Team **CARROT:**

Compact **A**erial **R**adio **R**elay for **O**bscure **T**errain

Test Readiness Review

March 1, 2023

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Project Overview

Mission Statement

The goal of **CARROT** is to develop a human-portable, manufacturable, low-cost, and rapidly deployable unmanned aircraft system (UAS).

This system will be utilized to assist with multiple mission profiles, including search and rescue. The aircraft will be capable of meeting the demands of the mission including agility, low-costs, high persistence, and broad coverage capability.

Objectives

- Ease of transportability
- Ease of manufacturability
- Cost efficient
- High endurance for continuous overwatch

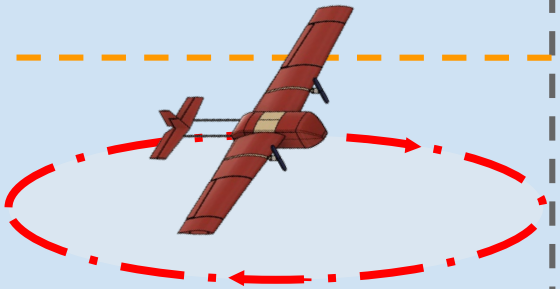
Customer CONOPS

10,000 ft MSL

Mission Altitude Block

5,000 ft MSL

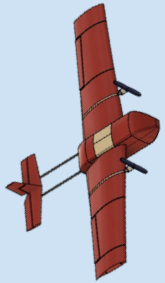
UAV climbs to mission altitude block while withstanding winds and sharp-edged vertical gusts up to 20 mph



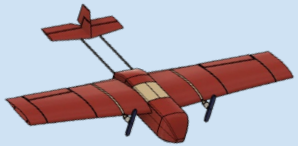
UAV descends while withstanding winds and sharp-edged vertical gusts up to 20 mph
Another UAV is deployed to maintain mission coverage

UAS (with 1 or more UAV) is transported to mission location

UAV is launched by **single operator** using launch rig



UAS and **UAV** will be able to:
Orbit over mission location
Maintain 12 hours of continuous coverage
Withstand winds up to 30 mph and sharp-edged vertical gusts up to 20 mph
Provide communication to ground support team
Collect any necessary mission information

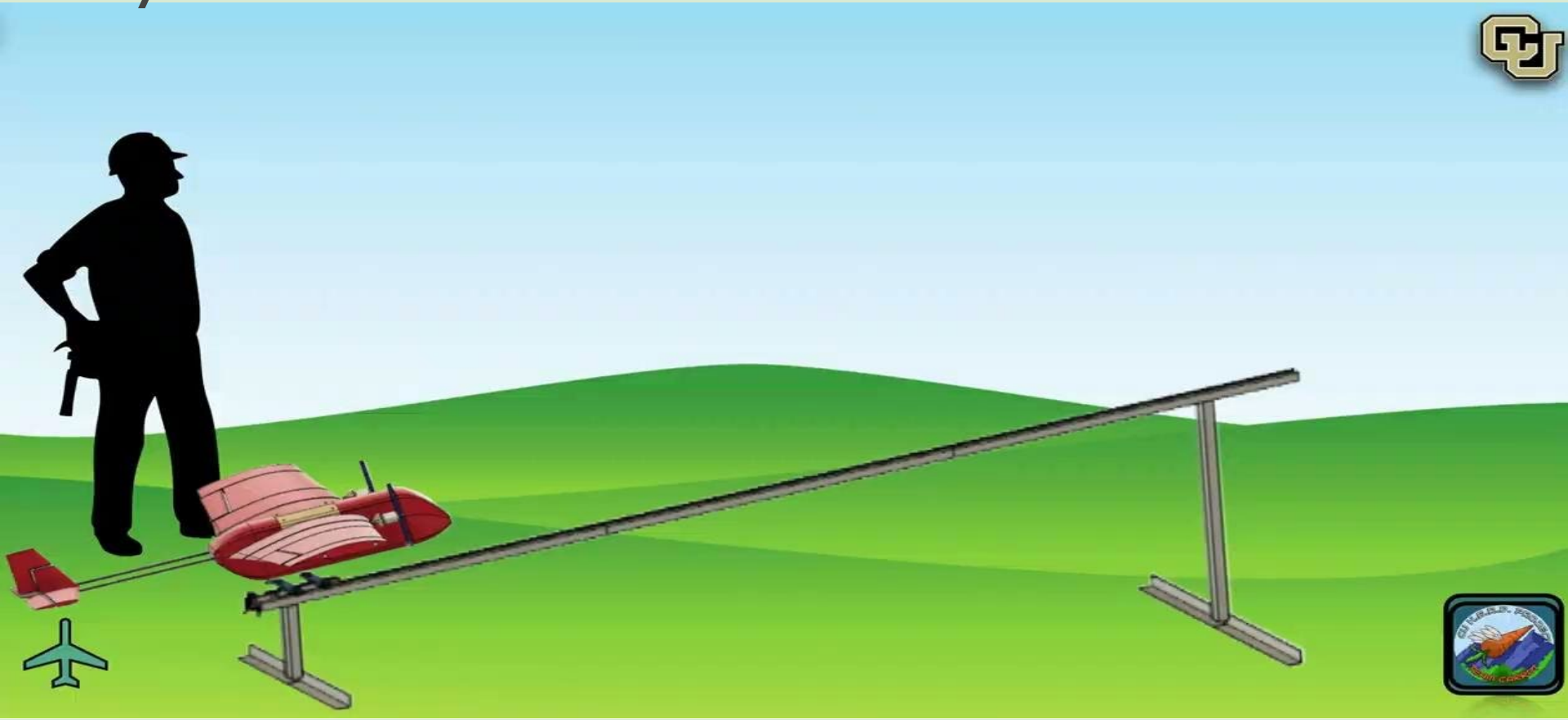


UAV lands on a recoverable area (no runway)

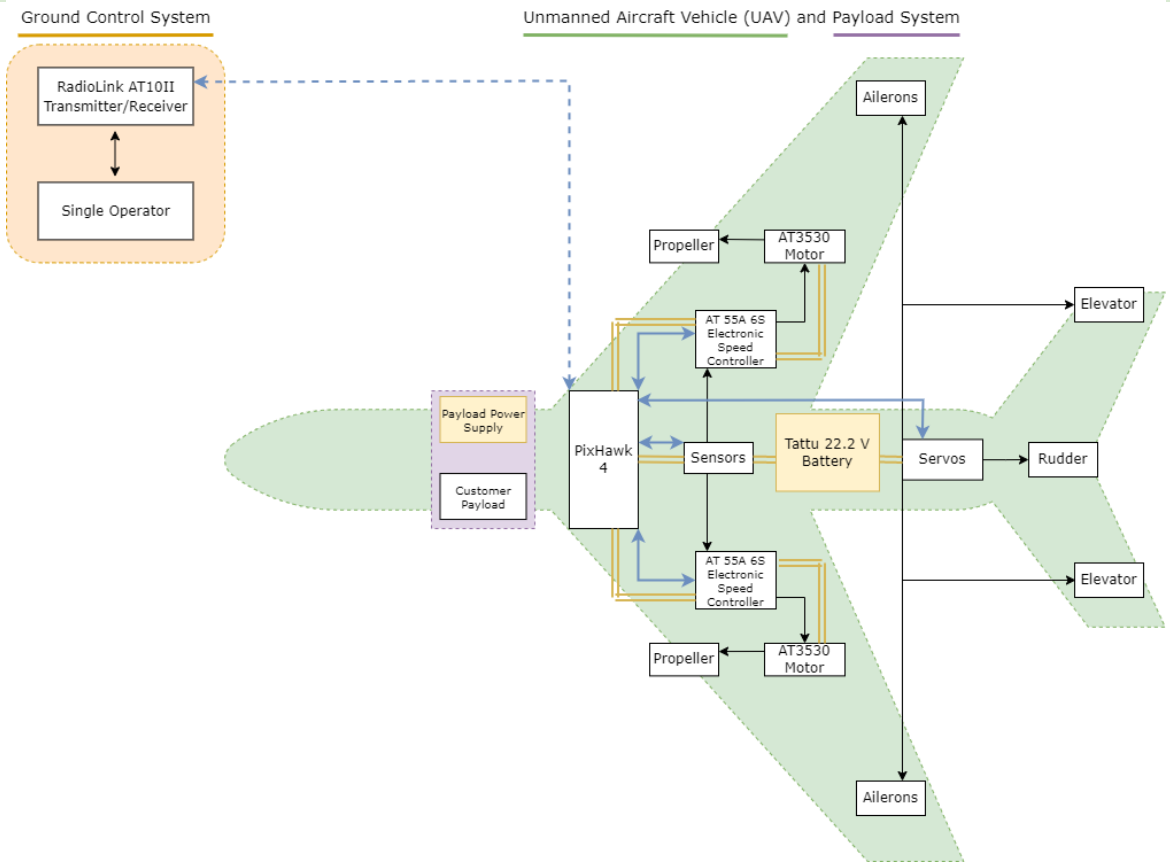
Single operator, when safe, recovers UAV from landing area

Launch | Climb | Loiter | Descend/Launch | Recovery

A day in the Life CONOPS



Functional Block Diagram



Key:

Physical Connections

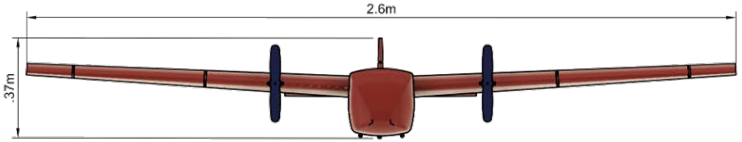
Data Connections

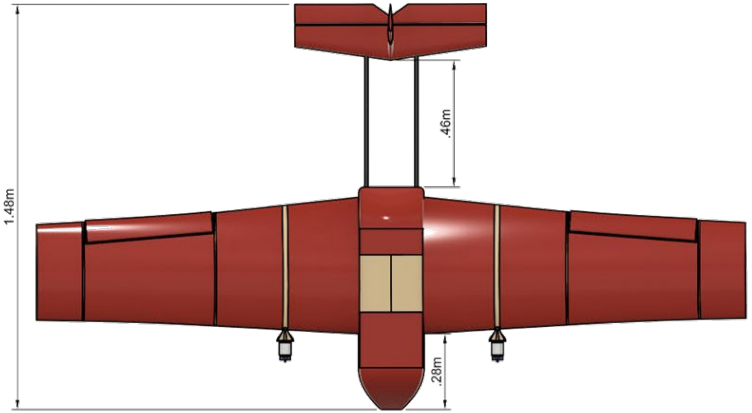
Wireless Data Connections

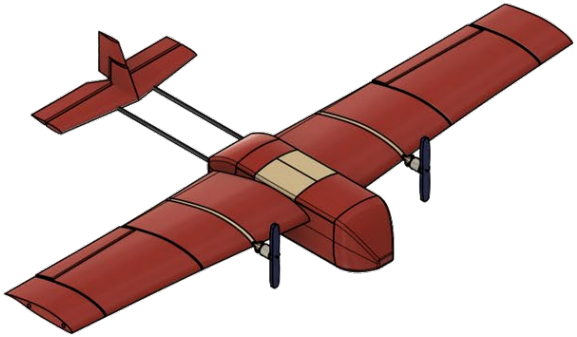
Power Supply

Baseline Design

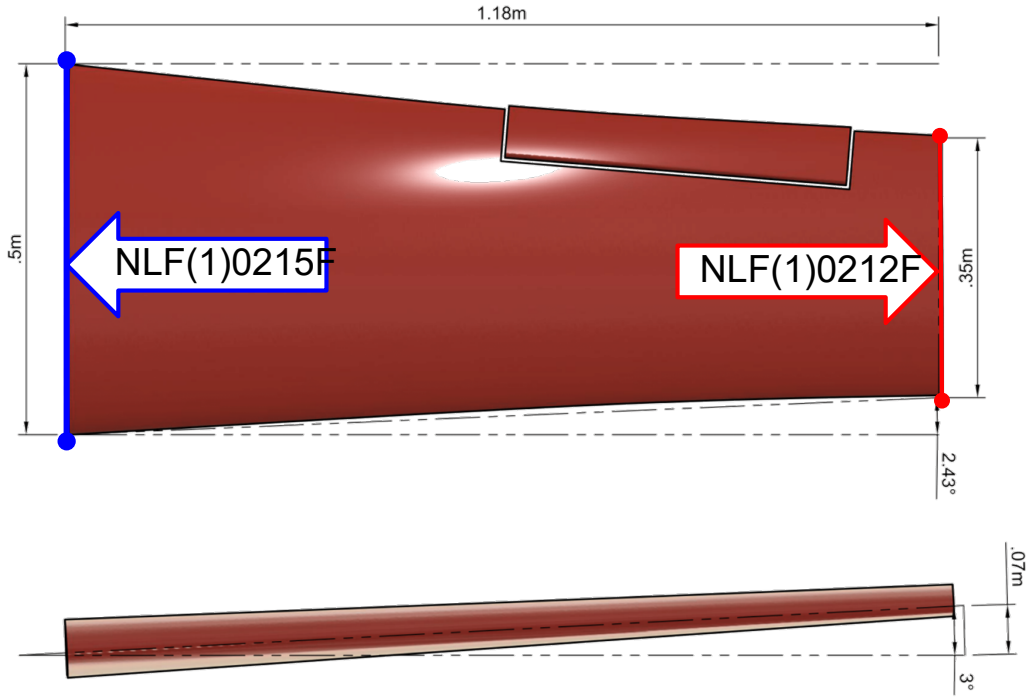
CARROT UAV	Specifications
Wingspan	2.60 meters
Aspect Ratio	5.55
Length	1.48 meters
Mass	11.5 kg (~25.3 lbs)





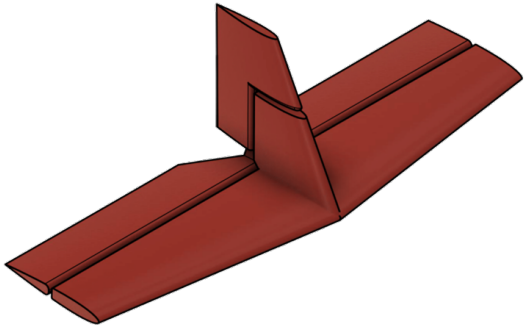


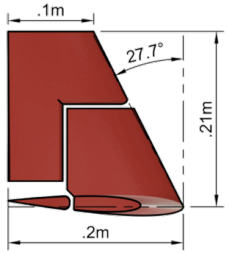
Design Solution - Wing

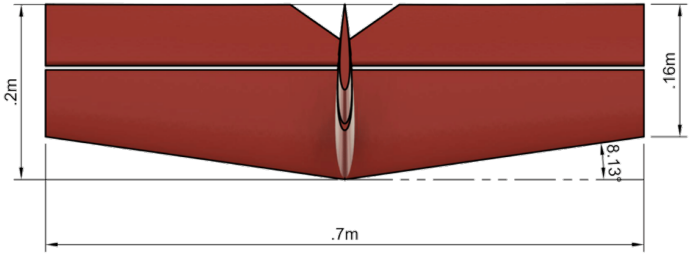


CARROT UAV	Specifications
Half Span	1.18 m
Wing Area	1 m²
Aspect Ratio	5.55
Root Airfoil	NLF(1)0215F
Tip Airfoil	NLF(1)0212F
Tip Twist	-3°
Incidence Angle	3°

Design Solution - Empennage







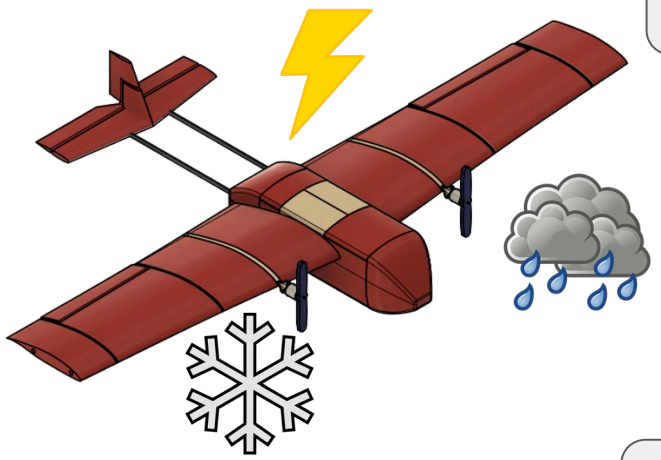
Vertical Stabilizer	
Airfoil	NACA 0012
Area	.03 m²
Lever Arm	.98 m
Horizontal Stabilizer	
Airfoil	NACA 0012
Tail Incidence	-2°
Area	.12 m²
Lever Arm	.98 m

Critical Project Elements

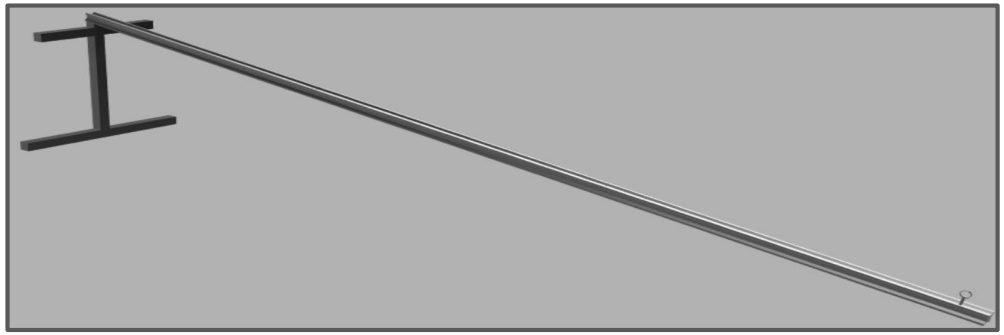
Critical Project Element	Description	Functional Requirement
CPE 1: Operability	Achieve operability by following FAA 14 CFR Part 107 and MIL-F-8785C requirements	F.R. 1
CPE 2: Design - Minimizing size and weight of aircraft	Achieve lightweight and portability features utilizing appropriate materials and modularization	F.R. 1 F.R. 2 F.R. 3
CPE 3: Manufacturing	Achieve manufacturing and repairability ease by the end user by utilizing low-cost, COTS materials and additive manufacturing methods	F.R. 4 F.R. 6
CPE 4: Design - Maximizing endurance through aerodynamics and propulsion	Meet endurance goals through extensive aerodynamic design & modeling and propulsion system design & modeling	F.R. 7
CPE 5: Design - Maintaining durability	Ensure structural integrity throughout flight profile given disturbances, weather variation, temperature, and maintaining static stability	F.R. 8

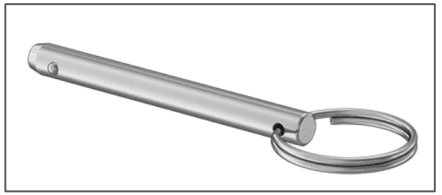
Functional Requirements

1. UAS shall adhere to FAA Part 107 and MIL-F-8785C
2. UAS shall be human portable
3. UAS shall clear short takeoff and landing areas and be able to deploy with unprepared launch surfaces and obstructed climb windows
4. UAS components shall be easily manufacturable, replaceable, or repairable by the end user.
5. UAS shall support a payload with a weight ranging from 1.5 - 3 kg
6. UAS shall be low-cost and utilize COTS components
7. UAS shall provide continuous coverage for the duration of the mission profile
8. UAS shall be durable and reliable throughout the mission profile
9. UAS shall utilize only open-source or team-developed software for mission critical components



Changes Since CDR - What we presented in the Fall



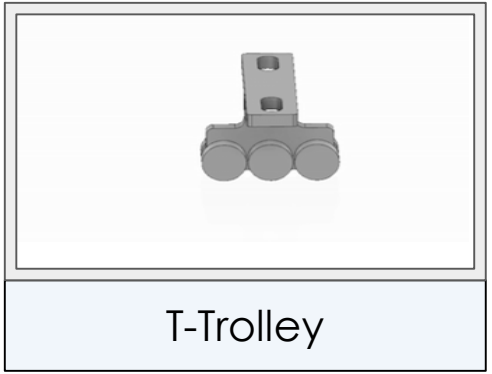


- Dimensions
  - 10 degree angle
    - Creates optimal angle of attack
  - 3 m length
    - Requires 280 N elastic force

- At Takeoff
  - Place aircraft and retention pin
  - Stretch bungee/elastic around UAS
  - Increase throttle to highest setting
  - Release retention pin

What Changed ?

1



T-Trolley

Quantity: 2

Height: 2.75 inch
Length: 5.9 inch
Width: 3.35 inch

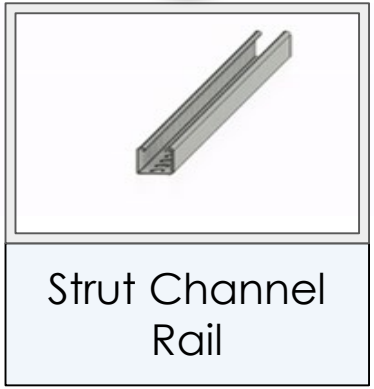
2

Rotary Latch

Quantity: 1

Height: 3.5 inch
Length: 1.1 inch
Width: 0.78inch

3

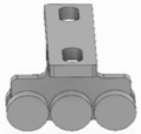


Strut Channel Rail

Quantity: 3

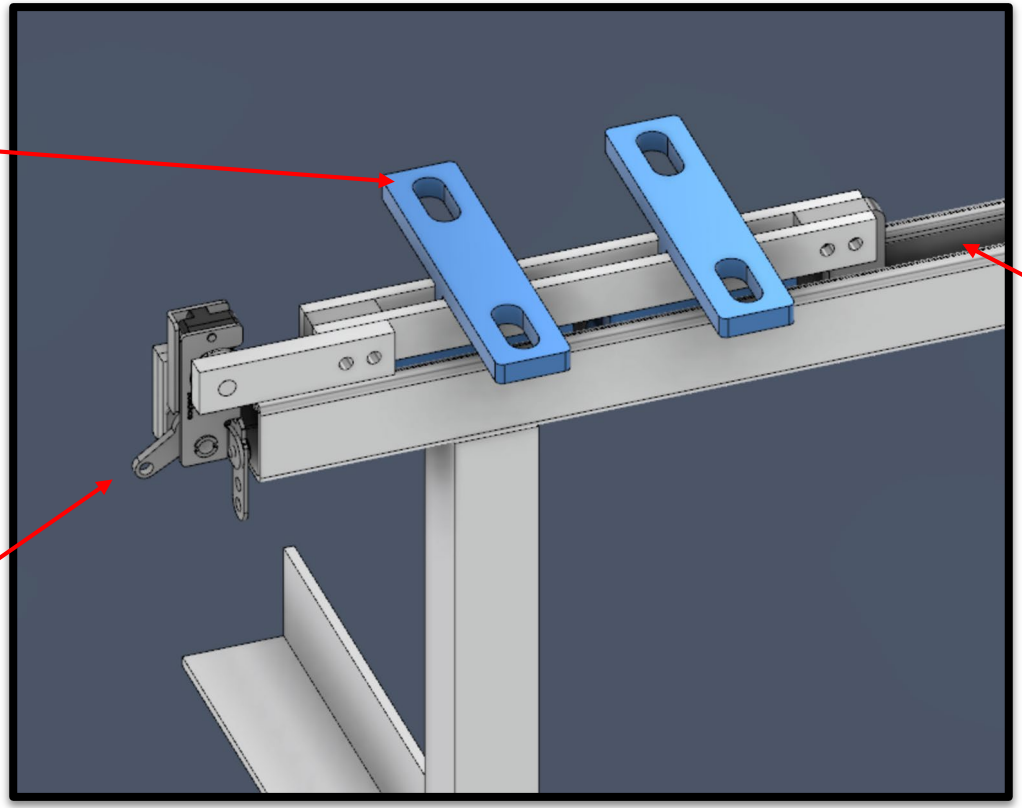
Height: 1.5 inch
Length: 4 ft (each)
Width: 1.62 inch

All Together



T-Trolley

Rotary Latch



Strut Channel Rail

Rail Change Summary

OLd

Specs

Length:	9.8 ft
Bungee:	External
Release:	Pin Removal

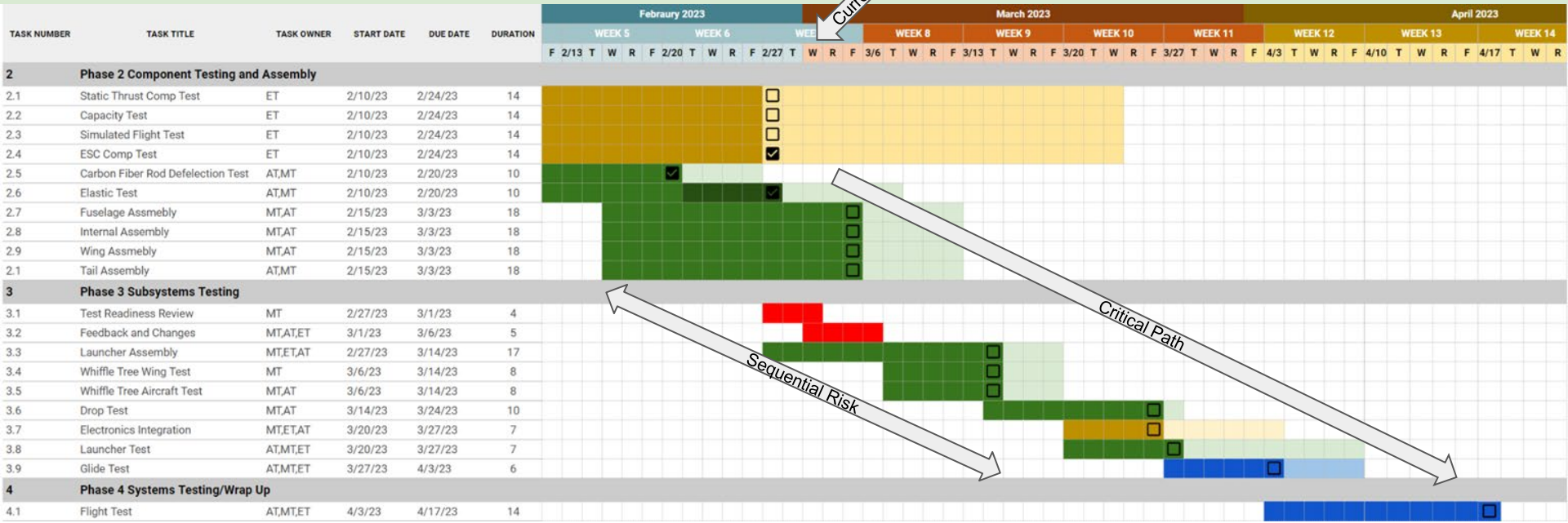
New

Specs

Height:	12 ft
Bungee:	Internal
Width:	Rotary Latch

Schedule

Testing Schedule



TASK NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION
2	**Phase 2 Component Testing and Assembly**				
2.1	Static Thrust Comp Test	ET	2/10/23	2/24/23	14
2.2	Capacity Test	ET	2/10/23	2/24/23	14
2.3	Simulated Flight Test	ET	2/10/23	2/24/23	14
2.4	ESC Comp Test	ET	2/10/23	2/24/23	14
2.5	Carbon Fiber Rod Defelection Test	AT,MT	2/10/23	2/20/23	10
2.6	Elastic Test	AT,MT	2/10/23	2/20/23	10
2.7	Fuselage Assmebly	MT,AT	2/15/23	3/3/23	18
2.8	Internal Assembly	MT,AT	2/15/23	3/3/23	18
2.9	Wing Assmebly	MT,AT	2/15/23	3/3/23	18
2.1	Tail Assembly	AT,MT	2/15/23	3/3/23	18
3	**Phase 3 Subsystems Testing**				
3.1	Test Readiness Review	MT	2/27/23	3/1/23	4
3.2	Feedback and Changes	MT,AT,ET	3/1/23	3/6/23	5
3.3	Launcher Assembly	MT,ET,AT	2/27/23	3/14/23	17
3.4	Whiffle Tree Wing Test	MT	3/6/23	3/14/23	8
3.5	Whiffle Tree Aircraft Test	MT,AT	3/6/23	3/14/23	8
3.6	Drop Test	MT,AT	3/14/23	3/24/23	10
3.7	Electronics Integration	MT,ET,AT	3/20/23	3/27/23	7
3.8	Launcher Test	AT,MT,ET	3/20/23	3/27/23	7
3.9	Glide Test	AT,MT,ET	3/27/23	4/3/23	6
4	**Phase 4 Systems Testing/Wrap Up**				
4.1	Flight Test	AT,MT,ET	4/3/23	4/17/23	14

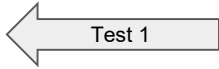
Critical Path

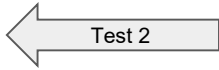
Sequential Risk

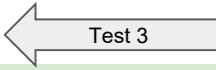
Test Readiness

Test Status

Tests	Status
Carbon Fiber Rod Deflection	Completed
Elastic Band	Completed
Capacity Test	In Progress
Static Thrust	In Progress
Simulated Flight Endurance Test	In Progress
Whiffletree Test	Prepping
Drop Test	Prepping
Electronics Integration	Prepping
Glide	Prepping
Flight Test	Waiting Approval and Prepping







Test Readiness: Electronics

Test Readiness - Electronics

Rationale for Testing: Summary

Test Name	Reason for Test
Static Thrust Test	Validate Physics Model
	Validate Motor & Prop Selection
Capacity Tests	Validate Manufacture Specs
	Determine Safe Battery Cut-off
Simulated Flight Endurance Test	Validate Endurance Models
	Determine Loiter Capacity Safe Return

Test Readiness - Electronics

Rationale for Testing:

Functional Req. 7: UAS shall provide continuous coverage for the duration of the mission profile

Design Req. 7: Maximize endurance for **4 hours** flight time (without autonomous control) at 6,000 ft MSL

Metrics of success:

1. Test stand tests power draw matches model within **± 10%**
2. Battery mock-flight is able to achieve at least **1.7 ± 0.2** hours of endurance

Test Readiness - Electronics

Rationale for Testing:

Functional Req. 7: UAS shall provide continuous coverage for the duration of the mission profile

Design Req. 7: Maximize endurance for **4 hours** flight time (without autonomous control) at 6,000 ft MSL

Matlab models currently show **1.7 ± 0.2 hours** of flight time

Verified by:

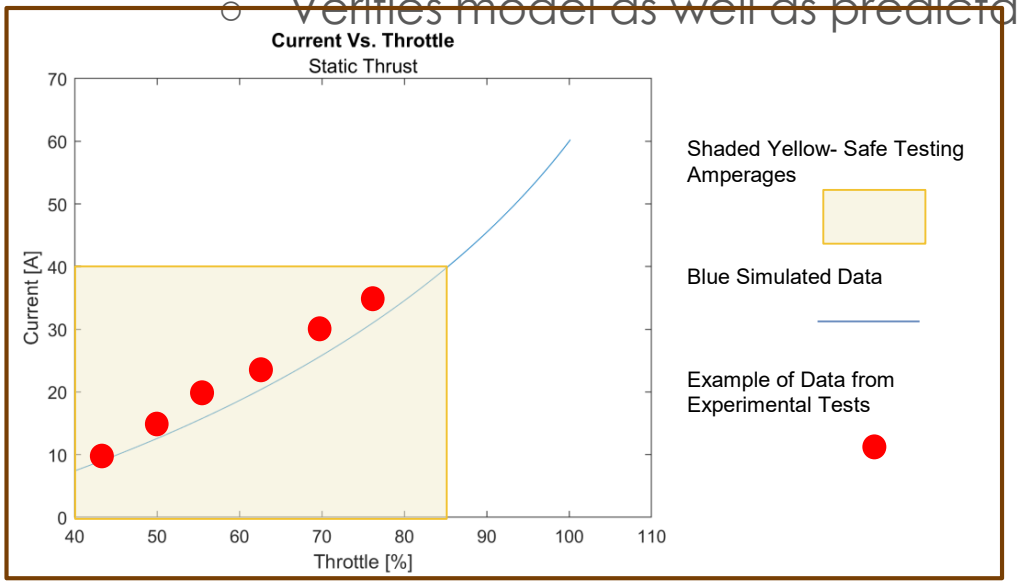
1. Refining Matlab model using experimental thrust and power measurements
2. Full characterization of actual power draw using endurance test
    a. Determination of battery cutoff point
    b. Full mock-flight on test stand to confirm battery endurance

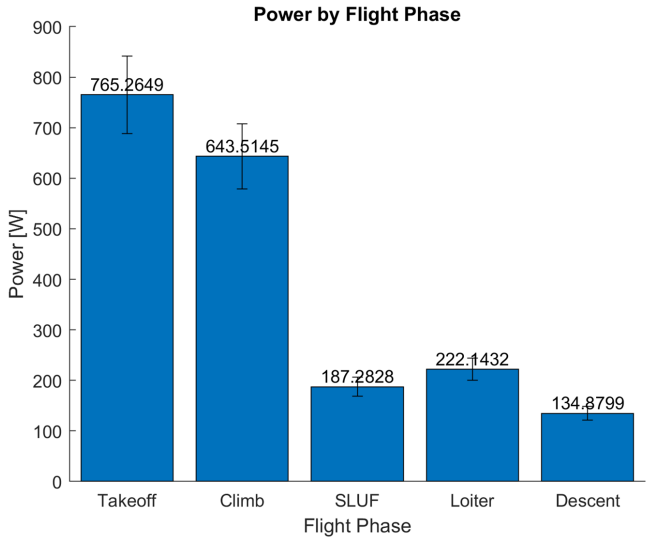
Test Readiness - Electronics: Comprehensive Battery Endurance Validation

Rationale for Testing:

Functional Req. 7 & Design Req. 7

- Thrust-based endurance models show 1.7 ± 0.2 hours of endurance
- True capability needs to be verified by experimental data
  - Verifies model as well as predictability of integrated system





Test Readiness - Electronics: Comprehensive Battery Endurance Validation

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Functional Req. 7 & Design Req. 7

- Thrust-based endurance models show **1.7 ± 0.2** hours of endurance
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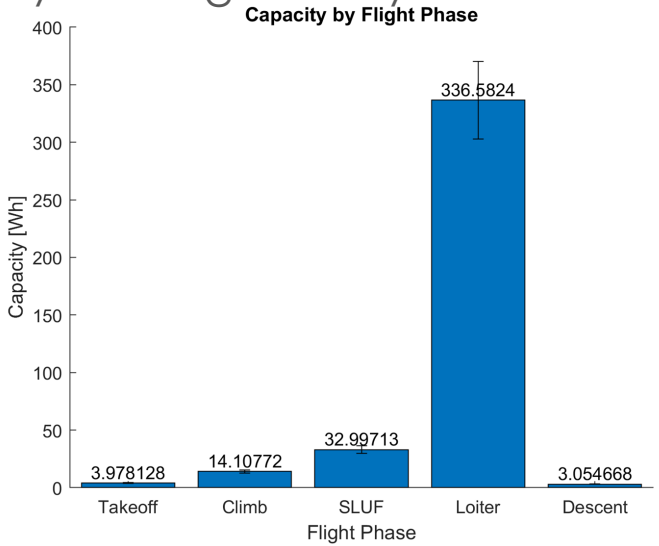
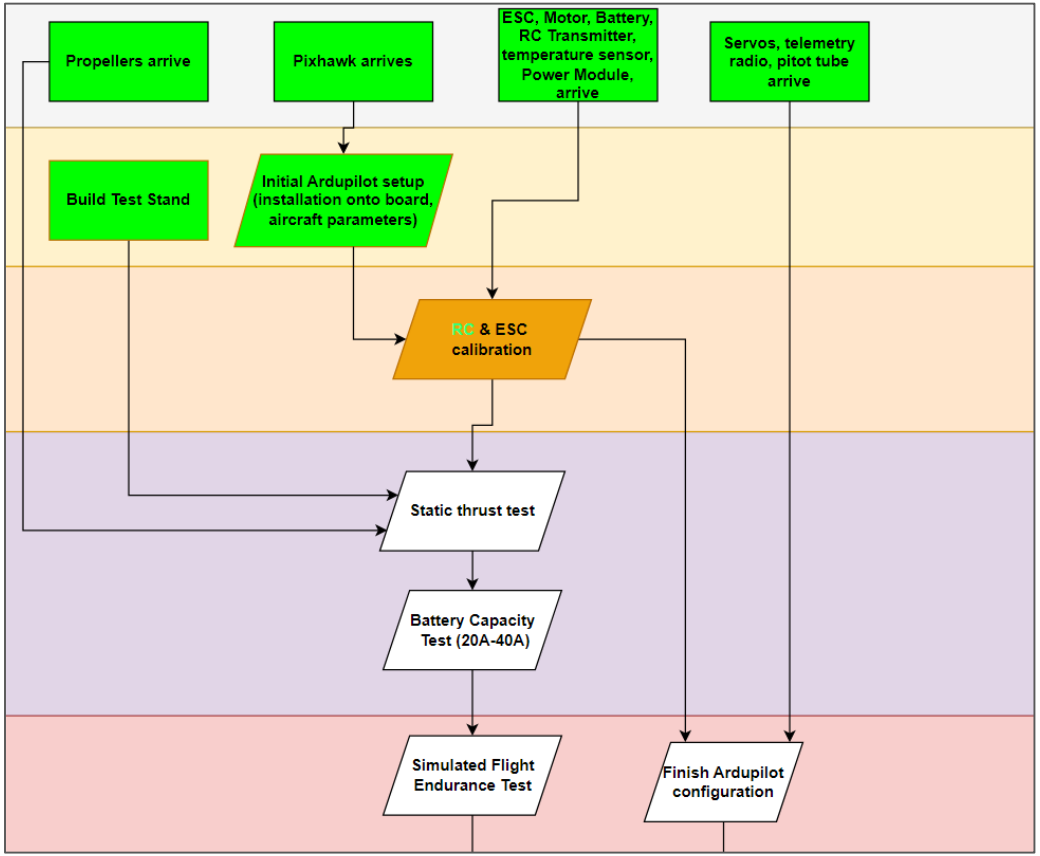
    - Verifies model as well as predictability of integrated system

Flight Model Assumptions:

- Takeoff: 2.72 kg thrust for 17.7 seconds
- Climb: 2.06 kg thrust for 75.5 seconds (5 deg climb)
- SLUF Flight Phase: 0.78 kg thrust for 5 min
- Loiter: 0.88 kg thrust for remaining capacity
- Descent: 0.63 kg thrust for 75.5 seconds (5 deg descent)



Test Readiness - Electronics: Test Flow



Functional Req. 7 & Design Req. 7

Test	Date	Status
RC & ESC Calibration	Feb 27th	Completed
Static Thrust Tests	March 6th	In Progress
Battery Endurance Tests	March 8th March 13th	In Progress
Simulated Flight Capacity Test	March 15th	In Progress

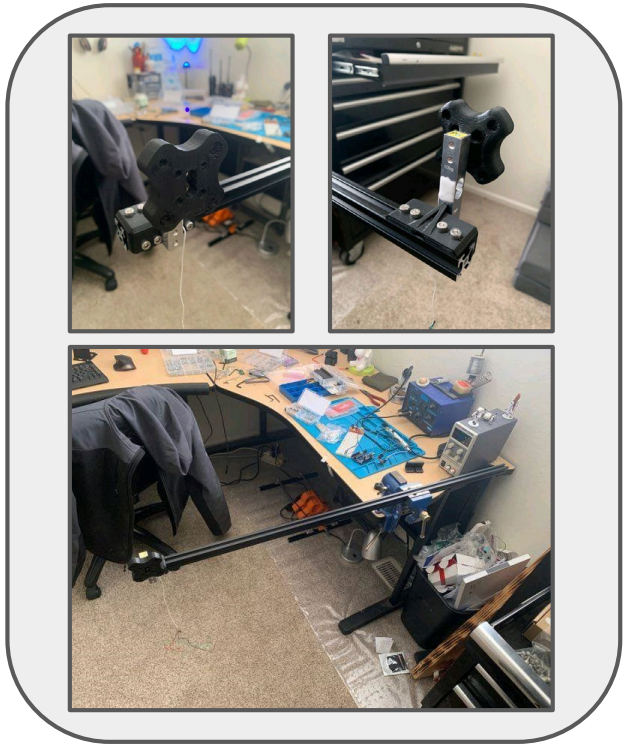
Note : Electronics integration begins March 20th

Test Readiness - Electronics:

Functional Req. 7 & Design Req. 7

Prerequisites for Testing:

- Calibrated load cells
- Arduino scripts to read and save load cell data.
- ESC and RC calibration
- Integrated electronics: arduino, amplifier, load cells, hobbyboard, thermocouples.
- Test Procedures
- Test Cards
- Test Safety Procedures
- Integration with Test Stand in Engine Test Cell

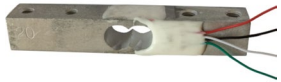


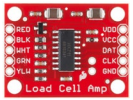
Test Readiness - Electronics: Comprehensive Battery Endurance Validation

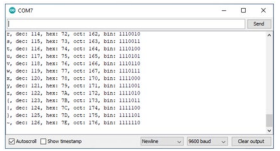
Data Acquisition: Arduino

Functional Req. 7 & Design Req. 7

- **Load Cell → provides Thrust data:**



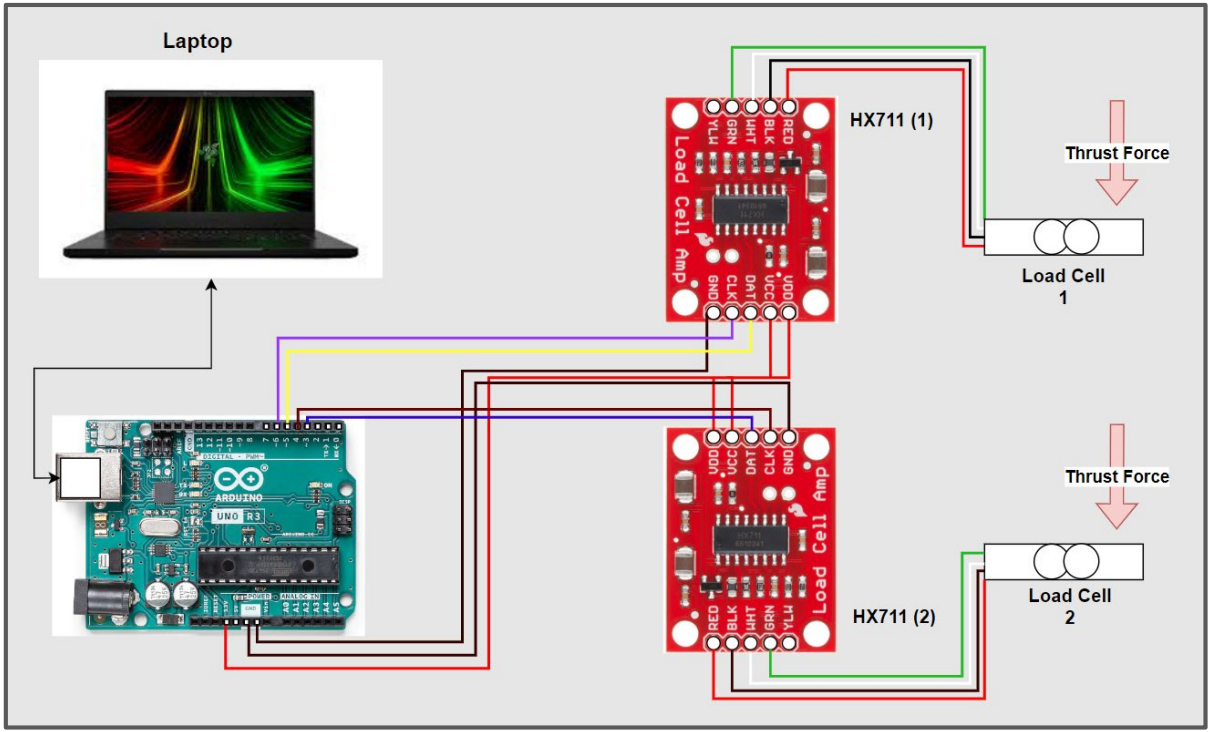




Load Cell → HX711 amplifier → Arduino ADC → Arduino Serial Monitor → Convert to Text File → Convert to CSV → Import to MATLAB → Process for Visualization

Data Acquisition: Arduino - Diagram

Functional Req. 7 & Design Req. 7

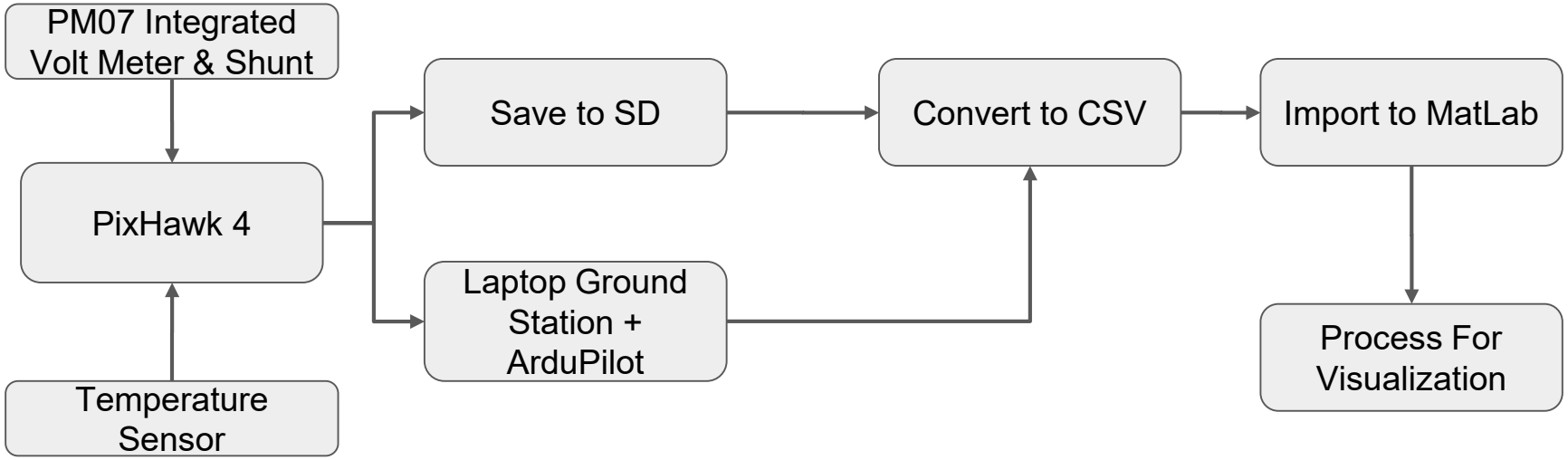


Test Readiness - Electronics: Comprehensive Battery Endurance Validation

Data Acquisition: PixHawk 4

Functional Req. 7 & Design Req. 7

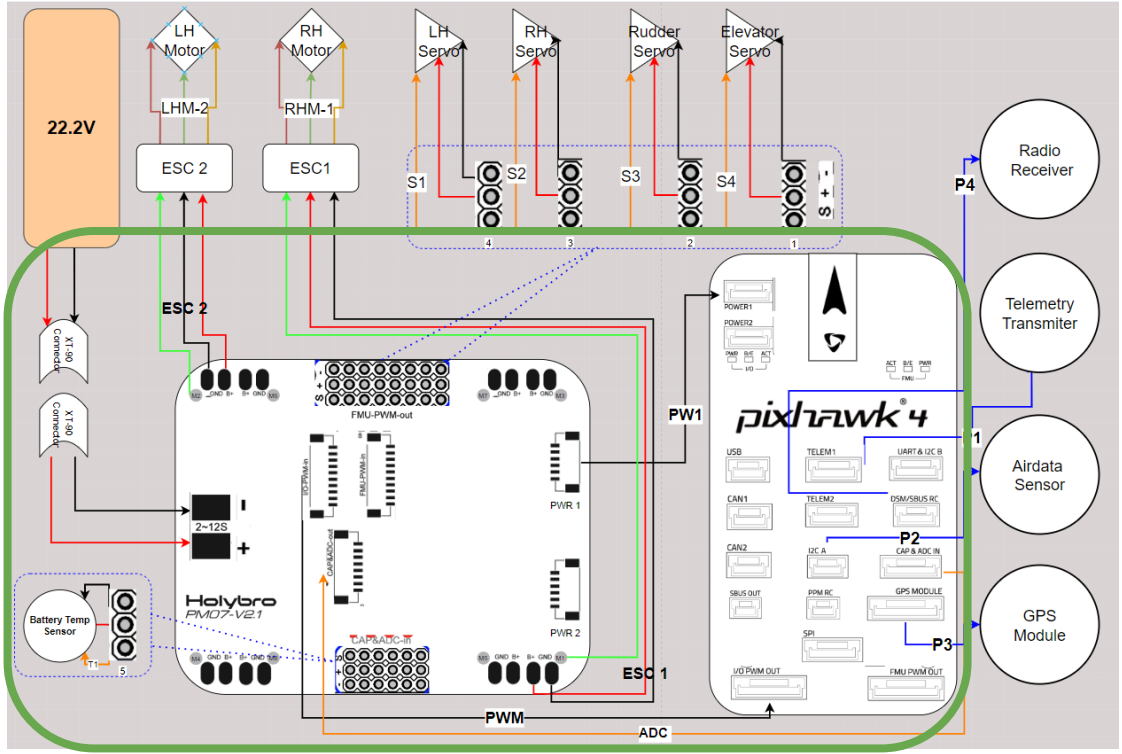
- **Battery Thermocouple → Provides Battery Temperature Data:**
- **Battery Voltmeter → Provides Nominal Load/Unload Battery Voltage**
- **Battery Integrated Shunt → Provides Battery Current Measurement**



Test Readiness - Electronics: Comprehensive Battery Endurance Validation

Data Acquisition: PixHawk 4 - Diagram

Functional Req. 7 & Design Req. 7

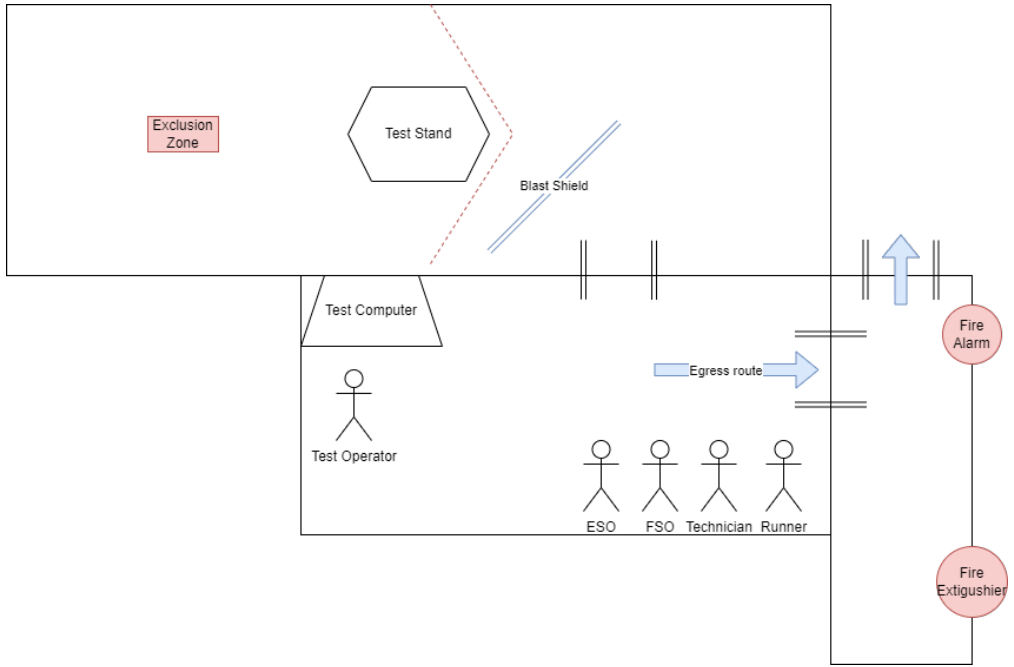


Test Readiness - Electronics

Functional Req. 7 & Design Req. 7

Test Safety:

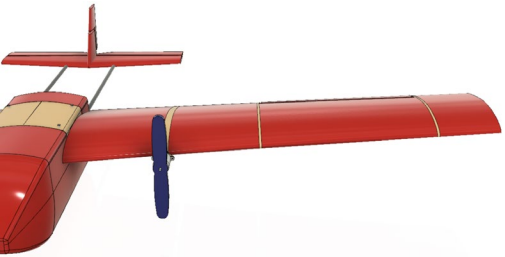
- Test Safety Procedures: HERE
- Fire Safety Procedure: HERE
- Health Emergency Procedure HERE
- Pre-test Safety Item Checklist HERE
- Test Procedure HERE



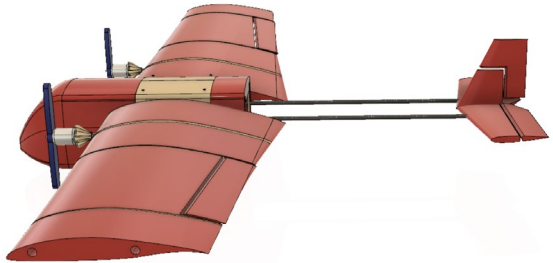
Test Readiness: Structures

Structural Test

1 — Wing



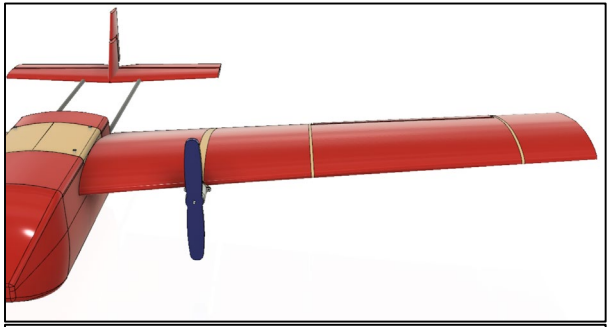
2 — Tail



3 — Fuselage

Methods for Testing

Wing



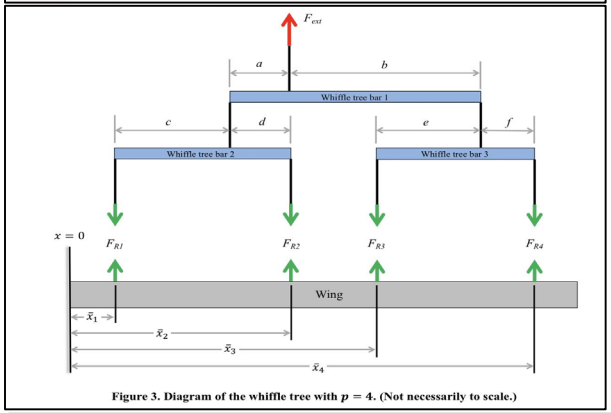
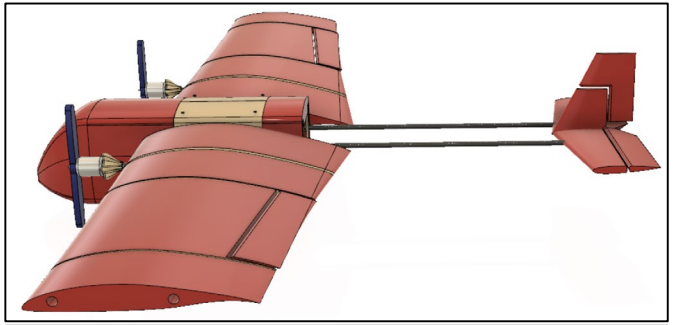
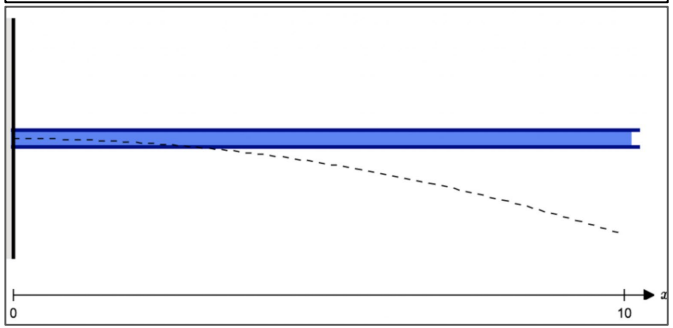


Figure 3. Diagram of the whiffle tree with $p = 4$. (Not necessarily to scale.)

Whiffletree Test

Tail





Tail Deflection Test

Fuselage

Drop Test

Reason for Testing

UAS shall be durable and reliable throughout the mission profile

FR8, DR8

Wing

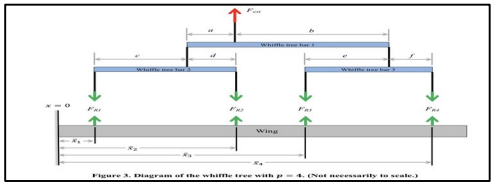
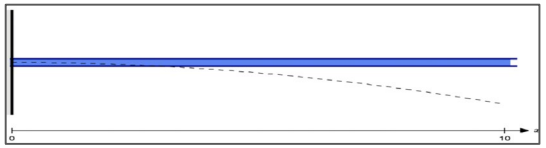


Figure 3. Diagram of the whiffle tree with $p = 4$. (Not necessarily to scale.)

Whiffletree Test

- Wings must sustain payload and aircraft weight.
- **Fuselage + Wing Test**
  - Ensure modularity does not compromise aircraft structure.

Tail



Tail Deflection Test

- **Tail deflection test**
  - Ensures stability can be maintained.
- Tail provides pitch and yaw stability for the aircraft.

Fuselage

Drop Test

- Fuselage and its housings must survive expected landing speeds.

When are we testing?

Wing	Tail	Fuselage

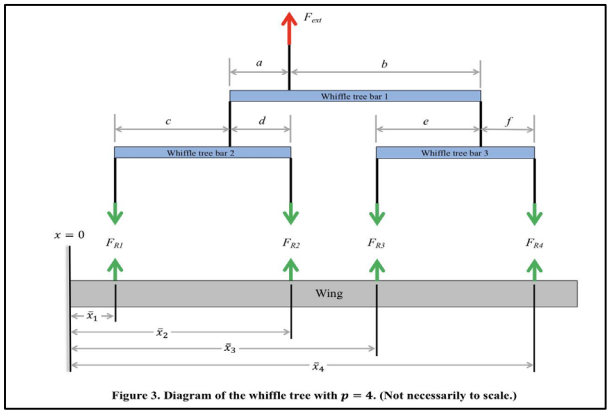
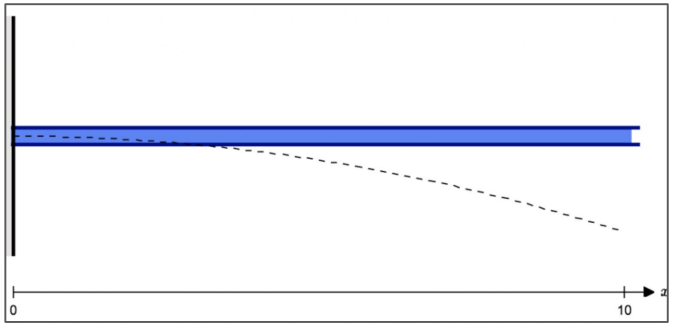


Figure 3. Diagram of the whiffle tree with $p = 4$. (Not necessarily to scale.)



Whiffletree Test	Tail Deflection Test	Drop Test
Scheduled	Scheduled	Scheduled

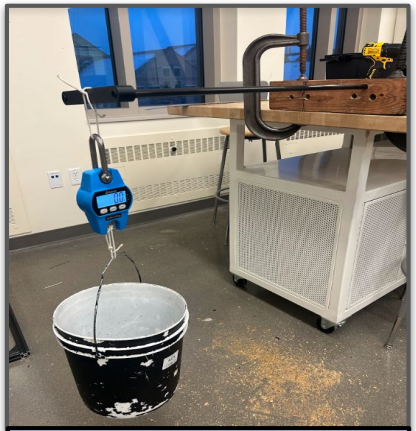
Critical Prerequisite Tests Completed

Pre Test - Tail Spar Deflection

Objective: Verify tail spars can withstand expected loads independently prior to full structure test

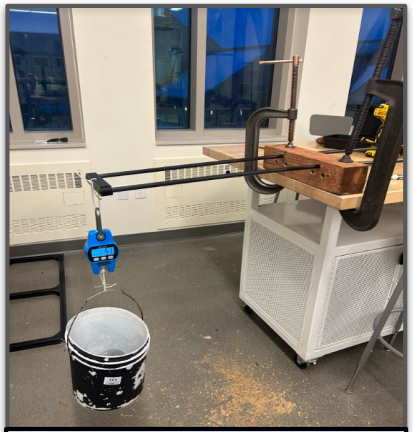
Expected Loading: **2.4 kg** point load on the end of the spars

Loads Applied: **5 kg** point load at the end of one set of spars



Test Setup No Load

3kg point load



5kg point load

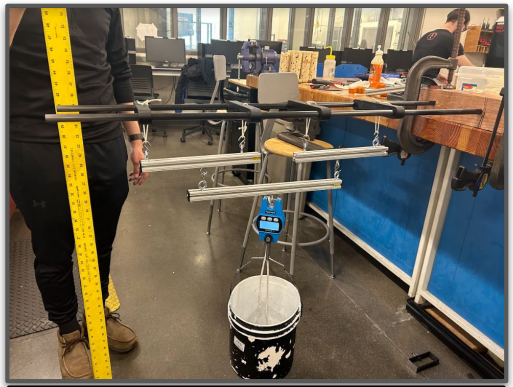
Pre Test - Wing Spar Deflection

Objective: Verify wing spars can withstand expected loads independently prior to full structure test

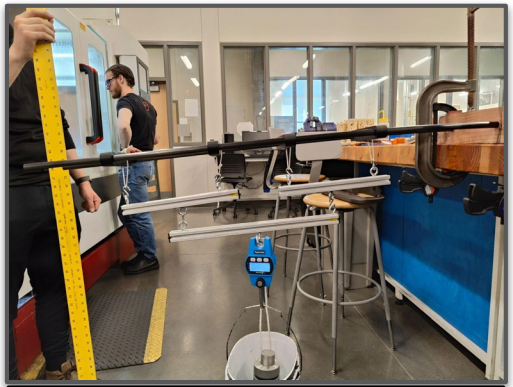
Expected: **11 kg** distributed load on each pair of spars

Loads Applied: **15 kg** distributed load to one pair of spars

Wing Spar Mounting

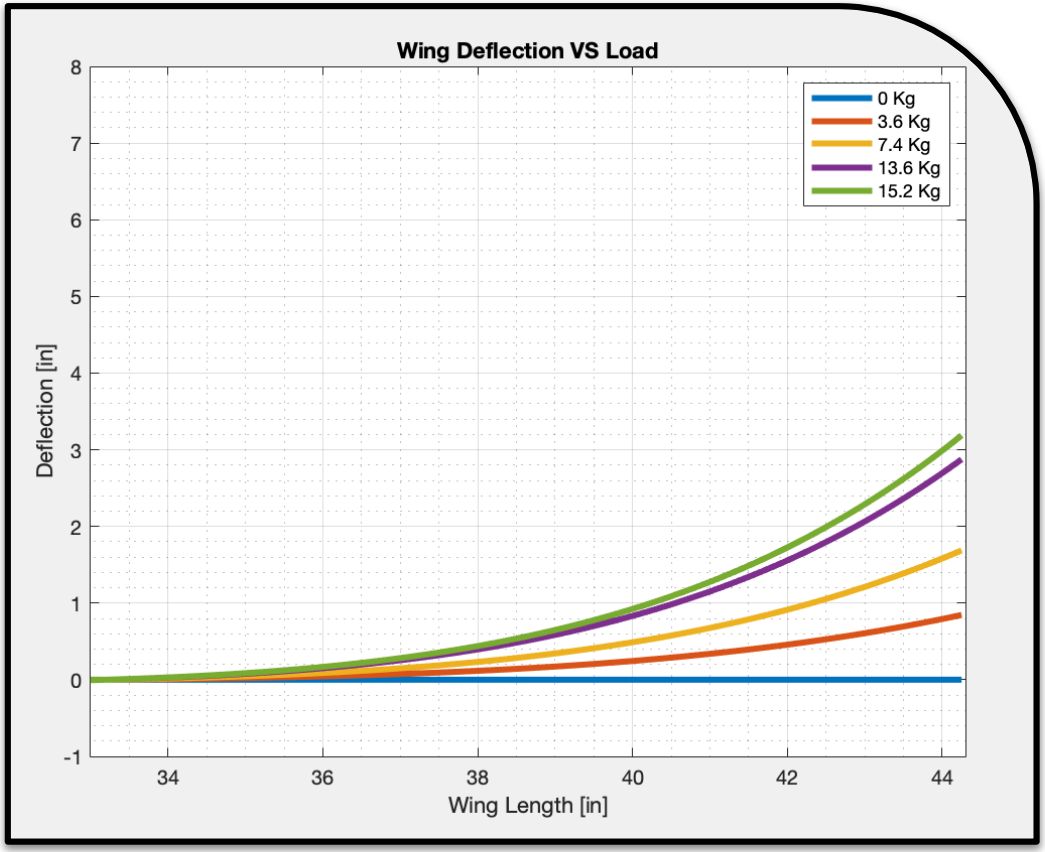


Test Setup Unloaded



Test with 15.2 kg load

Pre Test - Wing Spar Deflection



Model Predicted - Worst Case Scenario

Max Lift Force: ***215 Newtons***

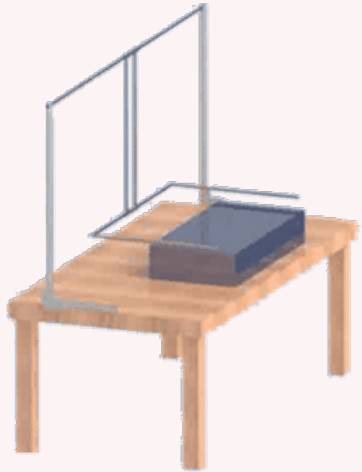
Our Tested Force: ***298.12 Newtons***

Safety Margin: ***36 %*** with ***4.12 degree*** deflection

One Procedure Completed

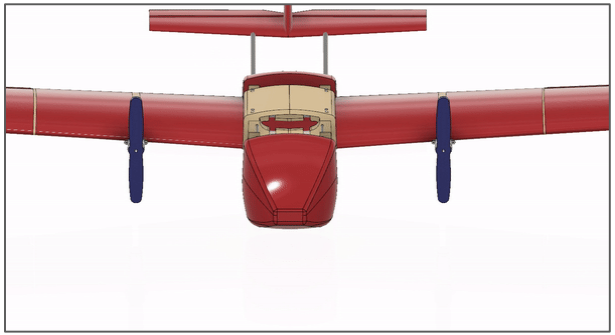
Wing Foam Cutting

- One section cut



Our Focus for this Presentation

Structure Junction



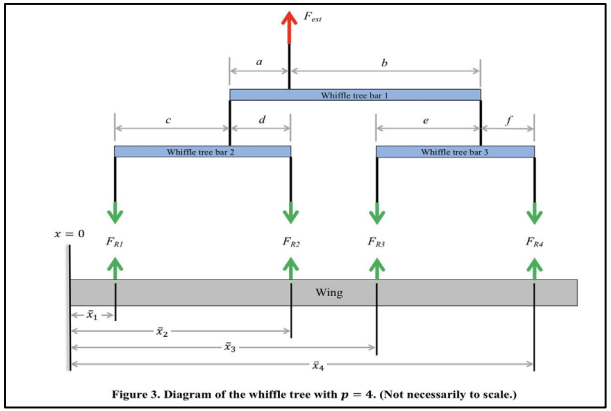


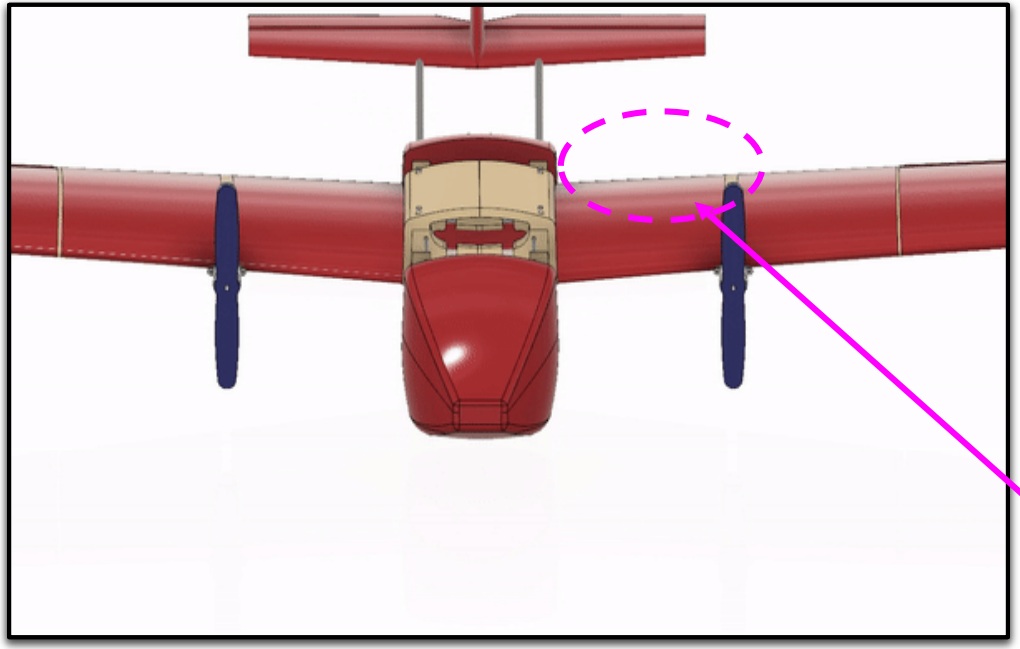
Figure 3. Diagram of the whiffle tree with $p = 4$. (Not necessarily to scale.)

Whiffletree Test

Tail

Fuselage

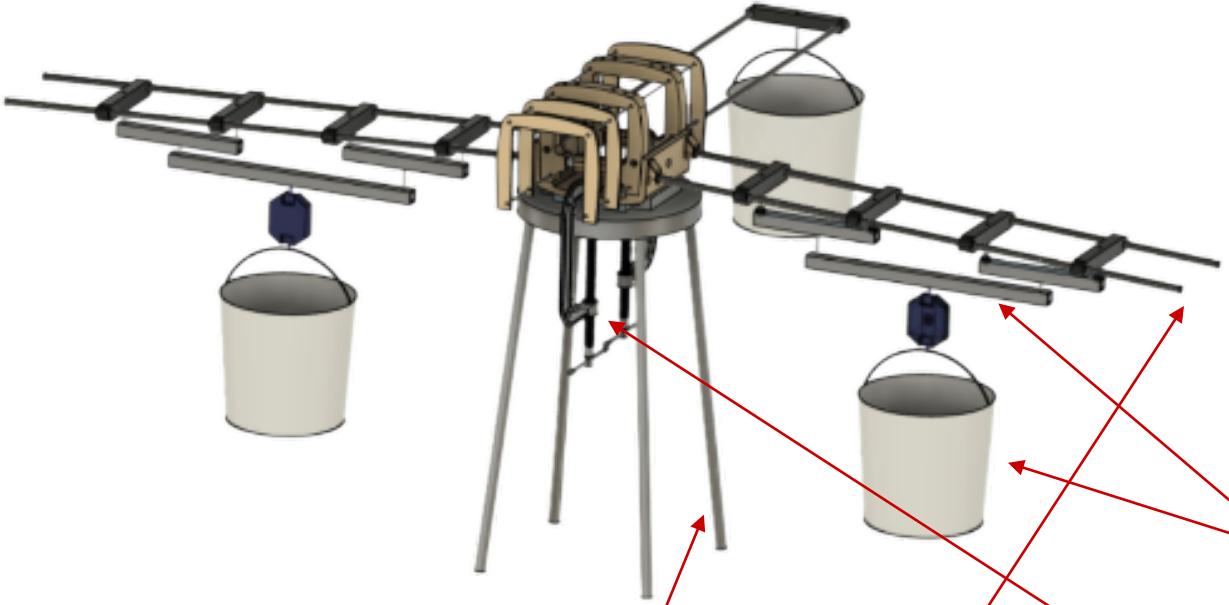
What we are Looking For:



Wing-Fuselage-Pin Junction

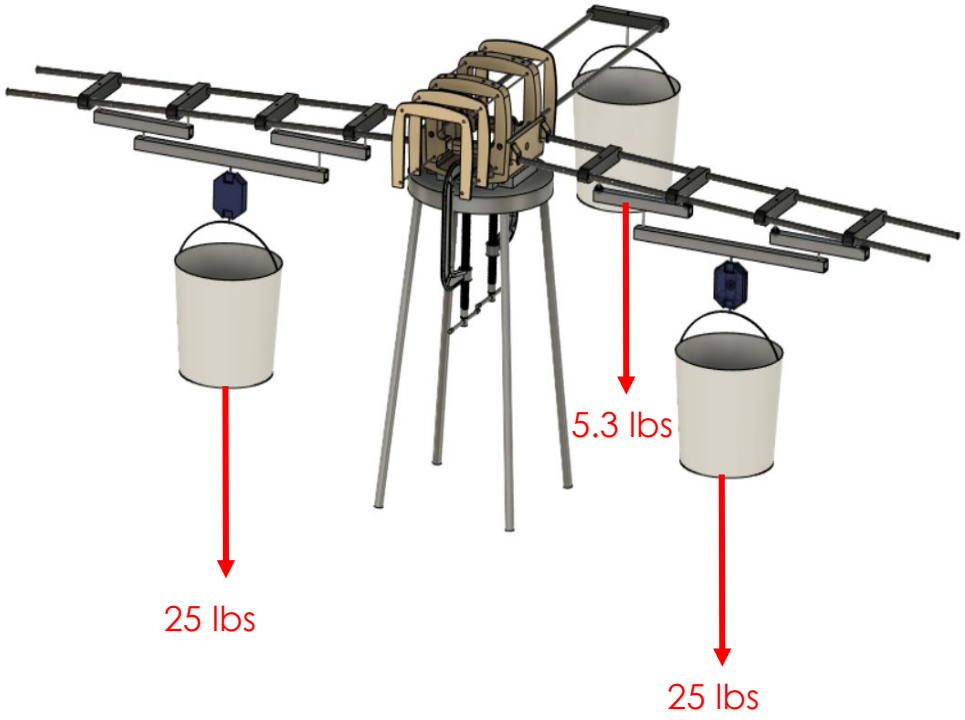
- Predicted Lift Force
- Predicted Compressive Stress
- The Analysis

Test CONOPS



Operator	Safety Wear	Chair/Base-Set-up	Structure	Clamps	Whiffletree	Bucket & Scale

What we are Testing



How much Weight?

Wing

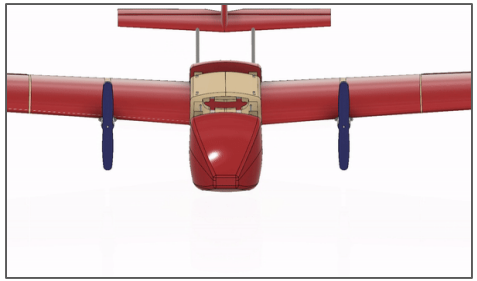
- **215 Newtons = 48.44 lbf**
  - Load wings with **50 lbs** minimum to guarantee survivability of worst case scenario.

Tail

- **23.5 N = 5.3 lbf**
  - Model expectation is 2.4 kg

Procedures - Safety Risks - Mitigation

Wing & Fuselage : Whiffletree



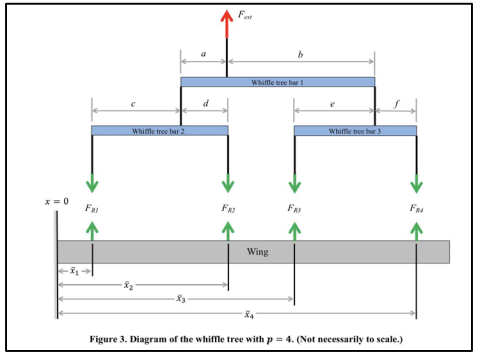


Figure 3. Diagram of the whiffle tree with $p = 4$. (Not necessarily to scale.)

Whiffletree Test

Procedure	Safety Risk
1. Have Structure 2. Secure structure (clamp ribs) 3. Attach loading housings around wings 4. Outermost bar attached to bucket. 5. Fill bucket until wing snaps or reaches design limit (**215 Newtons**)	• Structure Fails or Cable Snaps • Clamp Failure • Structure Falls • **Mitigate By** - Wear closed toe shoes - Wear glasses (debris) - Ensure tight clamp

Mitigation Example

Wing and Fuselage

General Checklist

	Yes	No	N/A	Comment	Student Initials
1 Safety Glasses On?				Everyone has safety glasses on.	X.X
2 Others with you?				All team is here and faculty staff aware of our test.	X.X

Clothing Checklist

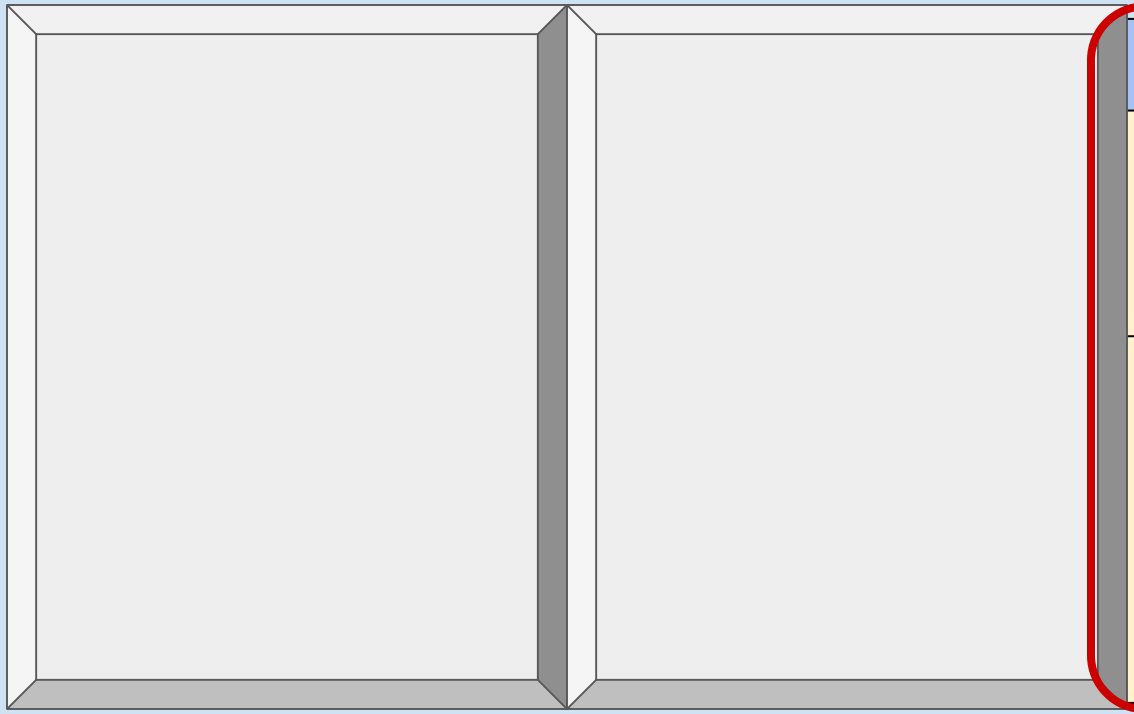
	Yes	No	N/A	Comment	Student Initials
1 Closed Toed-Shoes?				Everyone is wearing closed toed shoes	X.X
2 No hanging jewelry?				Everyone has appropriate clothing and no dangling jewelry.	X.X

Procedure

	Yes	No	N/A	Comment	Student Initials
1. Attach Clamps				They have been attached and double checked for tightness.	X.X
2 Get Measuring device				We have a ruler, it was attached to background reference.	X.X

Full Checklist

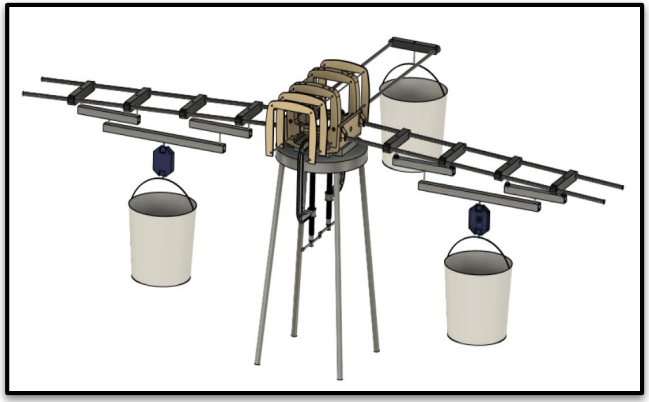
Test Equipment and Facilities



For this Test
Wood and Composites Shop • Sanding machine and Painting
Machine Shop • Drill Bits • Drill Press • Saw • Clamps

Structures Progress Timeline

1



Construction in Progress

2

Complete

3

✓ Model Verified

Testing Complete

Test Readiness: Full-System

Test Readiness - Full Flight Integration

Rationale for Testing:

Functional Req. 1: UAS shall adhere to **FAA Part 107** and **MIL-F-8785C**

Functional Req. 5: UAS shall support a payload with a weight ranging from **1.5 - 3 kg**

Functional Req. 8: UAS shall be durable and reliable throughout the mission profile

Design Req. 2: Modularization of airframe wings, weight limit of **15.8 kg**

Design Req. 8: Static and Dynamic Longitudinal Lateral Stability

Metrics of success:

1. CARROT UAS achieves stable flight
2. CARROT UAS experiences minimal damage to control surfaces/structure/fuselage during Take-off, flight and landing

Test Readiness - Full-System Flight #1

Prerequisites for Testing: PASS Whiffletree , Static Thrust, Glide, Launcher Test, Drop Test

No prohibiting NOTAMs, No Red Flag conditions, winds less than 8 m/s (17mph), certified Boulder EMS Pilot

Purpose of Prerequisites:

Whiffletree - Structure can withstand expected forces

Static Thrust - Wiring correct and motors capable of required thrust

Glide - UAS capable of transmit and receive. Confirm Airframe stable

Launcher - Subsystem 'Safe' and capable of placing aircraft in flight

Drop Test - Battery Secure

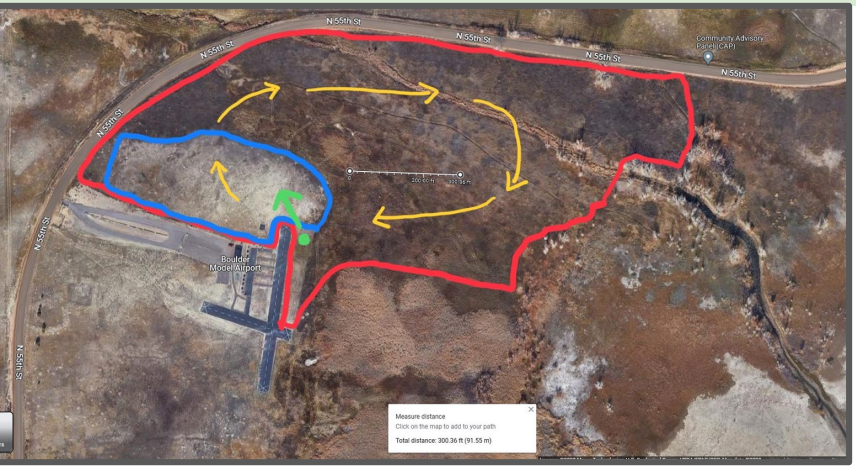
Lower the risk of Radio Frequency interference, Fire, and UAS being 'stuck' further away

Test Readiness - Full-System Flight #1

Scope of the Testing Tasks:

- Full flight test, test cards for flight maneuvers.
- Operational/Functional CARROT UAS, Boulder Model Airport Access
- Launcher to place UAS in Flight, Test Cards to verify maneuverability and control surface functionality. First full landing.
- Focus on durability and being flight capable

Test Readiness - Full-System Flight #1



Red - Area where no escort required. Faster response to crash

Blue - Dirt patch. Desired area for controlled crash low fire hazard

Green - Launcher placement and direction

Orange - Flight path

Fire extinguisher and smothering sand will be in place and ready to respond to crash

Maintain constant communication with pilot and observer(s) with binoculars

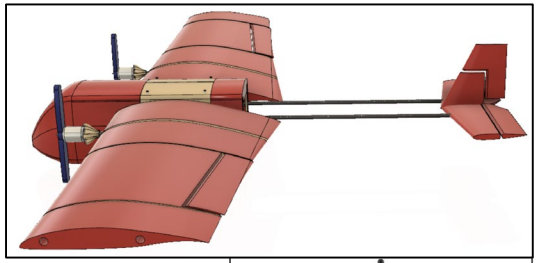
Designated steps in test cards verify performance/cancel test

Monitor Battery to remain at or below 110 F during flight

Designated Emergency responders with fire extinguishers and smothering sand ready

Test Readiness - Full-System Flight #1

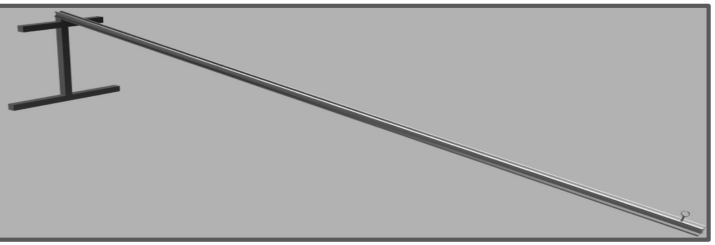
Functional Reqs. 1, 5 & Design Req. 2



- Phase 1 - Set up
  - Pre-Brief - Safety
  - Pre-Position Equipment
  - UAS Pieced together
- System Checkout
  - Hook up Battery
  - Power on
  - Check transmission Range
  - Verify UAS will continuously Receive commands and transmit telemetry

Test Readiness - Full-System Flight #1

Functional Req. 8 & Design Req. 8



- Phase 2 - Launch
  - Launch Rail configured
  - CARROT Loaded
  - Launch
- Phase 3 - Flight
  - 16 m/s (36mph) at 122 m (400 ft) AGL
  - 4 Deg angle of attack
  - No lower than 91m (300 ft) AGL
  - Multiple test cards
    - PID Calibration
    - Slow Climb and Dive
    - Slow bank to left and right
    - Multiple points to check with pilot and observers for test cancellation

Test Readiness - Full-System Flight #1

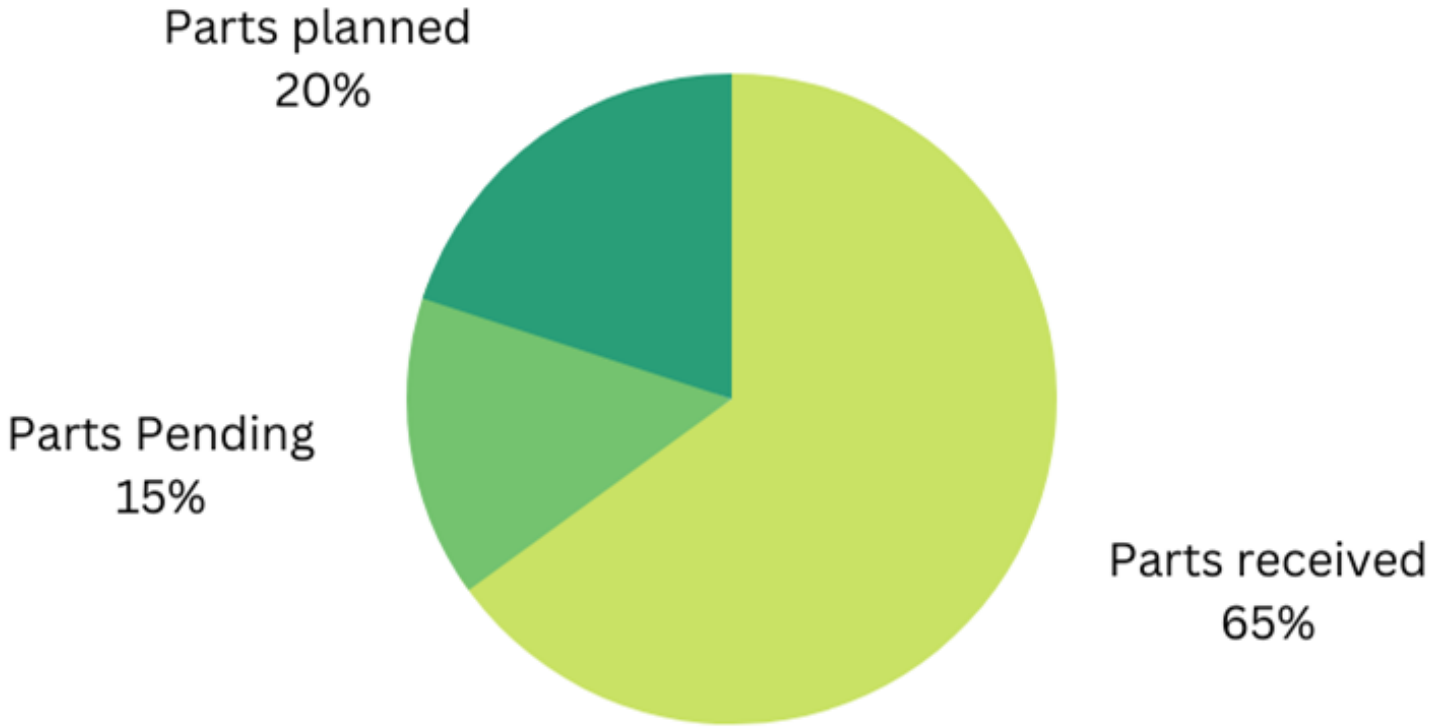
Functional Req. 8

- Phase 4 - Landing
  - Coordinate Landing area in dirt field
  - Fire response ready
  - Verify battery survival
  - Verify Propeller survival
  - Check overall damage
  - Modify/repair as required

- If significant damage sustained
  - FR#4, Easy manufacture and repair

Budget Analysis

Test Readiness - Budget Analysis



Test Readiness - Budget Analysis

- ✓ Carbon Fiber Rods
- ✓ PLA Filament
- ✓ Launch Rail
- ✓ Battery
- ✓ Pixhawk
- ✓ ESC
- ✓ Motors

Functional Reqs. 3, 7, 8 & Design Req. 3, 7, & 8

1 ½ Week Lead Time

77% Replaceability

Questions?

Test

1.Battery Comprehensive Test

2.Static Thrust Test

3.ESC Test

4.Whiffletree Component Test

5.Whiffletree Wing Test

6.Whiffletree Full Body Test

7.Drop Test

8.Launcher Test

9.Glide Test

10.Flight Test

11. Car Test

12. Elastic Test

Changes in the Schedule

What has Changed Since CDR?:

- Electronics Component Testing has been pushed to occur in the month of February and early March
- Component testing has been done in February rather than March
- Sub system testing is the main focus now for the Month of March
- Full System Test is occurring at the start of April now instead of Late March to Allow team more time

Critical Path and Dependency:

- Assembly of the Aircraft is our highest priority, if not done Subsystems Test are put on stand by till completion
- Big margins for the Assembly phase, these will affect the Flight Test mainly

Hidden Slides

Systems Engineering

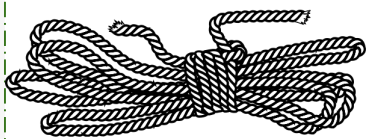
Changes Since CDR - Our Improvements

Launching Rail

- Safer Design Updates

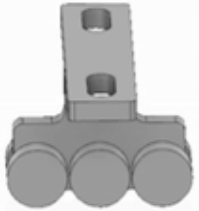
New Components

- Internal Bungee to Rail
- UAV locking Latch
- Safety Release Rope
- Modular Design



The New Components

1



T-Trolley

2

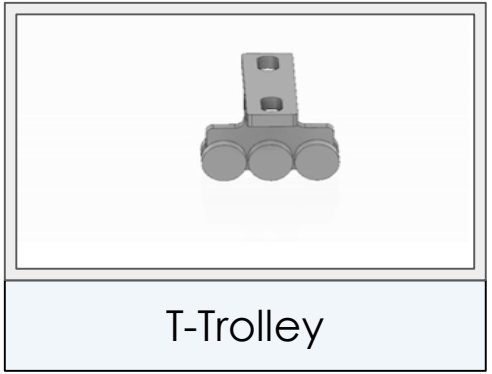
Rotary Latch

3

Strut Channel Rail

What Changed ?

1



T-Trolley

Quantity: 2

Height: 2.75 inch

Length: 5.9 inch

Width: 3.35

2

Rotary Latch

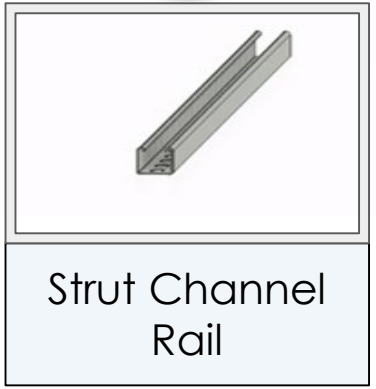
Quantity: 1

Height: 3.5 inch

Length: 1.1 inch

Width:

3



Strut Channel Rail

Quantity: 3

Height: 1.5 inch

Length: 4 ft (each)

Width: 1.62 inch

All Together

Manufacturing

Backup Slides Electronics Tests

Test Readiness - Static Thrust Test

Rationale for Testing:

- To verify MATLAB thrust and power models

Prerequisites for Testing:

- Calibrated load cells
- Arduino scripts to read and save load cell data.
- ESC and RC calibration
- Integrated electronics: arduino, amplifier, load cells, breadboard.

Test Readiness - Static Thrust Test

Scope of the Testing Tasks:

- Test Fixtures:
  - Custom mounting attachment for test stand inside engine test cell
- Test equipment:
  - Pixhawk, Arduino UNO, HX711 amplifier, battery, SMEAD engine test cell, load cell (2), motor, propeller, ESC
- Test safety procedures on hand https://docs.google.com/document/d/1koiVchc_i4zeOp6lZrNLoZtorCjkap-tWB8YLxxbGQw/edit
  - Fire Safety Procedure: HERE
  - Health Emergency Procedure HERE
  - Pre-test safety item checklist

Test Readiness - Static Thrust Test

Scope of the Testing Tasks:

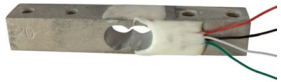
Sensors:

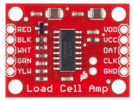
- **Sparkfun LOAD CELL - 10KG STRAIGHT BAR TA**
  - Calibration complete
  - Open source Arduino IDE code to determine a calibration factor.
  - Known weight was placed on cell and calibration factor adjusted until read weight matched known weight (+/- .05 pounds).
- **Temperature sensor:**
  - Calibration and Pixhawk integration complete
  - Data automatically acquired digitally by Pixhawk and Ardupilot

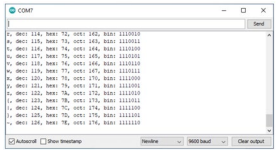
Data Acquisition: Arduino

Functional Req. 7 & Design Req. 7

- **Load Cell → provides Thrust data:**







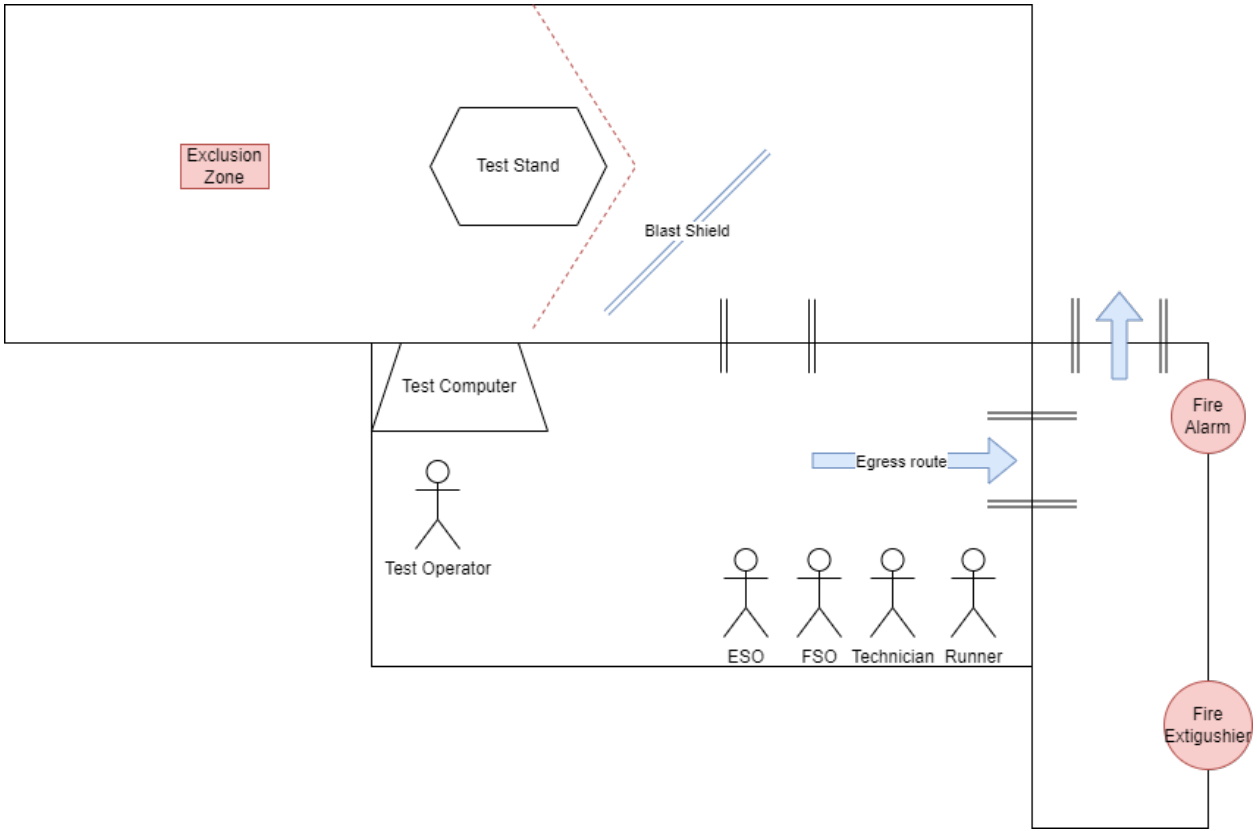
Load Cell → HX711 amplifier → Arduino ADC → Arduino Serial Monitor → Convert to Text File → Convert to CSV → Import to MATLAB → Process for Visualization

Test Readiness - Static Thrust Test

Test Procedure Overview:

1. Connect sensor equipment and motor to test stand
2. Connect Pixhawk to ground station laptop and RC transmitter
3. Slowly ramp up throttle to 100% and back down to zero
4. Monitor motor and battery temperature
    a. Stop test if motor temperature reaches 100 C or battery reaches 110 C
5. Monitor current draw
    a. Stop test if current draw reaches 40 A
6. Repeat 3 times
7. Compare thrust measurement to power and current draw to verify model

Test Readiness - Static Thrust Test - Diagram

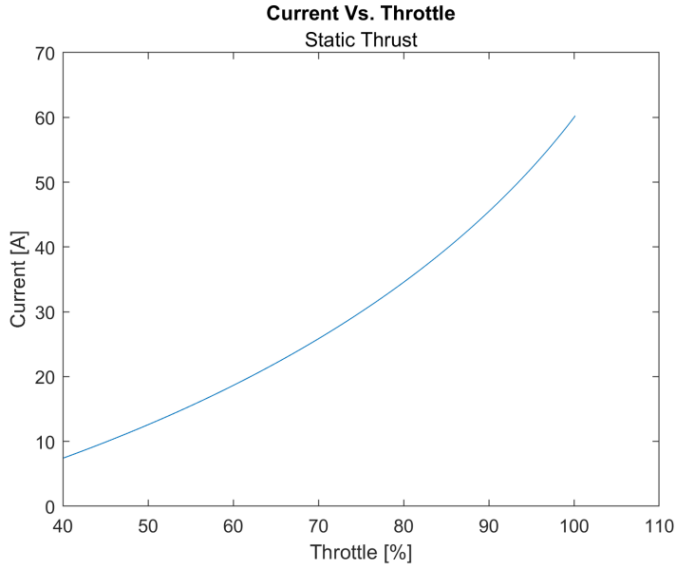


Test Readiness - Static Thrust Test

Requirements Verification:

Functional Req. 7: UAS shall provide continuous coverage for the duration of the mission profile

Design Req. 7: Maximize endurance for **4 hours** flight time (without autonomous control) at 6,000 ft MSL



- Matlab endurance models based on thrust
  - Need experimental data to confirm power draw and thrust models
- Verification of models allows for greater fidelity of endurance target

Fire Safety Procedure

- Remotely terminate the test
  - First terminate through software/controls
  - If that fails, terminate by cutting electrical power
- **Emergency Operations Officer** will call **Matt Rhodes *and*** send the **Runner** for notification of a fire emergency.
- Fire Safety Officer will assess fire
  - Is fire isolated to the battery bunker or LiPo bag?
    - If YES, *Wait for for further instructions from **Matt Rhodes***
      - **DO NOT** enter test cell.
      - Monitor from Operations bunker
      - Technician, Runner, and Emergency Officer will exit the Operations Bunker and wait in the hallway.
    - Proceed to Operations bunker and wait until smoke stops completely
    - If NO, evacuate all personnel from the area. Communicate with Matt Rhodes for further instructions.
  - Has fire spread beyond the test operations area to other areas of the test cell?
    - If YES, is the state of fire a spreading battery fire?
      - If YES
        - Evacuate personnel (do NOT attempt to extinguish).
        - Call **9-1-1**
          - Give address below
          - Inform Fire department this is at CU
          - 3775 Discovery Dr, Boulder, CO 80303
        - Have runner go outside of building and coordinate with fire department personnel when they arrive

Emergency Health Procedure

If a health emergency occurs, the Emergency Operations Officer will immediately contact 9-1-1 and stay next to the individual experiencing a health emergency.

Is the health emergency due to a spreading fire? If YES, evacuate to a safe area.

DO NOT CONDUCT LIFE SAVING MEASURES IN AN UNSAFE LOCATION

- Remove injured and remaining personnel from the unsafe environment
- Contact 9-1-1
  - Coordinate using the following address 3775 Discovery Dr, Boulder, CO 80303
  - Have runner go outside of building and coordinate with Emergency Response personnel when they arrive
- Test Operator will terminate test and retrieve AED + Medical kit
- Fire Safety officer will contact **Matt Rhode: 303-492-7556**
- All personnel will follow any instructions from the 9-1-1 operator.

Pre-test Safety Checklist

1. Is all safety equipment in working order?
    - Goggles
    - Welding gloves
    - Polycarbonate shield
    - Fire extinguisher- Class D
    - Smothering Sand and bucket
    - First aid kit
        - Burn treatment
        - Gauze and tape
        - Surgical gloves
1. Are all personnel in proper clothing?
    - No open toe footwear
    - Full length pants and long sleeve top
    - No synthetic clothing
    - No baggy clothes
    - Long hair tied up
    - No dangly jewelry
1. Is all test equipment in good condition?
2. Has a pre-test brief been conducted?
3. Is the battery in a LiPo-safe bag?
4. Are all non test related combustibles at a safe distance from battery and projectile zone?
5. Are all personnel in the operations bunker?

Test Readiness - ESC Calibration

Rationale for Testing:

- To calibrate motors and RC system to Pixhawk and Ardupilot

Prerequisites for Testing:

- Ardupilot installed and configured on Pixhawk
- RC transmitter calibrated to Ardupilot

Test Readiness - ESC Calibration

Scope of testing tasks:

- Test fixture:
  - Custom mounting attachment for test stand inside engine test cell
- Sensors and data acquisition:
  - No data collected, ESC and Pixhawk calibrate ESC automatically

Test Readiness - ESC Calibration

Procedure overview:

1. Connect motor (WITHOUT PROPS) to test stand Pixhawk to power module
2. Connect RC and telemetry radio to Pixhawk. Connect Pixhawk to Mission Planner.
3. With ESC disconnected from power, move throttle stick to maximum
4. Connect ESC to power, wait for beeps, then return throttle quickly to zero
5. Ensure ESC calibration successful by slowly raising throttle and motor should spin

Test Readiness - ESC Calibration

Requirements Verification:

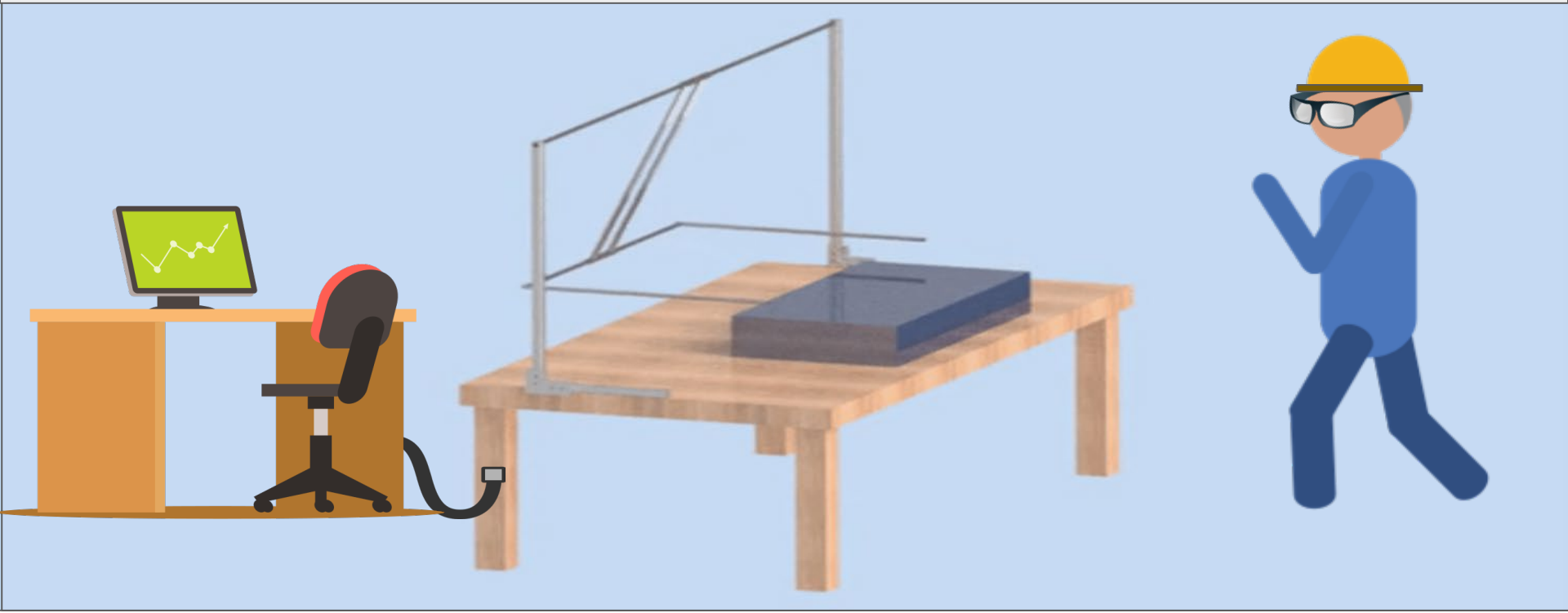
- No requirements directly verified
- Calibration ensures accurate and precise control over motors

Test Readiness - Full System Integration

- Validation of connectors
- Servo operability
- Lights
- Range of motion test

Backup Slides Manufacturing Test

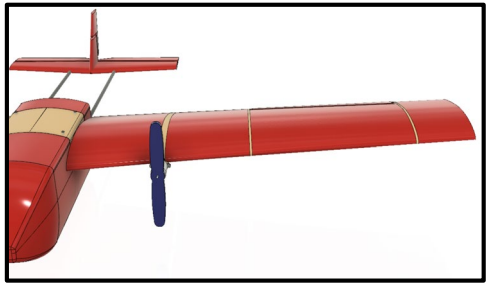
Hot-Wire Cutting Machine CONOPS

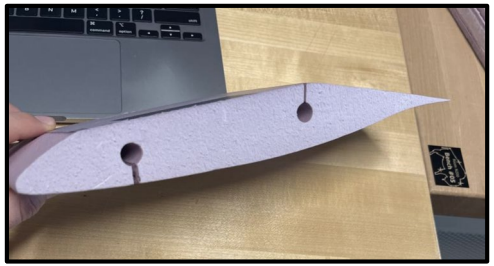


Operator	Safety Wear	Computer + Software	Hot-Wire Machine	Foam	Connection

Procedures and Safety Risks

Wing Hot-Wire Machine



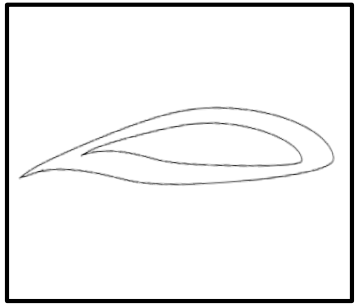


Foam Cut Wing

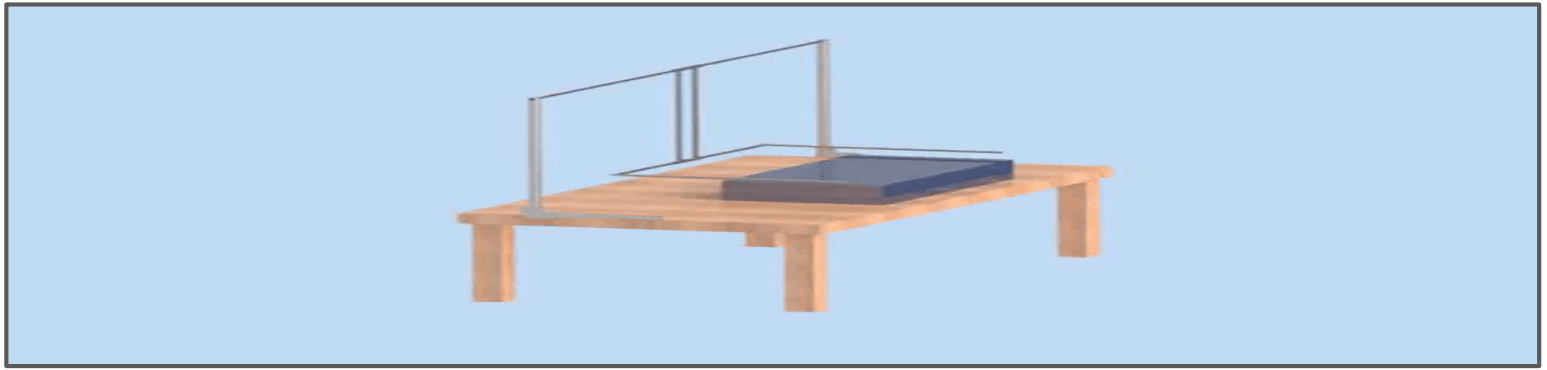
Procedure	Safety Risk
1. Access to hot-wire machine 2. Make sure nothing obstructs the machine's path 3. Open DevCAD 4. Upload file 5. Let machine operate	• Machine: **High Temperature** • **Burn & Fire** - Stay vigilant of surroundings. So nothing gets caught on fire. - Wear glasses - Keep fingers and hands out of the way.

Procedure and Equipment

Hot-Wire Cutting Machine



Cutting Airfoil



Procedure	Equipment
1. Access to hot-wire machine 2. Open DevCAD 3. Upload file 4. Let machine operate	1. Hot-Wire Machine 2. Foam 3. Room 218 4. DevCAD 5. Profili2

Safety Checklist

Hot-Wire Machine

General Checklist

	Yes	No	N/A	Comment	Student Initials
1 Have you done x?					
2 Is x on?					

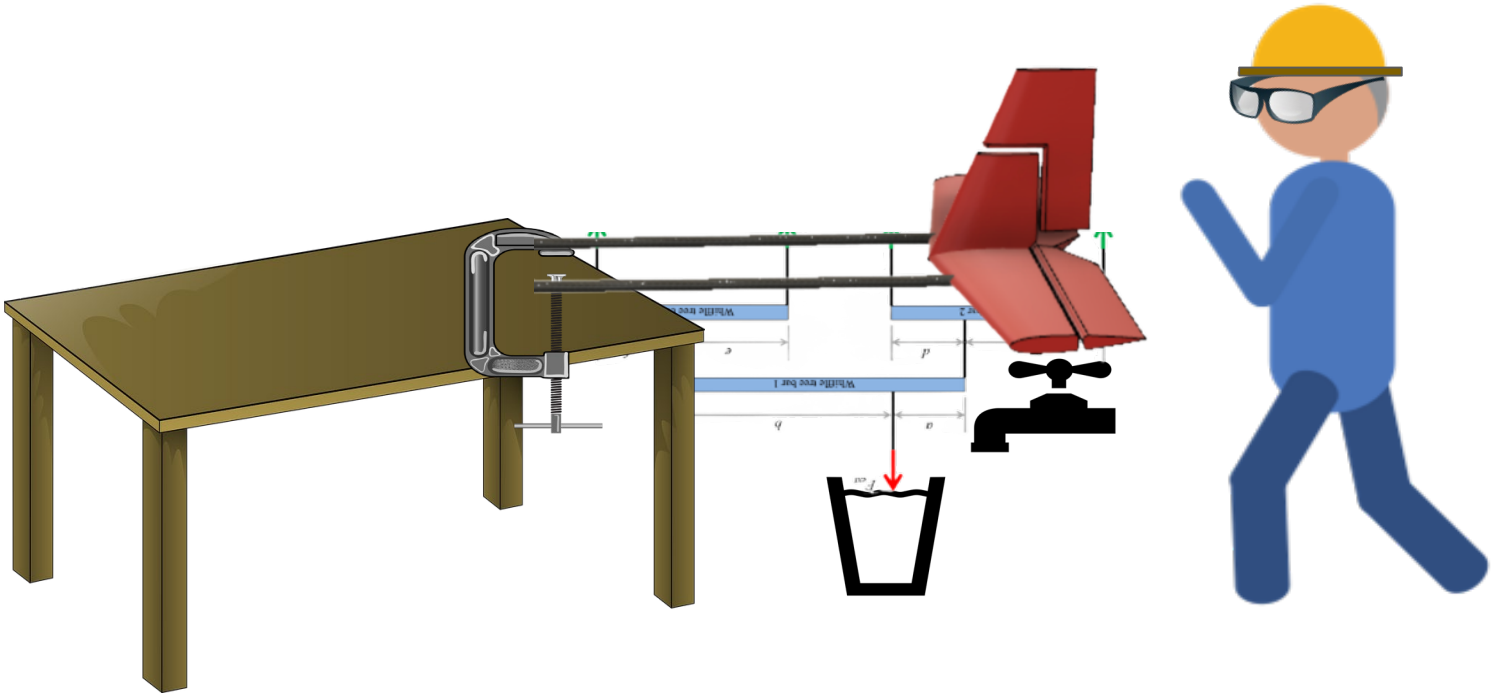
Clothing Checklist

	Yes	No	N/A	Comment	Student Initials
1 Have you done x?					
2 Is x on?					

Electrical Checklist

	Yes	No	N/A	Comment	Student Initials
1 Have you done x?					
2 Is x on?					

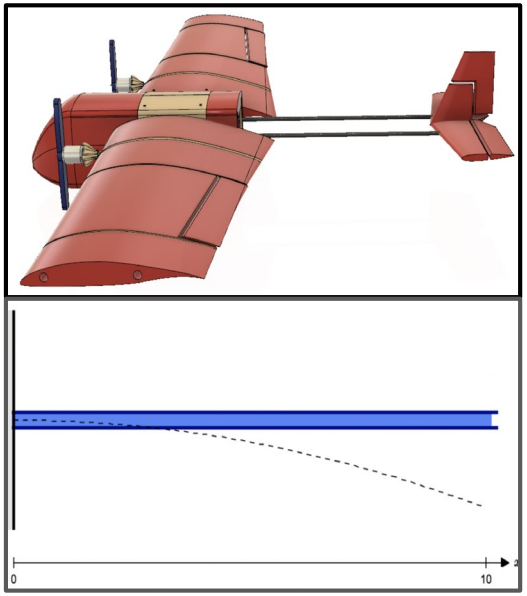
Tail Deflection CONOPS



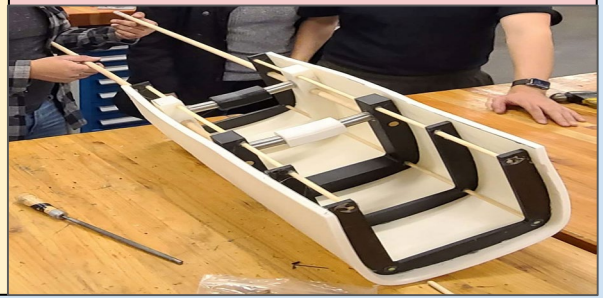
Operator	Safety Wear	Table/Workspace	Tail	Clamp	Whiffletree	Bucket

Procedures and Safety Risks

Tail Deflection

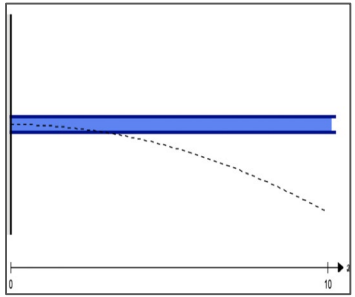


Tail Deflection Test

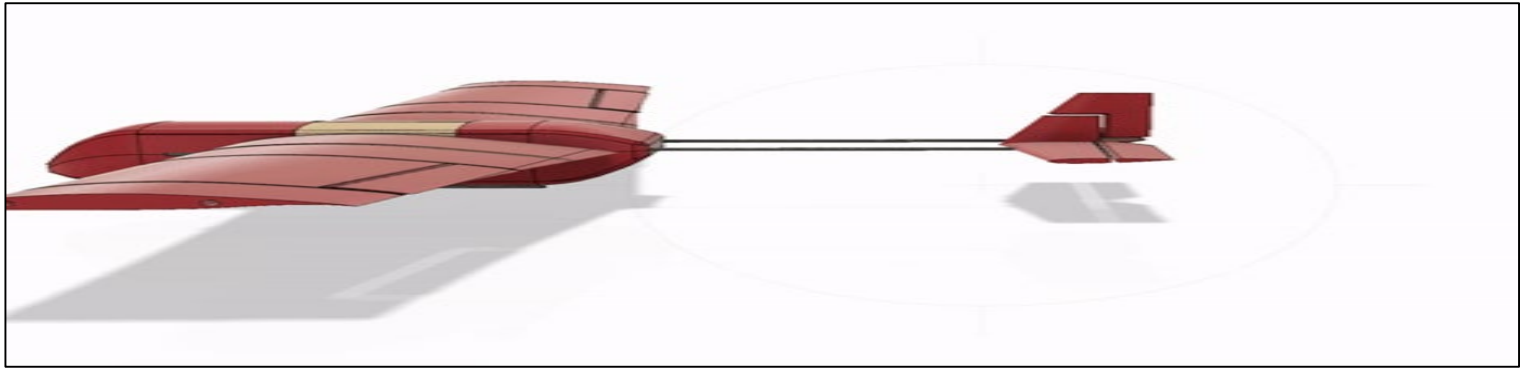
Procedure	Safety Risk
1. Have Fuselage & Tail Structure 2. Secure fuselage (clamp the ribs to table) 3. Attach two cables to each rod 4. Tie cables to bucket. 5. Fill bucket until designed deflection is achieved or failure arises	• Rod failure or Cable Snaps • Clamp Fails - Wear closed toe shoes - Wear glasses (debris) - Ensure tight clamp 

Procedure and Equipment

Tail



Tail Deflection



Procedure

1. Have Fuselage &Tail Structure
2. Secure fuselage (clamp the ribs to table)
3. Attach two cables to each rod
4. Tie cables to bucket.
5. Fill bucket until designed deflection is achieved or failure arises

Equipment

1. Measuring Device +Cable
2. Bucket
3. Water/ Sand/ Books/ weights
4. Clamps

Safety Checklist

Tail Deflection

General Checklist

	Yes	No	N/A	Comment	Student Initials
1 Have you done x?					
2 Is x on?					

Clothing Checklist

	Yes	No	N/A	Comment	Student Initials
1 Have you done x?					
2 Is x on?					

Electrical Checklist

	Yes	No	N/A	Comment	Student Initials
1 Have you done x?					
2 Is x on?					

Drop Test CONOPS

Operator	Safety Wear	Workspace	Structure	High Stance

Procedures and Safety Risks

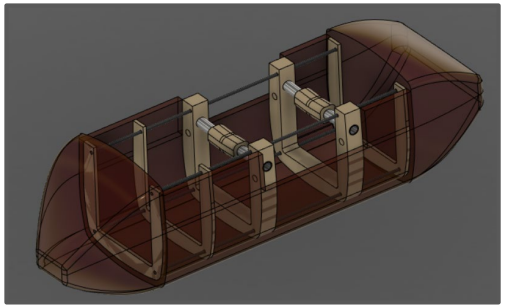
Fuselage Drop Test

Drop Test

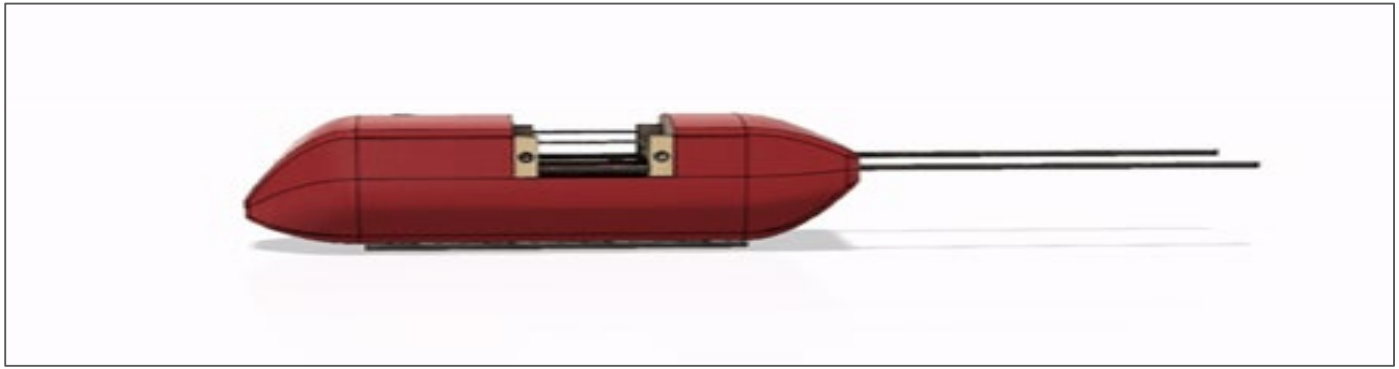
Procedure	Safety Risk
1. Have fuselage structure 2. Load fuselage to payloa 3. Lift fuselage ~15 feet with forklift 4. Drop fuselage and note analyze for damage 5. Repeat until fuselage failure or design's resistance is achieved.	• Height Drop - Wear closed toe shoes - Wear glasses (debris) - Helmet if possible • Forklift - Standing too close can be cause for injury if operator is unaware. - Stay visible - Wear fluorescent clothing if possible.

Procedure and Equipment

Fuselage Drop test



Fuselage Structure



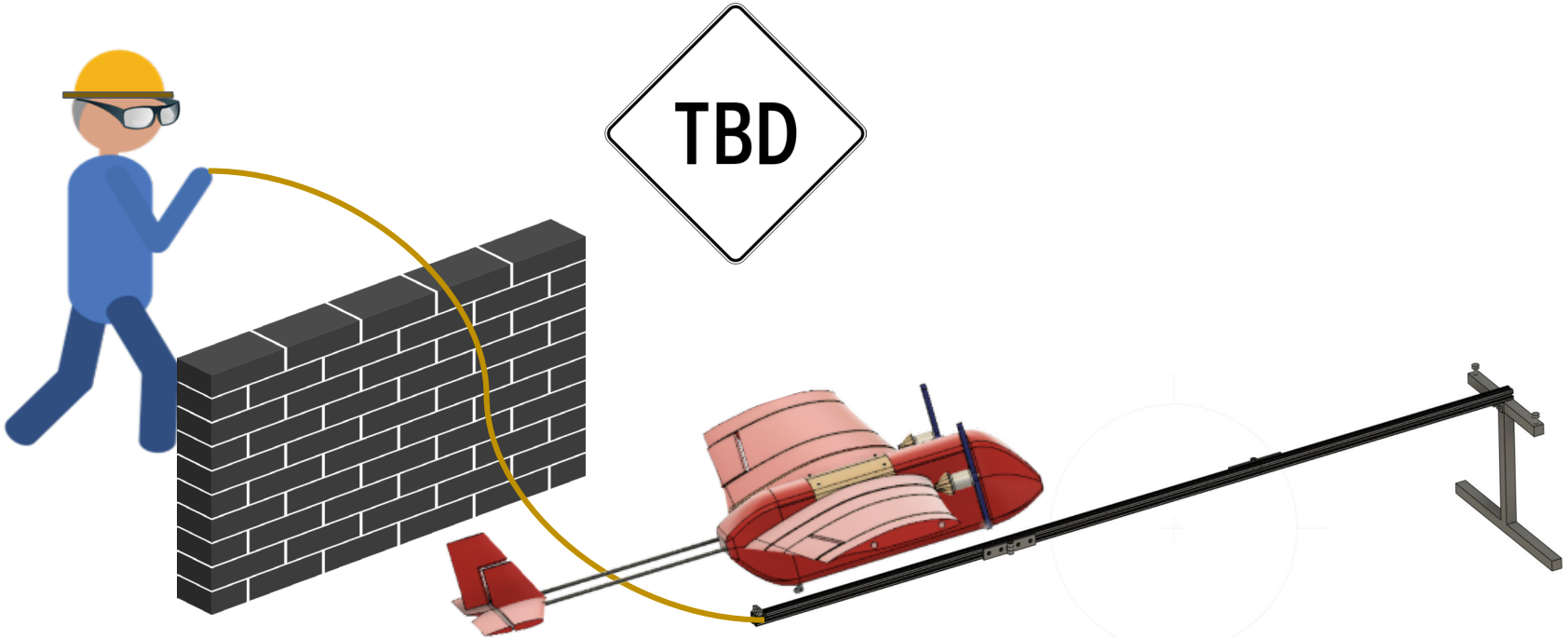
Procedure

1. Have fuselage structure
2. Load fuselage to payload
3. Lift fuselage 1-15 feet with forklift
4. Drop fuselage and note analyze for damage
5. Repeat until fuselage failure or design's resistance is achieved.

Equipment

1. Forklift or High Lifting Stance
2. Measuring Tape
3. Open Space

Launch Rail CONOPS



Operator	Safety Wear	Workspace	Structure	Shield

Launching Rail

Equipment

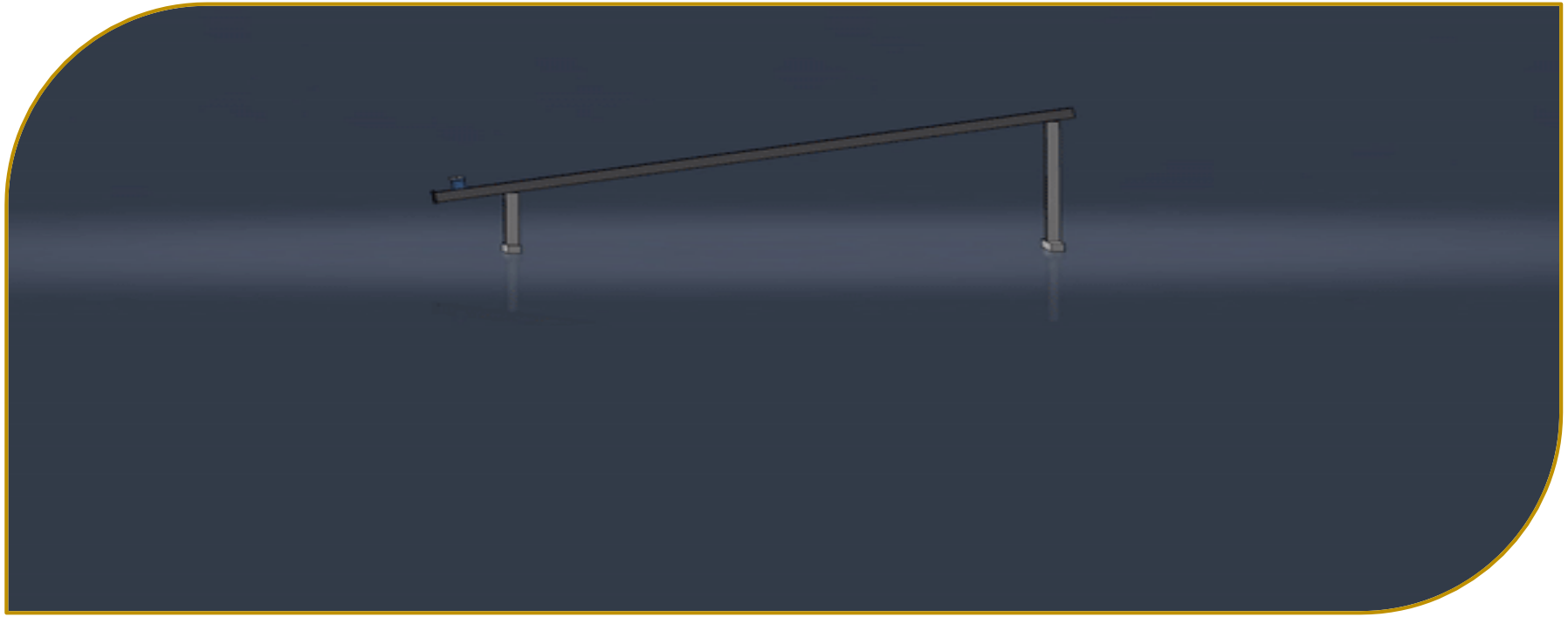
1. Bungee Cords
2. Safety Release Cable
3. Protective Shield
4. Open Space

Procedure	Safety Risk
1. Unfold 8020 rail (unfold hinges) 2. Place 8020 on rail stand 3. Get bungees and secure them to the two stand hooks 4. Put bungees over plane hook. And pull back into position 5. Stand behind shield (plywood or any form of protector) 6. Release Aircraft	• **High Tensioned Bungee** - Wear closed toe shoes - Wear glasses (debris) • **Aircraft is *On*** - Standing too close can be cause for injury. - Stay behind shield or carry shield with you if possible - Have others observing

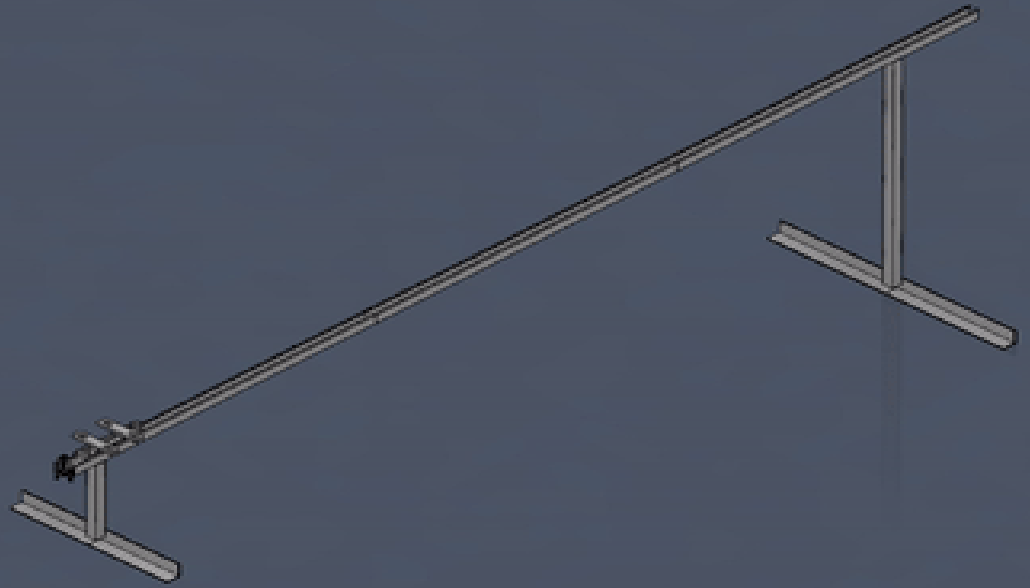
Wing Foam Cutting

Whiffletree Equipment + Fuselage & Wing Test Preparation

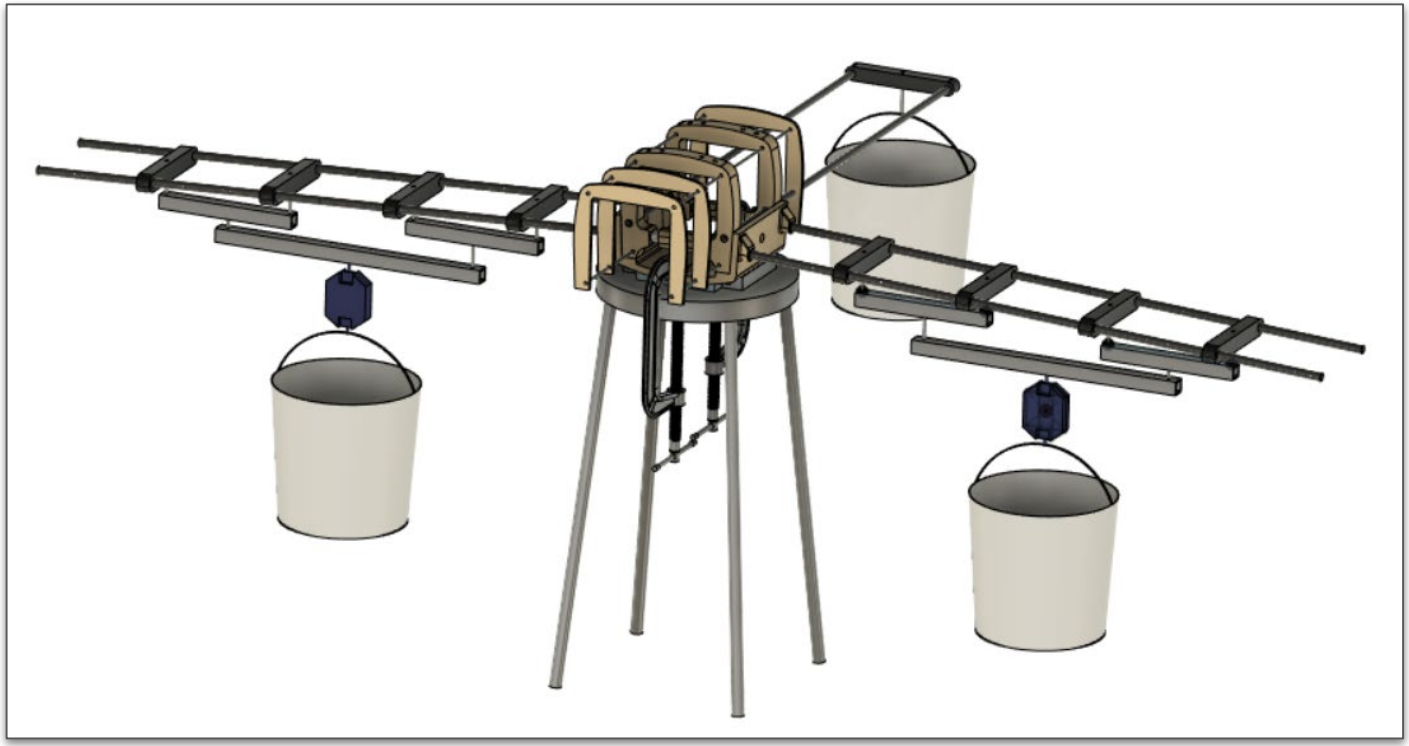
Our New Design:



All Together



What it will Look Like?



Test Equipment

Wing & Fuselage : Whiffletree

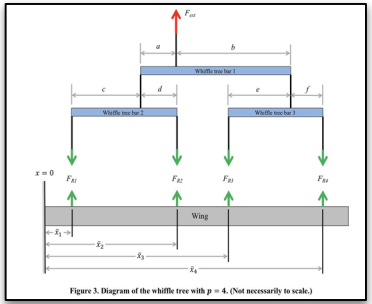
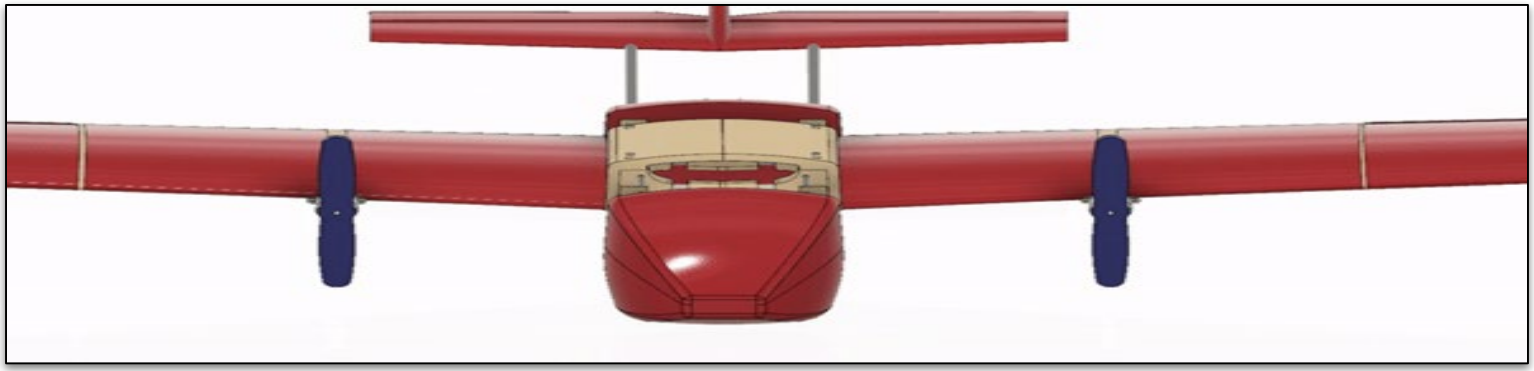


Figure 3. Diagram of the whiffle tree with $p = 4$. (Not necessarily to scale.)

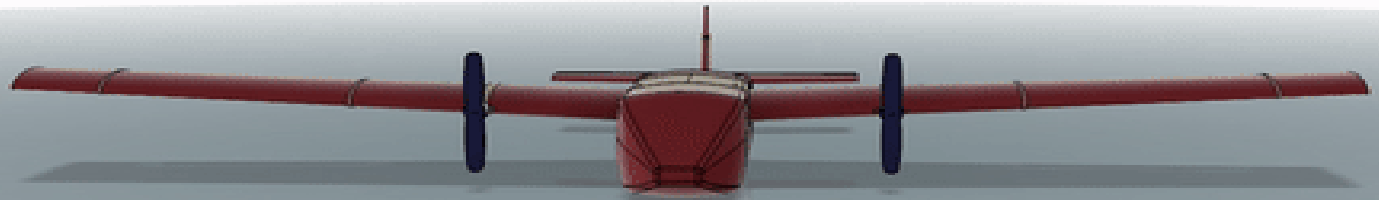
Whiffletree



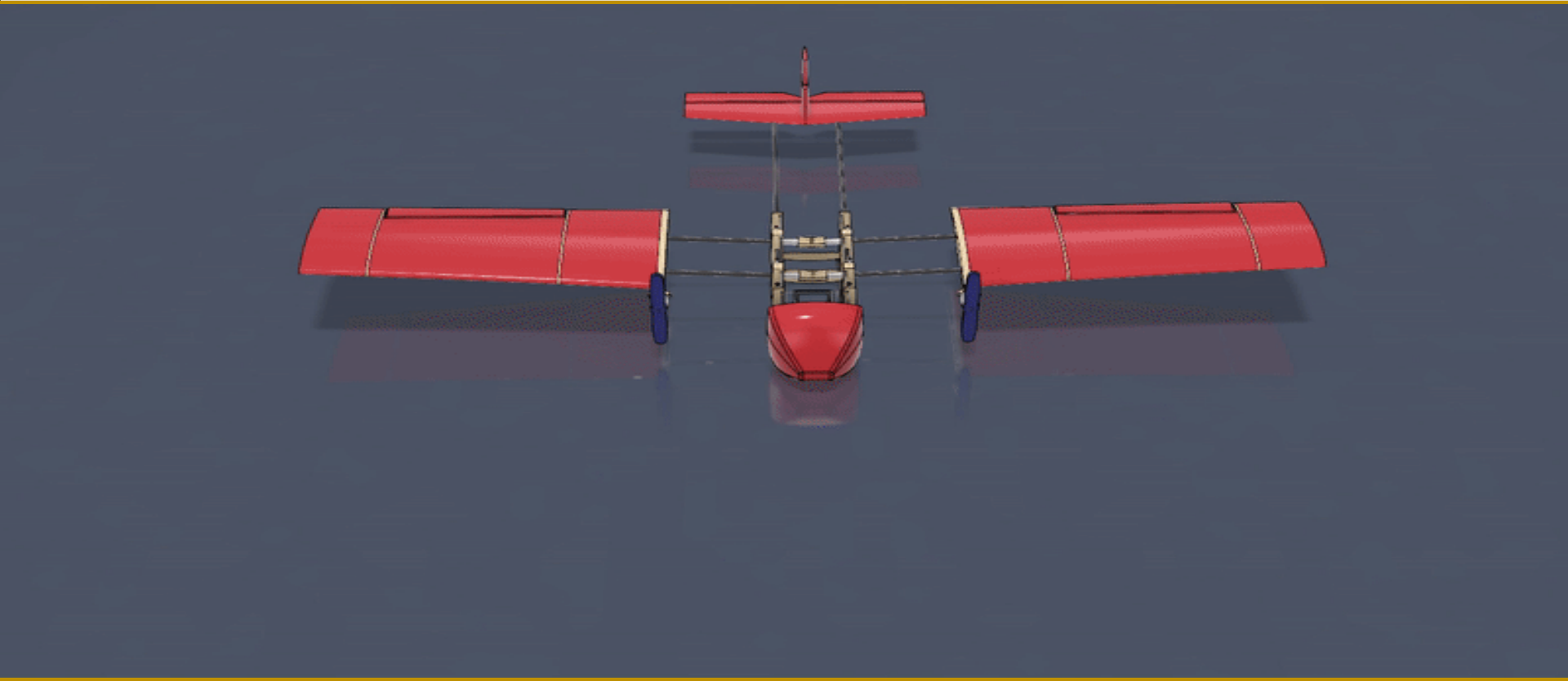
Equipment

1. Measuring Device
2. Bucket
3. Weights
4. Clamps
5. Whiffletree
6. Weight Scale

Our Model



Our Model



Link to video

Backup Slides Aerodynamic Test

Test Readiness - Lift and Drag Determination (Car Test)

Rationale for Not Conducting the Test:

- The airflow seen by the UAS during the test is not indicative of an actual flight
- Too many sources of error
  - The test stand isn't rigid enough and produces a lot of vibrations
  - Ground effect
  - Crossflow
  - Resulted in VORTEX having a standard deviation of at least 2 in their load cell data
- Fuselage required modifications/compromised to conduct test disturbing airflow further
- The time it would take to improve/conduct the test better spent on Launcher and Glide test

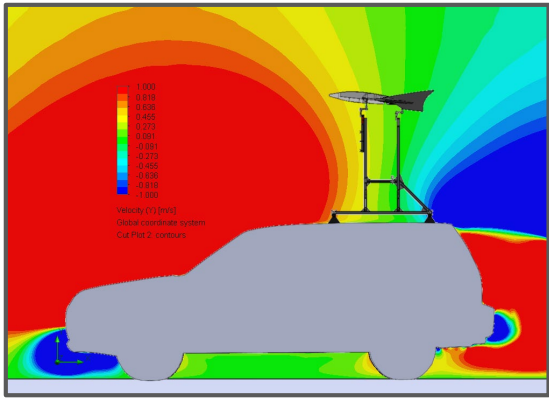


*Image courtesy of team VORTEX

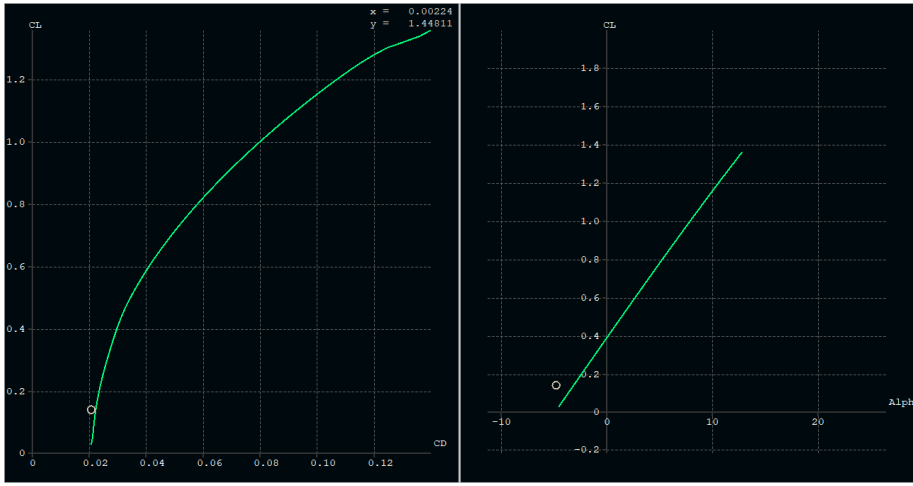
Test Readiness - Lift and Drag Determination (Car Test)

Functional Req. 7 & Design Req. 7

Rationale for Testing:

- To obtain through physical means the lift and drag slope of the aircraft
- Increase confidence in XFLR5 modelling
- Better determine what the expected endurance of the UAS is

Requirement	Description
DR #7	**Maximize endurance for 4 hours flight time**

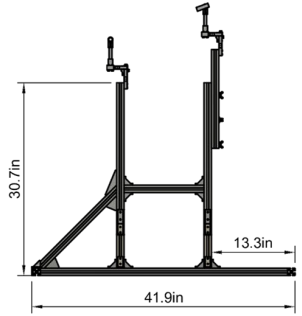


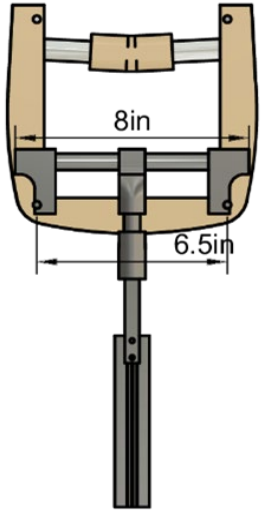
*Lift and Drag Characteristics Predicted by XFLR5

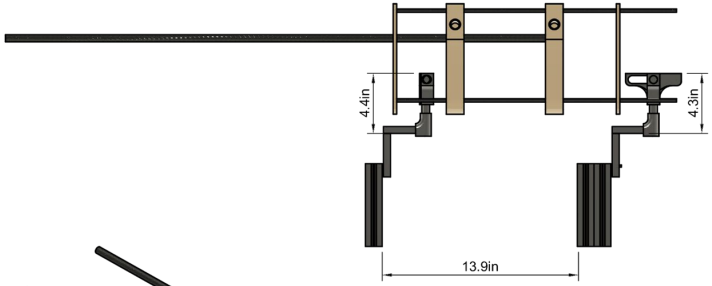
Test Readiness - Lift and Drag Determination (Car Test)

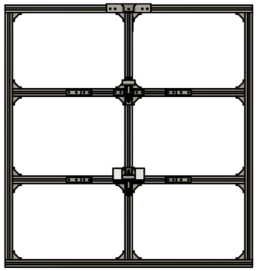
*Image Courtesy of 2019 Team VORTEX

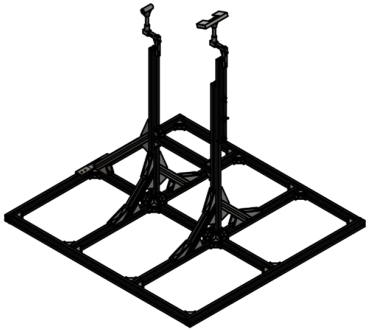
Test Readiness - Lift and Drag Determination (Car Test)

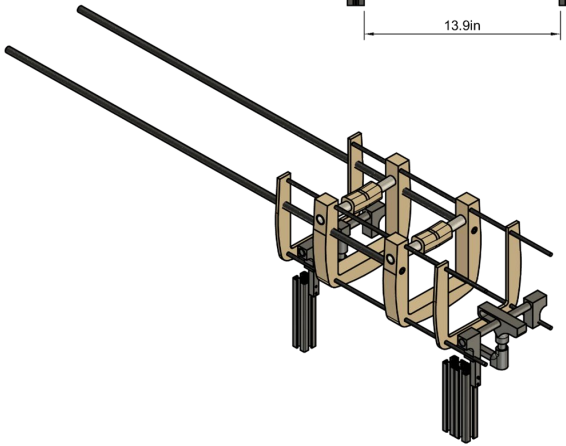




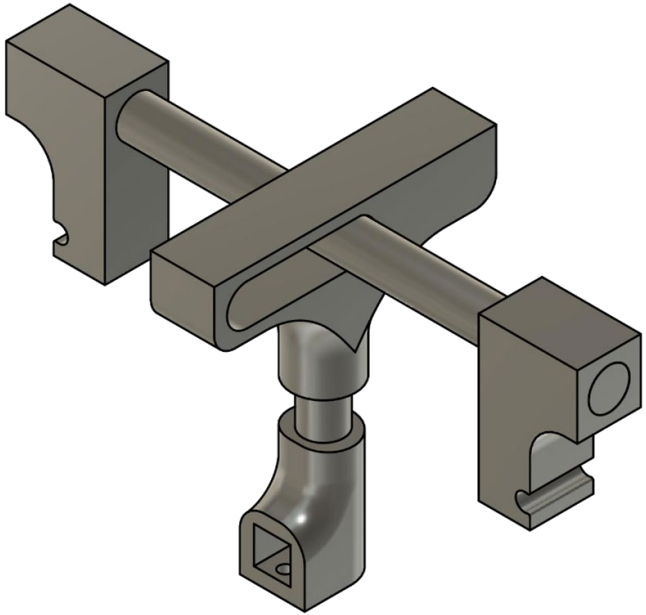


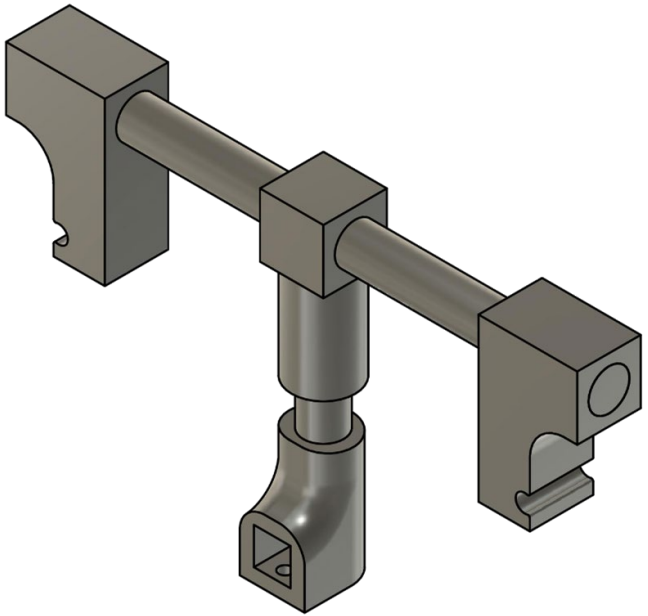






Test Readiness - Lift and Drag Determination (Car Test)





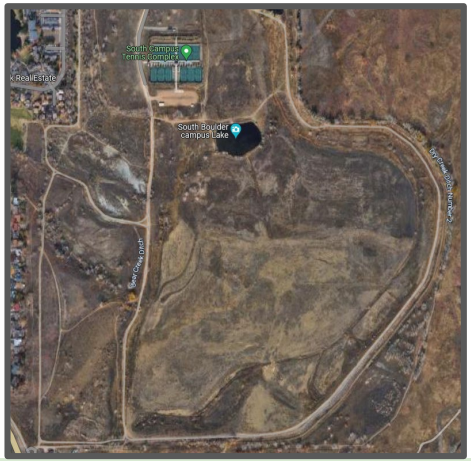
Test Readiness - Stability Glide Test

Functional Req. 8 & Design Req. 10

No location secured.

Will coordinate with PAB on procedure if/when location to conduct test is secured.

Waiting on responses for: Aero, Discus range, Table Mesa Location



Test Readiness - Stability Glide Test

Functional Req. 8 & Design Req. 10

Rationale for Testing:

- To determine through experimentation if the aircraft is dynamically stable during flight

Prerequisites for Testing:

- A full scale model of the UAS
- Suitable testing environment for conducting the test
  - Wind no greater than 5 mph and at least 20 meters of altitude above ground level

Test Readiness - Stability Glide Test

Functional Req. 8 & Design Req. 10

Scope of the Testing Tasks:

- Design of test fixtures, selection and calibration of sensors, data acquisition plans
- Test equipment and/or facilities needed
- An overview of the test and safety procedures

Describe how test will reduce risk to meeting requirements, expected results, and how models will be validated:

- Functional Requirement 8 states that the UAS must have static and dynamic longitudinal and lateral-directional stability naturally

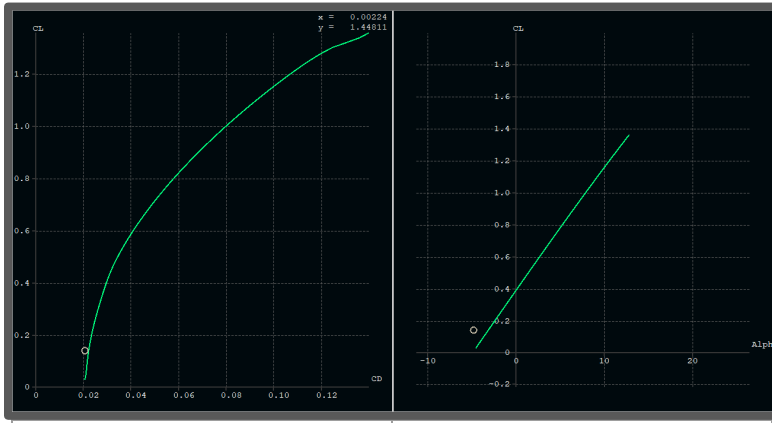
Test Readiness - Full-System Flight #2 and #3

Test Flight #2

- Battery Characterization while flying (Servo Power draw)
- Climb Angles/Speed

Test Flight #3

- Lift/Drag Profile
- Test Stall, Velocity and AoA



Requirement	Description
FR #3	Short Take Off and Landing
DR #3	Min Time Set up 800 ft Range 30m Height
DR #7	Endurance

Budget

https://docs.google.com/spreadsheets/d/1ZDexDB7CJIagfgYeeEVnTCXh-xhqPNrOj3FR00FAOfY/edit?usp=sharing

Budget

Team & Item Category	Item	Cost [USD	Cost Mar	Vendor (Link)	Quan	Shipping [US	Shipping M	Total [USD]	Total Margin [I	Use	expected delivery date
Airframe / manufacturing	replace wing set: ~250										
	foam for wing 3x	$25.50	$2.55	https://foammart.cor	2	33	3.3	$84.00	$8.40	foam to construct the wing	std shipping
	foam wing 4x - shipping as of 2/8	$54.50	$5.45	https://foammart.cor	2	0	0	$109.00	$10.90	foam to construct the wing	
	Diameter : .250", Length : 96", Resin : Epoxy	$17.95	$1.80	https://store.acpcom	1	$37.54	$3.75	$55.49	$5.55	Structural support in fuselage	2/9
possibly rebuy after trr	Dimensions : .625" OD X .515" ID, Length : 48	$37.72	$3.77	https://store.acpcom	4	Shipping included in first		$150.88	$15.09	Structural support in wings]	
	Dimensions : .500" OD X .394" ID, Length : 48	$39.58	$3.96	https://store.acpcom	2	Shipping included in first		$79.16	$7.92	Structural support in tail	
	Epoxy - 8 oz. ClearWeld Pro	$21.98	$2.20	https://www.homede	1	In-store picku	N/A	$21.98	$2.20	Glue Biding mechanism	2/24
landing rails - hold off on this	Dimensions : .625" OD X .515" ID, Length : 48	$37.72	$3.77	https://store.acpcom	2	Shipping included in first		$75.44	$7.54	Structural support	
	Bungee Cord	25$	3$	https://superbungee	2	In-store picku	N/A	59.38	5.938	UAV launch	2/24
	pla - gave to manu team	20$	2$	https://www.amazon	1						2/8/23
	launch shield - contact Matt Rhodes or Josh Mellin										
	fee for paved road? - eric is finding out on monday			make mellow arrangement							
	launch rail	38$	4$	https://www.mcmast	3	27	2.7	129$	13$	launch rail component	2/19
waiting on tax exemption ema	t bolt -can make on own	7$	1$	https://shop.southco	2			15$	1$	launch rail component	
	launch rail component: R4-10-30-705-10	18$	2$	https://shop.southco	1			20$	2$	launch rail component	
	6 Wheel T Type Trolley Assembly Electric Hoi	68$	7$	https://www.amazon	1			75$	7$	launch rail component	2/22
	Hinges	5$	0$	https://www.mcmast	4			20$	2$	launch rail component	
	6x6x0.3125 Aluminum	13$	1$	https://www.mcmast	1			14$	1$	cart on launch rail	
	0.25x0.875x24 Aluminum	6$	1$	https://www.mcmast	1			7$	1$	launch rail	
	0.375x1x6 Alumium	3$	0$	https://www.mcmast	1			4$	0$		
	Latches	9$	1$	https://www.mcmast	1			10$	1$		
	U-bolt	6$	1$	https://www.mcmast	1			7$	1$		
	U-bolt Plate	2$	0$	https://www.mcmast	1			2$	0$		
	Angled Bracket	1$	0$	https://www.mcmast	2			2$	0$		
	Rail Leg Base Short (2ft)	29$	3$	https://www.mcmast	1			32$	3$		
	Rail Leg Base Long 3	42$	4$	https://www.mcmast	1			46$	5$		
	Rail Legs short	20$	2$	https://www.mcmast	1			22$	2$		
	Rail Legs Long	48$	5$	https://www.mcmast	1			53$	5$		
walky talkies?	get from bobby										
symposium poster		150$	15$					165$	17$		
Electromechanical											
Main ESC - i paid - waiting on	AT 55A 6S	$30	$3	https://store.tmotor.c	2	free	N/A	$60	$6	Motor power	2/20
Flight Controller + GPS - got t	Pixhawk 4		$0	https://www.dronecc	1		$0.00	$0	$0	Flight Controller and GPS	delivered
Main Motor - - i paid - waiting	AT3530	$100	$10	https://store.tmotor.c	2	free	N/A	$200	$20	Motor	2/20
Main Propeller - i paid - waitin	APC 11x10E	$3.97	$0.40	https://www.apcprop	2	$6.12	$0.61	$14.06	$1.41	Propellor	in preshipment phase
RC Receiver (Appropx.)	FrSky X4R-SB	$37	$4	https://www.amazon	1	Free with prir	N/A	$37	$4	RC Controls receiving	2/9
Telemetry Radio (Approx.) - a	3DR 500MW Radio Telemetry Kit	$87	$9	https://www.amazon	1	Free with prir	N/A	$87	$9	Telemetry data tx/rx	2/9
Handheld Controller (Approx.	Taranis Q X7S	$127	$13	https://www.amazon	1	Free with prir	N/A	$127	$13	Control of A/C	2/10
Battery	Tattu 22.2V	$475	$48	https://genstattu.com	1	$46.50	$4.65	$522	$52	Power	delivered 2/13
Air Data Sensor (Approx.) - g	mRo I2C Airspeed Sensor JST-GH-MS4525D	$87	$9	https://store.mroboti	1	Free	N/A	$87	$9	Speed Sensing	1-5 days, ordered on 2/3/23
Anticollision lights	Arc "V" Drone Strobe Light Full Navigation Kit	$13	$1	https://www.amazon	1	Free with prir	N/A	$13	$1	FAA regulations for visability	March 1
Servos	8 kg thin wing servo	$29.99	$3.00	https://www.amazon	2	Free with prir	N/A	$59.98	$6.00	Acuation of control surfaces	2/9
Motor wire	8 guage red / black	$26.98	$2.70	https://www.amazon	1	Free with prir	N/A	$26.98	$2.70	Power wire from supply to ESC	2/9
Xt90-S Connector - reorder ar	Battery connector	$12.99	$1.30	https://www.amazon	1			$14.29	$1.43	connect to battery to board	2/10
3 prong terminal MT60	ESC to motor connector	$8.99	$0.90	https://www.amazon	0					connect esc to motor	
Temperature sensor	TSYS01	$21.48	$2.15	https://www.te.com/i	1	Free		$23.63	$2.36	battery temp sens for telemme	5-7 days , ordered on 2/3/23
Power Managment Board - i c	Powers... Everything	$42.00	$4.20	https://shop.holybro.	1	24	2.4	$72.60	$7.26	power module for entire aircraf	ordered 2/13
UBEC Convertor	Powers the Servo Rail	$17.99	$1.80	https://www.amazon	1	0	0	$19.79	$1.98	powers servos via rail. connecl	2/9
Servos Tail	Rudder/elevator	$14.99	$1.50	https://www.amazon	1	0	0	$16.49	$1.65		2/21
Servo hardware	Aileron/Rudder/Elevator	$10.38	$1.04	https://www.amazon	1	0	0	$11.42	$1.14		2/21

Budget

Long rods - wait	TBD		$0.00		1			$0.00	$0.00		
GPS module - hear from talor	GPS antenna for Pixhawk	$30.00	$3.00	https://www.amazon	1	$0.00	$0.00	$30.00	$3.00	Any M8N GPS module will wor	2/28
RC Transmitter battery	FrSky 2000mAh 7.2v NiMH Battery for Taranis	$24.98	$2.50	https://www.amazon		$0.00	0	$24.98	$2.50	Battery for handheld controller	2/23
lipobag	Battery Bag	$11.99	$1.20	https://www.amazon	1	0	0	$13.19	$1.32	safety precaution for battery	

	Cost	Margin
Airframe / manufacturing	1382.1192	138.21192
Electromechanical	1606.0812	160.60812
Total Cost (including margin):	2988.20	
Total Budget	$4,000.00	
Remaining Balance	$1,011.80	

Key:

- complete and delivered
- ordered
- amazon reorder
- not ordered

money spent without margin	$2,364.74
with margin	$2,601.21
money left including margin	$1,398.79
cost of good left to buy	386.99
cost leftover (including margir	$1,011.80
cost of crticical item:	
battery	
3d filament	
carbon fiber rods	