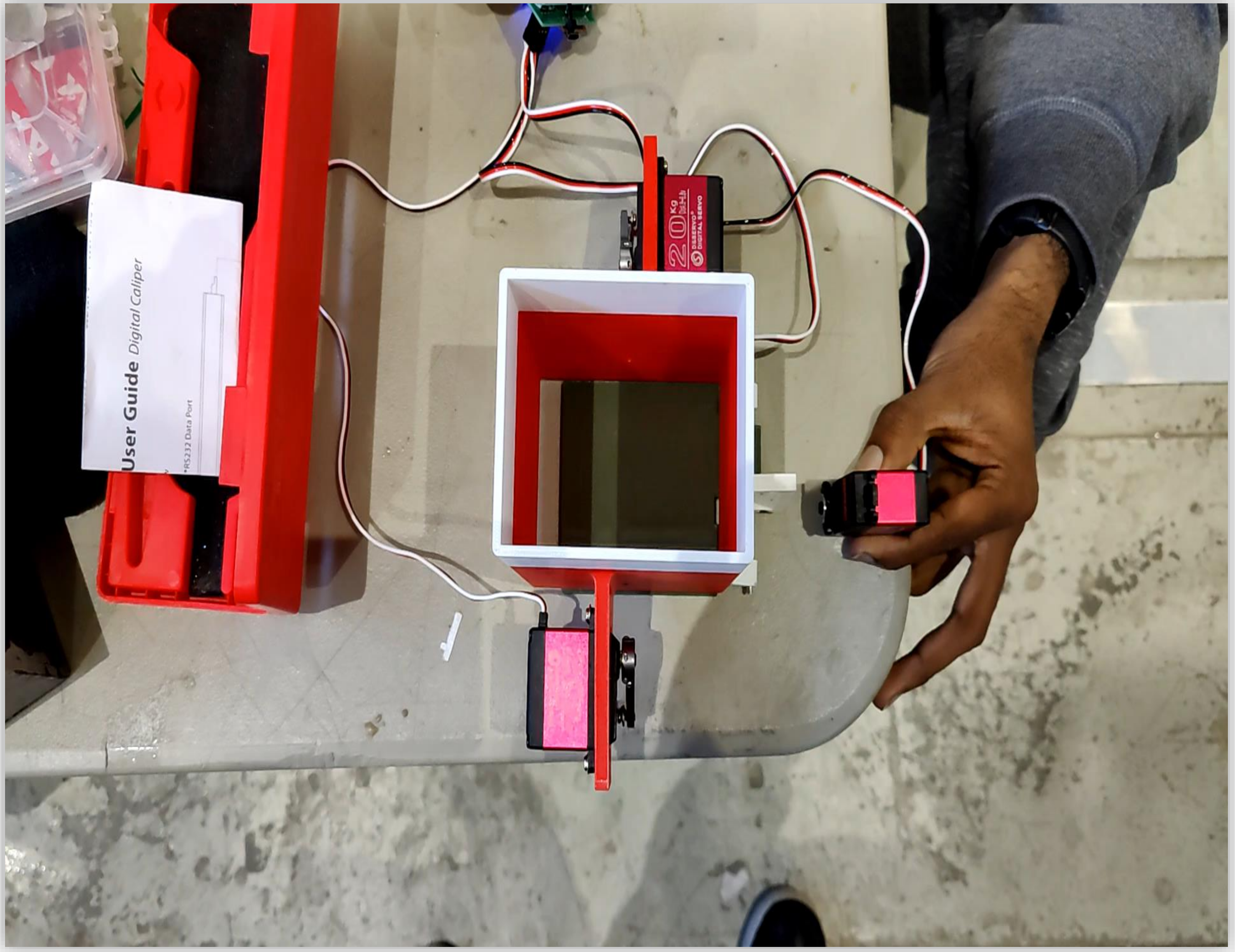
Payload Bay Door

- Single door with hinge on one side
- Door opens from left to right
- Incorporated into Payload Bay structure for easy assembly
- Servo will need to open door to a 90-degree angle and then close after kit is dropped

Blower Rated for 235 MPH Wind Speed

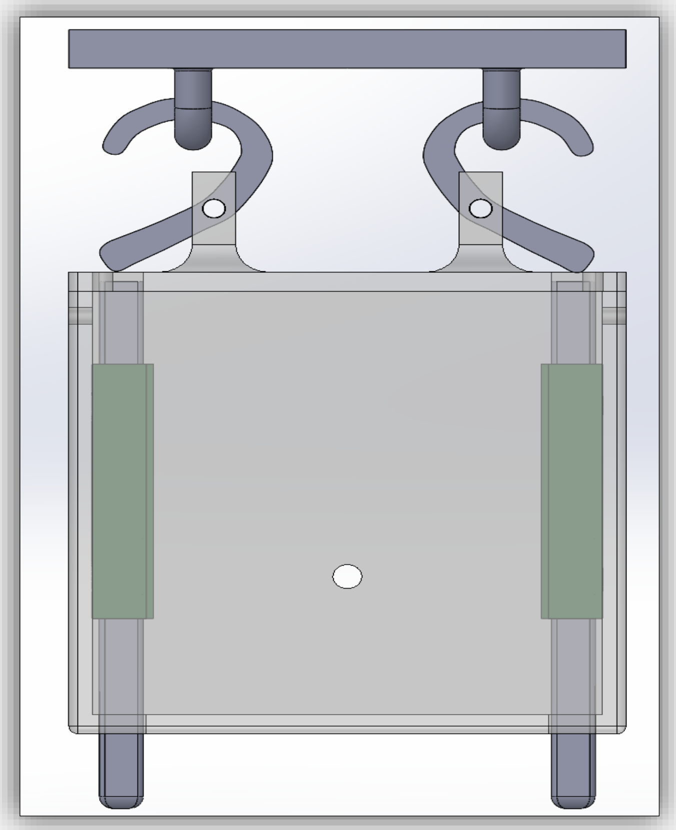
Door + Sequence Testing with Software





Parachute

Alternative #1
Removable Slab

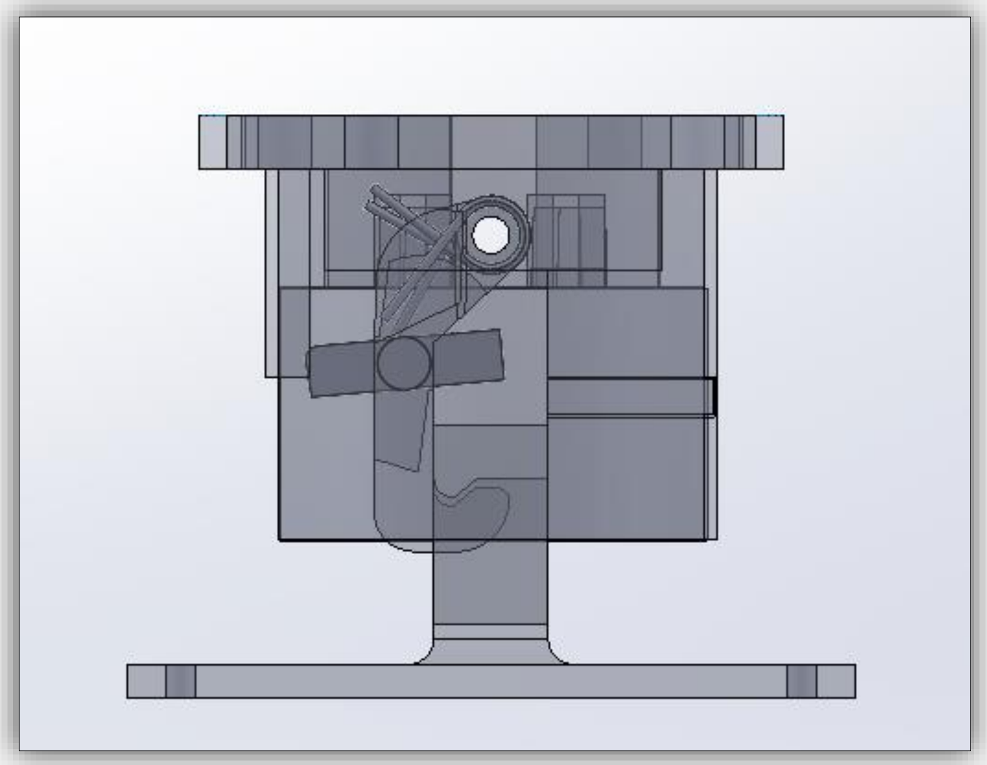


- Parachute sits on top of slab connecting to 2 side hooks
- 2 rods on the side of the kit will push the hooks up
- Latch will swing to separate payload from parachute slab

Parachute

- 24in Rocketman Ultra Light High-Performance Parachute
- Descent rate: 17.33 ft/s at 2.50lbs
- Weight: 0.044lbs

Alternative #2
Removable Cylinder

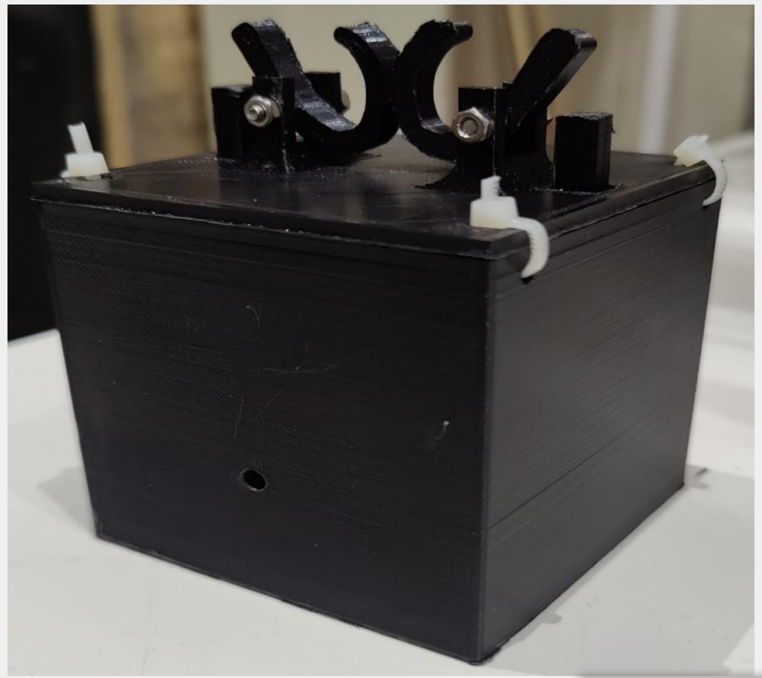


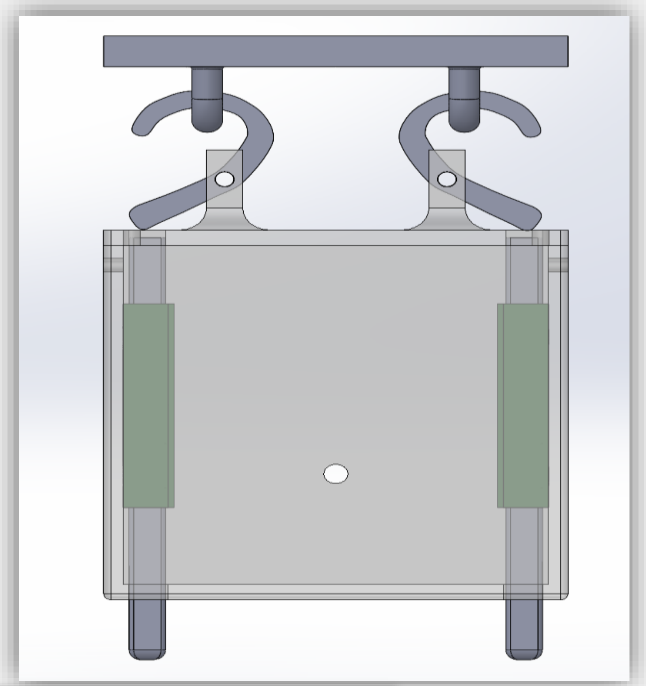
- Parachute constrained to cylinder on top of kit
- Impact from survival kit hitting the ground will release cylinder and parachute

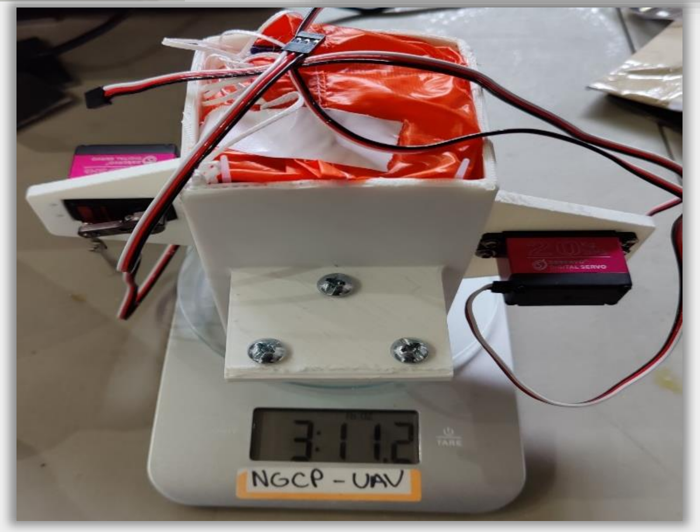
Trade Study: Parachute Mechanism

FOM's	Functionality		Factor of Safety		Reliability		Installation/Packing		Manufacturability		Dimensions		Design Simplicity		Weighted total = Sum (W)
	1.530252887		1.747825467		1.422130394		0.514656606		0.369932108		0.410860132		1.004342406		
Alternative Configurations	U	W	U	W	U	W	U	W	U	W	U	W	U	W	
Removable Slab Design	9	13.77227599	9	15.73043	7	9.954913	9	4.631909	7	2.589525	7	2.58952	9	3.329389	52.597966
Detachable Cylinder Design	7	10.71177021	9	15.73043	5	7.110652	5	2.573283	5	1.849661	3	1.1098	7	2.5895248	41.675116

- Reasons for Selection
  - –Easy to actuate and de-actuate
  - –Allows for more space to pack parachute
  - –Easy to integrate to the payload bay structure
  - –More durable and less likely to prematurely actuate
    - Alternative 2 snapped when attempting to pack inside structure

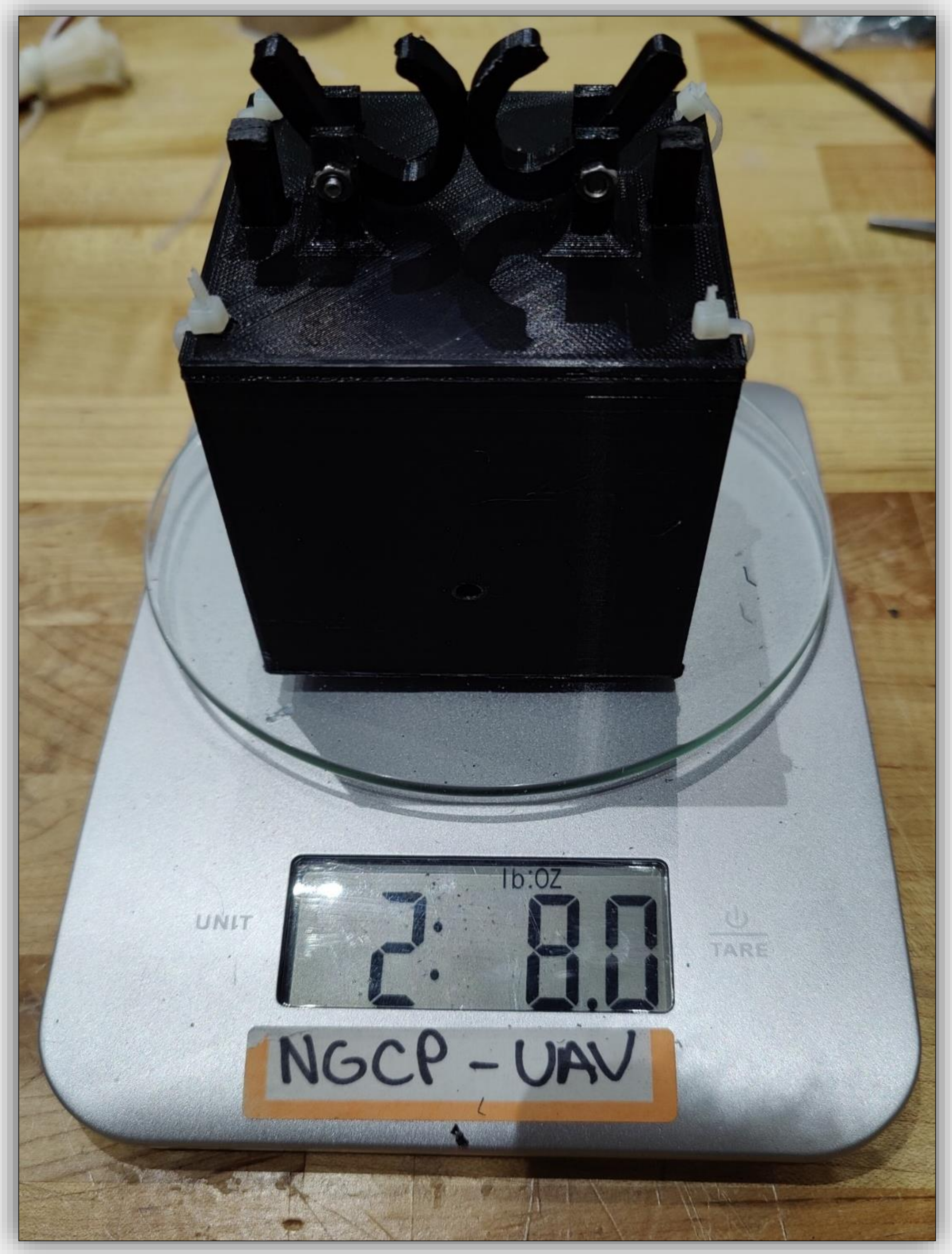




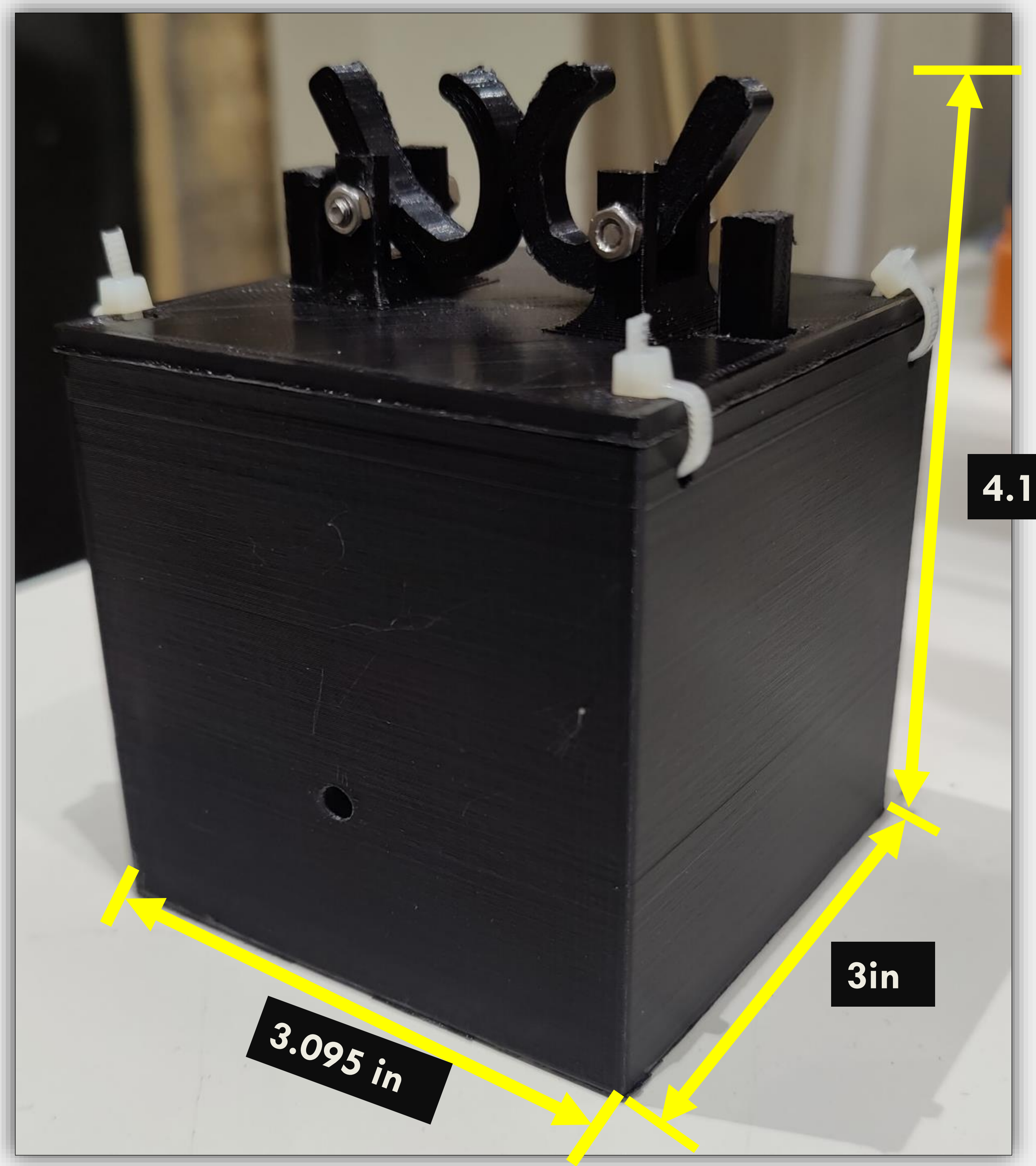


Survival Kit

- Specifications:
  - 3" x 3" x 3" 3D Printed Box (parachute mechanism not included)
  - Body is one piece while lid is printed separately
  - Zip-ties used to keep lid closed
  - Interface points have been removed



Survival Kit Dimensions

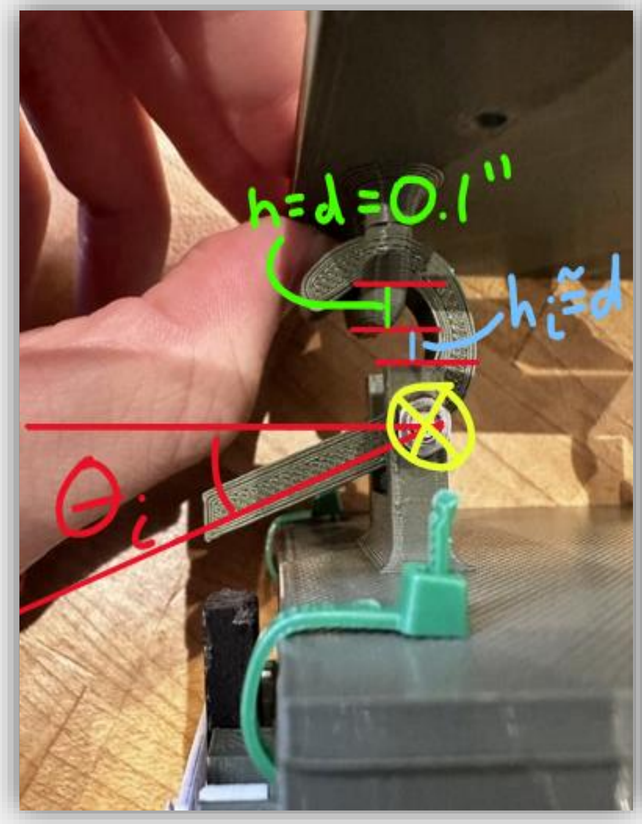


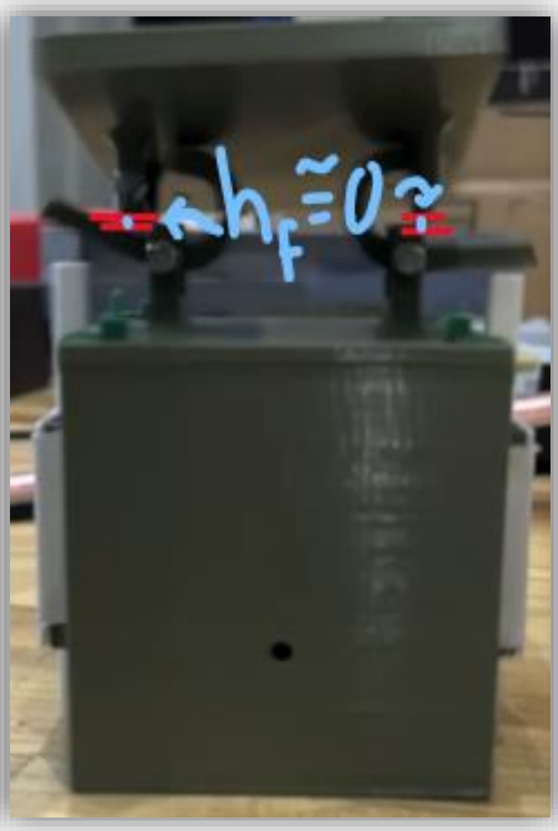
Impact Force

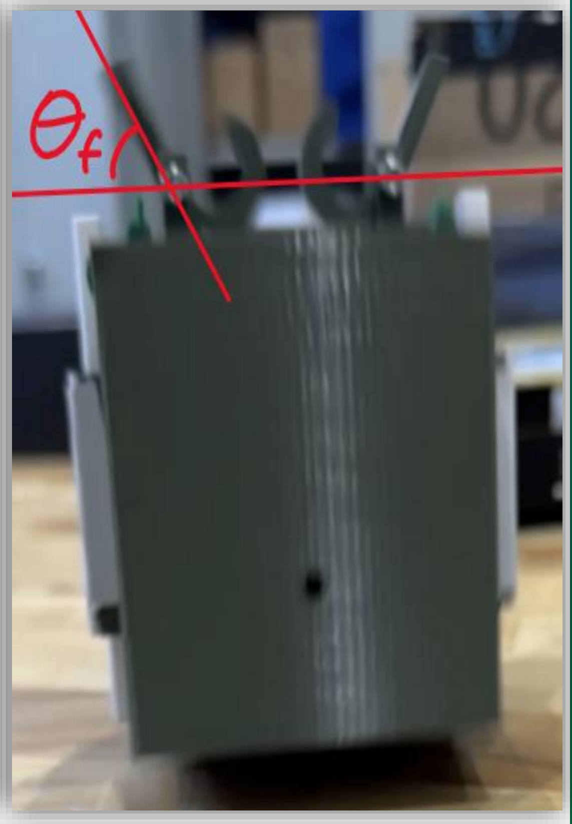
- Calculated impact force from found terminal velocity
  - 17.74 ft/s
  - Integrity of box analyzed
- Results
  - $F_{avg} = 3725.9 lbf$
  - $\sigma = 413.99 lbf$
  - Factor of Safety for PLA Box: 21.02
  - Factor of Safety for Metal Box: 63.06

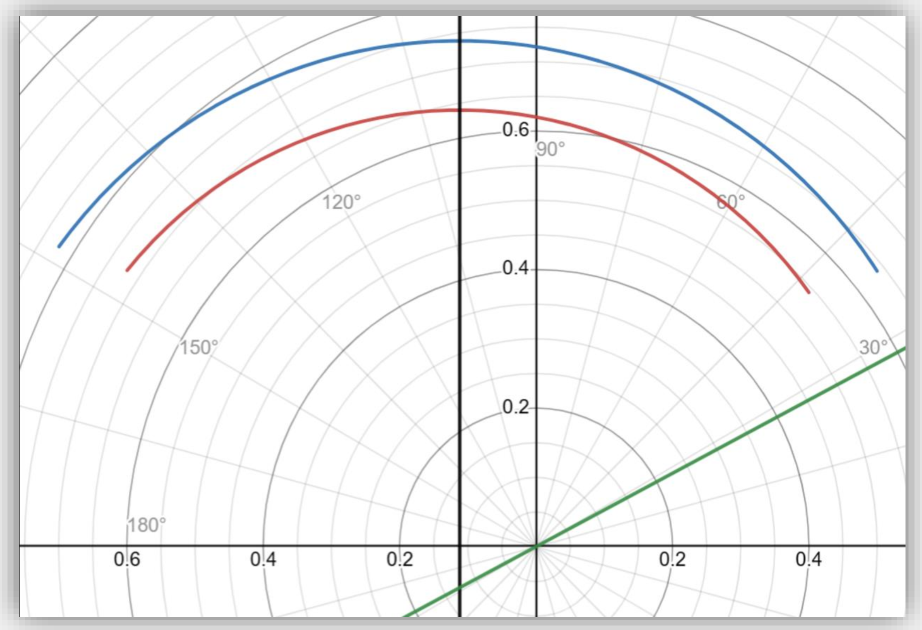
Parachute Calculations: Alternative #1

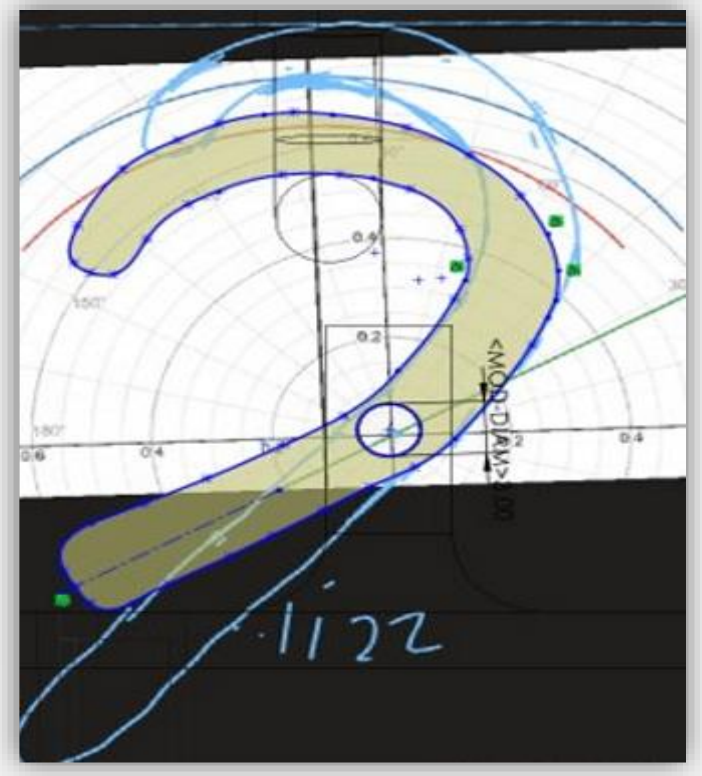
- Calculations develop hook design
  - Secure fit during drop (bigger hook)
  - Release platform (smaller hook)
- Results
  - θ_{max} =85 degrees
  - H=0.1 inches (1 platform hook diameter)
- Plotted on graph
  - Green Line – slope from screw to edge of platform
  - Blue and Red Line – Distance between determines the gap between the tip and equilibrium point on the bottom edge of hook
  - Black Line – Distance from equilibrium to screw





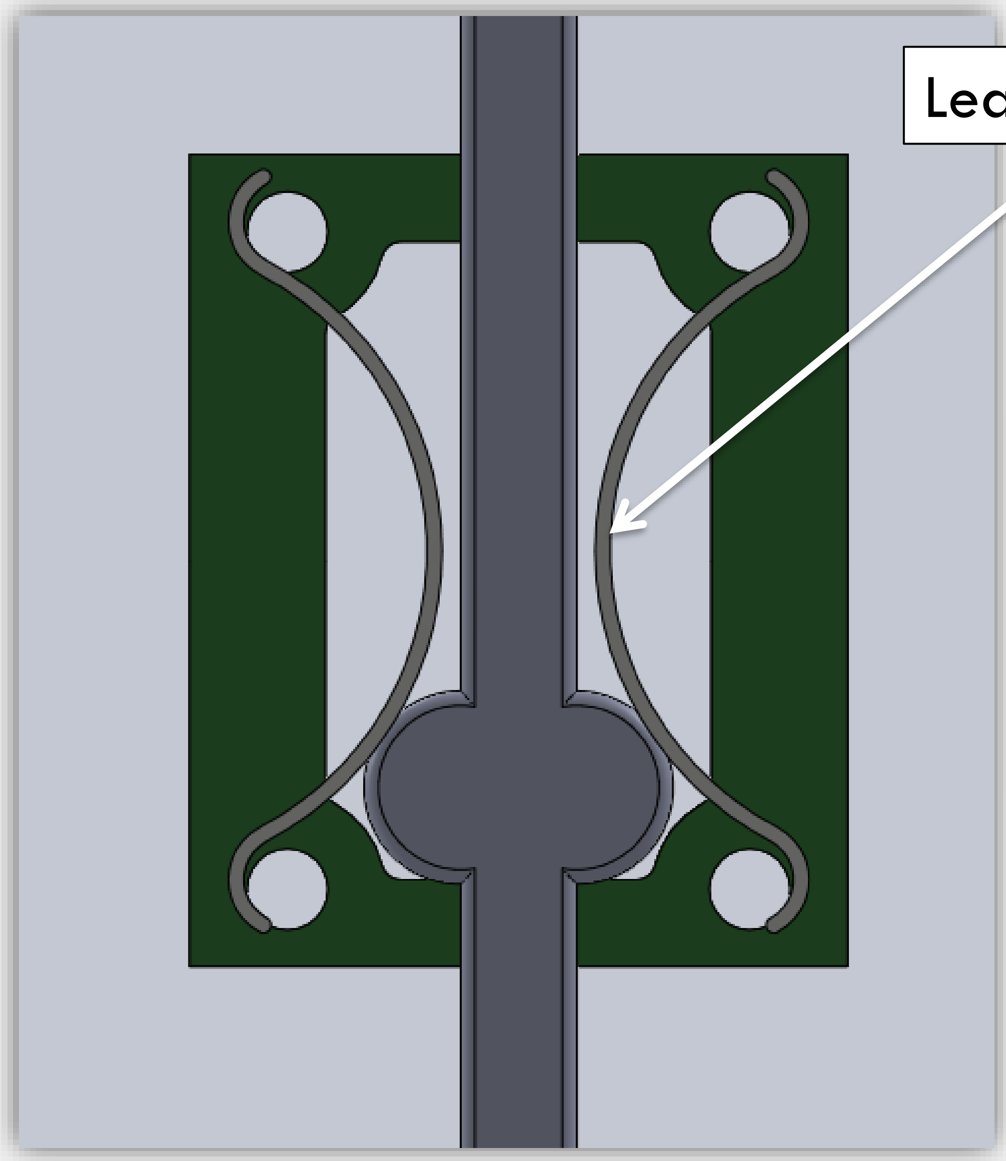


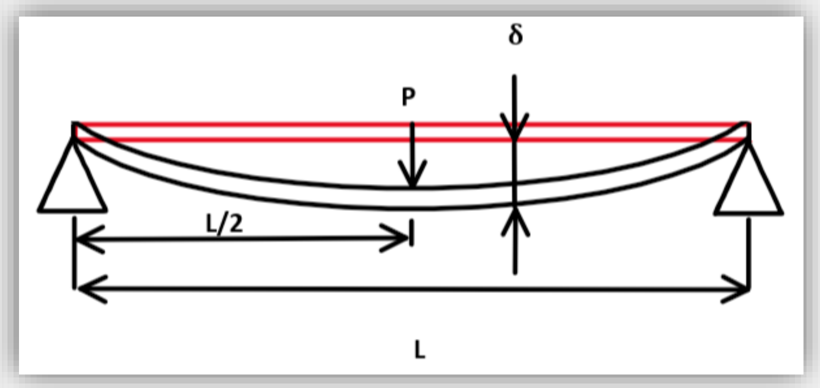




Alternative #1: Leaf Spring Stress Calculations

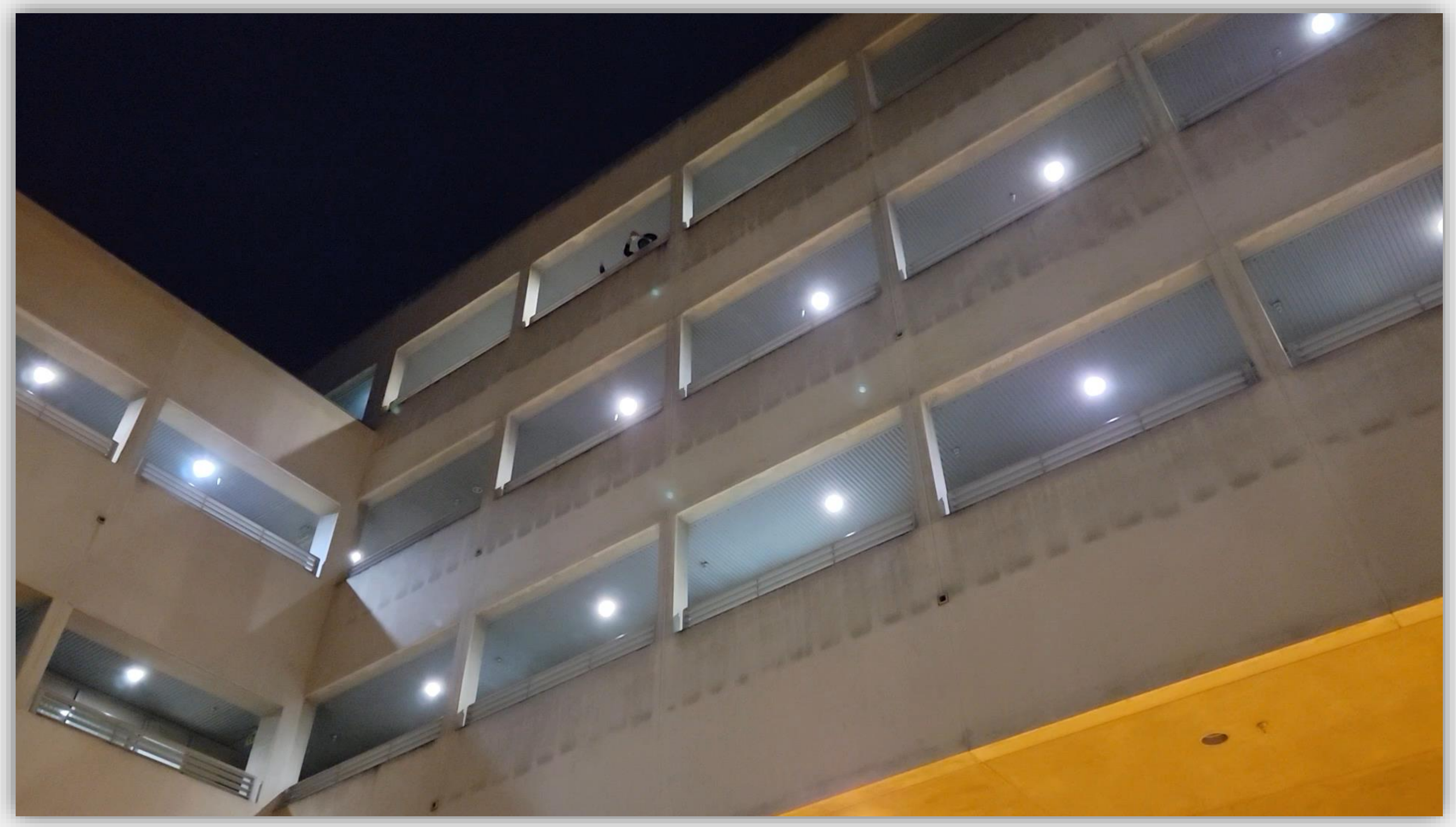
- Leaf Spring Stress Calculations
  - Leaf spring considered to be a single Leaf Spring
- Results
  - Bending Stress: 1253 psi
  - Factor of Safety: 6.95
  - Displacement: 0.047 in





Alternative #1: Testing

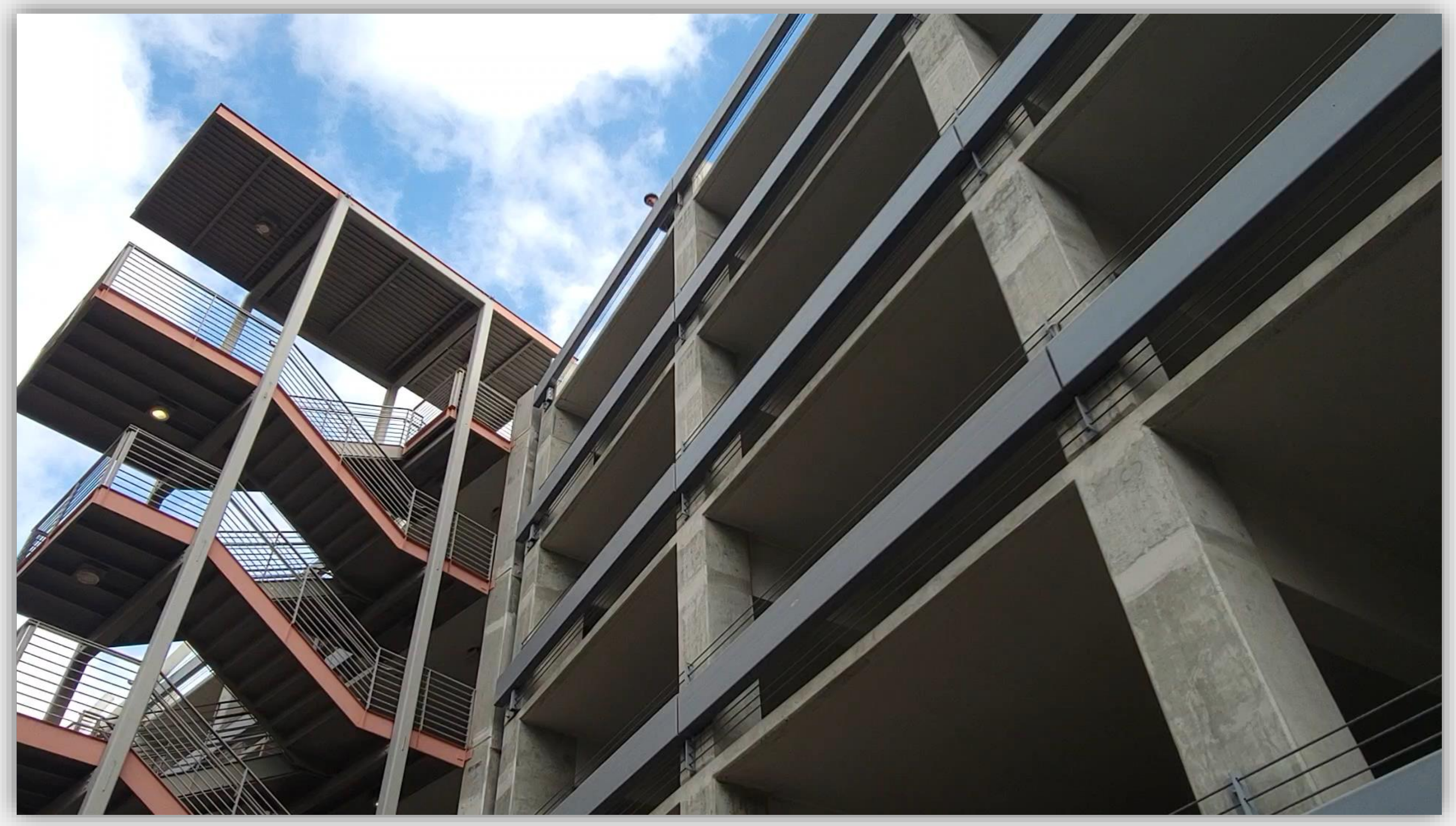
Wind 8mph East, No Weight



Wind 3.4 mph West, With 2.5lbs Weight

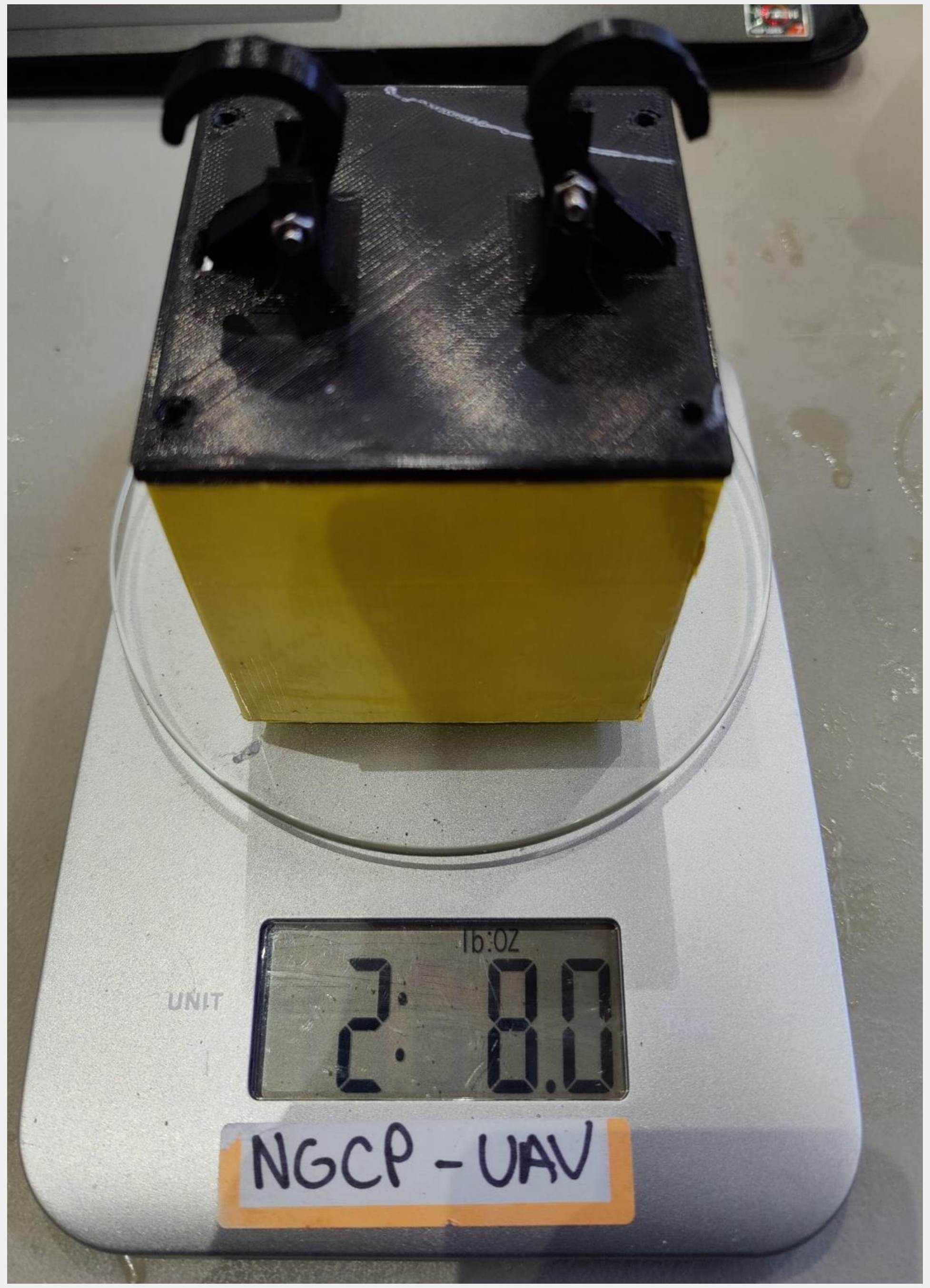
Alternative #2: Testing

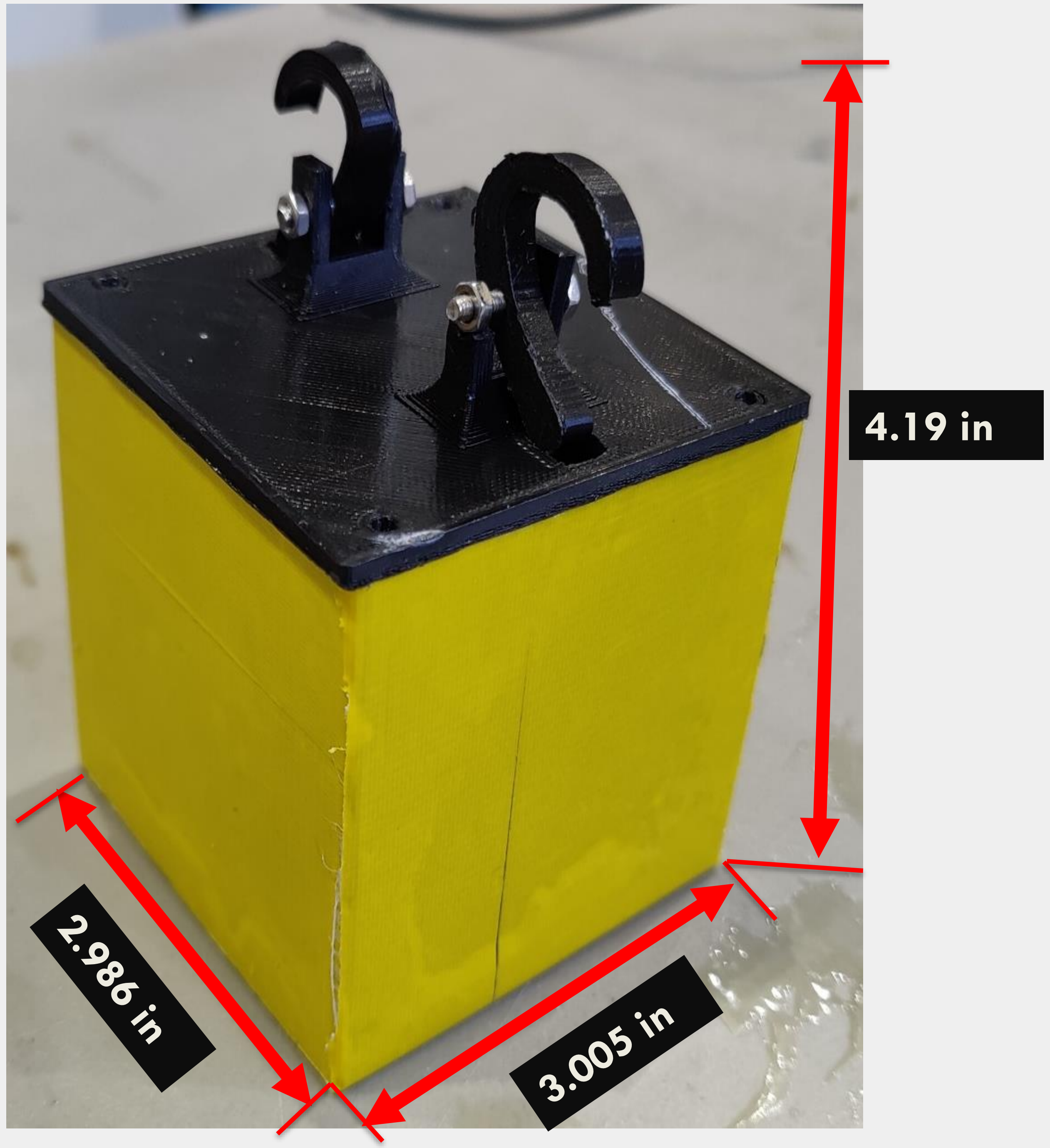
Wind 13 mph Southwest, No Weight



Survival Kit

- 3D printed 2.5lb kit broke from impact with ground in removable slab test #2
- Will revert back to metal box with 3D printed lid
- 3/16 in. Plain steel flat bar stick welded (SMAW)



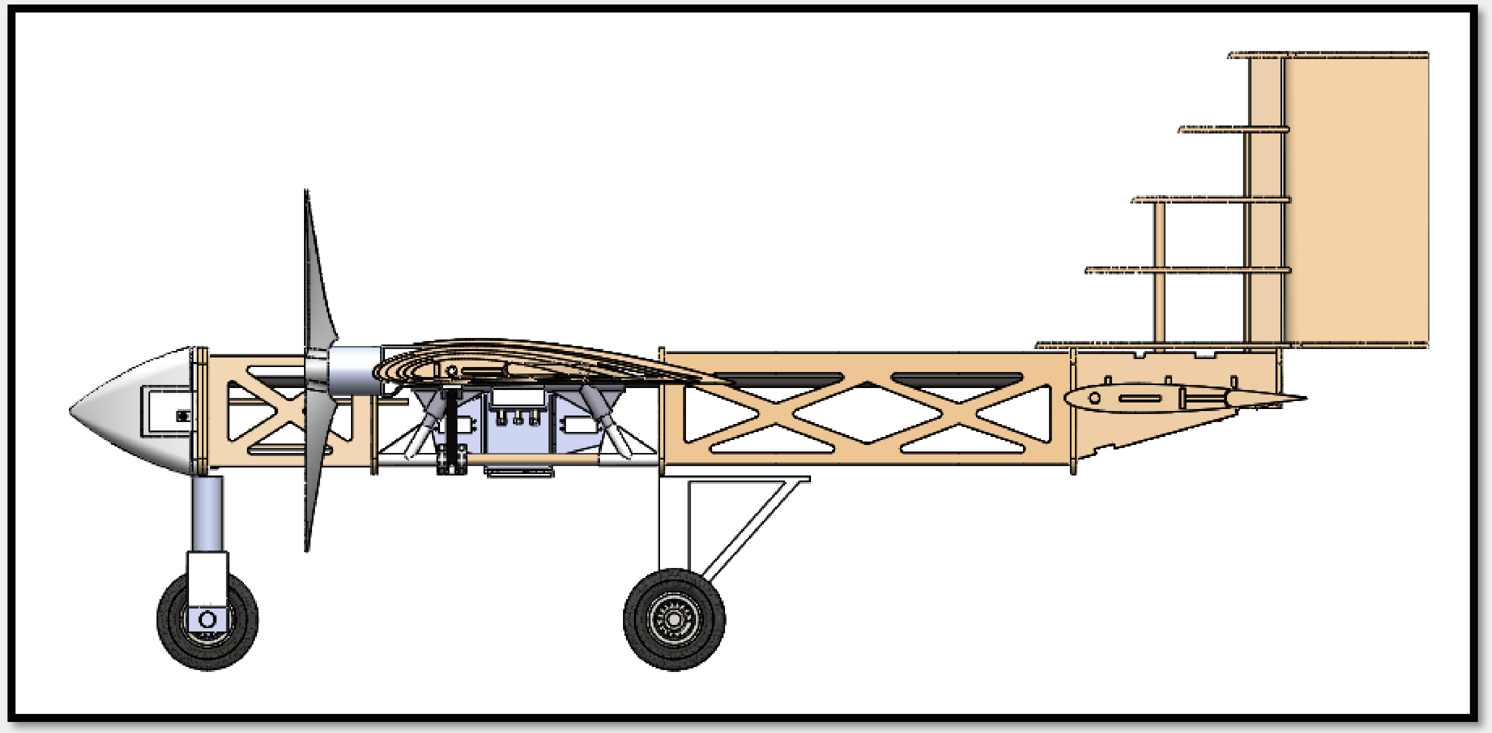


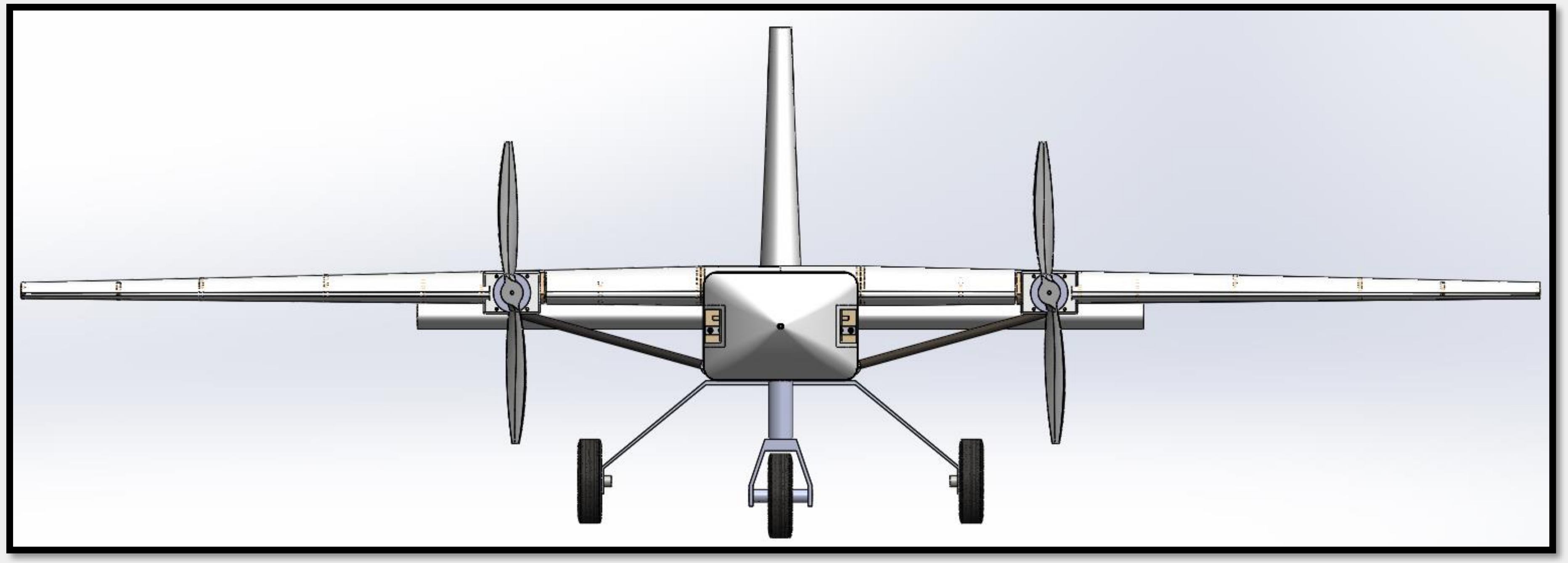
Next Steps

- Finalize metal survival kit and perform more drop tests
  - May be able to drop from higher altitude with drone
  - May attempt to incorporate Arduino Nano and IMU sensor to track fall velocity
  - Finalize parachute release mechanism as needed
- Perform sequence testing with software
  1. Secure kit in bay manually
  2. Open door to 90-degree angle
  3. Release kit
  4. Close door

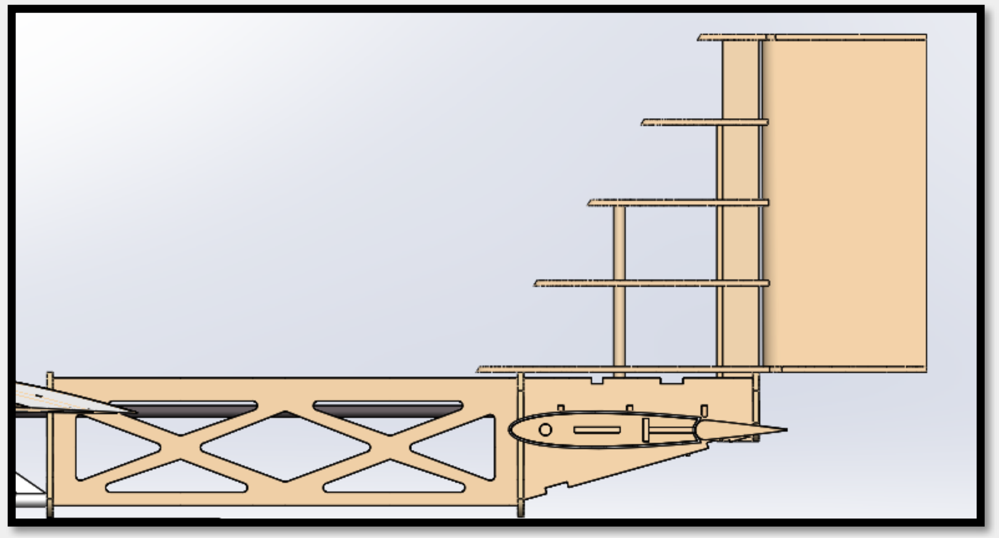
Structural Analysis

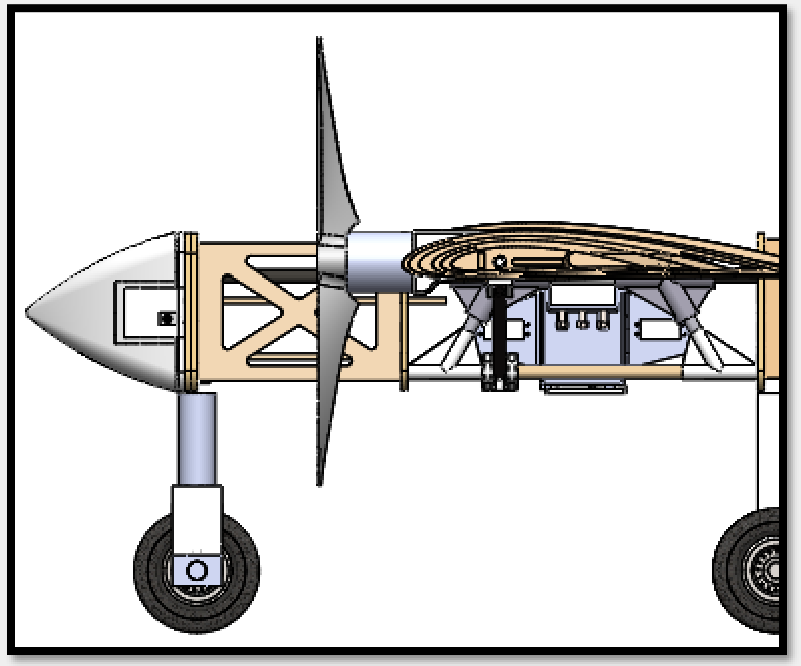
Internal Structure Reference

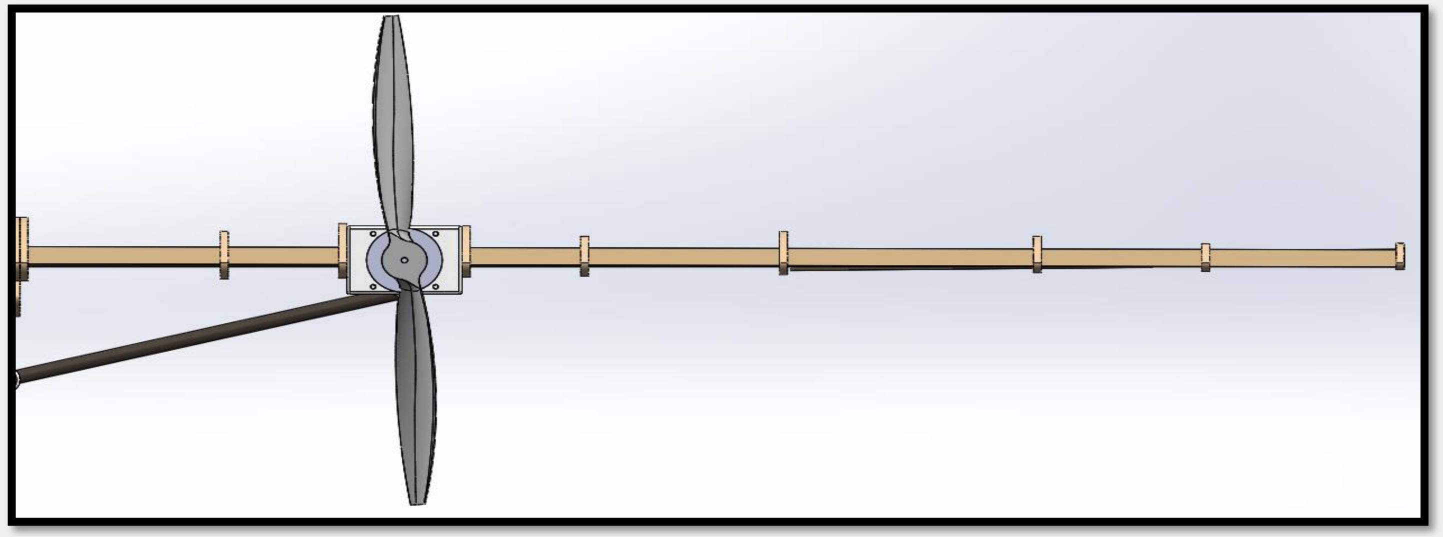




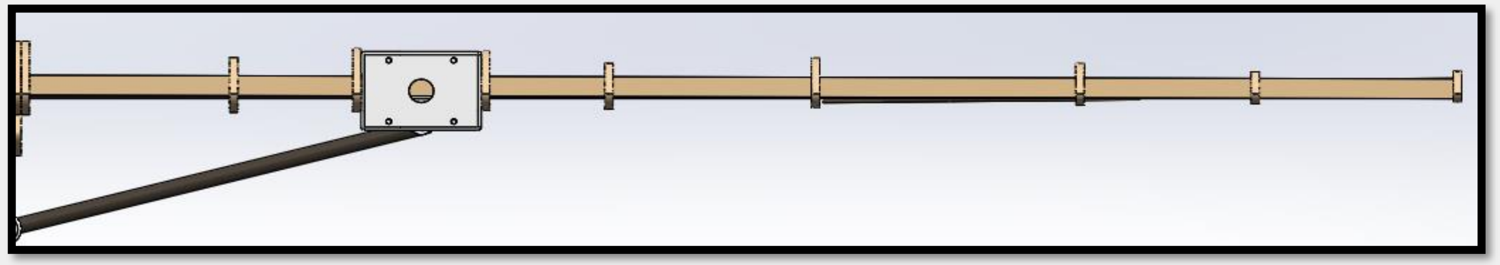
Structural Sections

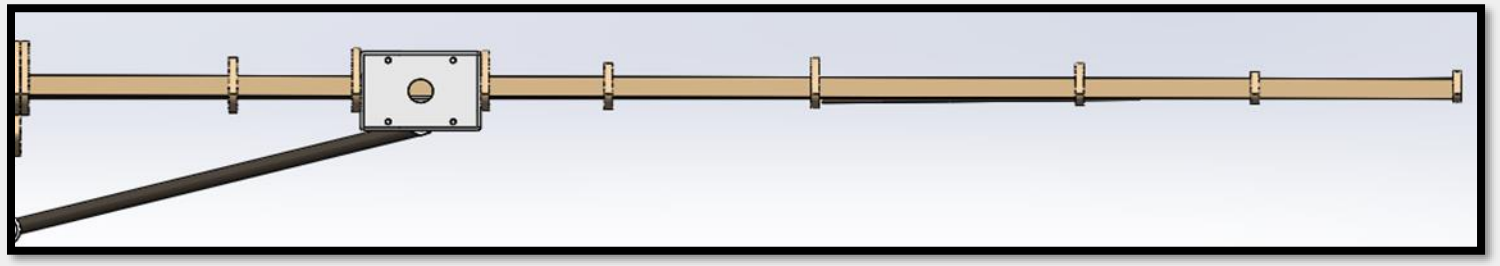


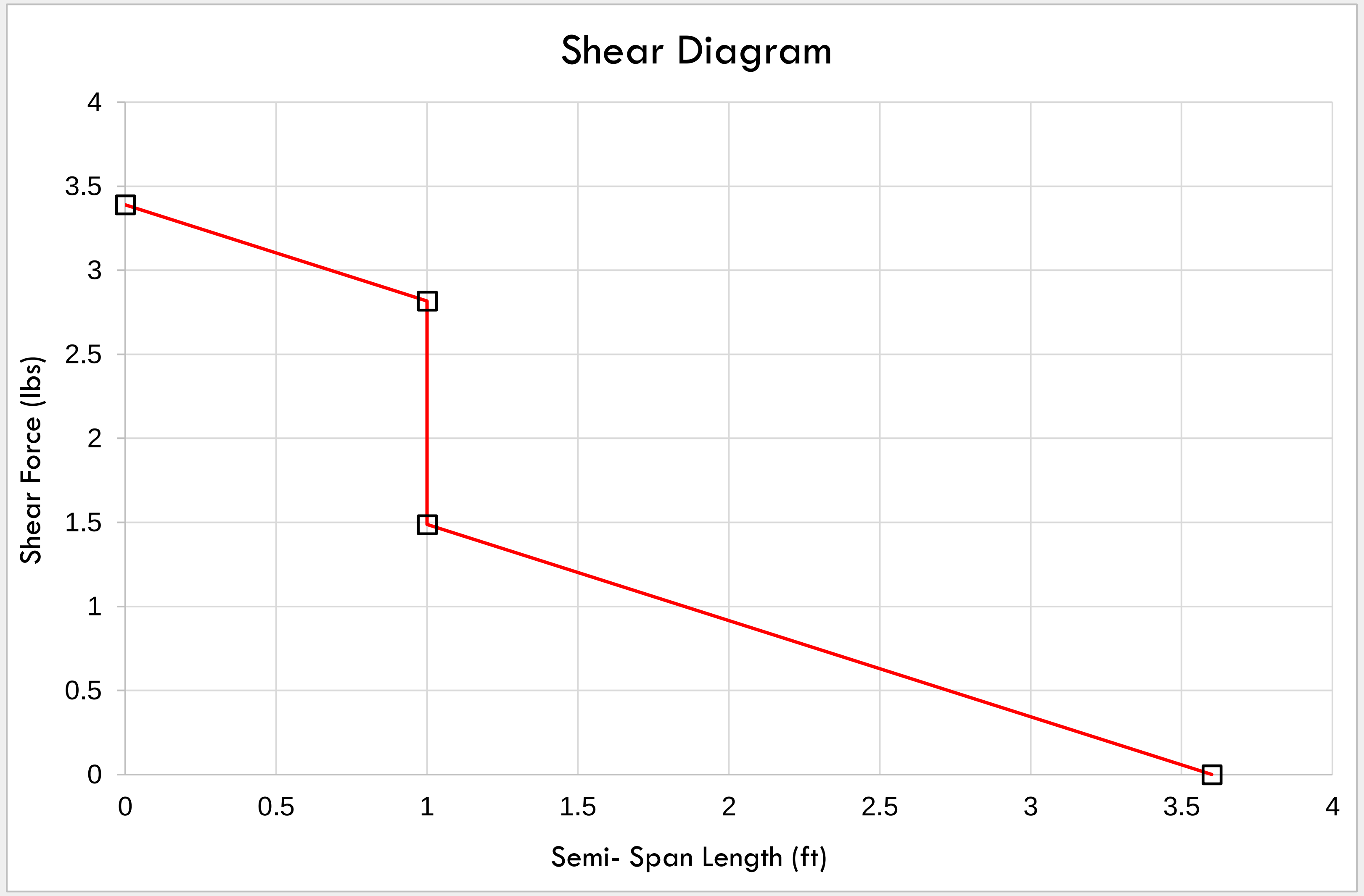


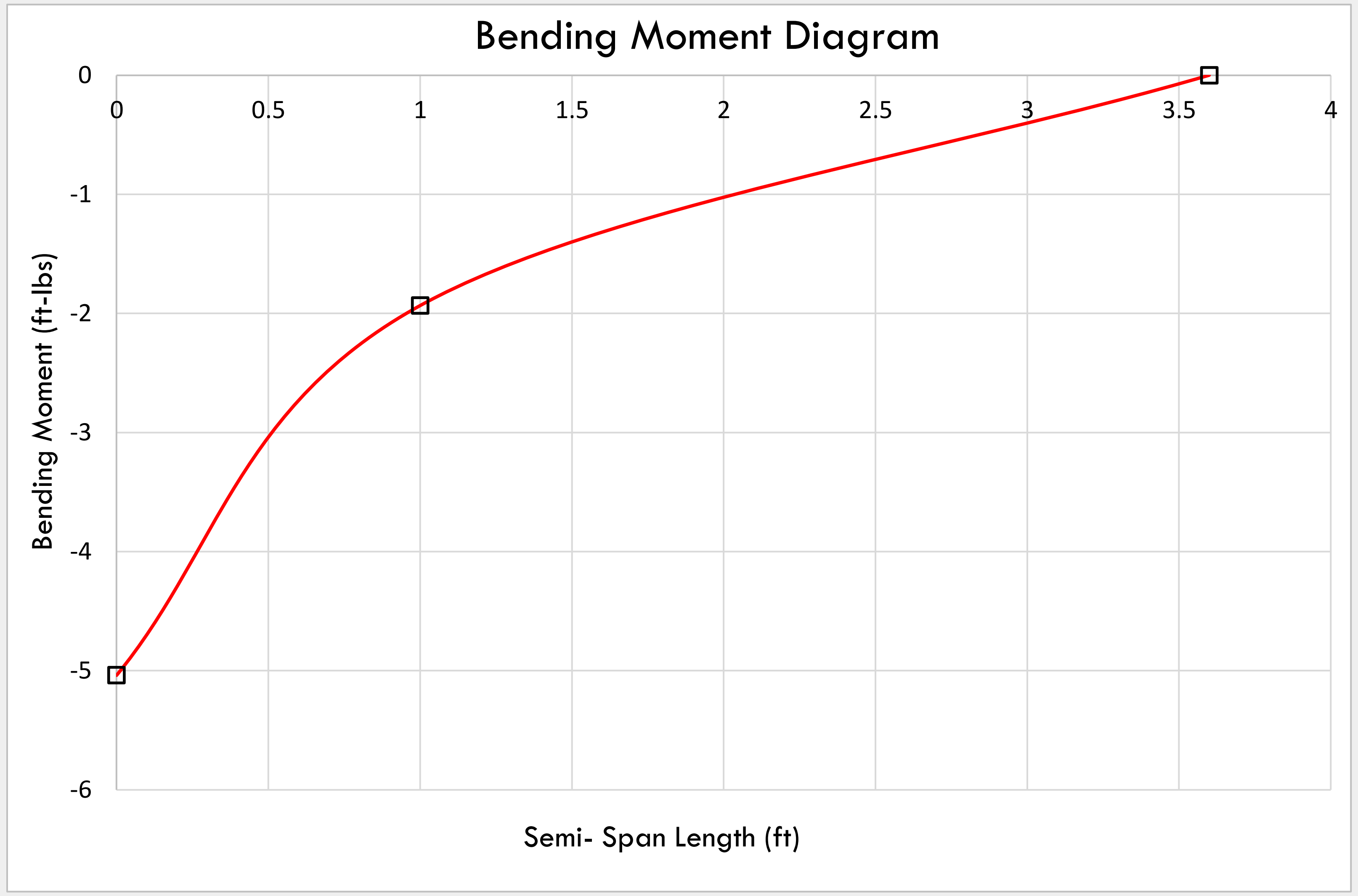


Shear and Moment Diagrams









Note: Static analysis for shear and bending moment

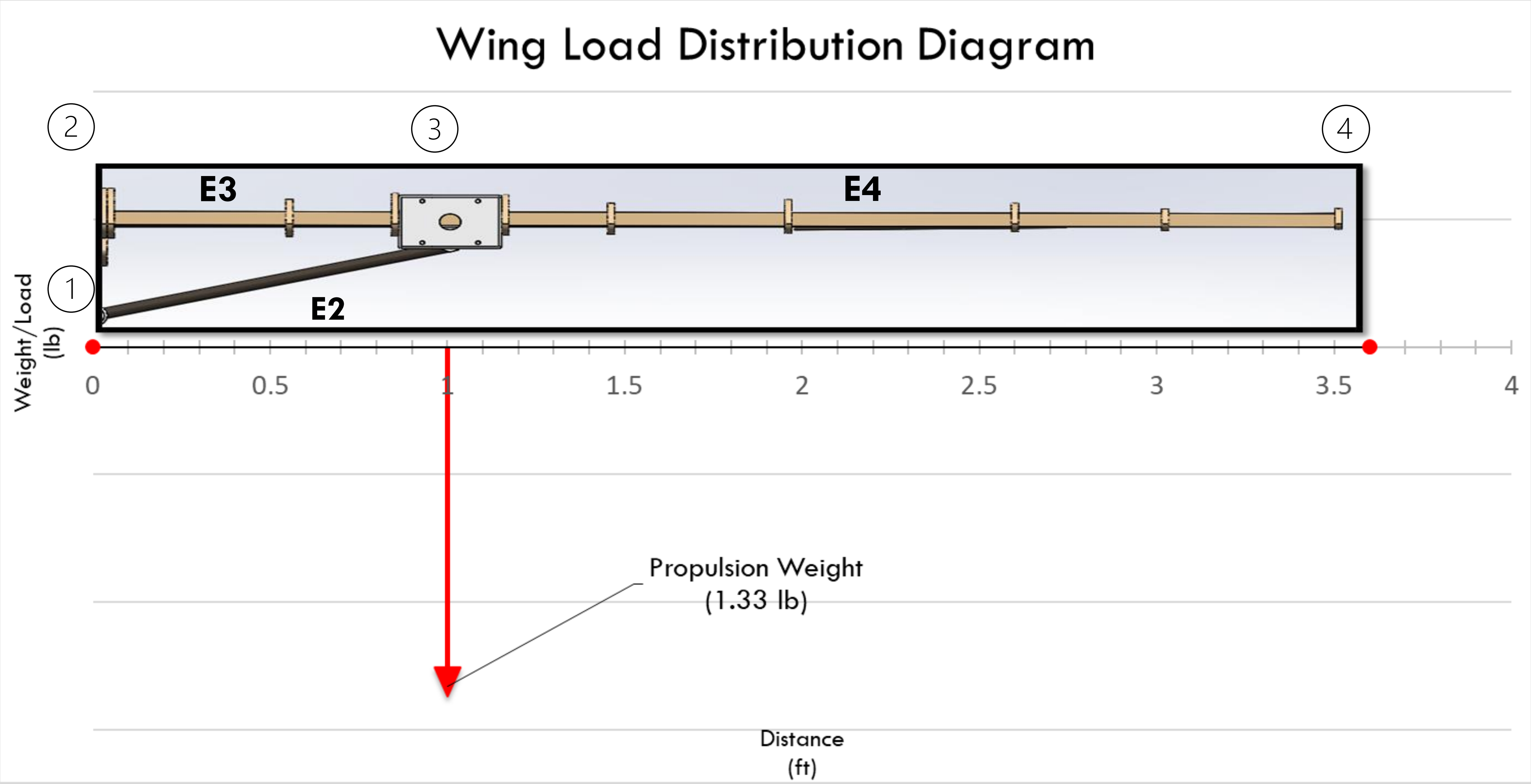
Static Wing Calculation

NASTRAN Results

Displacement			
Node	T1	T2	T3
1	0	0	0
2	0	0	0
3	0.0011	-0.01	0
4	0.0011	0	0

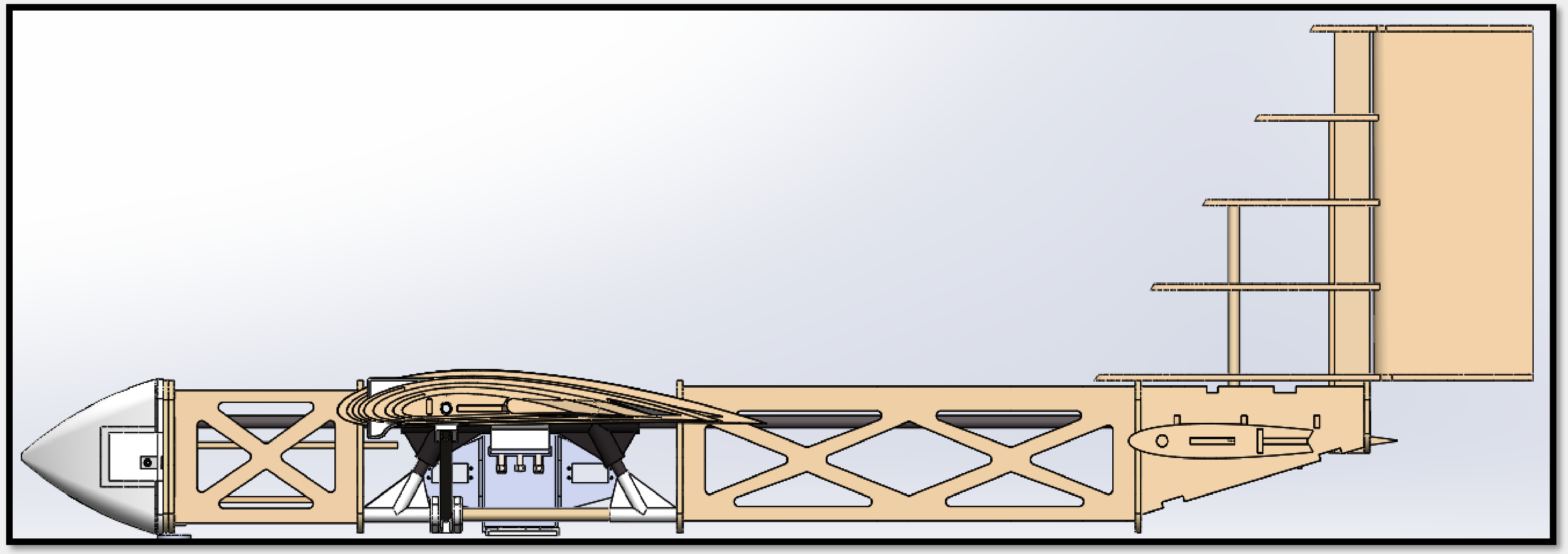
Forces of Single Point Constraint			
Node	T1	T2	T3
1	5.11	1.33	0
2	-5.11	0	0

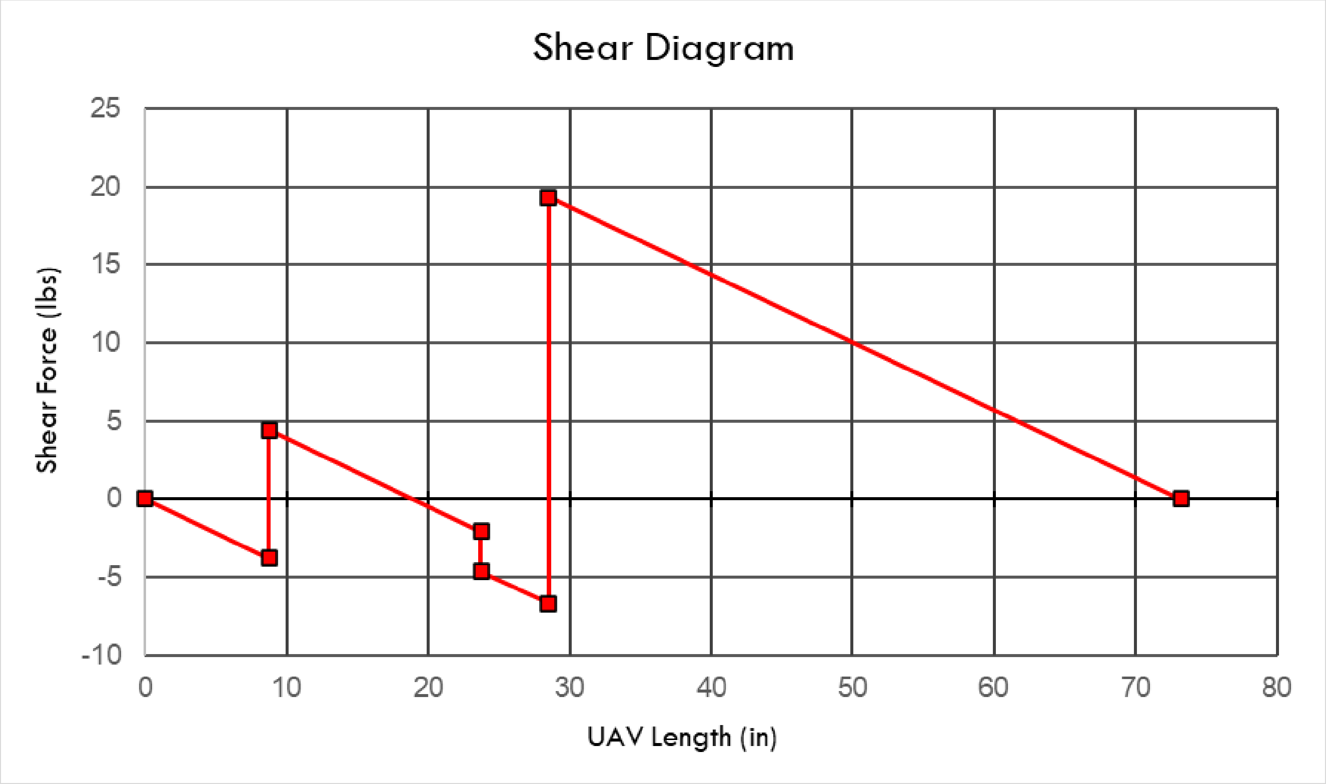
Forces in Rod Elements		
Element	Axial	Torque
1	0	0
2	-5.28	0
3	5.11	0
4	0	0

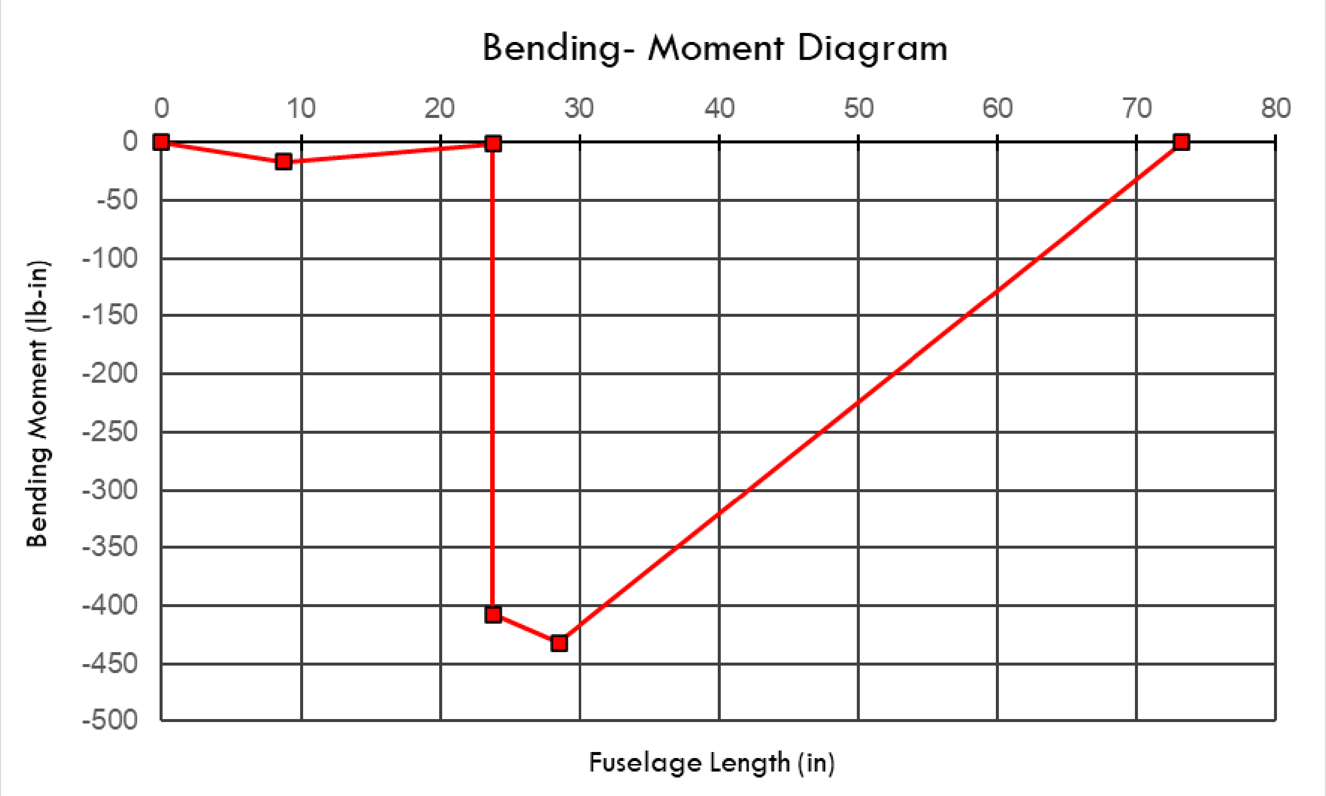


- Displacement rotational DOF is equal to zero
- Strut effectively supports motor weight
- Element 2 in compression; Element 3 in tension

Airframe Structure Running Load







- CF tube beam is main load bearing support
- Cantilever beam analysis with an assumed fixed point at CG
- Aids in internal loads analysis (structural sections)

Spar Stress Analysis

Sectional Properties							
Outer Diamter (in)	Inner Diameter (in)	Wall Thickness (in)	Ao	Ai	Total Area	Intertia	Length
0.5	0.375	0.0625	0.1963	0.1104	0.0859	0.0336	48
0.5	0.25	0.125	0.1963	0.0491	0.1473	0.0460	48
0.5	0.375	0.0625	0.1963	0.1104	0.0859	0.0336	48
0.5	0.25	0.125	0.1963	0.0491	0.1473	0.0460	48
0.5	0.375	0.0625	0.1963	0.1104	0.0859	0.0336	48
0.5	0.25	0.125	0.1963	0.0491	0.1473	0.0460	48

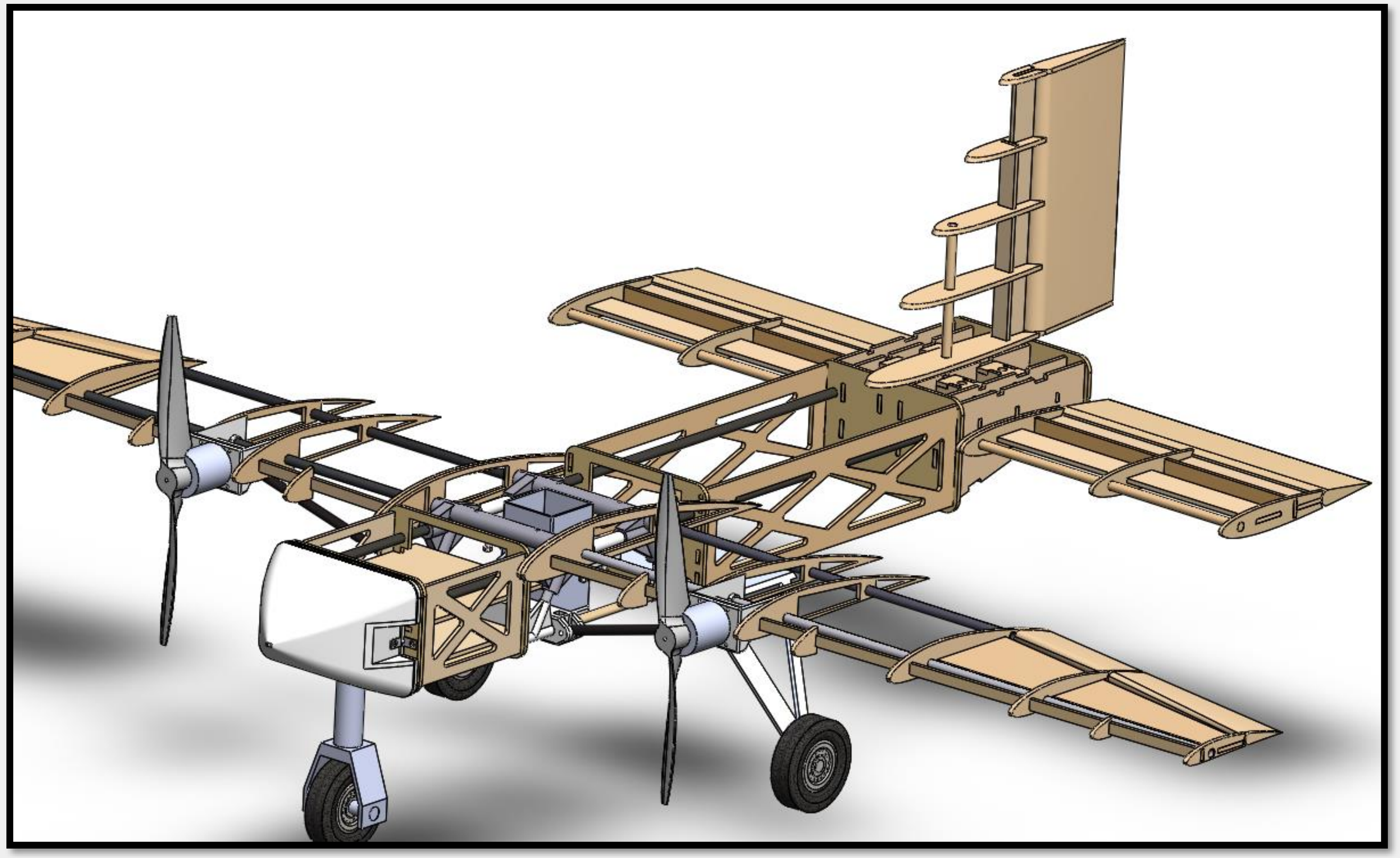
Loading Parameters				
Load Factors	MTOW (lb)	Total Lift Load (lb)	Wingspan (in)	Lift (lb/in)
3.8	35	133	96	1.3854
3.8	35	133	96	1.3854
3.8	38	144.4	96	1.5042
3.8	38	144.4	96	1.5042
3.8	40	152	96	1.5833
3.8	40	152	96	1.5833

Max Deflections					
Material	MTOW (lb)	Length (in)	Intertia (in^4)	Dist. Load (lb/in)	Max Deflection (in)
CF	35	48	0.0336	-1.3854	0.4349
CF	35	48	0.0460	-1.3854	0.3171
CF	38	48	0.0336	-1.5042	0.4721
CF	38	48	0.0460	-1.5042	0.3443
CF	40	48	0.0336	-1.5833	0.4970
CF	40	48	0.0460	-1.5833	0.3624

Calculations			
I_{max} (lb/in)	$Stress_{max}$ (psi)	FS	MS
6,384.00	47,562.53	3.67937	2.6794
6,384.00	34,681.01	5.04599	4.0460
6,931.20	51,639.31	3.38889	2.3889
6,931.20	37,653.67	4.64762	3.6476
7,296.00	54,357.17	3.21945	2.2194
7,296.00	39,635.44	4.41524	3.4152

Material Selection: Trade Studies

- Selected material was ideal candidate for forming structural pieces and members
- Cutouts and slots aid in joining and reinforcing structural members



FOM's	Cost		Bending Strength		Torsional Strength		Manufacturability		Weight		Weighted total = Sum (W)
	0.42		1.15		0.60		1.2		0.7		
Alternative Configurations	U	W	U	W	U	W	U	W	U	W	
Birch	3	1.3	7	8.05	7	4.2	5	6	3	2.1	21.61
BC	5	2.1	7	8.05	7	4.2	5	6	3	2.1	22.45
Sande	9	3.8	5	5.75	5	3	7	8.4	7	4.9	25.83
Balsa	5	2.1	1	1.15	1	0.6	5	6	7	4.9	14.75
Stika Spruce	5	2.1	5	5.75	1	0.6	5	6	3	2.1	16.55

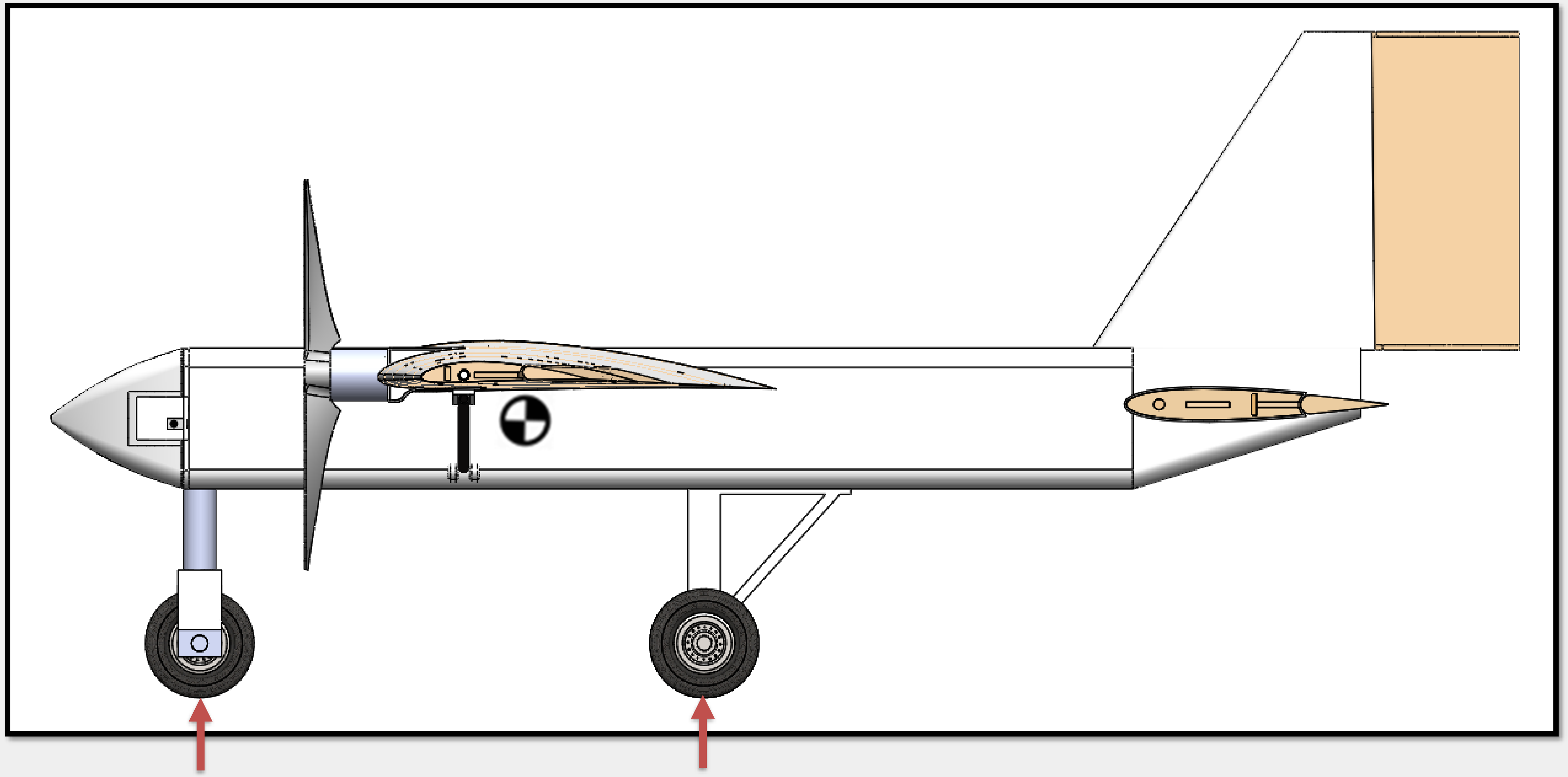
Landing Gear Loads (Tricycle)

<u>Landing Gear Loads</u>

- Main: 25 lbs
- Nose: 10 lbs

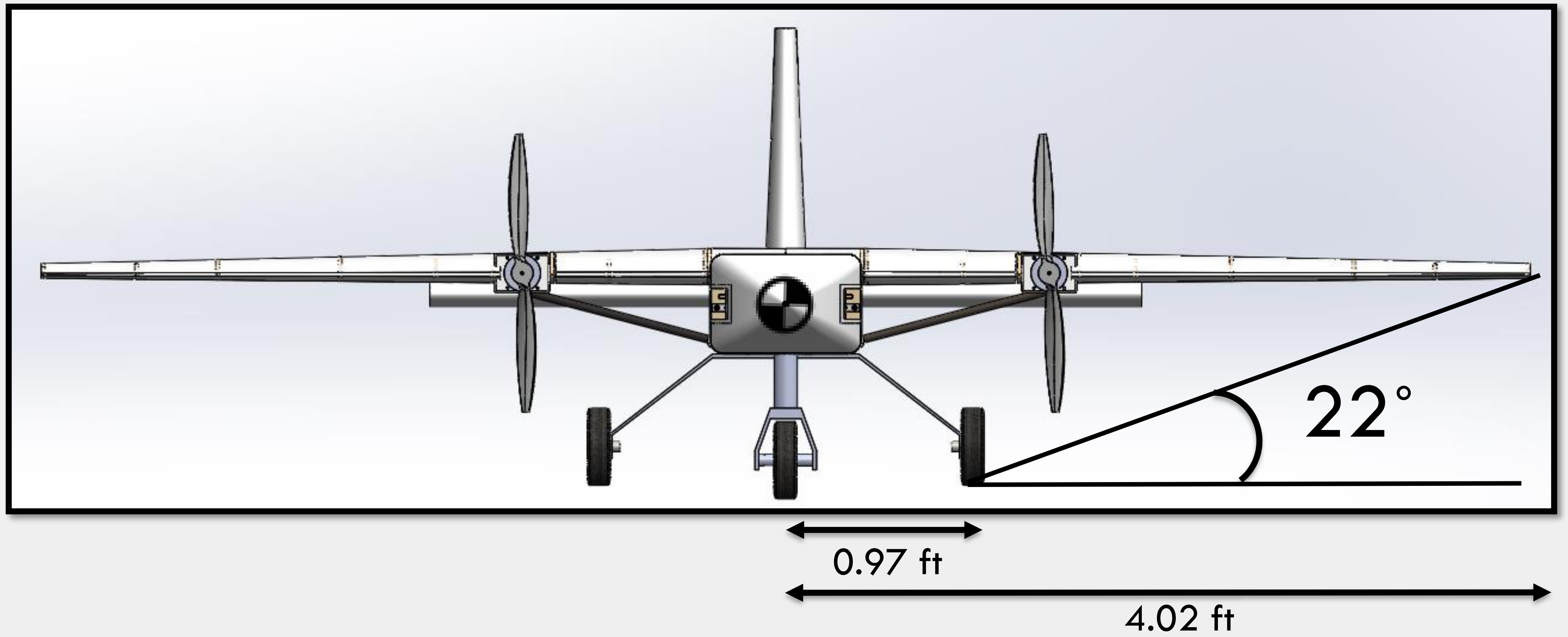
<u>MTOW</u>

- 35 lbs

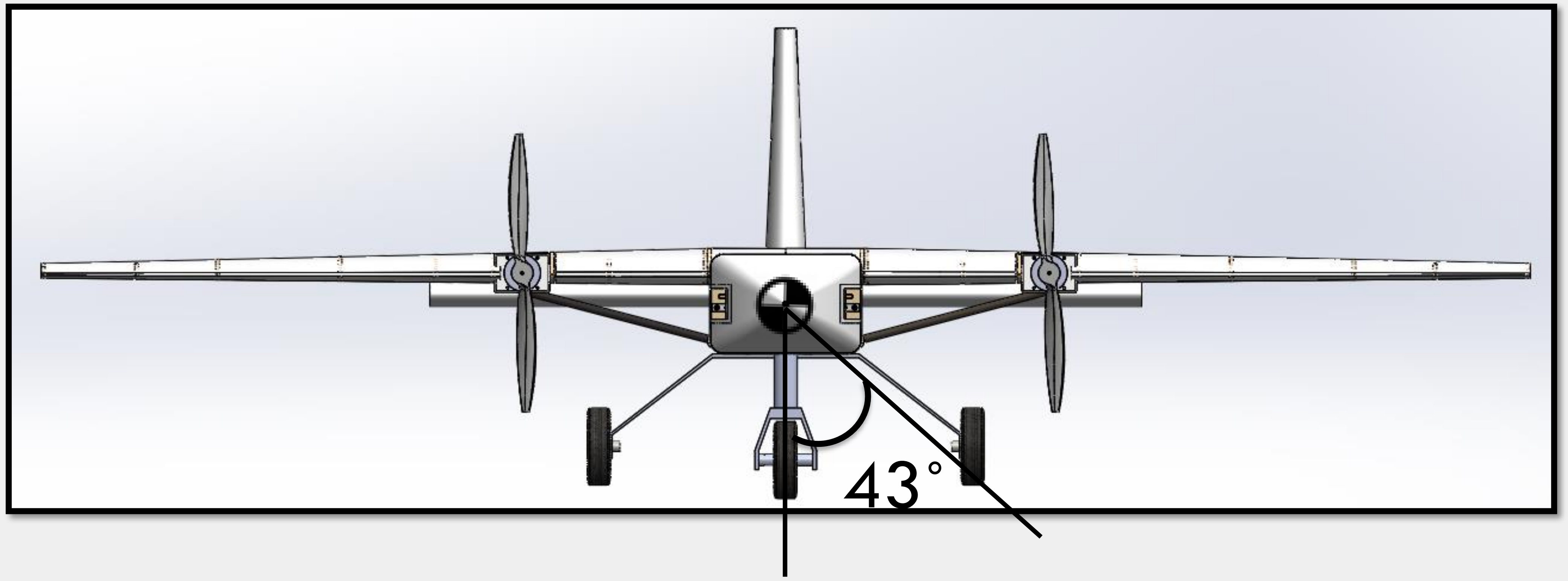


Landing Gear Clearance

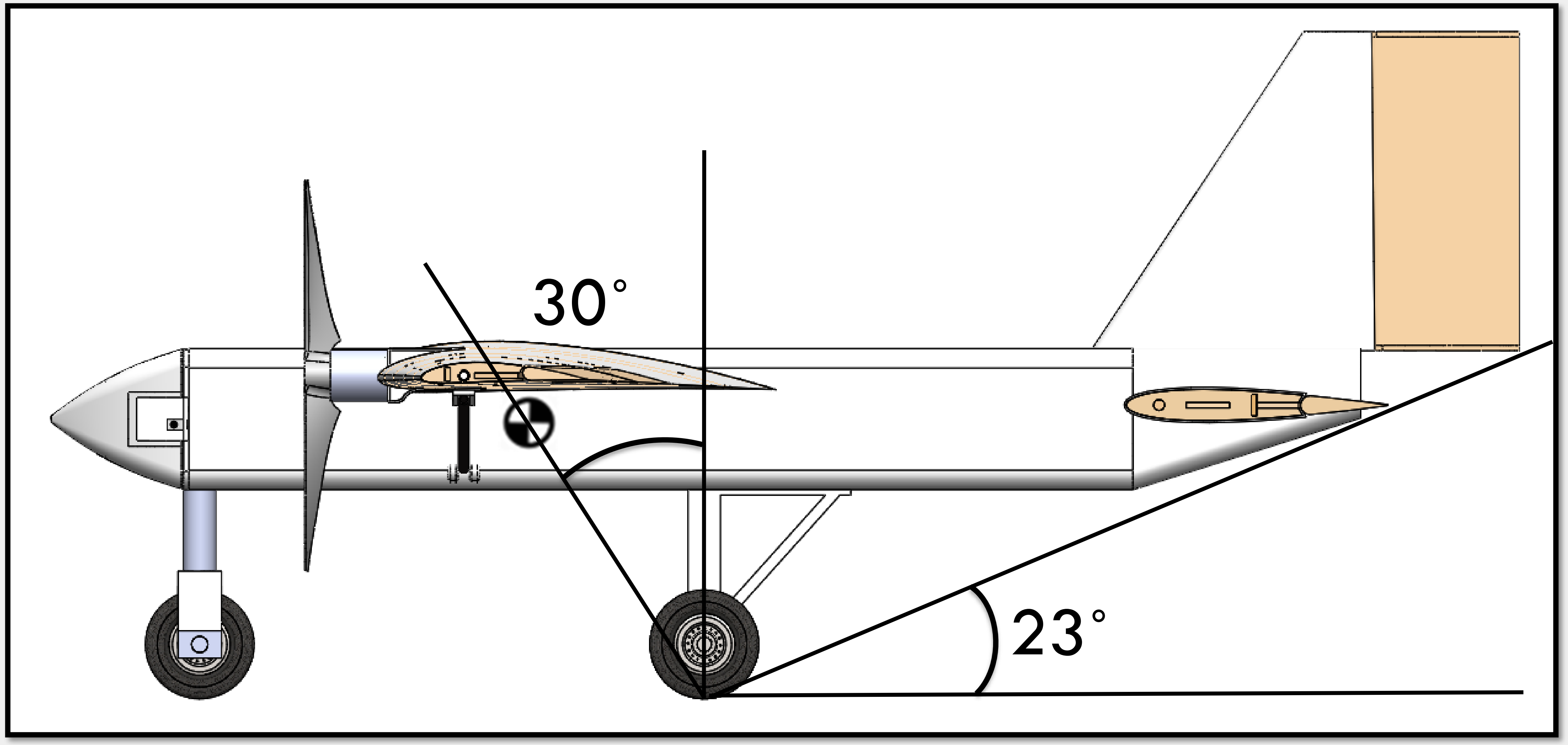
Roll Clearance:



Overturn Angle:



Landing Gear Tail-Strike Clearance



Material Testing - Skin

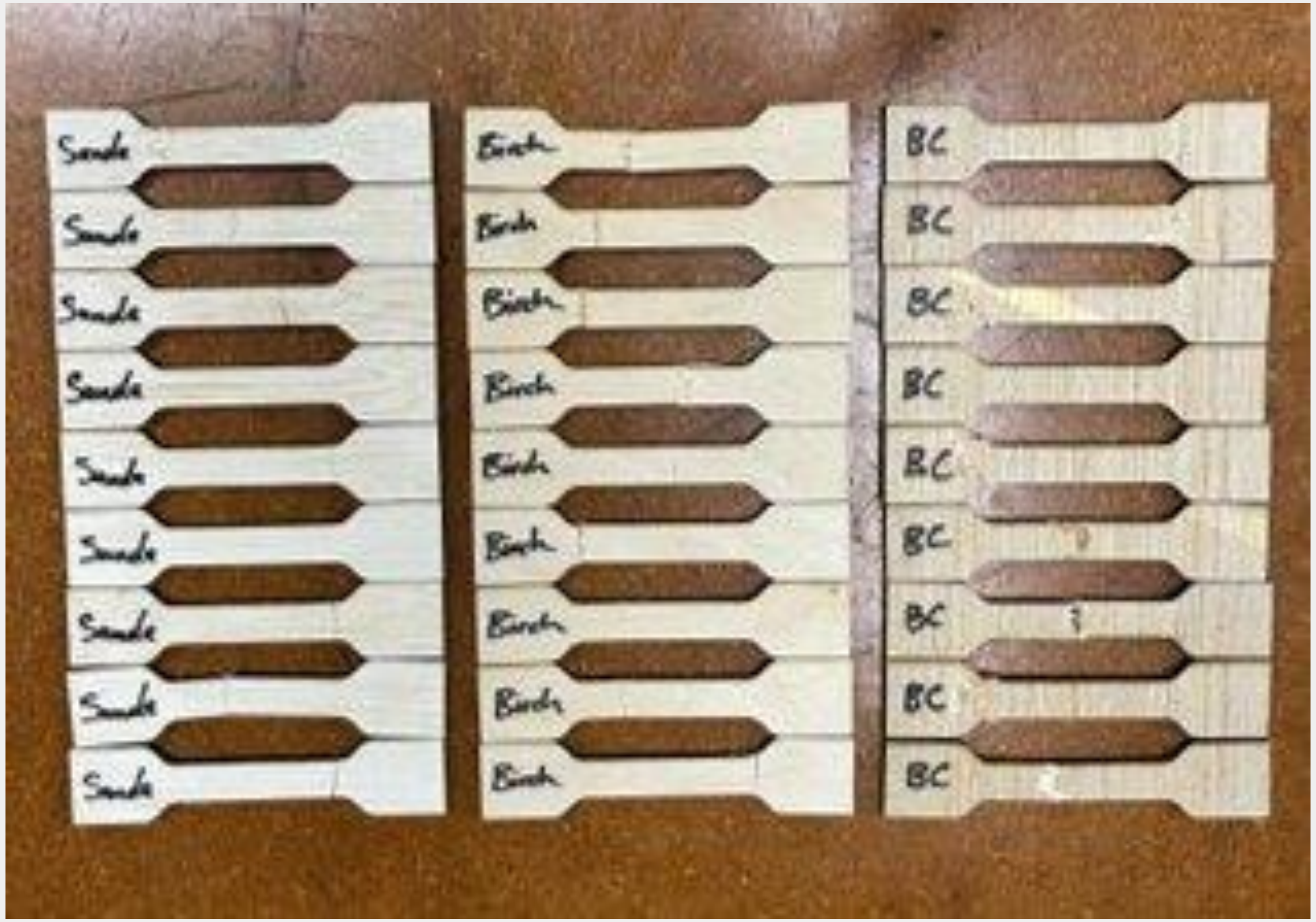
- Purpose
  - –Test tensile strength and bond strength of Ultracote vs Monokote
  - –Attractive alternatives to foam board due to shrink fit and application procedures
- Results
  - – Monokote withstood a load of 32 pounds
  - – Ultracote could only withstand 26 pounds

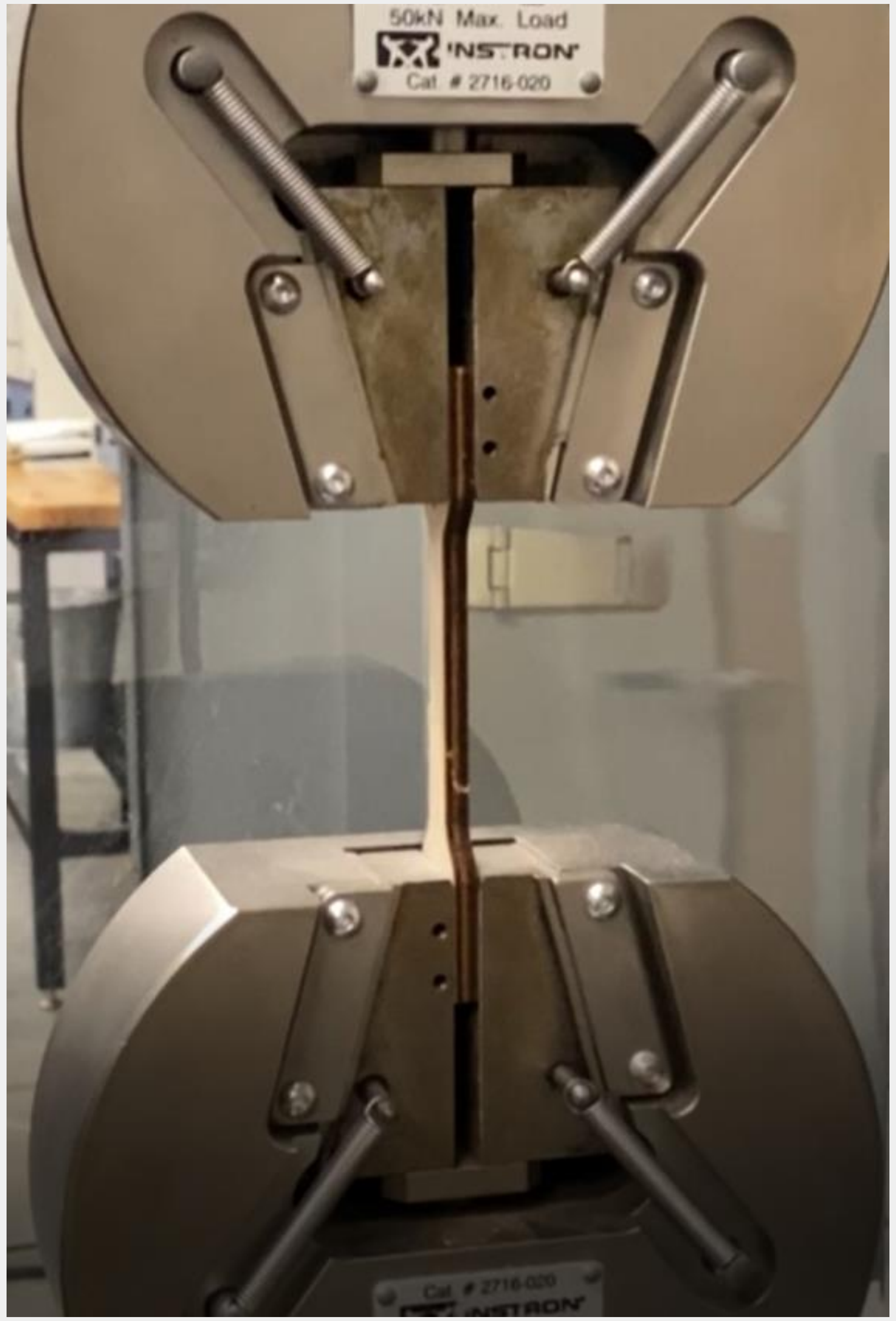
Foam Board is the best option due to versatility

Material Testing - Structure

- Purpose
  - Test tensile strength of three types of plywood:
    - Sande, Birch, BC
      - Determine type of plywood to be used for 100% model structure
      - Sande
- Results
  - Elastic modulus:
    - Sande: inconclusive – approximately 300 ksi
    - Birch: ~ 590 ksi
    - BC: ~ 1060 ksi

Material Testing - Structure

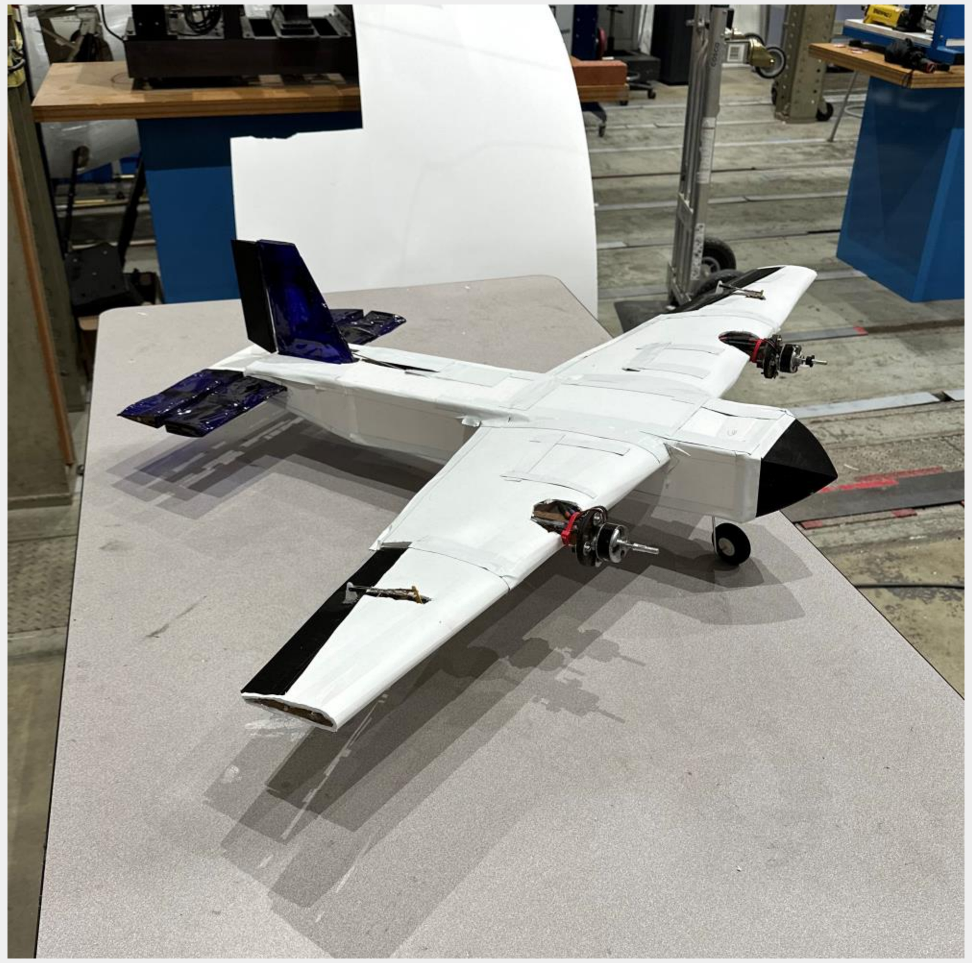




Production

50% Prototype

- Purpose
  - –Test static margin and aerodynamic stability
  - –Validate endurance of propulsion system
  - –Verify calculations and simulation results
    - •Structure integrity, Electrical Components



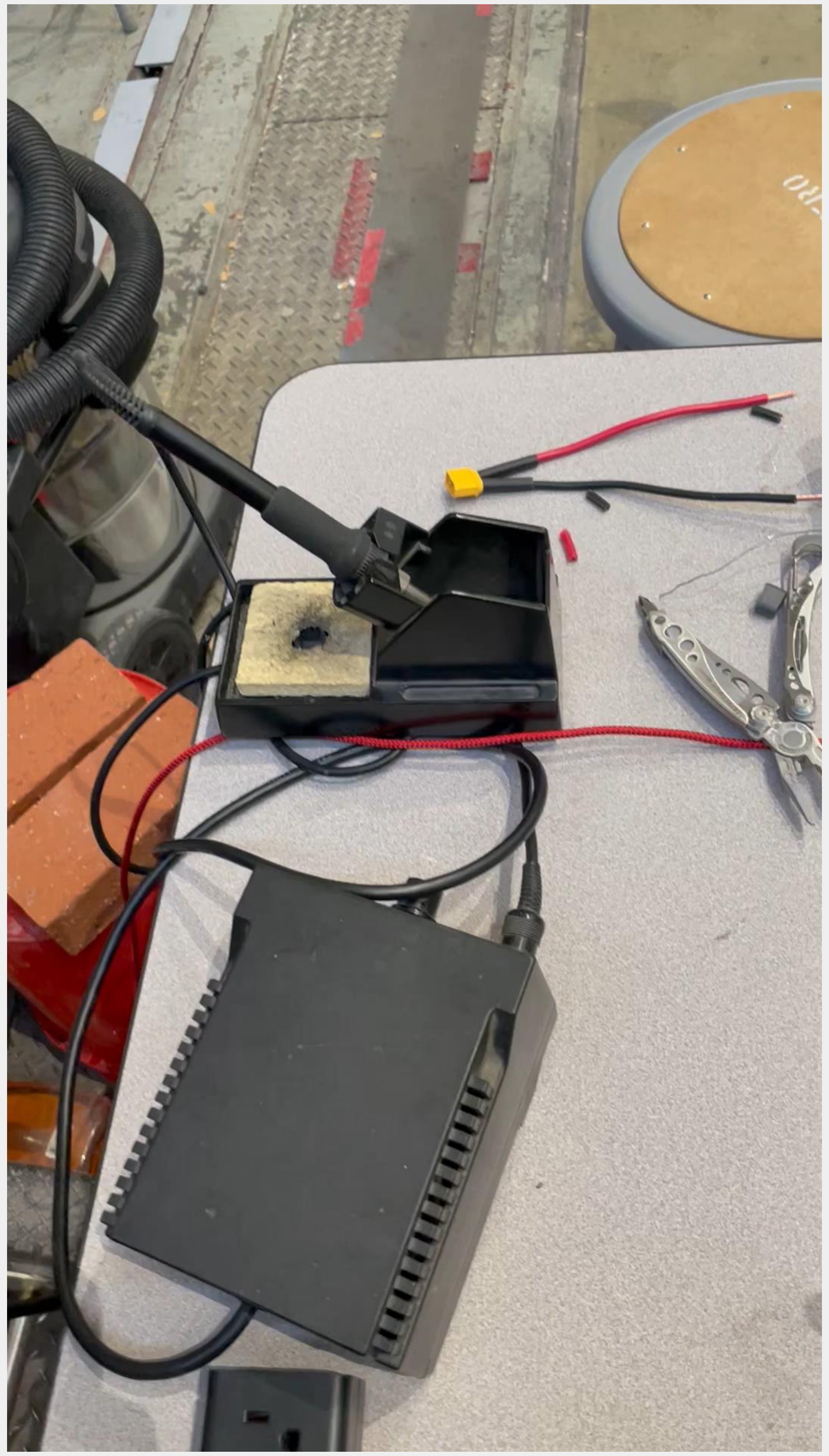
- Manufacturing
  - –Ultracote and foam board skin over hardboard structure
  - –Propulsion system sized for 10 pounds
  - –Exposed Team members to manufacturing methods for full scale

Full Scale Manufacturing Plan

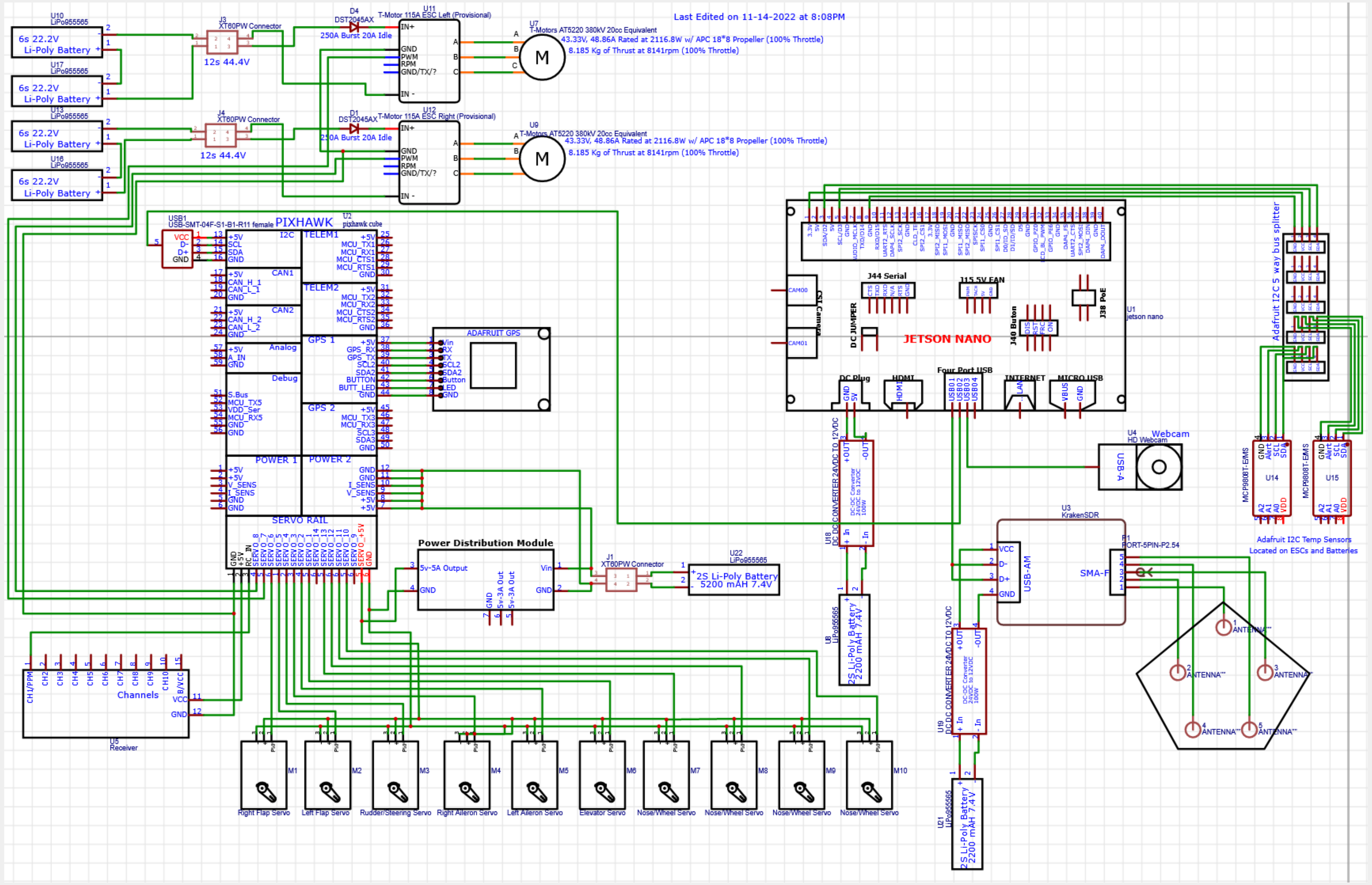
Part	Material	Process
Fuselage: 1. Body 2. Skin 3. Mounting Bracket	1. ¼ in. Sande Plywood 2. Foam Board Panels 3. Carbon Fiber Nylon	1. Laser Cut 2. Planform and Hot Glue 3. 3D Printed
Wing: 1. Body 2. Spars 3. Ribs 4. Skin 5. Ailerons	1. ¼ in. Sande Plywood 2. Carbon Fiber Dowels 3. ¼ in Sande Plywood 4. Foam Board Panels 5. PLA	1. Laser Cut 2. Purchased 3. Laser Cut 4. Planform and Hot Glue 5. 3D Printed
Tail: 1. Ribs 2. Horizontal Stabilizer 3. Vertical Stabilizer 4. Skin	1. ¼ in. Sande Plywood 2. PLA 3. PLA 4. Foam Board Panels	1. Laser Cut 2. 3D Printed 3. 3D Printed 4. Planform and Hot Glue
Landing Gear: 1. Struts and mount 2. Rims and tires	1. Aluminum Alloy 2. Aluminum Alloy & Rubber	1. Purchased 2. Purchased

List of Electrical Components

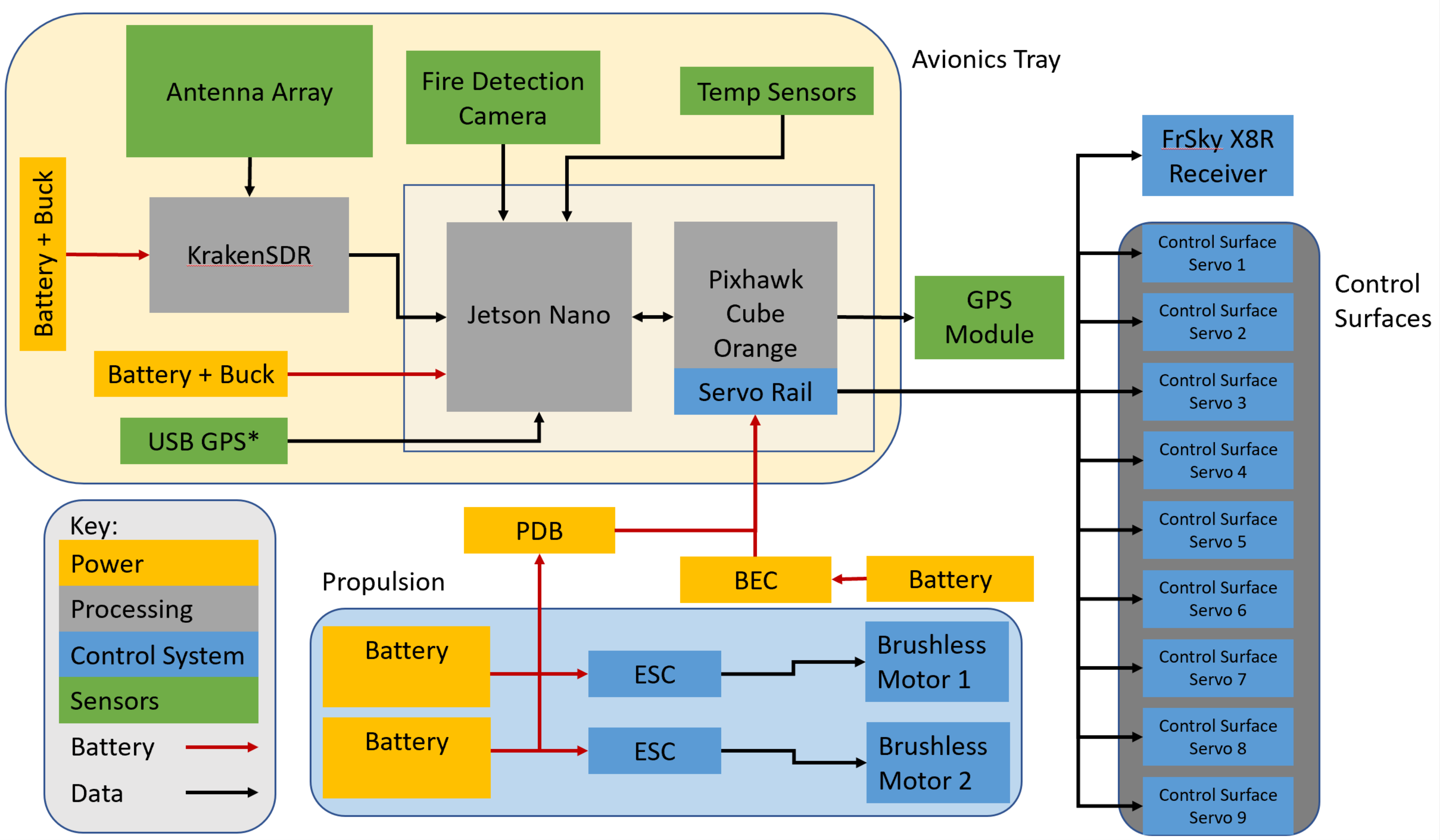
- Pixhawk Cube Orange
- Jetson Nano 4gb
- KrakenSDR
  - 5 Antenna Array
- FrSky X8R Receiver
- Webcam Module
- GPS
- Temperature Sensors
- 3 batteries
  - 2S 2200mAh x2
  - 2S 5200mAh



Electrical Wiring Schematic



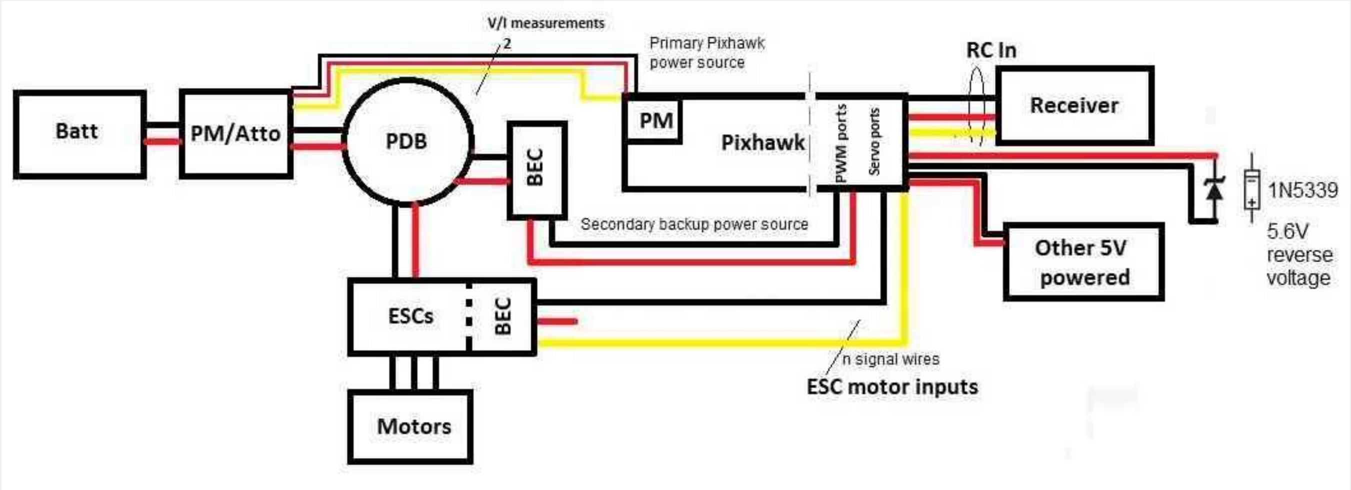
Block Diagram of Electronics



Flight Controller: Pixhawk Cube Orange

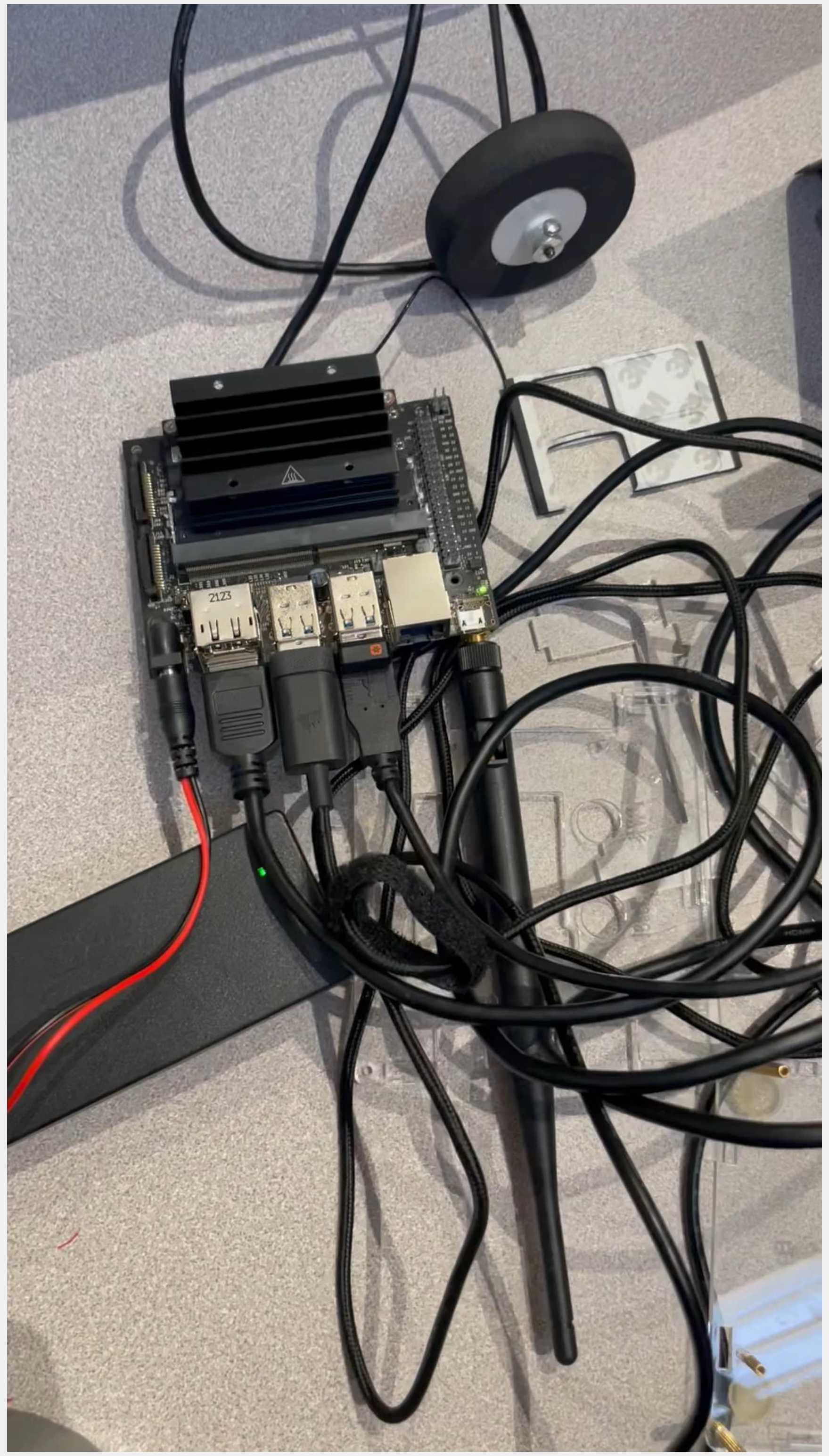
- Controls all control surfaces and allows for switching between autonomous and manual control
- Connected Sensors:
  - –GPS
  - –2S 2200 mAh battery – powering the servo rail
  - –9 servos
  - –FrSky Receiver
  - –2 ESCs
  - –5v PDB

- We are utilizing a triple redundant power supply to minimize the chances of power failure



Computer and Connected Devices

- The Jetson Nano will be used as the main processing unit
- Connected Peripherals:
  - –Pixhawk Cube Orange (primary power & telemetry)
  - –Logitech 1080HD Pro Webcam
  - –KrakenSDR
  - –2S 5200 mAh battery
  - –5V/5A Buck Converter



Selected Radio Direction Finding Method

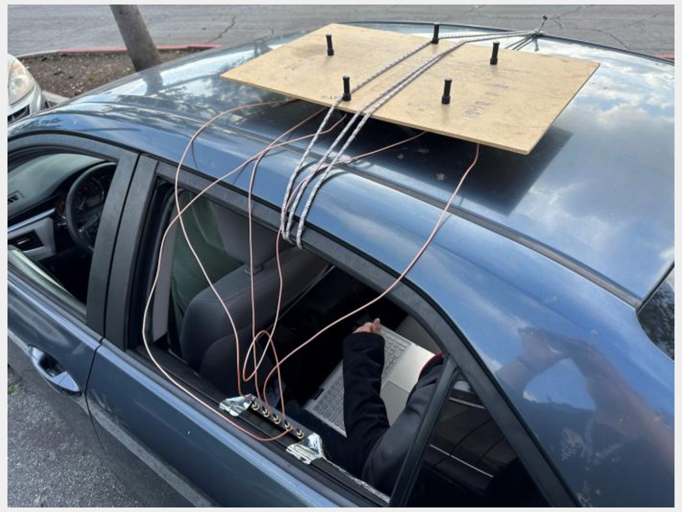
Correlative Interferometry –

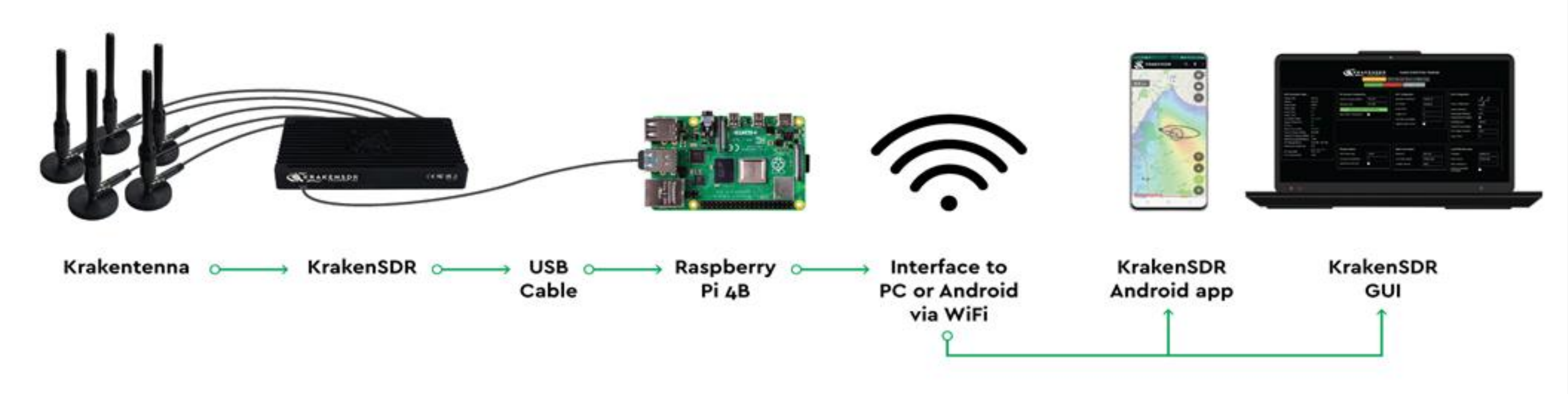
- Extracts the phase between signals received in an antenna array.
- We settled on utilizing Correlative Interferometry with a software defined radio (SDR). The hardware that we have opted to use is the KrakenSDR.

	FOM's	Weight		Cost		Dimensions		Accuracy		Range		Compatibility		
		0.978265149		0.220644456		0.495699552		1.423565187		1.31027294		1.571552717		
Alternative Configurations		U	W	U	W	U	W	U	W	U	W	U	W	Weighted total = Sum (W)
Time Difference of Arrival		6	5.869591	1	0.220644	5	2.478498	1	1.423565	5	6.551365	1	1.571553	18.11521571
Dirrectional Antenna Based		7	6.847856	9	1.9858	5	2.478498	7	9.964956	1	1.310273	1	1.571553	24.15893587
Pseudo-Doppler		1	0.978265	5	1.103222	3	1.487099	3	4.270696	3	3.930819	3	4.714658	16.48475861
Correlative Interferometry		3	2.934795	3	0.661933	3	1.487099	5	7.117826	7	9.171911	7	11.00087	32.374433

KrakenSDR

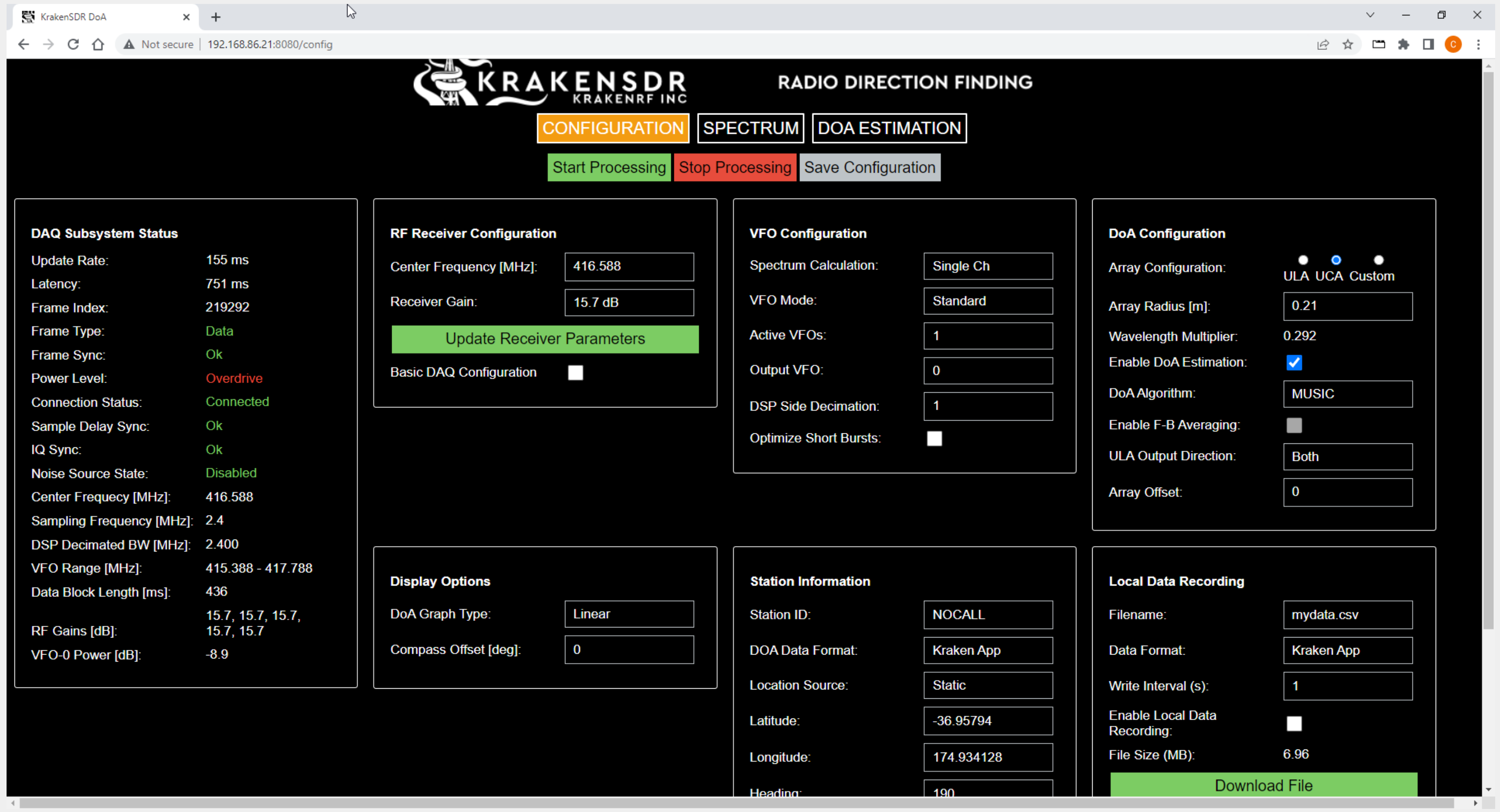
- Uses 5 antenna circular array all synchronized on one clock
  - Antennas must be of identical lengths
- Jetson will be connected for data only
- Interface through Web GUI as well as Android App for visualization
  - Can make use of modern smart phone technologies such as mapping, GPS and compass sensors

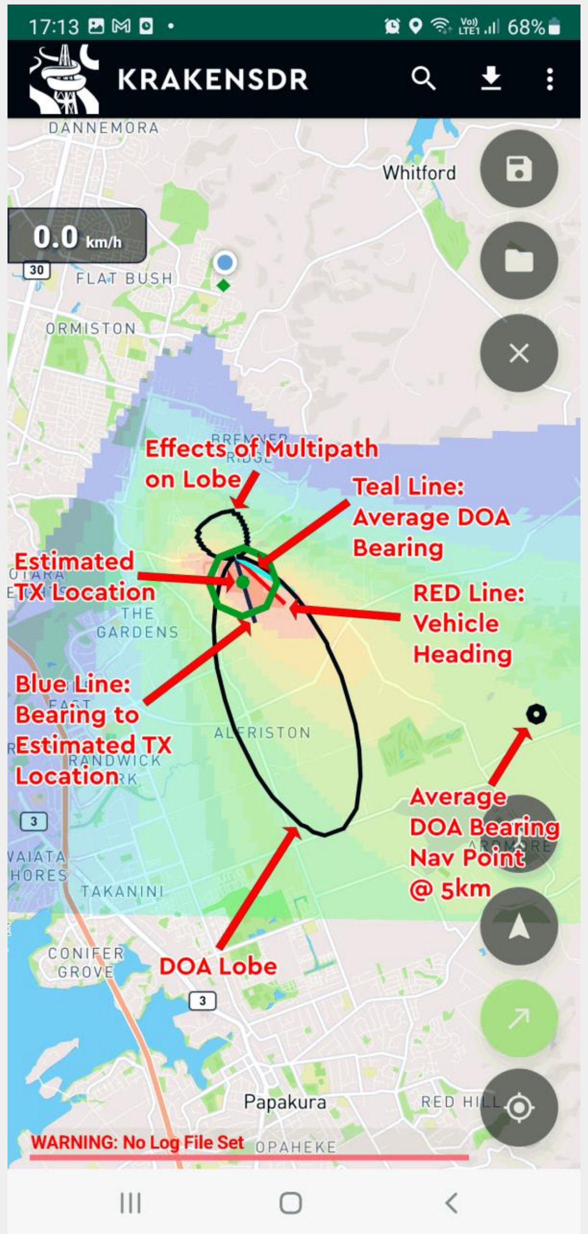




KrakenSDR

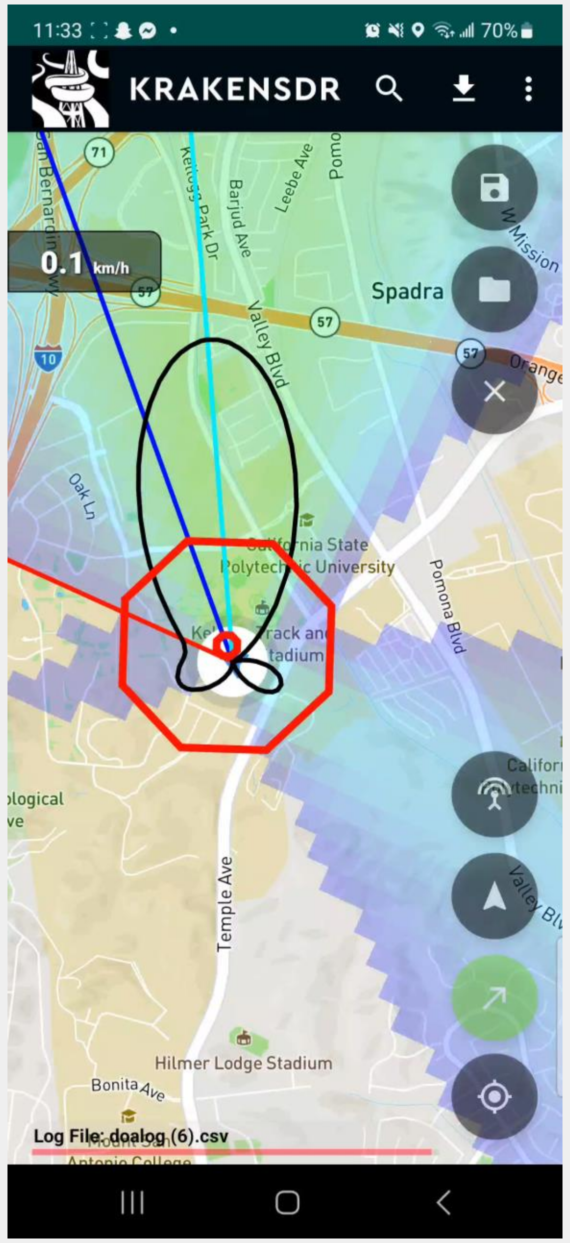
- Hundreds of bearings taken by automatically logging bearings generated against the current location
- The system over time generates an average intersection of these bearings, pinpointing the location of the transmitter
- Currently using the proprietary app for testing





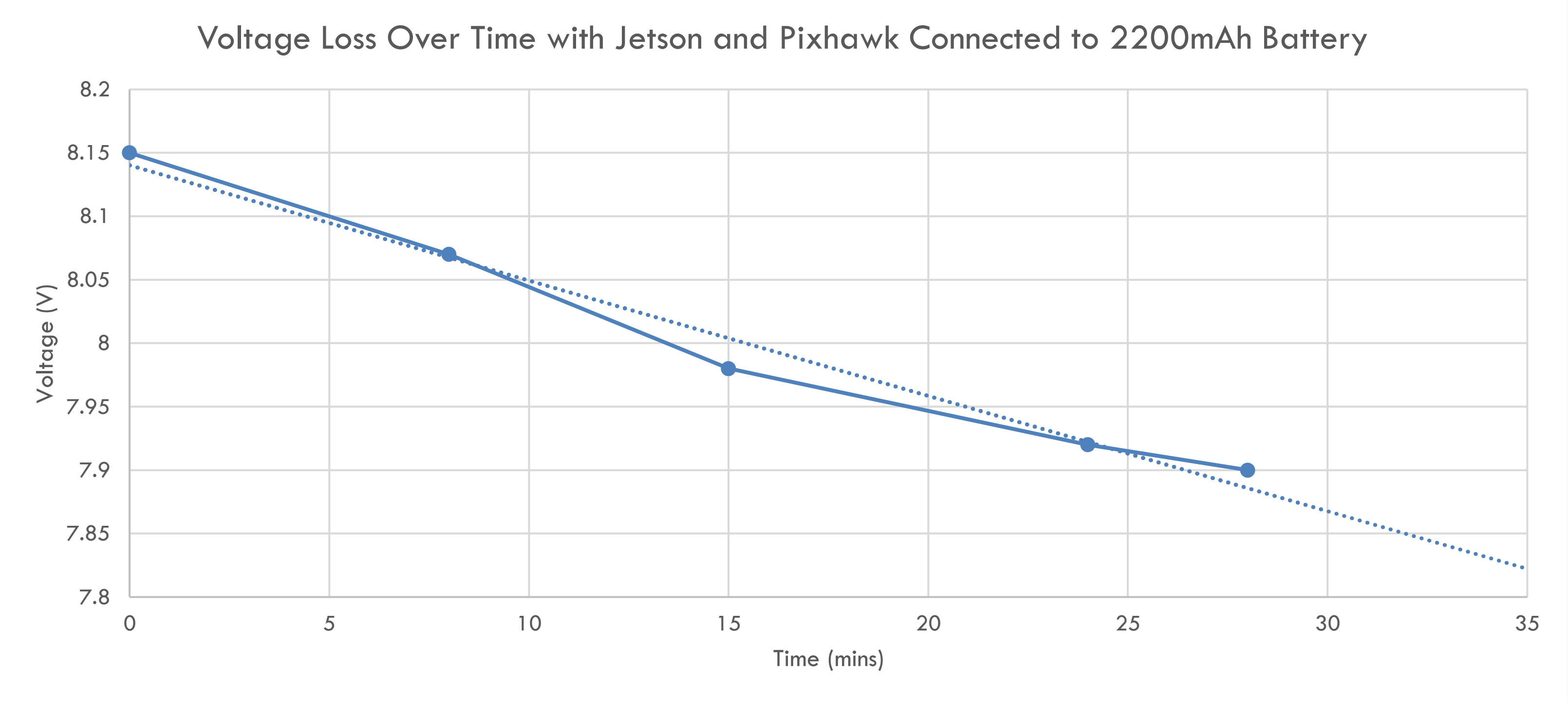
KrakenSDR Preliminary Results

- Intersection of the lines is the most accurate heading
  - Intersection bearings are recorded and are output to a data file on Jetson
- Working on streamlining the process to be start the program and processing more quickly
- Further tests required under more representative conditions
  - Currently working on improving accuracy
    - Currently accuracy is within 50ft
- Continue battery tests with the intended battery



Preliminary Battery Tests

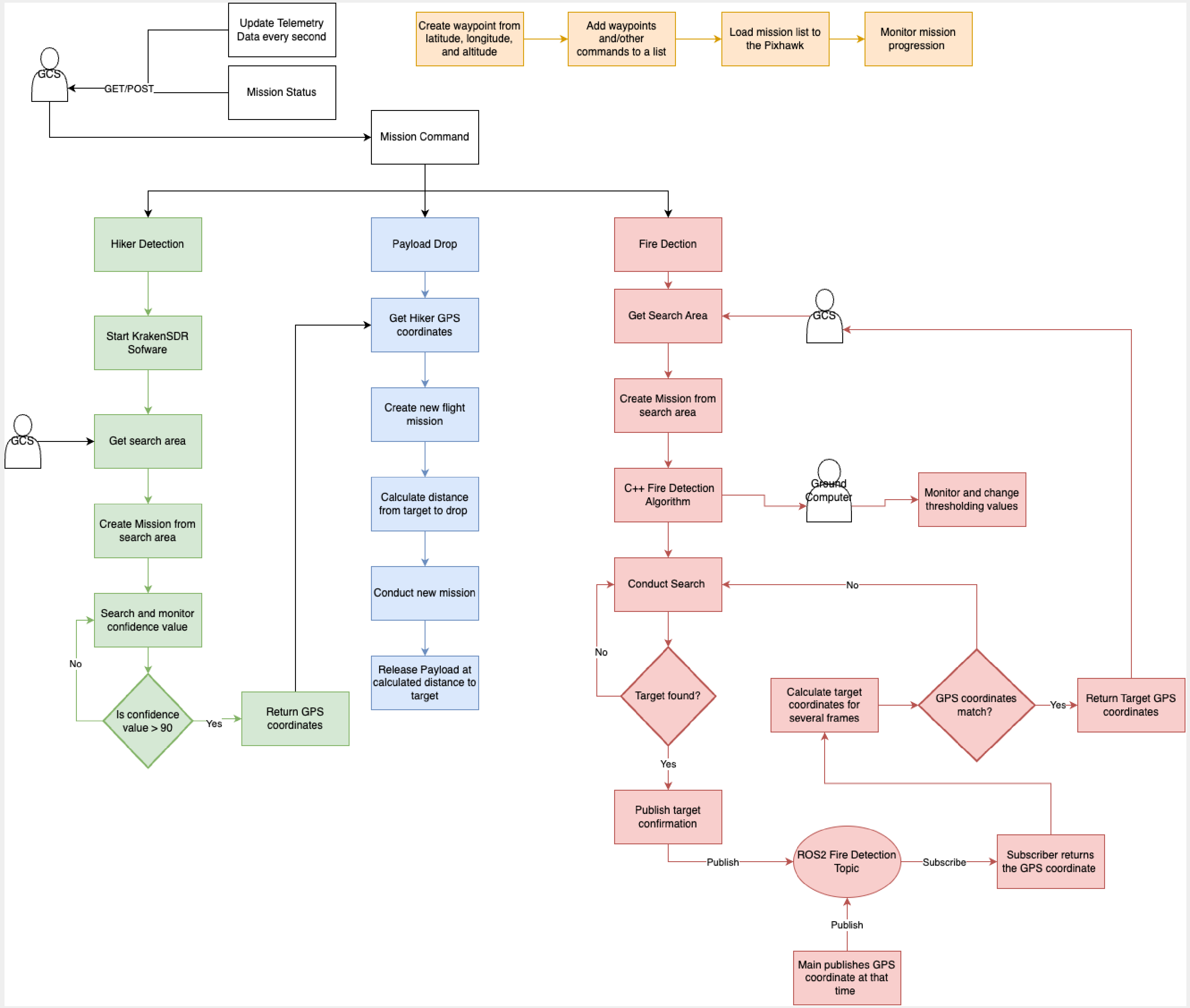
- Kraken radio location finding field test
  - Power on: 0 min, 8.37V
  - Program started: 7 min, 8.08V
  - Technical Difficulties: 7-25 min
  - Program Restarted: 25 min, 7.80V
  - Signal Found: 37 min, 7.63V
- Pixhawk battery test with 50% model peripherals
  - Control Surfaces
  - ESC
  - FrSky Receiver



Software Overview

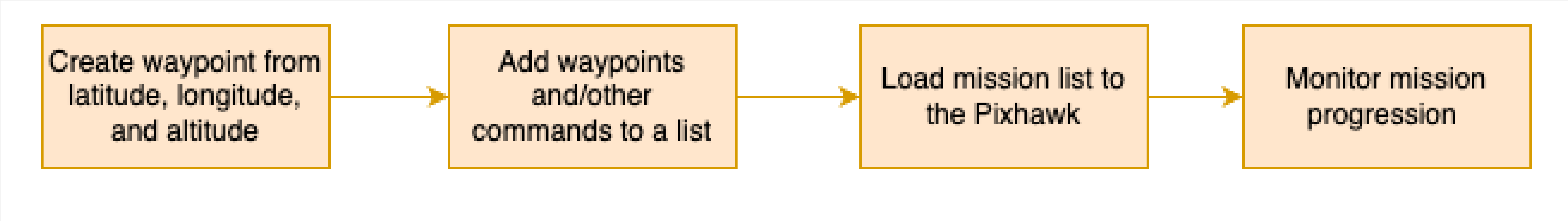
1. Autonomous Flight
2. Hiker Detection
3. Payload Drop
4. Fire Detection
5. Communications
6. Integration Testing

Software Flow Chart

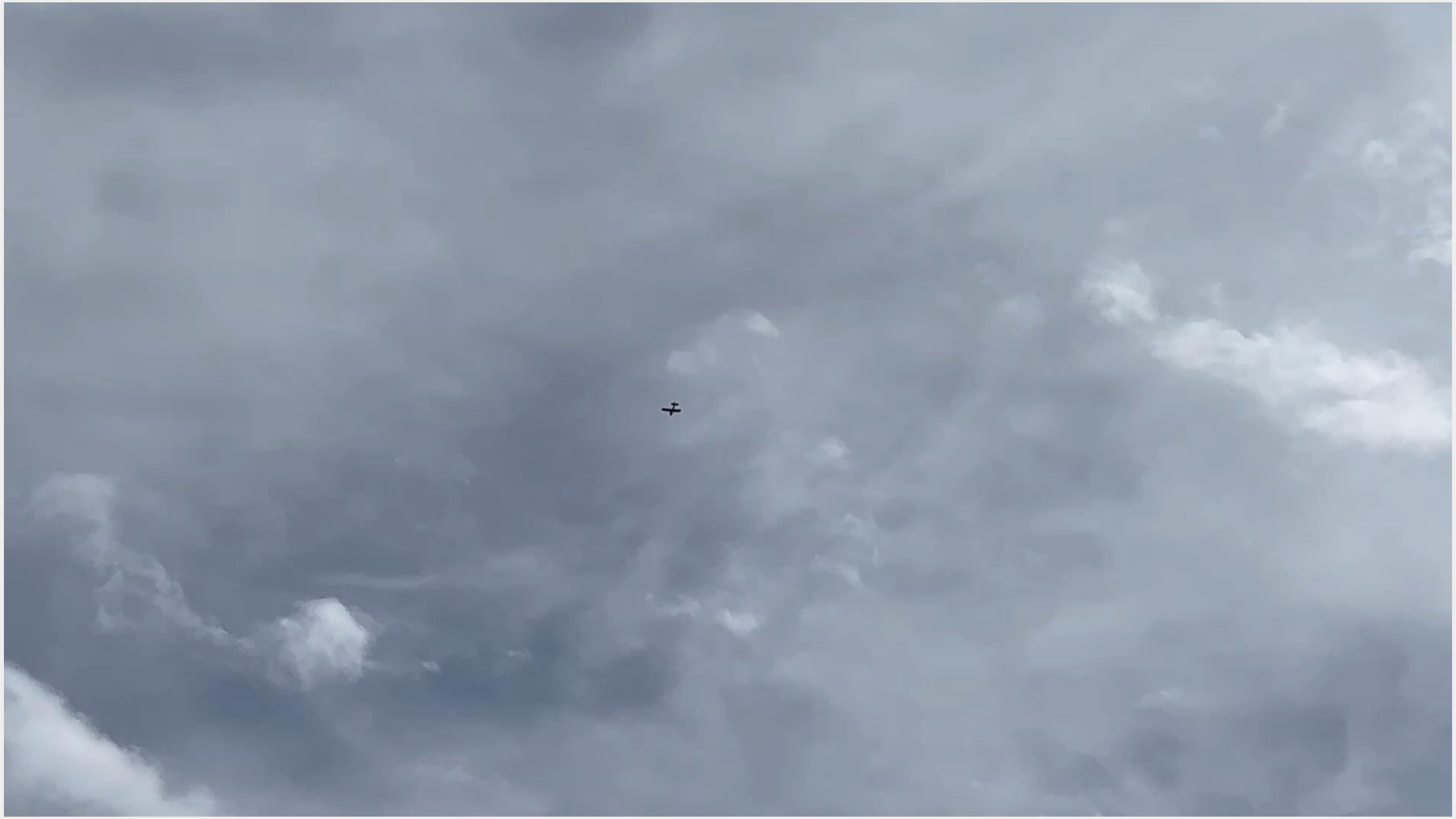


Autonomous Flight

- Utilized Dronekit + PyMavlink Python libraries
- Necessary functions and telemetry data variables contained within a Python class
- Conducted several autonomous flight tests using Apprentice STS RC plane

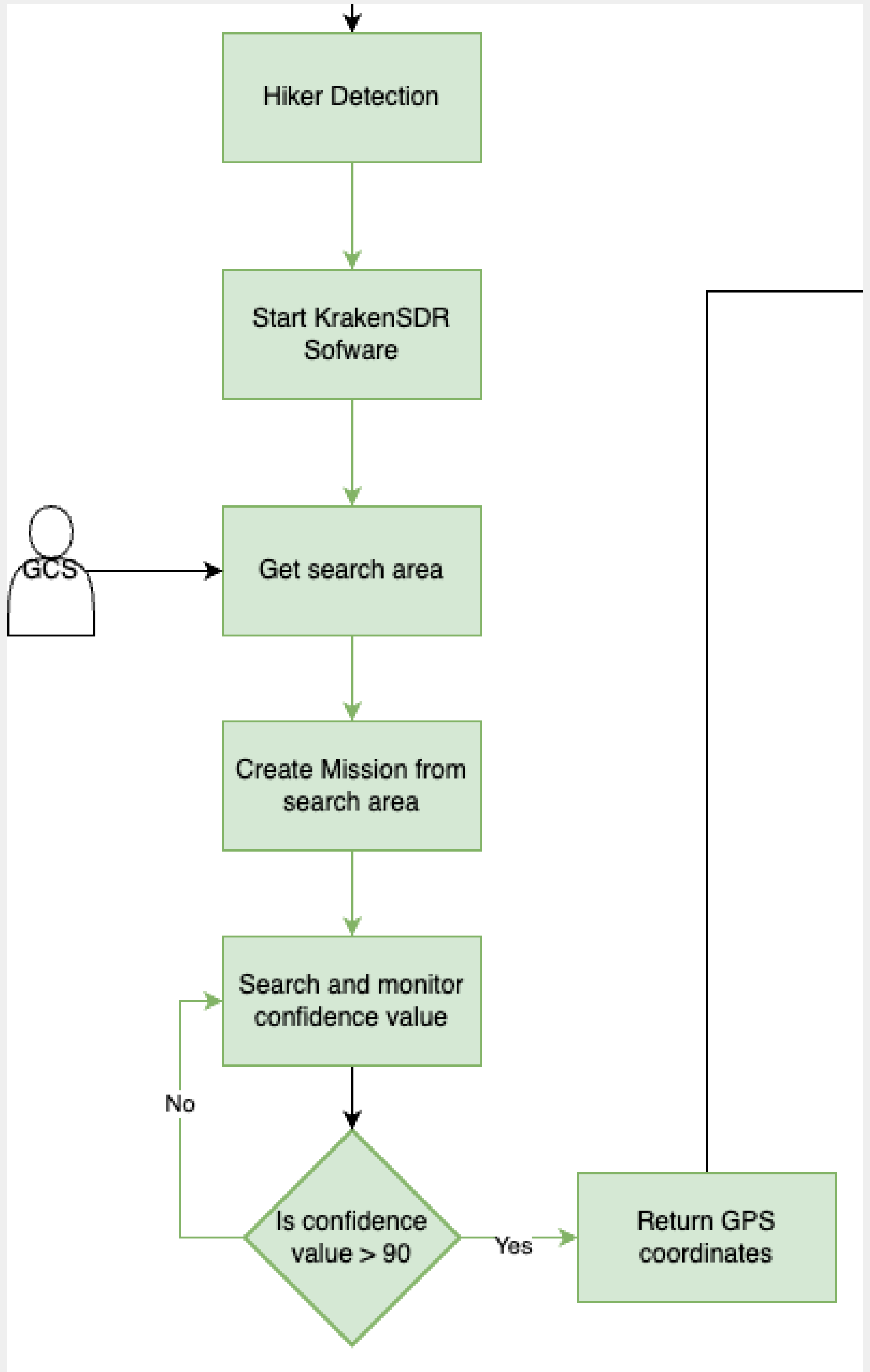


Autonomous Flight Test



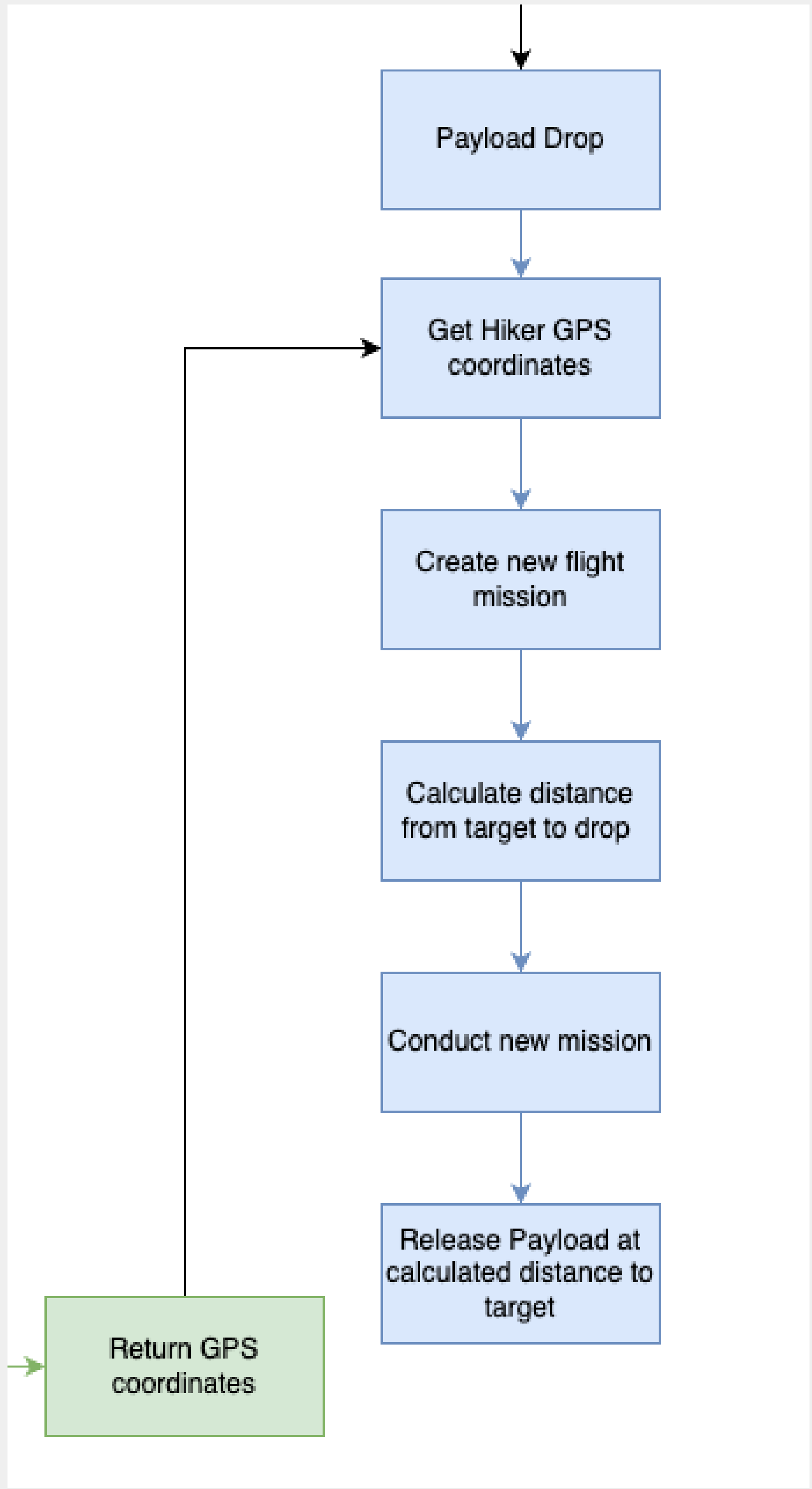
Hiker Detection

- KrakenSDR software on Jetson writes data to an output file every ~second
- Parse output for longitude, latitude, and confidence value(0-99)
- Output will be monitored every second and sent to GCS
- Final GPS coordinates will be determined by a confidence value > 90



Payload Drop

- Program payload servos using Dronekit and Mavlink
- Once hiker GPS coordinates are determined, payload mission is commenced
- Payload Mission Overview
  1. Create waypoint 100 meters from hiker coordinates at 100ft altitude
  2. Create waypoint from hiker coordinates
  3. Calculate distance to release payload from velocity of plane, altitude, and payload decent speed
  4. At calculated distance release payload

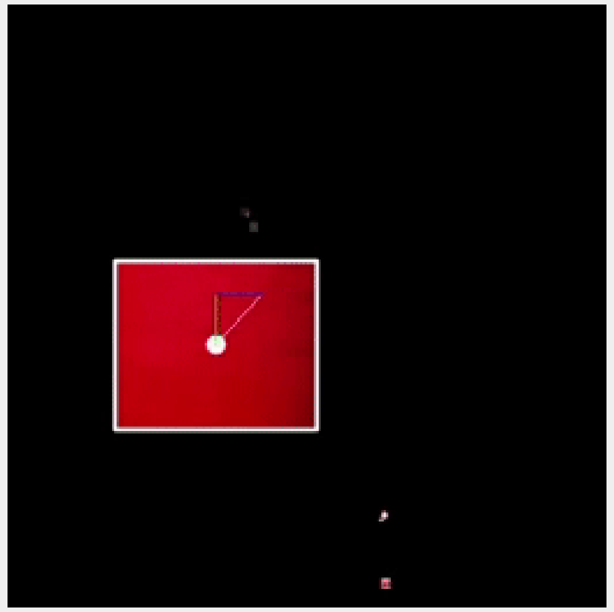


Fire Detection

- Color and square detection algorithm built with OpenCV in C++
- OpenCV used for image analysis & data streaming
- OpenCV processes ported to CUDA for improved performance
- ROS2 integration for language-independent communication between subprograms
- Developing a React.js + Flask web app to monitor and change values relating to the camera, target acquisition, and key algorithmic variables

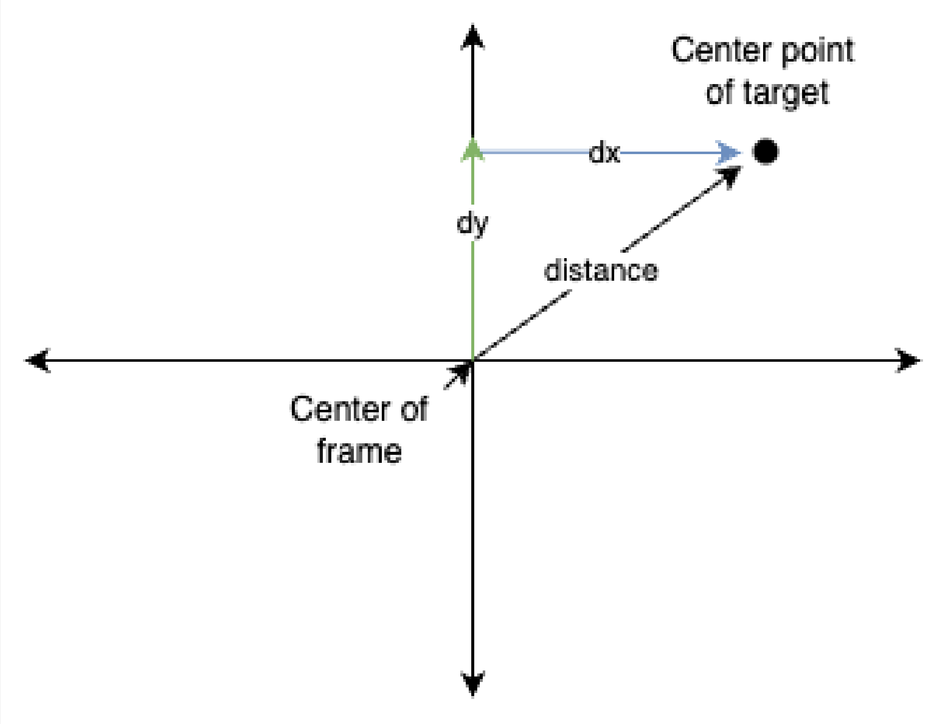
Fire Detection Algorithm

1. Bitwise mask for upper and lower red HSV values
2. Square detection using thresholding
   + findCountours()
3. Draw box around target using Moments and
   determine its center point using Mat

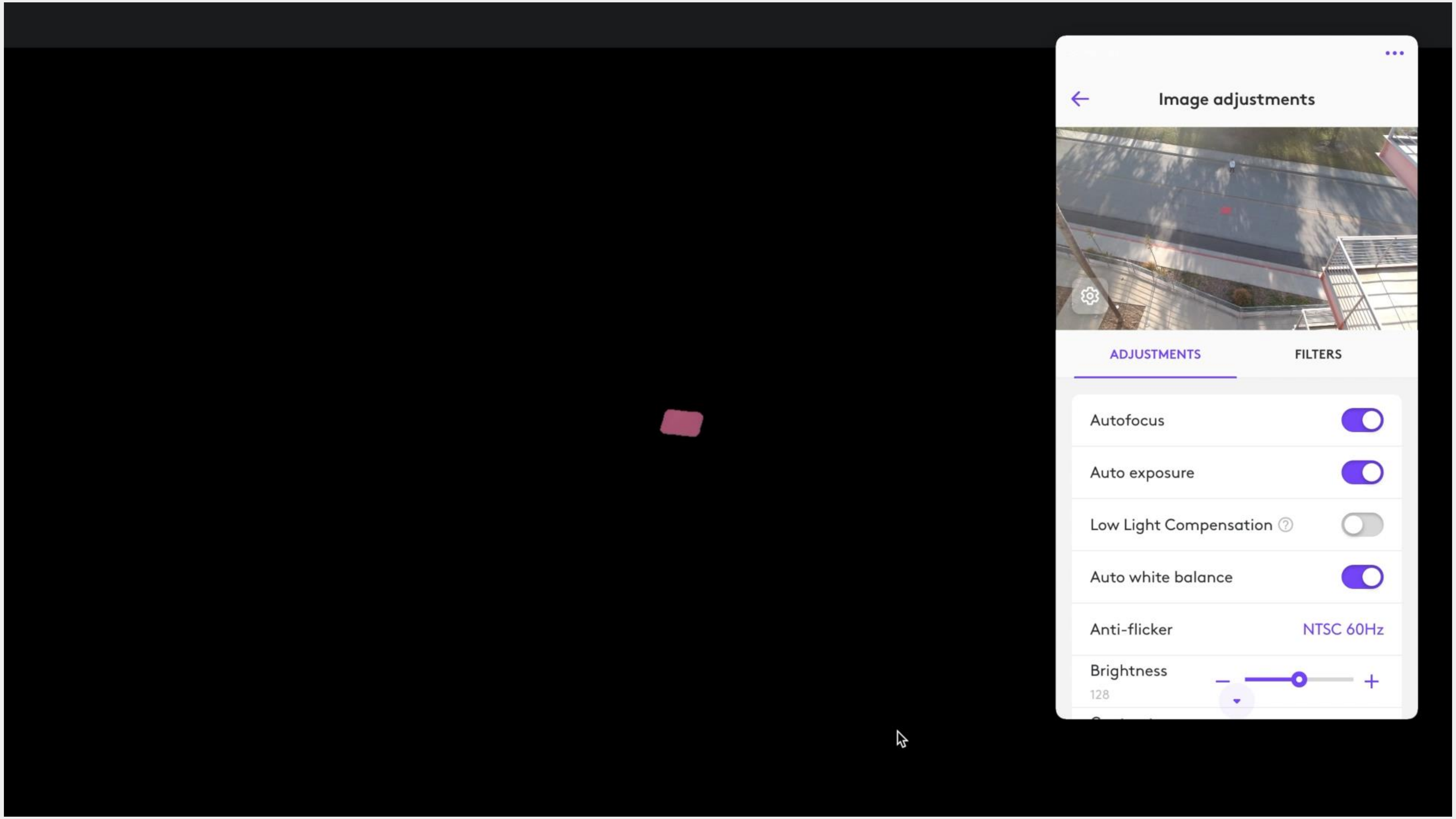


Fire Detection: Finding Target Coordinates

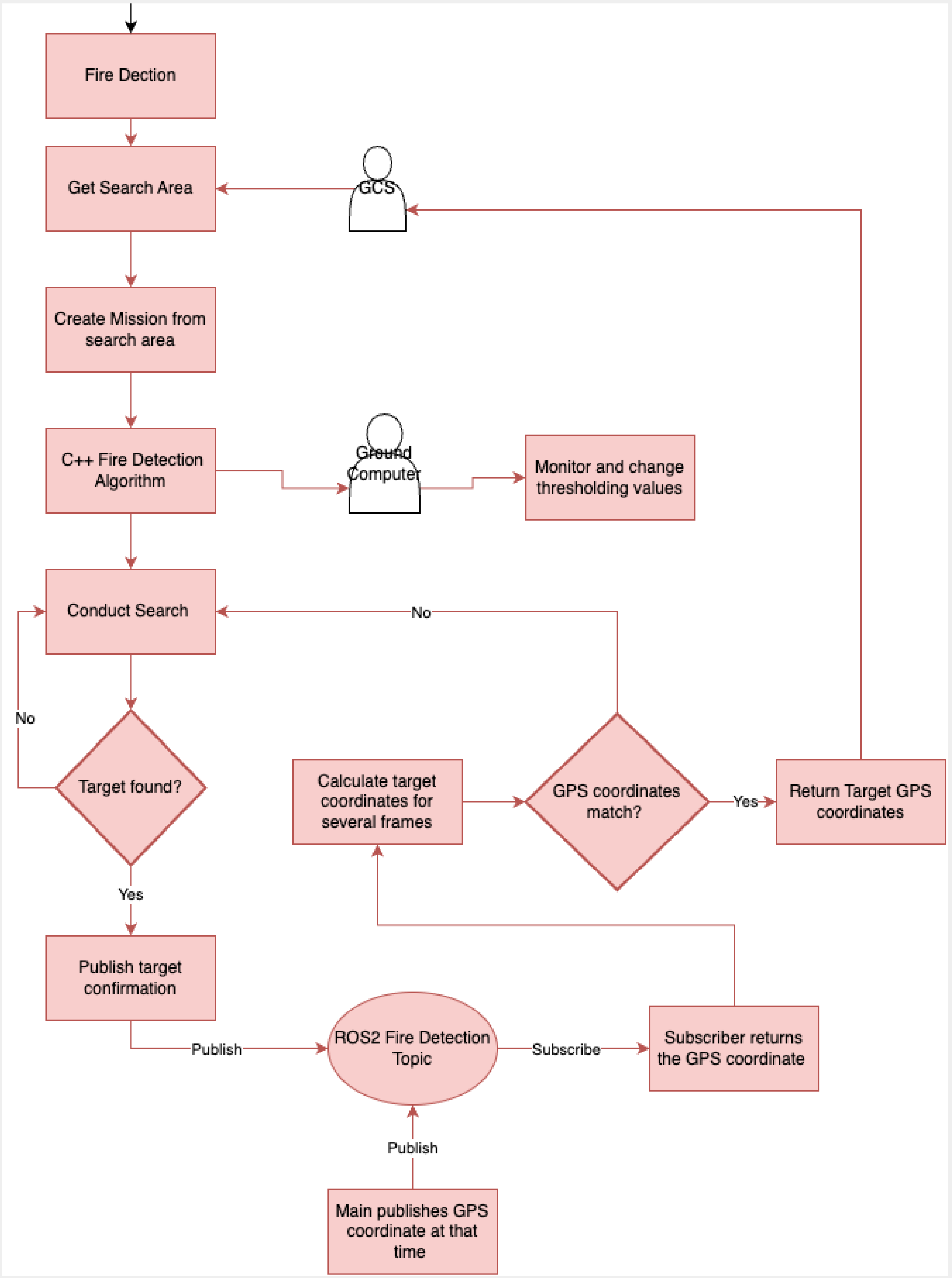
1. **distance_per_pixel** = (sensor_width * altitude * 100) / (focal_length * pixel_width)
2. **distance** = distance_per_pixel * pixel_length
3. **bearing** = $\sin^{-1}$(dx/distance) + current_bearing
4. Convert the current GPS coordinates, bearing, and distance to radians
5. Plug these values into the Haversine formula



Fire Detection Testing



Fire Detection Flow Chart



Communications

- Protocol: HTTP
- Software: Flask and Python Requests libraries
- Client(Jetson) sends GET/POST requests to GCS API endpoint
- Data to be monitored and sent every second:
  – Telemetry Data
  – Mission Status
  – Mission Start/Current Mission
- Tested on campus and determined about 2000ft range
- Tested communications between client(UAV) and simulated test endpoint

Integration Testing

- Test Flights:
  - Communications between Jetson and ground computer
  - Fire detection algorithm accuracy in the air and at different altitudes
  - Accuracy of target coordinate calculations
  - Realtime mission changes
- Run KrakenSDR software and parse output data in real time
- Conduct payload drop test using our software
- Test Payload drop mission in simulation

Path to Demo Day

- Complete analysis of planform and structure
- Feedback controller implementation
- Thrust ground-testing
- Landing gear design and testing
- Payload drop and parachute deployment testing
- Software autonomous flight and detection testing
- Communications testing
- Full scale model manufacturing

UAV Questions or Comments