D.R.O.P.S.
Test Readiness Review

February 16th, 2022
ASEN 4018-012 Team 8

Company Customer:
TB2 Aerospace

Faculty Advisor:
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Presenters:
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Presentation Overview

1. Project Overview ———— Dominic Dougherty
2. Design Updates ———— Ben Capeloto
3. Schedule Updates ———— Ben Capeloto
4. Test Readiness
   a. High-Power Test ———— Caroline Dixon
   b. Induction Charging Test ———— Danny Gutierrez Mendoza
   c. Periscope Drone Test ———— Mia Abouhamad, Alex Karas
5. Budget ———— Alex Karas

Project Overview

Background and Motivation

Background:

Autonomous drone delivery systems in development by

- *US Military*
- *Amazon Prime Air*
- *UPS Flight Forward*

However, **no standard exists** that allows **one cargo unit** to interface with different UAV types from different manufacturers

Motivation:

Effective: Standardize attachment methods across many drone platforms

Functional: Limit detrimental effect to drone performance

Safety: Create safe and reliable cargo delivery methods

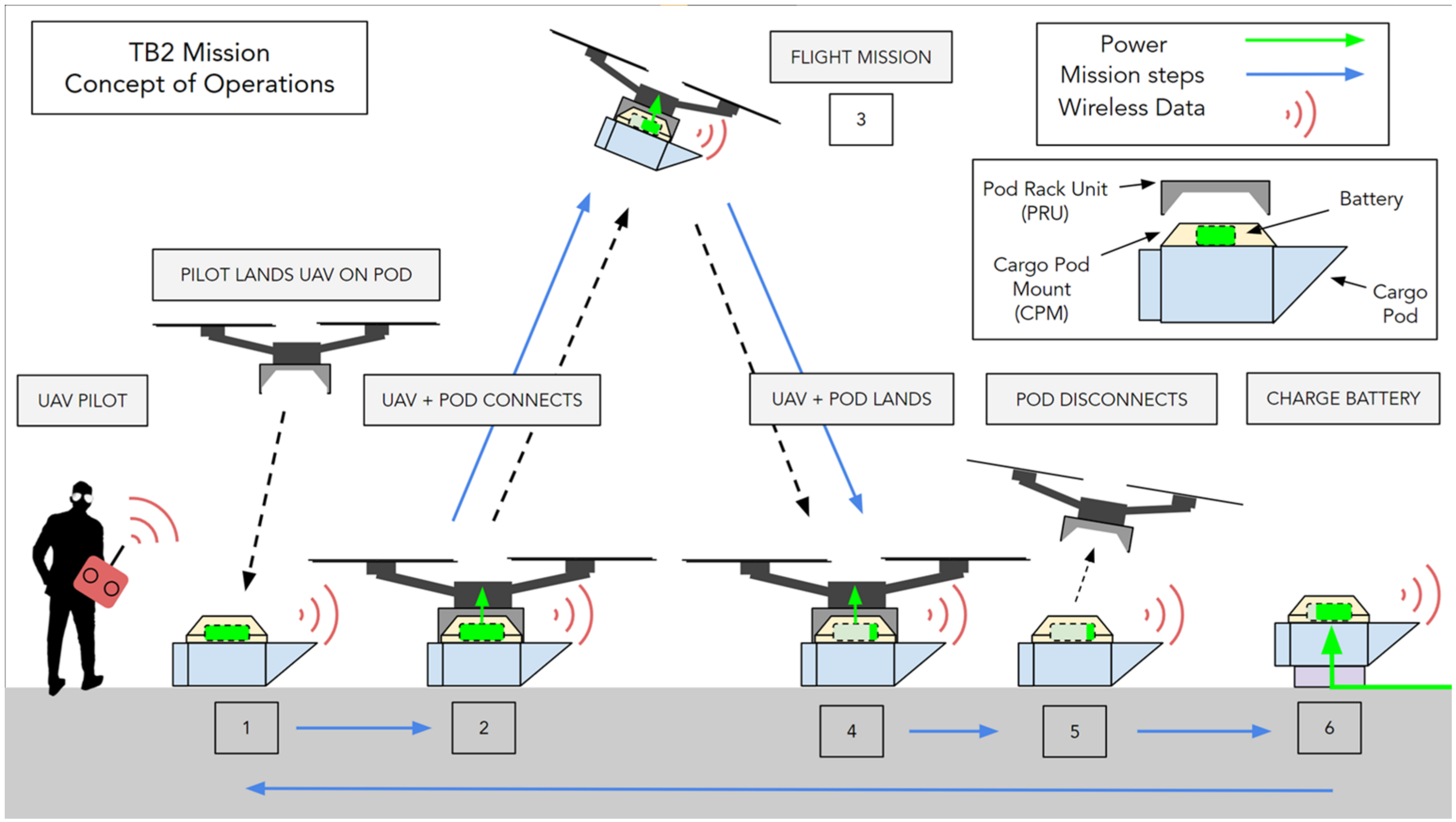
Mission Statement

The Drone Recharging Operational Payload System **(DROPS)** aims to standardize autonomous cargo delivery units for both **military and commercial applications**. Development of a docking system will permit **mechanical and electrical connection between class 2 UAVs** and powered cargo units **while increasing functional range**.

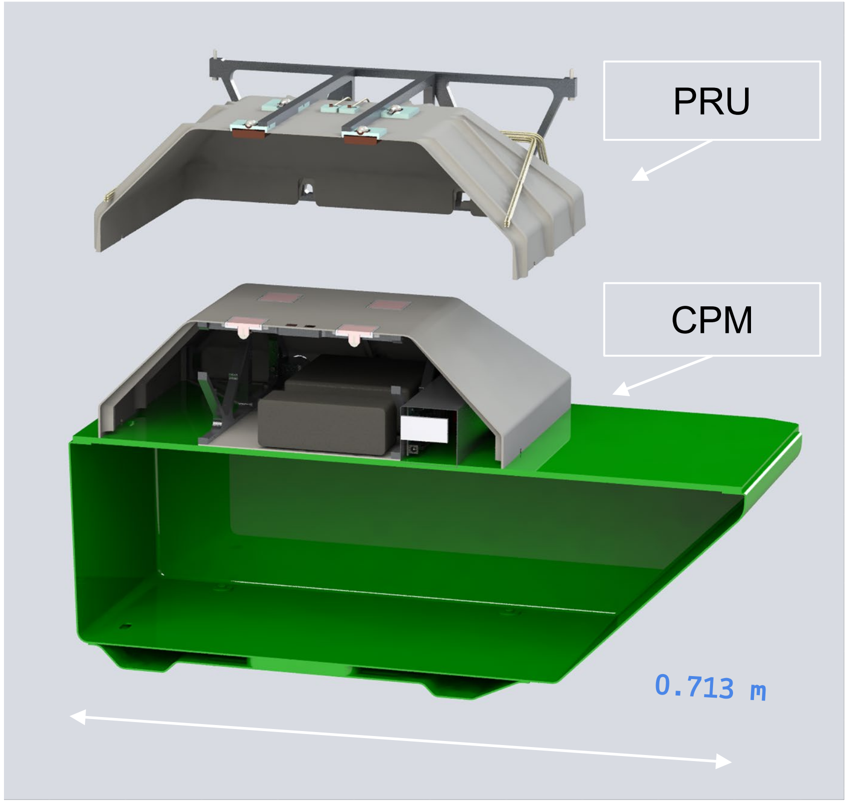
Primary Project Objectives

Structures	Demonstrate that the structure of the DROPS system will be able to withstand the forces on takeoff, in flight, and on landing with the Pod connected
Power Passthrough	Demonstrate power transfer capabilities from rechargeable batteries, through the DROPS system, to a UAV
Connection & Control	Demonstrate the ability to control the connection of the DROPS system after the alignment of UAV
Data Transmission	Demonstrate the ability to send telemetry between the DROPS system and an operator computer

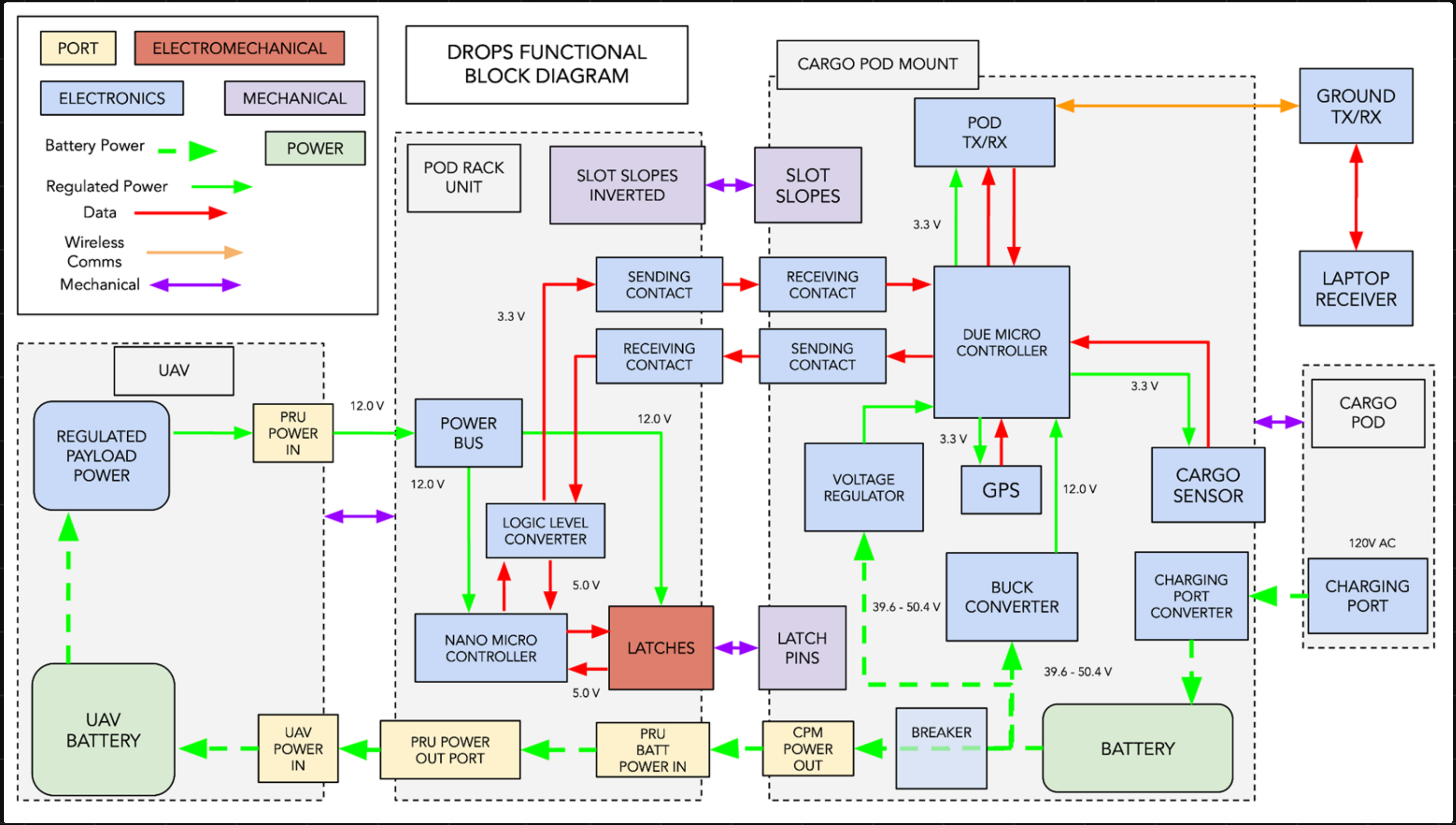
Concept of Operations



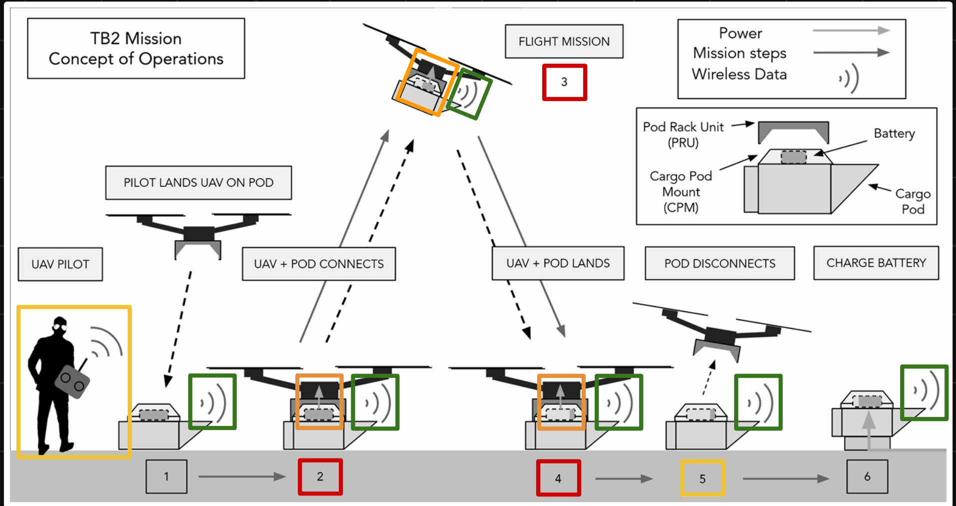
Baseline System Design



System Overview: Functional Block Diagram



Critical Project Elements

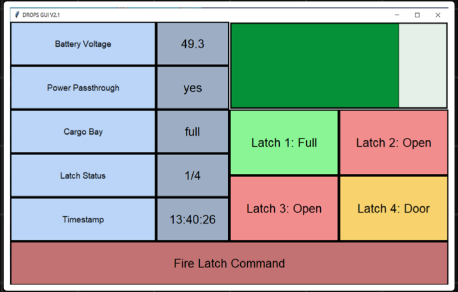


CPE	Description	Functional Requirements	Justification
Structures	The PRU and CPM structure can withstand all forces throughout the mission	2	The DROPS system needs to be able to withstand all resultant forces of takeoff, landing, and in flight
Power	There shall be power available to the UAV through a passthrough from the CPM to the PRU	4	The customer would like that DROPS can demonstrate this proof of concept; supplying power to extend the drone's range via additional battery power
Connection & Control	Operators shall be able to send lock/unlock commands and receive the status of latches	3, 7	Sending commands to disconnect from the Pod and knowing latch status is required for Pod delivery
Data Transmission	The status of the Cargo Pod shall be transferred to the operator	7	The status of the batteries, cargo, latches, and Pod must be known for system monitoring and for future autonomous design goals

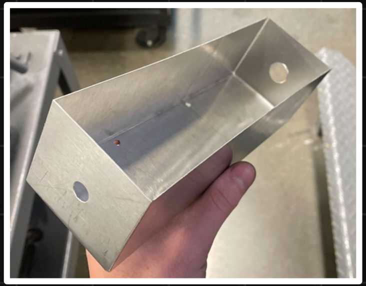
Design Updates

Major Changes from CDR

GUI Changed to Two-Way Communication

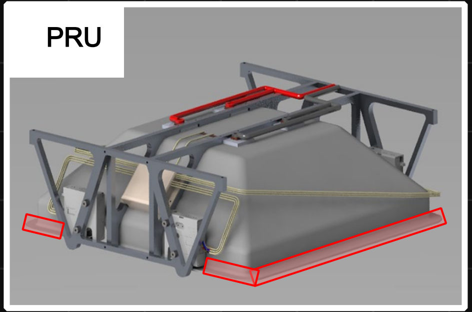


CPM Electronics RF Shielding



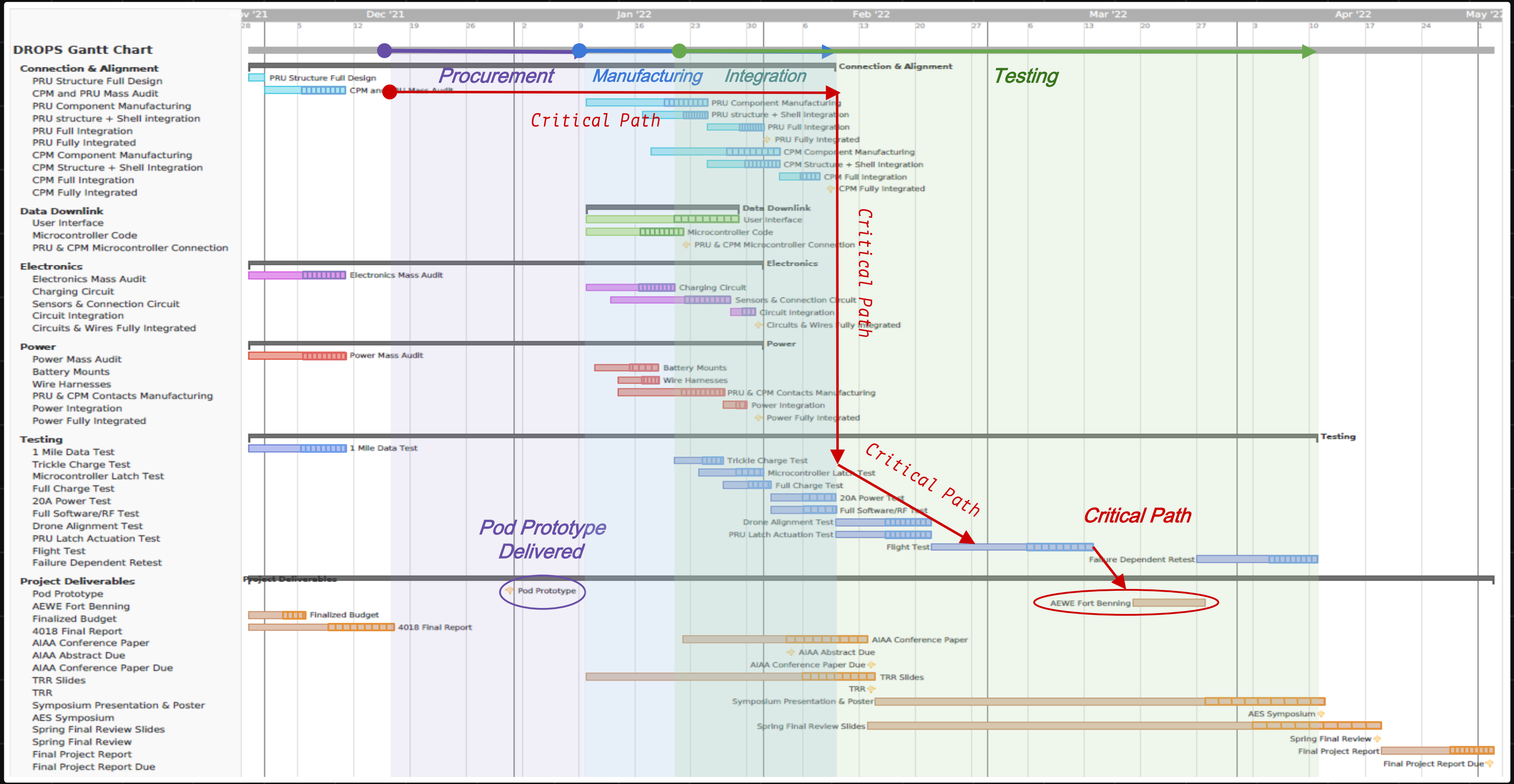
Shell Ribs for Stiffness

PRU Shell Bumpers

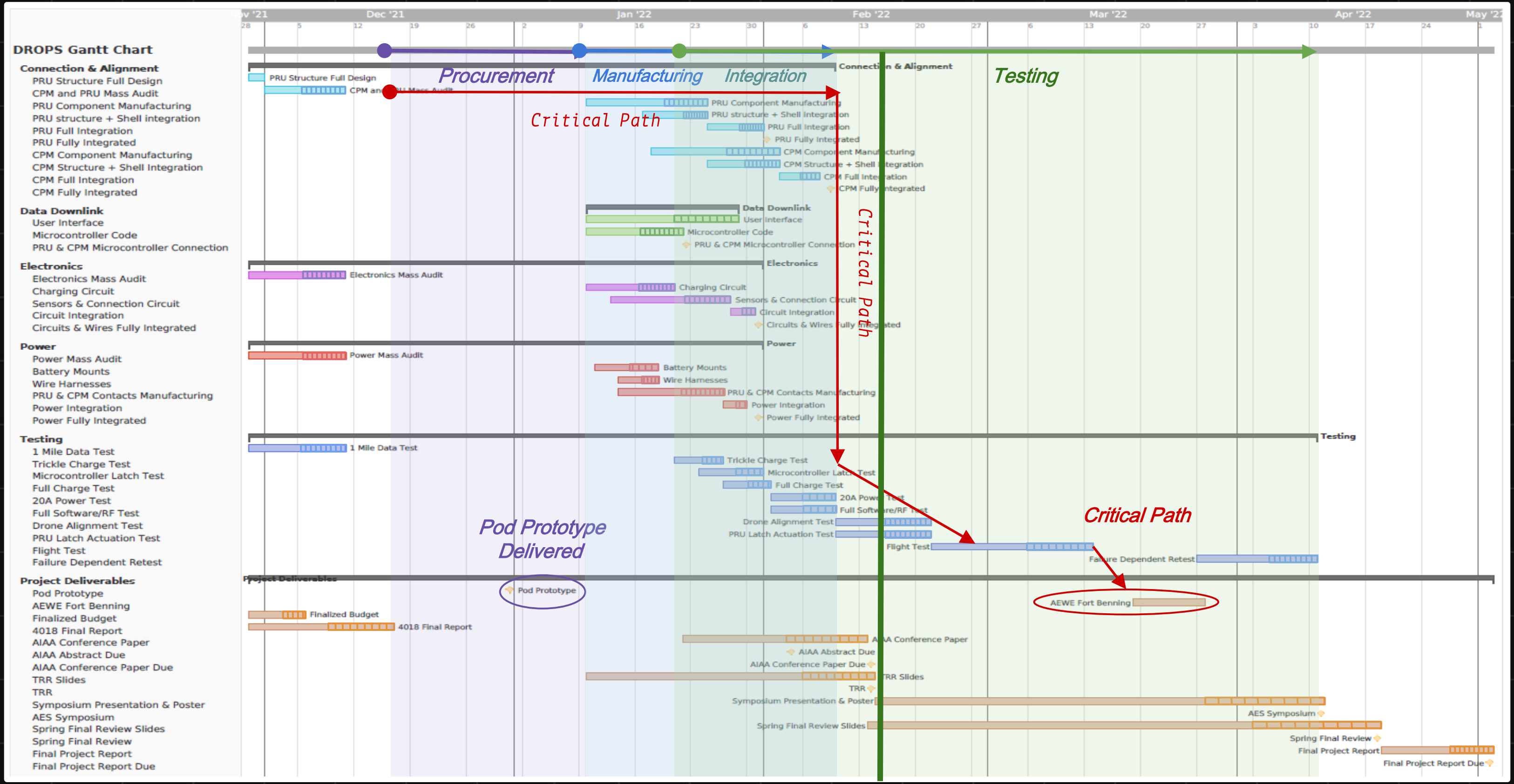


Test Scheduling

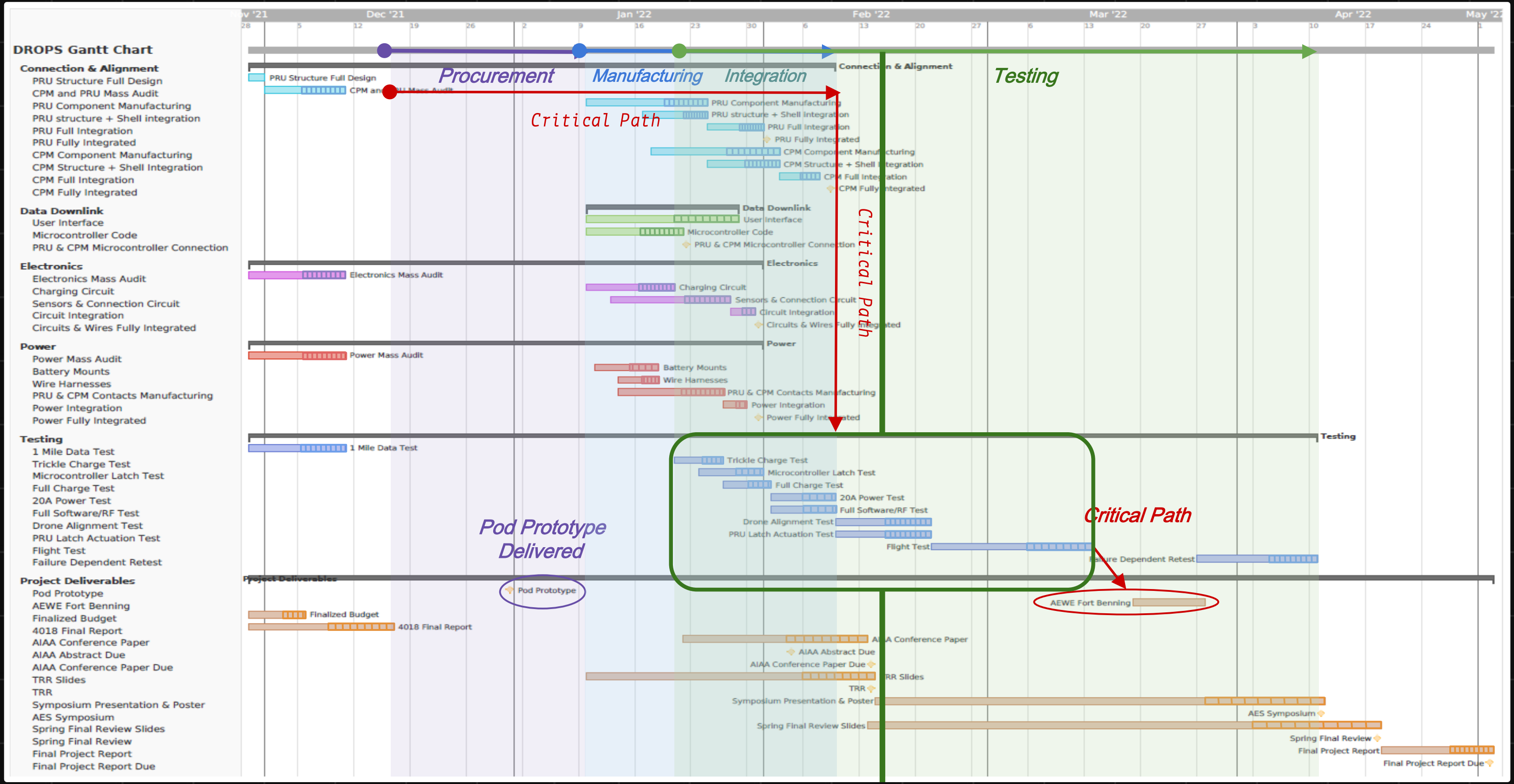
Spring 2022 Schedule



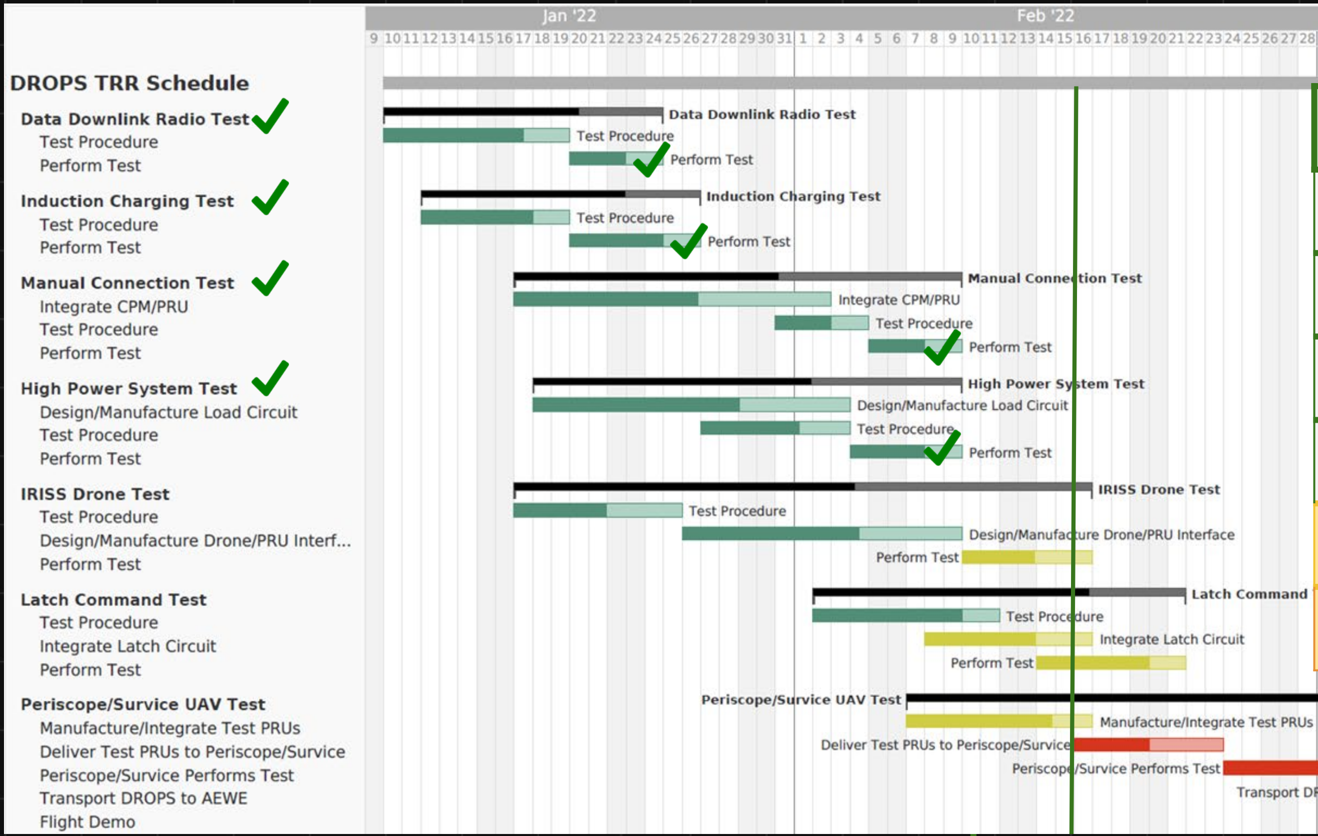
Spring 2022 Schedule



Spring 2022 Schedule



Testing Schedule



Progress	
Data Downlink	1/22
Induction	1/24
Connection	2/5
High Power	2/7
IRISS Drone	2/9
Latch Command	2/25

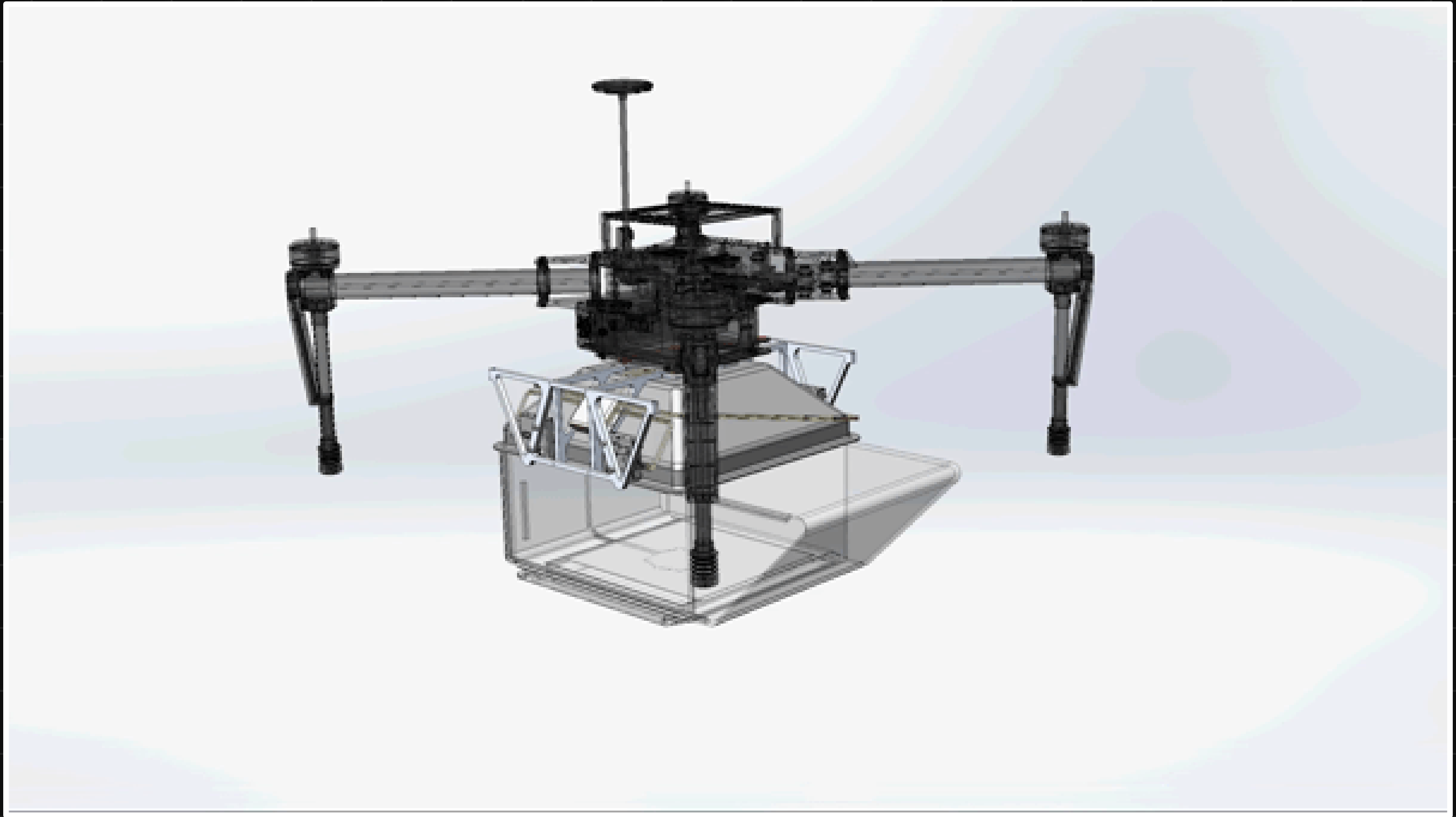
Test Readiness

Testing Summary

Test Name	Testing Level	Models Verified	Relevant CPE	Requirement Focus
Data Downlink Radio Test	Component	N/A	Data Downlink	7
Induction Charging Test	Subsystem	Extrapolation Model	Power Passthrough	5
Manual Connection and Disconnection	Subsystem	N/a	Alignment, Connection	1, 2
High Power System Test	Subsystem	Power Passthrough Layout	Power Passthrough	4
IRISS Drone Test	System	CAD offset, alignment tolerances	Alignment, Connection	1, 2
Latch Command Test	Subsystem	Timing model	Connection	2
Periscope Drone Test	System	PRU and and CPM FEA	Structures, Connection	3, 6, 7

High-Power Test

System Overview: Power Animation



High Power System Test [Completed]

Test Name	Testing Level	Models Verified	Relevant CPE	Requirements Closed
High Power System Test	Subsystem	Power Passthrough Layout	Power Passthrough	4

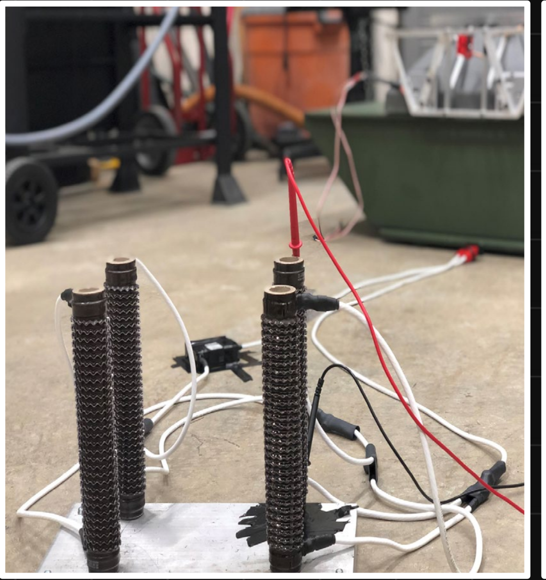
Motivation: Verify 20-25 Amps of current successfully flows through entire power passthrough

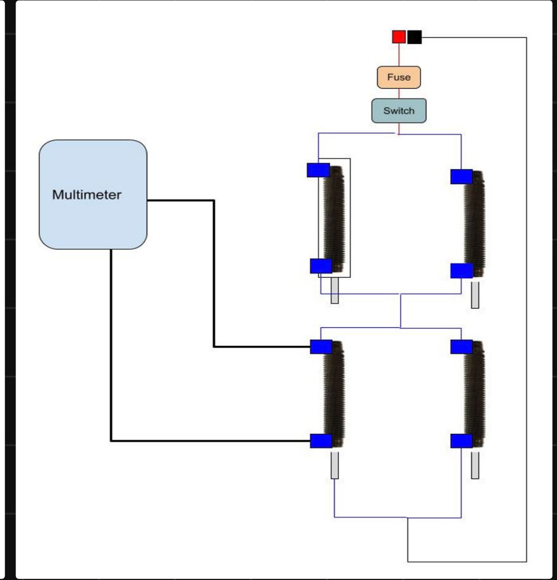
Equipment:

- CPM and PRU Units
- High Power Resistor Circuit
- Non-Contact Thermometer
- Multimeter/Alligator Clips
- Fan and Glove
- Personnel Safety Equipment

Location: Engine Test Cell

Expected Results: 22-24 Volts Measured at Resistor Terminals





High Power System Test - Methods & Results

Methods

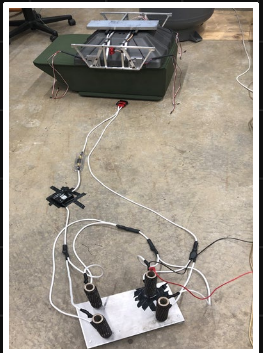
- 10 minute current pull
- Resistor voltage drop measurement
- Monitoring temperature of resistors
- Ohm's law to calculate current pull

Assumptions

- Constant resistance with temperature change
- Results based on values at **test start**

Results:

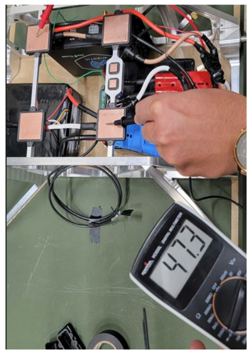
Voltage Drop 1 Resistor [V]	22.8 +/- 0.1
Voltage Drop 2x Batteries [V]	47.5 +/- 0.2
Total Circuit Resistance [Ohm]	2.3 +/- 0.1
Current Draw [A] = 47.5/2.35	~ 20.6 +/- 0.3



(Test Layout)

(Resistor Temp.)

(Circuit Resistance)



(Battery Voltage)

(Resistor Voltage)

High-Power Test Risk Reduction

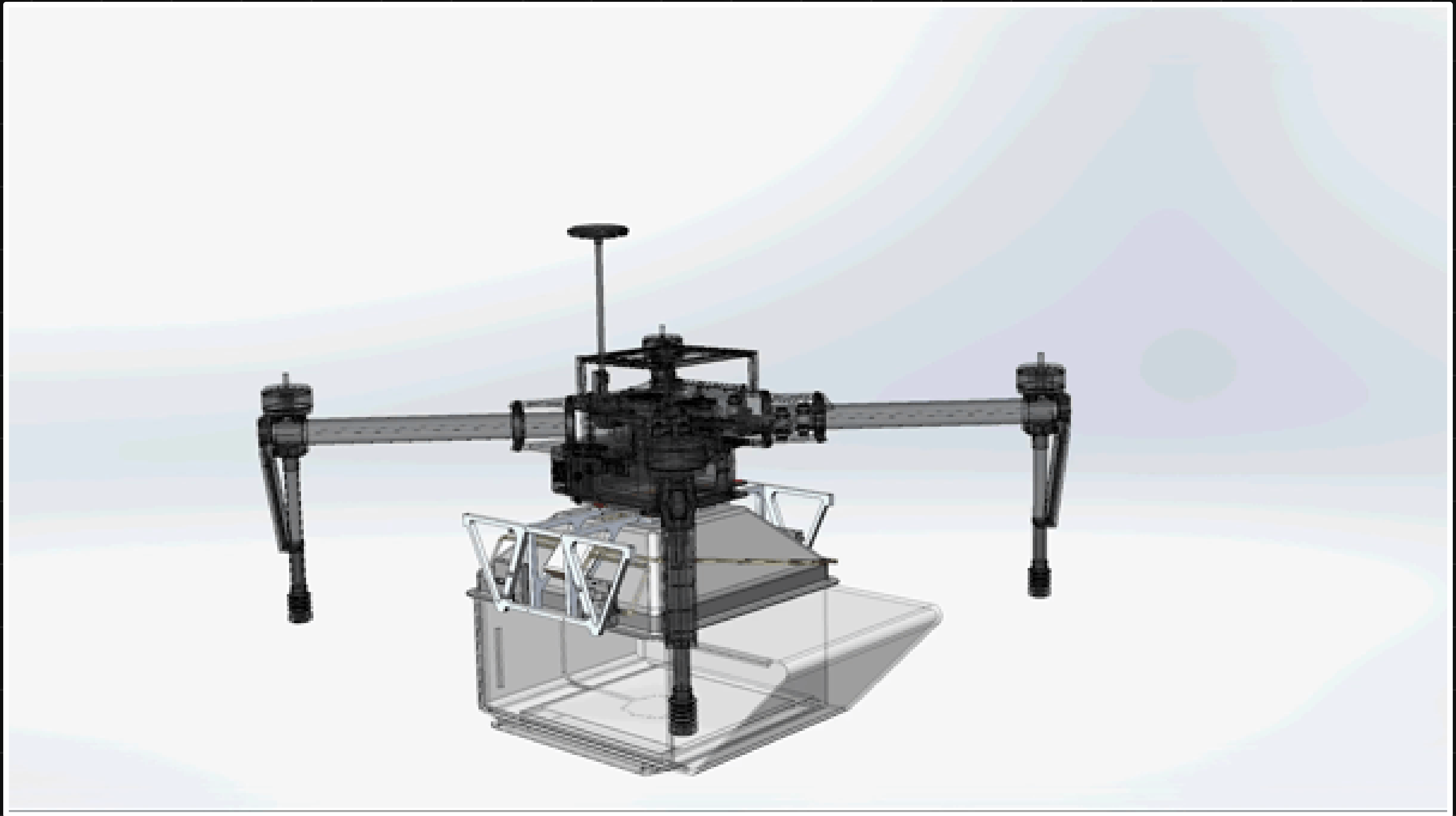
Reduced Risk To Personnel: Current only pulled when PRU and CPM are stacked. All metallic components covered properly to avoid shorting.

Reduced Risk To FR Failure: Current pulled successfully which validated requirement. Power values met required values.

Reduced Risk To Future Project Failures: Proves preliminary drone power capability through DROPS system for future iterations.

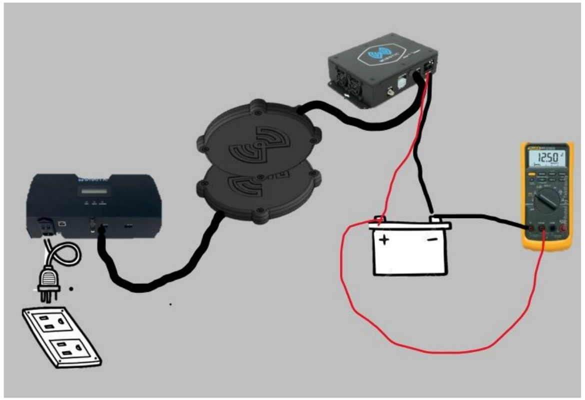
Induction Charging Test

Induction Charging Animation



Induction Charging Test [Completed]

Test Name	Testing Level	Models Verified	Relevant CPE	Requirement Closed
Induction Charging Test	Subsystem	Regression Model	Power	5



Motivation: 12 hour charging time requirement, System Verification

Testing Model: Discharge curve regression

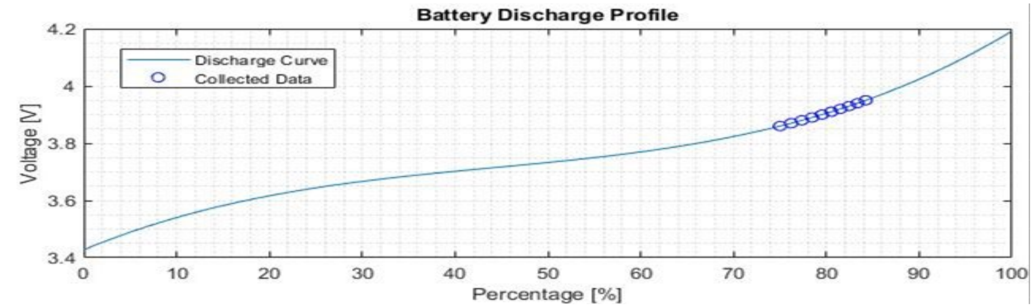
Equipment:

- Wibotics Induction Transmitter
- POD Induction-Battery system
- Safety Equipment
- Data Recording Devices

Location: Engine Test Cell

Expected Results: <12h Charging Time

Alternative Methods: Power Integration, 12h Test



Induction Charging Test - Methods & Results

Methods:

- 45 minute induction charge session
- 2 minute cell voltage measurements
- Voltage data fitted to the battery discharge curve by the manufacturer
- Minimum rate verification

Assumptions:

- Current is constant
- Efficiency is constant

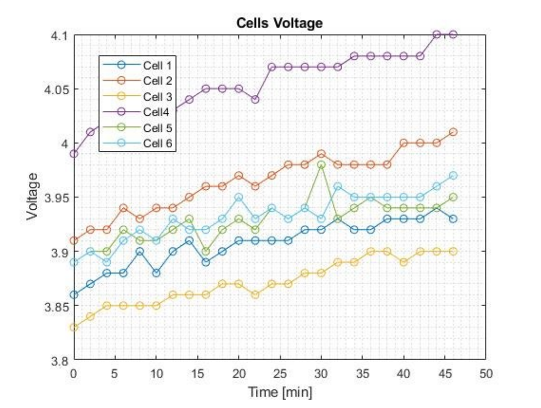
Results:

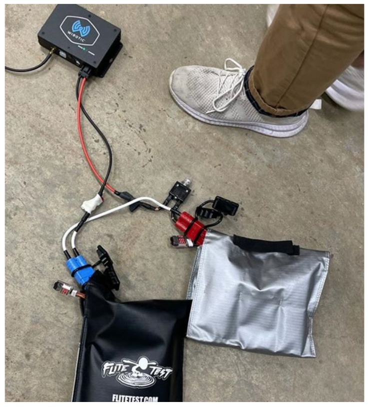
Best Estimate: 11.51 h ± 13 min

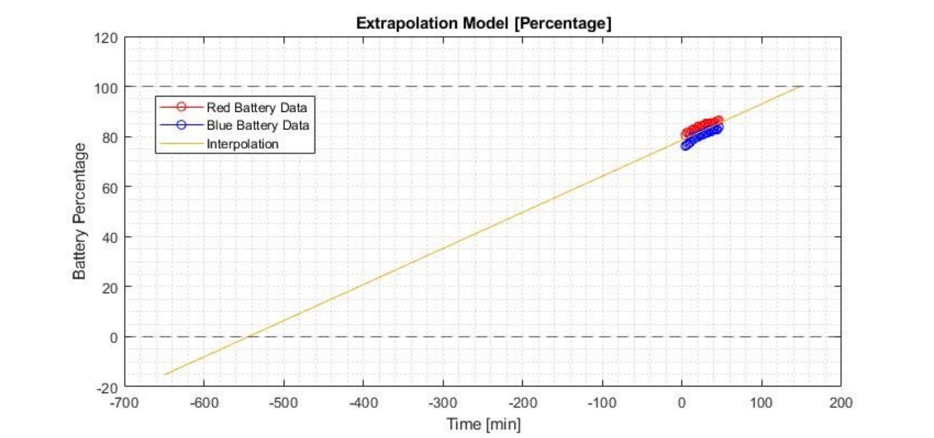
Current Used: 2.5 A

Charging Efficiency: 74%

Maximum Charging Current: 5 A







Induction Test Risk Reduction

Reduced Risk To Personnel: Battery failure odds reduced from testing charging system

Reduced Risk To FR Failure : Induction system can successfully charge batteries to sponsor specifications, FR closed.

Reduced Risk To Future Project Failures : Induction system can be integrated to future Pods successfully. Future drone charging procedures will pose less danger of malfunction.

Periscope Drone Test

Periscope Drone Test

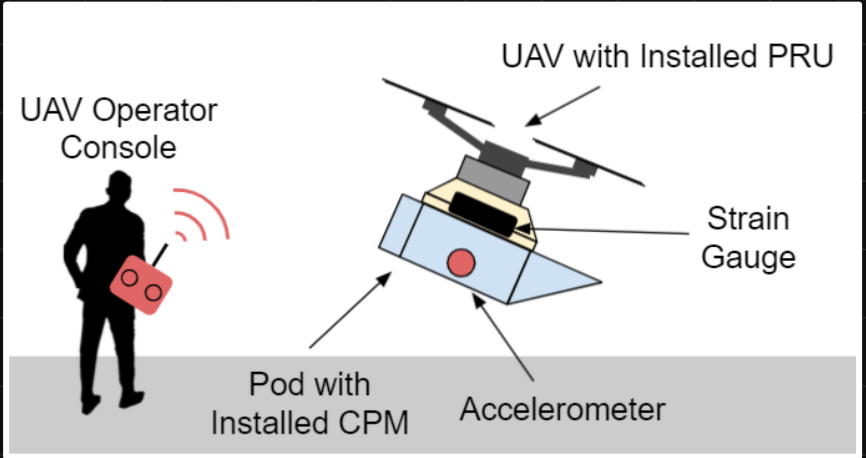
Test Name	Testing Level	Models Verified	Relevant CPE	Requirements Closed
Periscope Drone Test	System	FEA at key areas, Alignment, Connection	Structures, Connection & Control	2.2, 2.3

Motivation: Test the full system structural and connection functionality with full size drone

Rationale: Verify our calculated factor of safety for our integrated system

Equipment:

- Full system structure w/ latches
- Cameras (3)
- Compass/Accelerometer
- Strain Gauges
- Wireless DAQ



Location: Periscope Facility near Washington, DC

Periscope Drone - Methods & Results

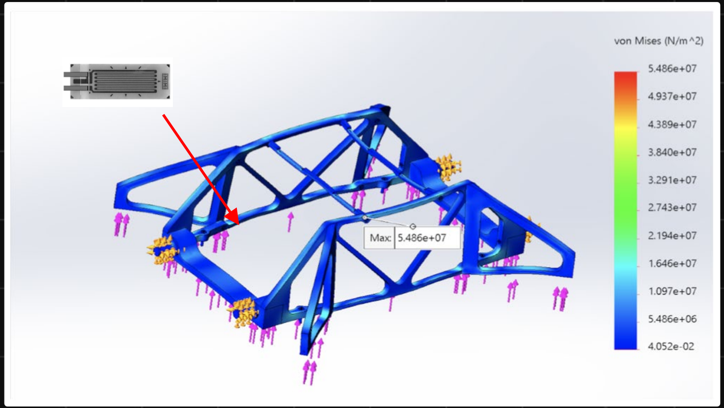
Methods

- Multiple flight scenarios of taking off and landing with the Pod attached to the drone

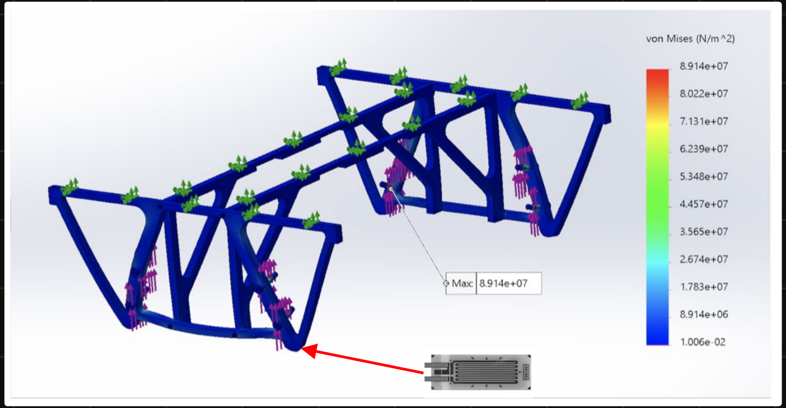
Assumptions

- The forces are equally distributed between the Striker bolts and connections

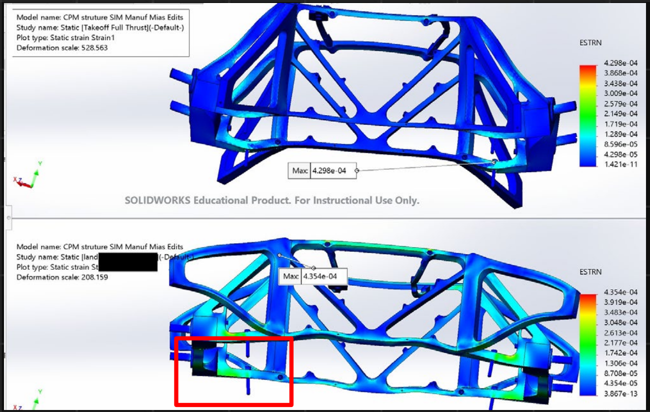
CPM Gauge Location – landing



PRU Gauge Location - landing



Periscope Drone Test - CPM Model



Takeoff

Landing

Expected Results :

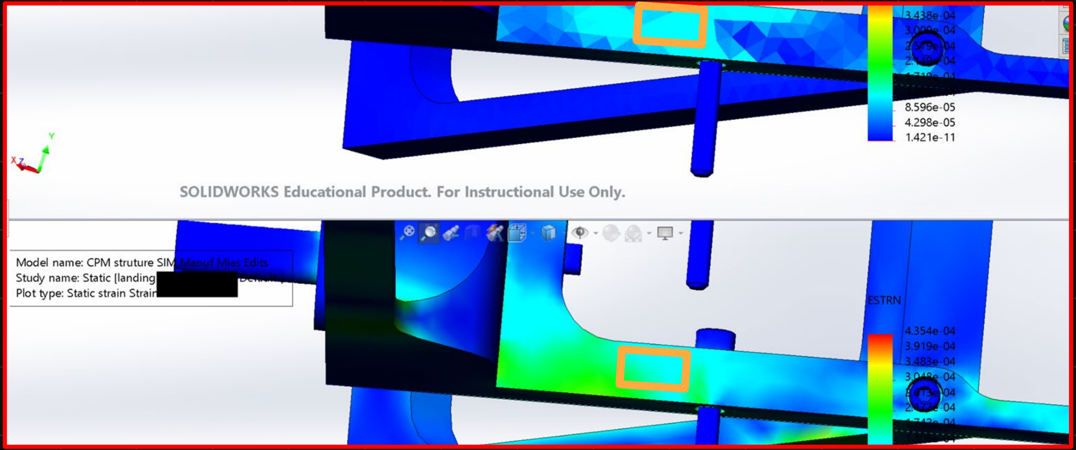
We expect the strain values to not exceed:

CPM Gauge~ -105.1 µstrain @takeoff

CPM Gauge~ 164.4 µstrain @landing

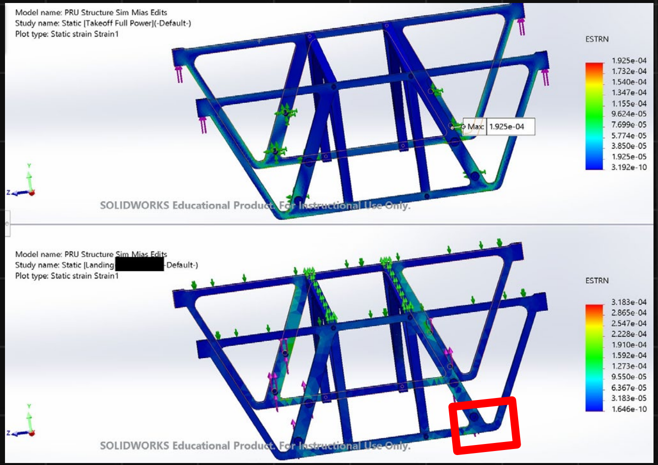
Takeoff

Landing



CPM gauge location

Periscope Drone Test - PRU Model



Takeoff

Landing

Expected Results:

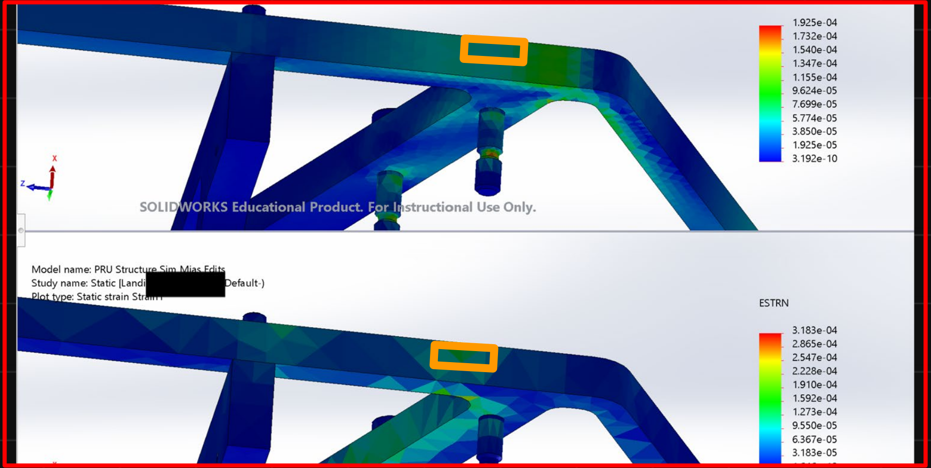
We expect the strain values to not exceed:

PRU Gauge ~ 63.5 µstrain @takeoff

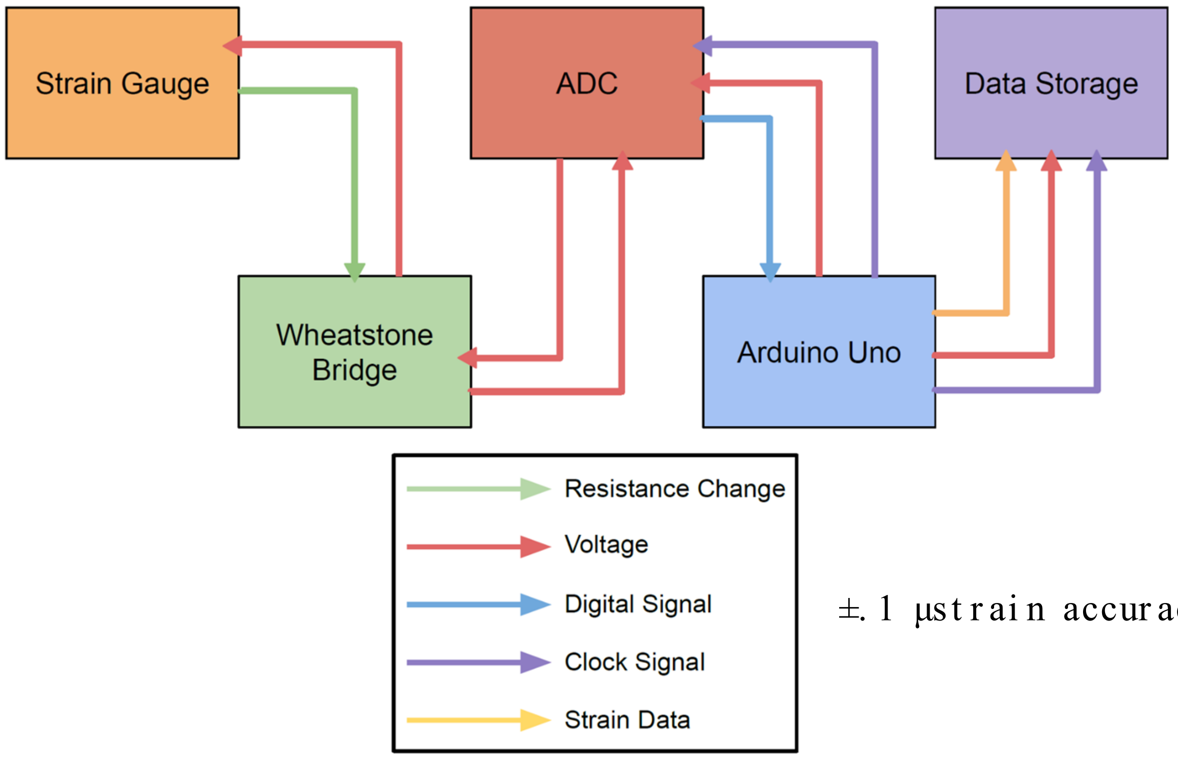
PRU Gauge ~ -126.8 µstrain @landing

Takeoff

Landing



Strain Data Acquisition System FBD



±.1 µstrain accuracy

Strain DAQ System Benchtop Testing

Finished:

1. Gauge Resistance: Red-White: 352, Red-Black: 352, White-Black: 2
2. Wheatstone Bridge Voltage: ~1.6 mV at zero strain
3. Signal verification via HX711: bend bar w/ hand → Success
4. Calibration run 1 - Tension testing

Action Items:

1. Calibration run 2 - Full range testing
2. Send data to/from Micro SD Card Reader
3. Save strain data to Micro SD Card Reader
4. Full system test to verify sitting FEA

Positive Strain

```
Reading: 0.2microstrain c
Reading: 1.0microstrain c
Reading: 3.4microstrain c
Reading: 6.8microstrain c
Reading: 8.9microstrain c
Reading: 11.7microstrain
Reading: 17.2microstrain
Reading: 25.9microstrain
Reading: 33.6microstrain
Reading: 37.4microstrain
Reading: 38.7microstrain
Reading: 38.7microstrain
Reading: 38.0microstrain
Reading: 38.1microstrain
Reading: 38.0microstrain
Reading: 36.8microstrain
Reading: 35.1microstrain
Reading: 33.8microstrain
```

Negative Strain

```
Reading: 1.1microstrain ca
Reading: -0.2microstrain c
Reading: -4.7microstrain c
Reading: -11.1microstrain
Reading: -13.9microstrain
Reading: -17.2microstrain
Reading: -23.3microstrain
Reading: -27.2microstrain
Reading: -29.6microstrain
Reading: -31.0microstrain
Reading: -30.4microstrain
Reading: -30.2microstrain
Reading: -31.6microstrain
Reading: -33.5microstrain
Reading: -35.3microstrain
Reading: -36.7microstrain
Reading: -37.7microstrain
Reading: -36.4microstrain
```

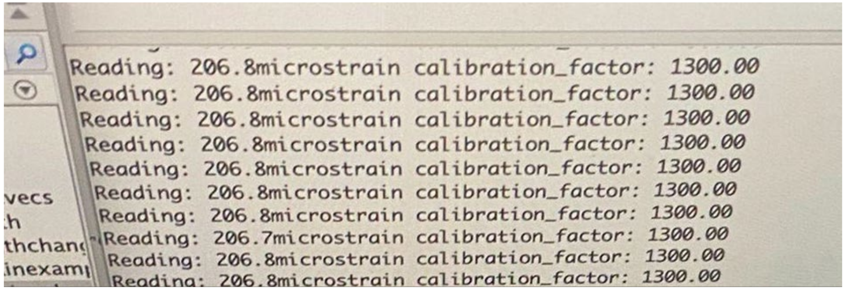
Strain DAQ System Calibration -> Checking Calibration/Results

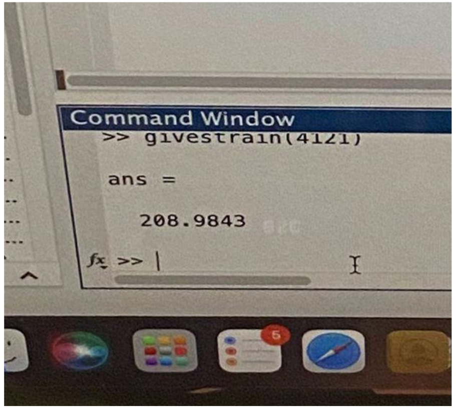
EXAMPLE:

1. MTS test stopped at ~4.12 kN
2. Run 'givestrain.m' with 4121 as the input (in Newtons)
3. Obtain desired microstrain value
4. Check reading -> only **~1% error!**
5. If desired, change calibration slightly to obtain correct value

Instron Force

Arduino





Predicted Value

Periscope Test Risk Reduction

Reduced Risk To Personnel: Mechanical failure of structures and projectile danger risk reduced due to accurate strain data.

Reduced Risk To FR Failure: Multiple connection/disconnection tests with success will reduce risk of latch failure in alignment and takeoff.

Reduced Risk To Future Project Failures: Reduced risk of being unable to adapt to various drone designs and architecture for flight and physical connection.

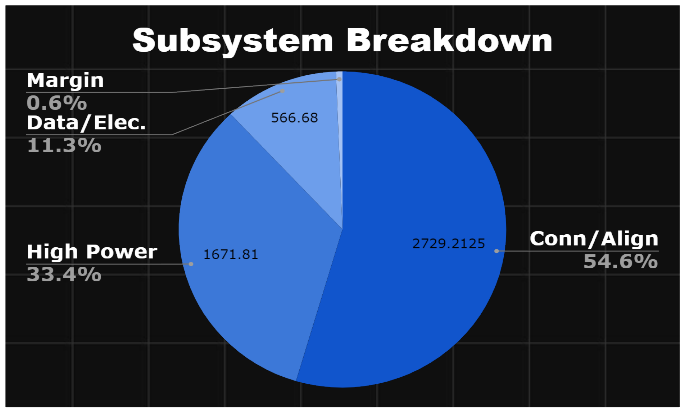
Testing Milestones and Requirements

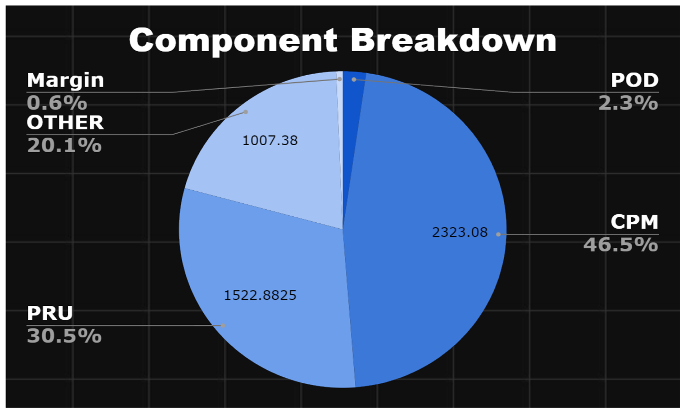
Test Name	Relevant Milestone
Radio Test	Functional Radios and Software
Induction Charging	Integrated batteries, functional induction charging system
High Power	Test circuit built, high power wiring integrated into CPM
Manual Connection	Manufactured and assembled CPM, PRU and Pod structures
IRISS Drone	Part 107 cert, operational remote latching system, integrated PRU and CPM
Latch Command	Full latch command system operational
Periscope Drone	DROPS shipped to Periscope, integration with Periscope, strain gauge system

Success Level	Requirements Closed
1	77%
2	50%
3	33%

Budget

Financial Update





Testing - Related Purchases:

Connection/Alignment	Cost
FAA Part 107 Exam Cost	$170
Strain Gauge Resistors	$70
Strain Gauges	$50
IRISS Drone Mounting Plate/Hardware	$25

Power/Charging	Cost
High Power Resistors	$100
Resistor Circuit Materials	$20
Lipo Bags and Sand	$15

Data/Electronics	Cost
Fuses/Breakers	$20
Antenne	$20

Future Purchases (Sponsor):

Item	Cost
Truss Stock for PRU/CPM Units 2 and 3	$750
3d Printing Material	$200
Any Extra Items	N/A

CURRENT PROJECT TOTA
$4967.70

Acknowledgements

Customer & Faculty Advisor:

Hank Scott & Dr. Jade Morton

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Michael Rhodes, Dr. Alireza Doostan, Dr. Nicholas Rainville,
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Dr. Kathryn Wingate, Dr. Jean Koster, Christopher Roseman,
Bobby Hodgkinson, Trudy Schwartz, KatieRae Williamson,
Josh Mellin, Harrison Bourne, Steve Taylor

TRR Reviewer:

Emma Markovich

Thank You!

Questions?

Backup Slides

Backup Slides

Data Downlink Test

Data Downlink Radio Test

Test Name	Testing Level	Models Verified	Relevant CPE	Requirement Closed
Data Downlink Radio Test	Component	N/A	Data Downlink	7

requirement, Systems Verification

Testing Model: Packets dropped over time
Rationale: Reliability of communication link between latches/sensors and GUI (ground station)

Equipment:

- Two laptops
- Two XBee radios w/ USB dongle

Location: US-36 Scenic Overlook

Expected Results: 5 packets dropped per test

Data Downlink Radio Test - Methods and Results

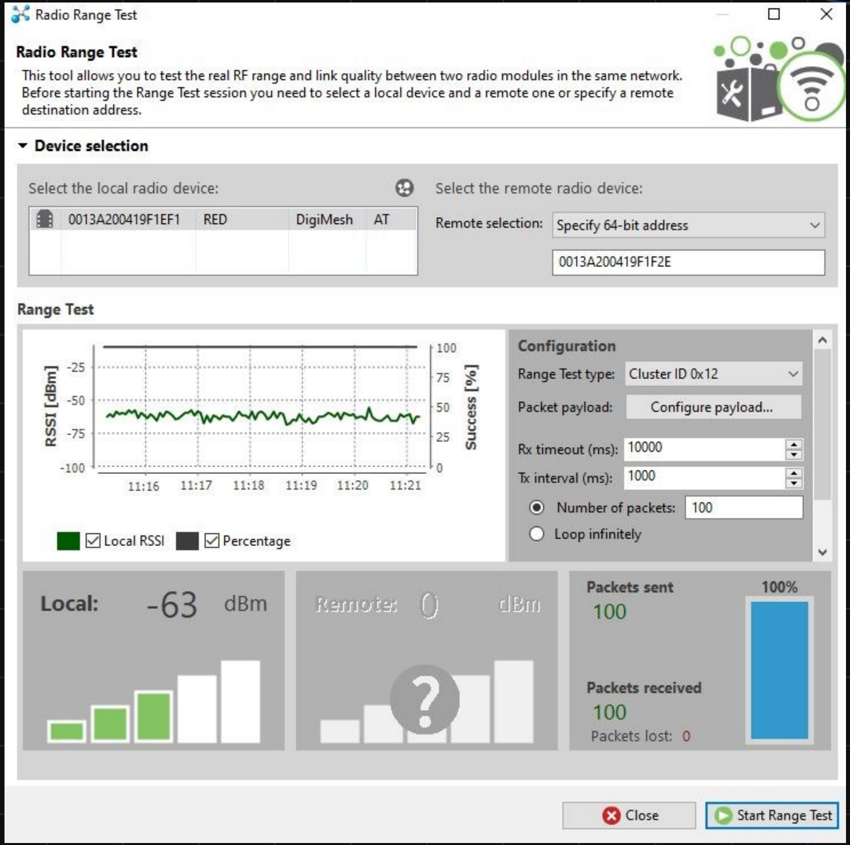
Methods:

- Send 100 data packets at 1 mile apart

Assumptions:

- Clear line of sight between radios

Results: Zero dropped packets over the three tests



Manual Connection & Alignment Test

Manual Connection & Alignment Test

Test Name	Testing Level	Models Verified	Relevant CPE	Requirements Closed
Manual Connection & Alignment Test	Subsystem	CAD offset, Alignment tolerances	Alignment, Connection	1, 2

Motivation: Align and connect/disconnect the PRU to the CPM via a manual operation by hand

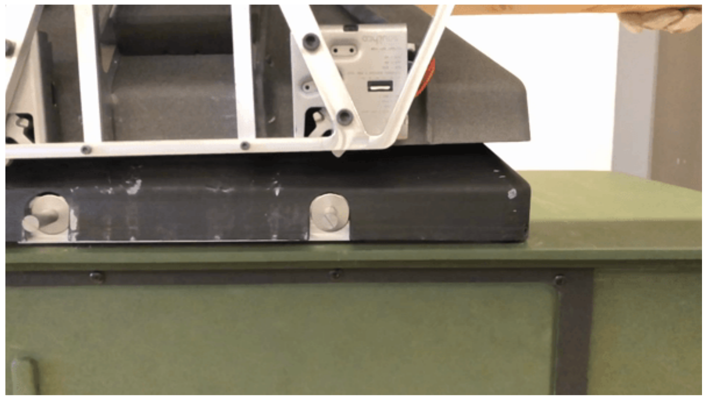
Rationale: Proves alignment and connection capability with physically controlled PRU and lifting capability

Equipment:

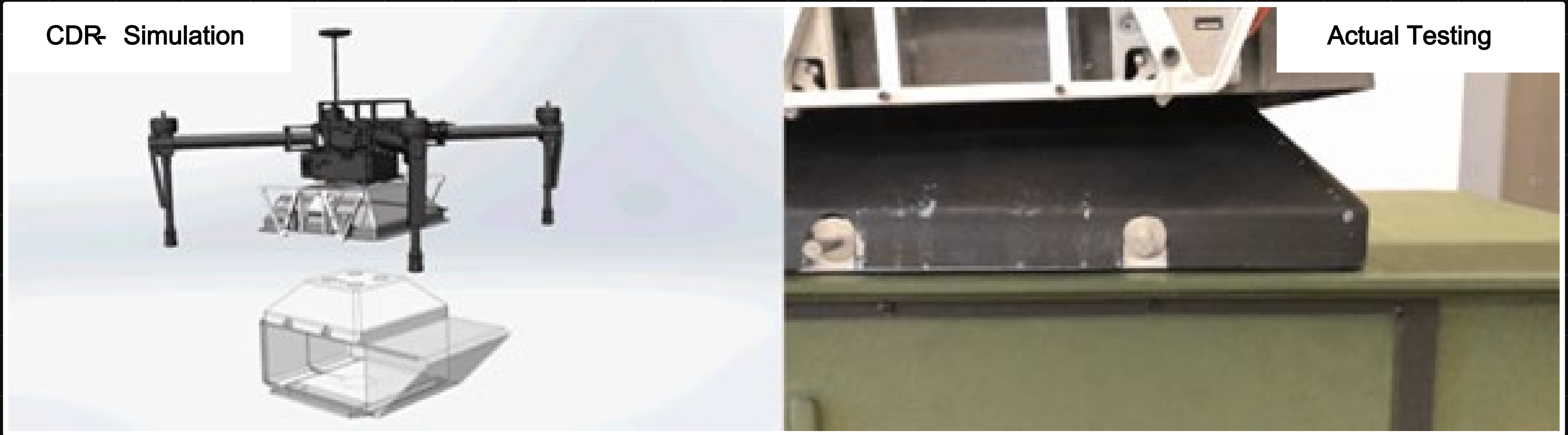
- Structurally complete CPM and PRU (latches included)
- 2x4 Wood Planks with C clamps
- Cameras

Location: Senior Projects Workspace

Expected Results: Ability to align and connect with sufficient force to close latches after manual alignment



Manual Connection and Alignment Demo



Manual Alignment & Connection of PRU/CPM System

- Binary Visual Verification of CAD simulation
- Requirement ## Confirmed for subsystem
- Predecesor for drone alignment testing

Key Information

- Mounting to 2x4s
- Post-completion of structural and latching elements
- Both connection, lift, and disconnection

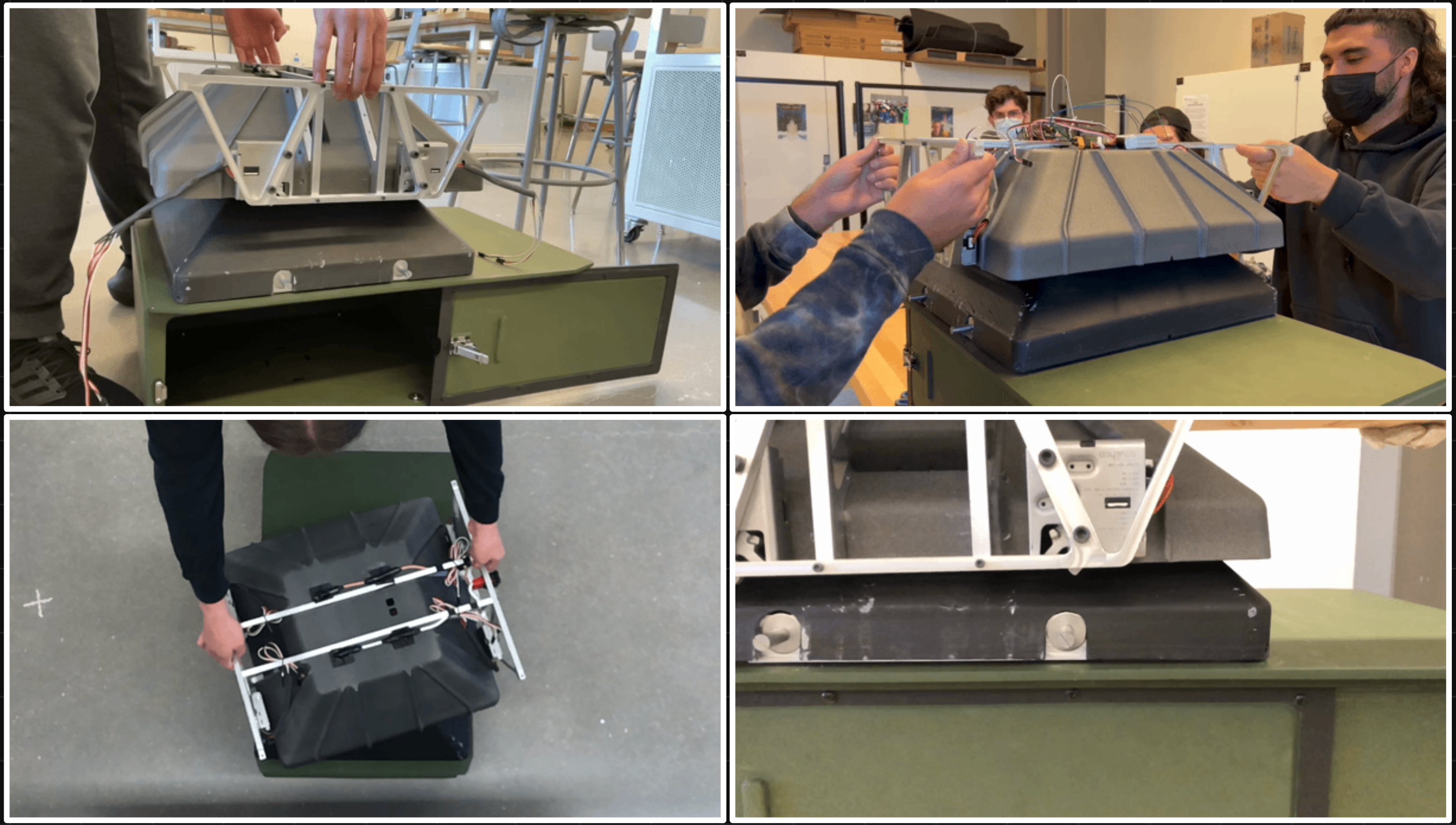
Induction Test Risk Reduction

Reduced Risk To Personnel: Secure latching mechanisms of latches to striker bolts reduces risk of unexpected disconnection and falling Pod/CPM

Reduced Risk To FR Failure : Repeated alignment success reduces risk of drone alignment failure tolerances

Reduced Risk To Future Project Failures : Distributed weight of 2x4 reduce risk of various drones being able to align and connect.

Manual Connection and Alignment Demo



IRISS Drone Test

IRISS Drone Test

Test Name	Testing Level	Models Verified	Relevant CPE	Requirements Closed
IRISS Drone Test	System	CAD offset, alignment tolerances	Alignment, Connection	1, 2

Motivation: Align and connect/disconnect the PRU to the CPM via a remote operator.

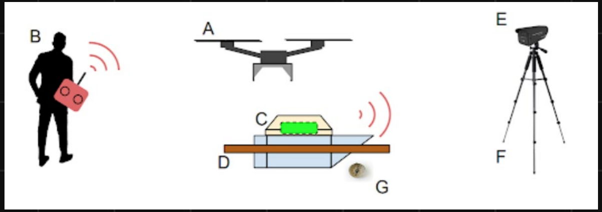
Rationale: Proves system functionality aside from picking up Pod.

Equipment:

- DJI S900 Drone + PRU
- Pod + CPM
- Meter sticks (2)
- Cameras (3)
- Compass

Location: ASPEN Lab

Expected Results: Ability to align and connect with up to 10 cm offset in x or y, and up to 20 deg in yaw



IRISS Drone Test

Methods:

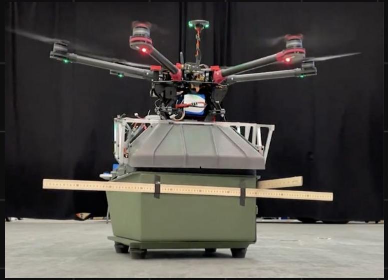
- Test alignment at various offsets in x direction up to 10 cm
- Test alignment at various offsets in y direction up to 10 cm
- Test alignment at various offsets in yaw up to 20 degrees

Assumptions:

- Only one direction varied at a time
- Weight distribution similar to Periscope drone in order to close latches

Results:

- Successfully aligned, connected, disconnected, and flew away
- Drone capabilities disappointing
  - Affected control
- Not all test cases were successful
  - Yaw offset only to 10 degrees
- Further day of testing to be scheduled
- Processing drone state data



Latch Command Test

Latch Command Test

Test Name	Testing Level	Models Verified	Relevant CPE	Requirement Closed
Latch Command Test	Subsystem	Timing model	Connection	2

Motivation: Need to unlatch from cargo pod after completing delivery

Testing Model: Timing between sent latch command and latch status verification
Rational: Verify latches will open and send latch status over XBee radios within required time

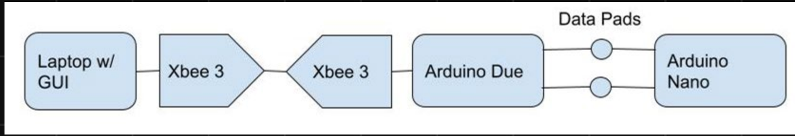
Equipment:
- PRU
- CPM and Pod
- Laptop w/ running GUI

Location: N200 Projects Room

Expected Results: SOMETHING

Latch Command Test

Goal	Verify that the GUI, CPM, and PRU communicate and execute commands within 1 second time constraint
Models verified	GUI to PRU Data Passthrough Flowchart and timing model
Data Collected	Time to receive/send data, time to execute command
Facilities	Lab Benchtop, Outdoor testing area
Steps	1. Create serial connection between two Arduinos (Nano & Due) 2. Send latch command from GUI through CPM microcontroller to PRU microcontroller 3. Verify lock on latch opens and closes 4. Verify response from Nano 5. Track time taken to complete
Requirements	FR 3, performance level 2



Test setup

Test Equipment

Arduino	2
Latch	1
Breadboard	1
XBEE Radios	2
Laptop	1

Latch Command Test [In Progress]

Test Name	Testing Level	Models Verified	Relevant CPE	Requirement Closed
Latch Command Test	Subsystem	Data Passthrough Flowchart	Data Downlink	2

Motivation: Verify that the GUI, CPM, and PRU communicate and execute commands within 1 second time constraint

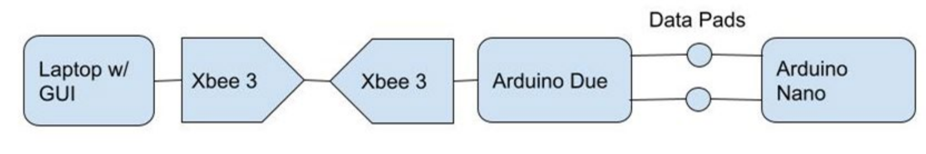
Testing Model: Data Passthrough Flowchart, Latch Command Timing model

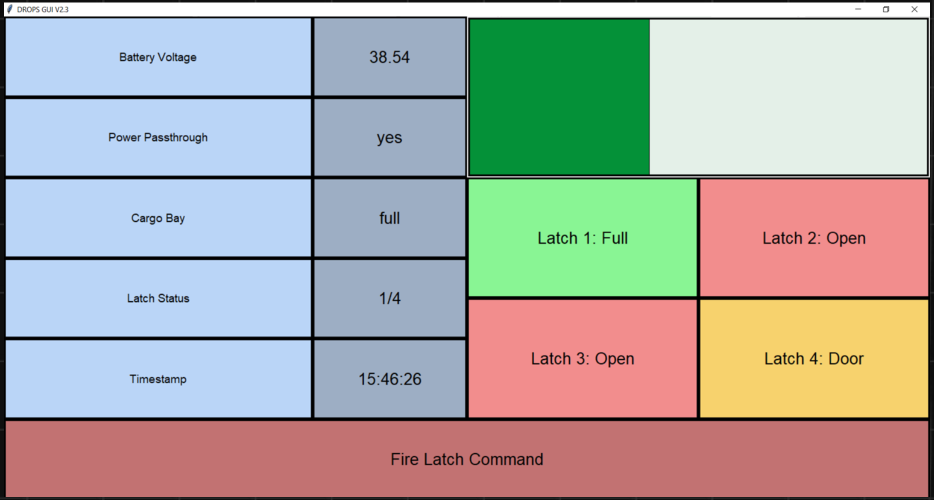
Equipment:

- Xbee 3 Pro x2
- Arduino Due and Nano
- Laptop with GUI

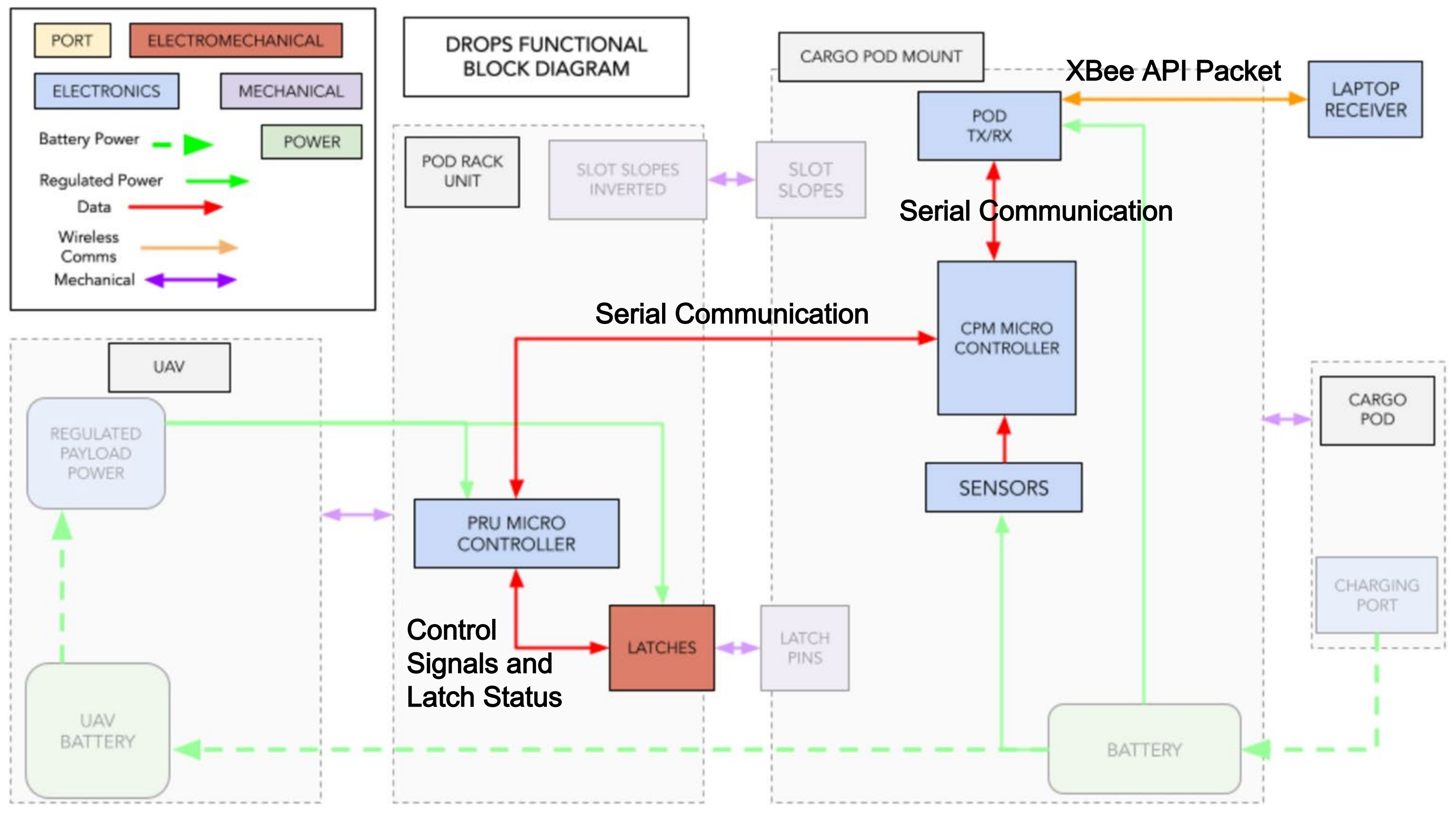
Location: N200, outdoor area

Expected Results: Latch commanded and statuses returned within 1 second





Latch Command Test- Data Passthrough Flowchart



Latch Command Test- Timing Model

- All data interfaces will be tested and timed individually to profile the impact of commanding and monitoring the latches to the overall runtime of the scripts then summed to get a total
- Afterwards, a full test is conducted, timed, and compared to the individual tests

GUI to XBEE	Xbee to Xbee	Xbee to Due	Due to Nano	Nano to Latches + ADC	Nano to Due	Due to Xbee	Xbee to Xbee	Xbee to GUI	**Total**
XXX ms	~0	XXX ms	XXX ms	XXX ms	XXX ms	XXX ms	~0	XXX ms	XXX ms

Latch Command Test- Methods

- Current Status - Milestones Reached
  - Data successfully transferred from GUI to latches but not yet timed
  - Code to time commands individually and in total being implemented currently
  - Current one-way latch command occurs in under a second
  - Team expects a negligible status return time compared to 1 second goal
- Full latch command test to be performed Wednesday, Feb 16th

Latch Command Test- Packet Definition

7E	Packet Length	Frame Type	Frame ID	Destination	Options	DATA	Checksum
	2B	1B	1B	8B	1B	65B	1B

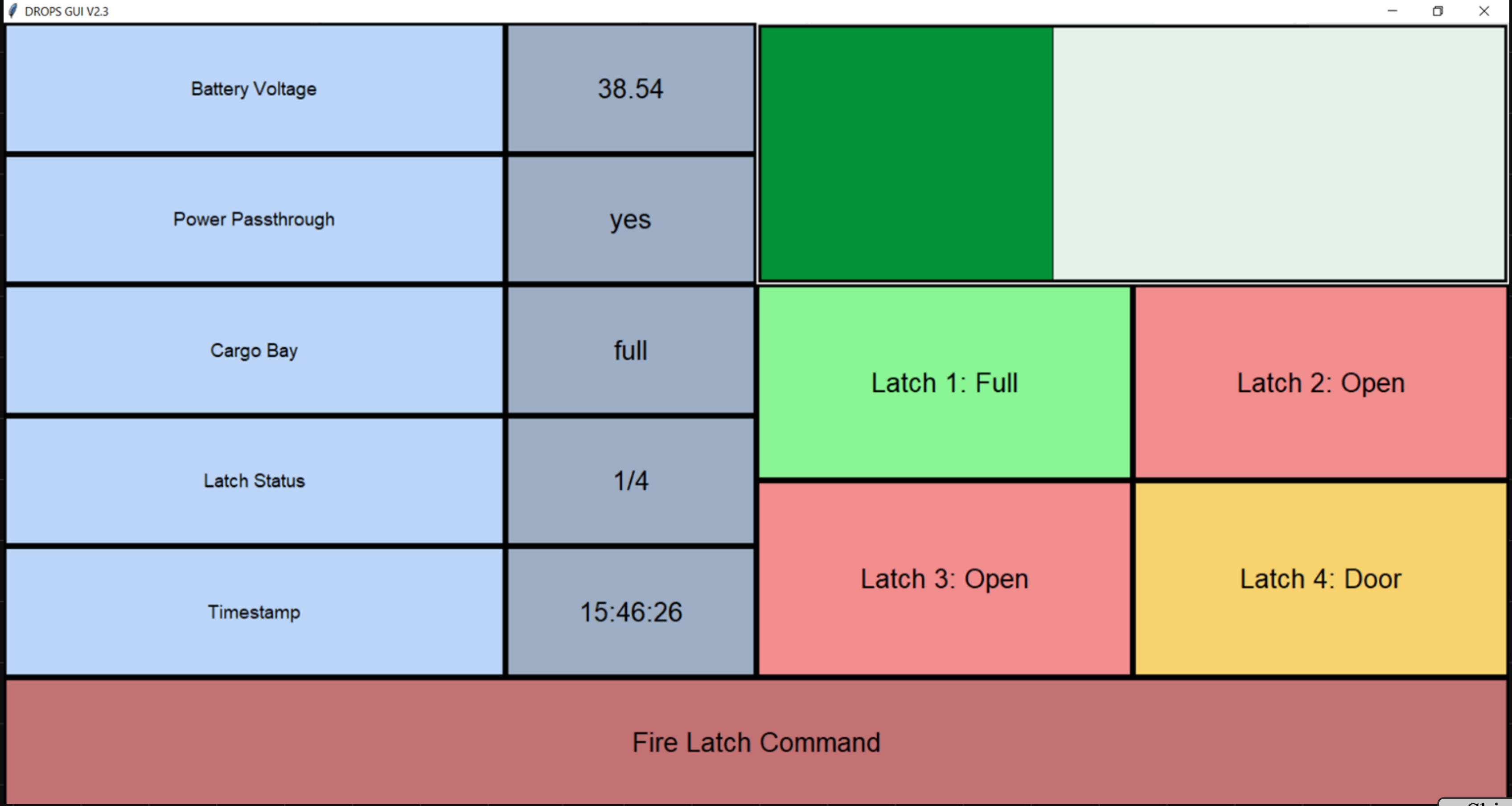
DATA

GPS Data	Battery Voltage	Connection Status	Cargo Status	Latch Status
50B	2B	4B	1B	8B

- Total Packet Size: 80B (640b)
- Minimum Packet Rate: 1Hz
- UART Default Data Rate: 9600 Baud

Back to Backup Slide Org Page

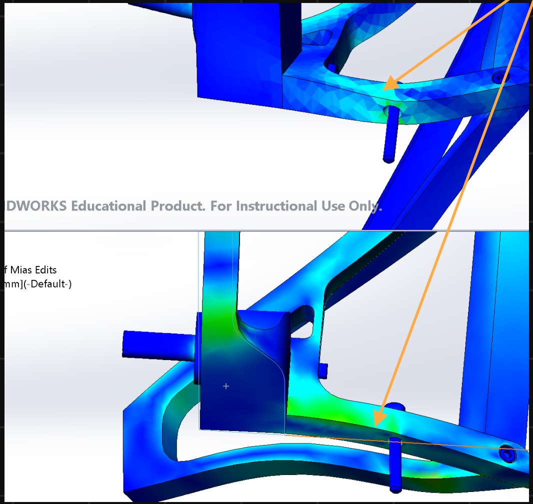
GUI


DROPS GUI V2.3
Battery Voltage
38.54
Power Passthrough
yes
Cargo Bay
full
Latch Status
1/4
Timestamp
15:46:26
Latch 1: Full
Latch 2: Open
Latch 3: Open
Latch 4: Door
Fire Latch Command

Periscope Drone Test

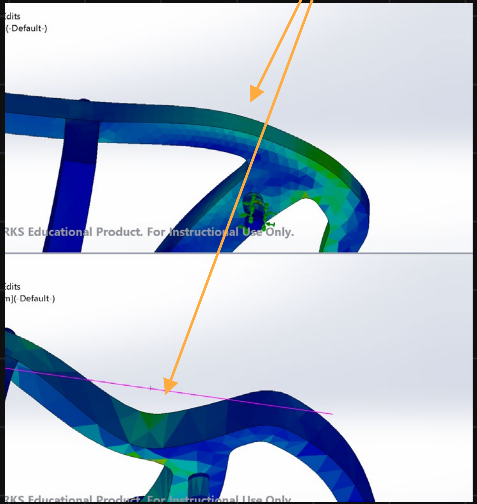
Periscope Drone Test - Model strain direction

Gauge Location



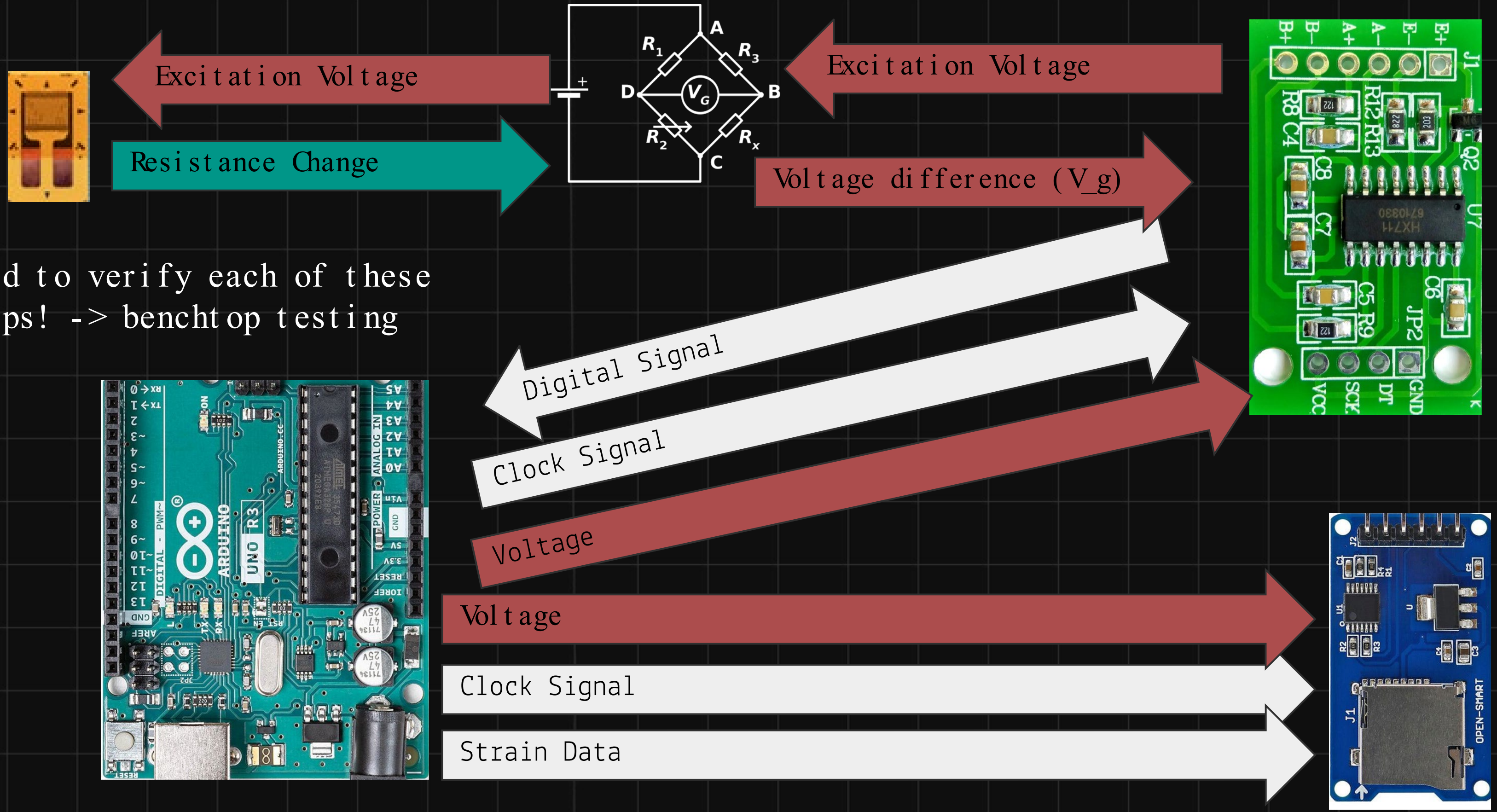
CPM Strain Direction Comparison

Gauge Location



PRU Strain Direction Comparison

Strain Data Acquisition System



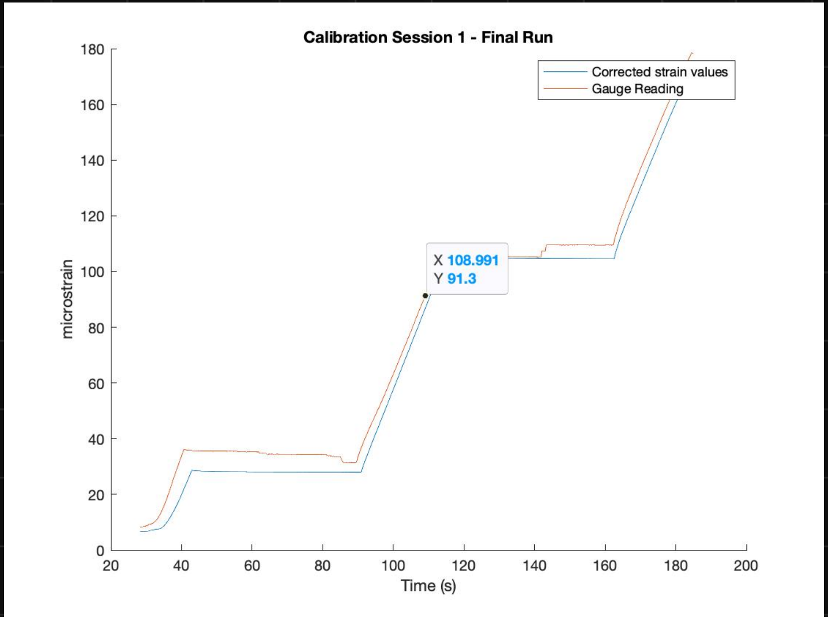
Need to verify each of these steps! -> benchtop testing

Arduino Code Structure

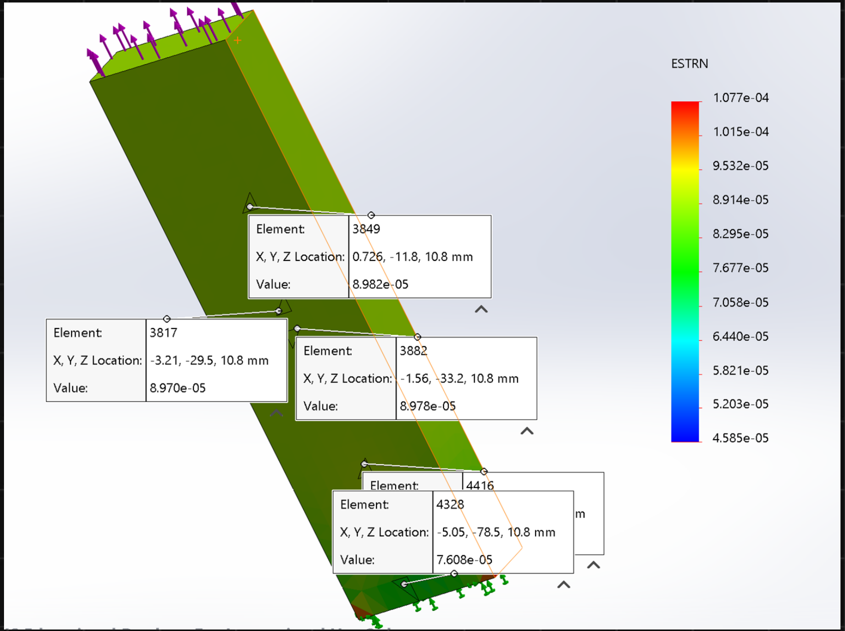
When pin is pulled
1 -> 30 second time delay
2 -> zeros the strain gauges
3 -> writes strain data to Micro SD Card

When pin is not pulled
1 -> time loop

Total 1st Calibration Run



Strain Values vs DAQ Reading



FEA for Aluminum Bar for Strain Correction

Strain Gauge Application SOP - backup slide

1. Use 120-grit sandpaper and then subsequently 1000-grit sandpaper on place to be gauged
2. Next, clean surface using isopropanol using lint-free cotton pads until the cotton pads come up clean
3. Next, apply Mprep conditioner A with lint-free cotton pads until the pads come up clean. Immediately apply Mprep neutralizer B and remove with lint-free cotton pad.
4. Apply gauging tape to area and pencil in crosshead for gauge. Line up gauge, apply isopropanol to both the gauge underside and the gauging surface. Wait to dry, then apply small amount of CA glue and press down for ~3 minutes.
5. Apply flux to gauge pads. Then, solder wires using MM brand solder on the lowest temperature setting.

Strain DAQ System Calibration

Instrumentation:
Gauge DAQ system
Aluminum sample with gauge attached
Instron 50 kN Universal Testing Machine
5 kN Load Cell
Getforce.m
Getstrain.m

1. Add 5 kN load cell and detach 50 kN load cell
2. Load aluminum sample into UTM
3. Set dz/dt to 0.010 mm/s
4. Press reset button to get control back to computer
5. Run Arduino code 'Drops_GaugeDAQ_Calibration.ino'
6. Stop UTM around 1 kN of force
7. Run Matlab code 'getstrain.m'
8. Send '+' or '-' to serial monitor as needed to increase/decrease calibration factor until gage reading matches code
9. Repeat every ~0.5 kN until 4.5 kN

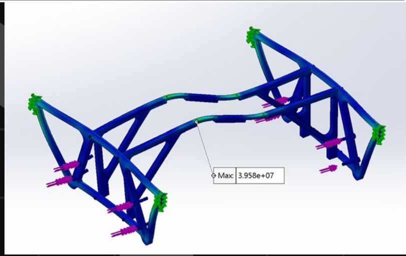
Verification and Validation (From CDR)

Testing Summary

Test Name	Relevant CPE	Relevant FR
Periscope Drone Test	Structures, Communication, and Control	3,6,7
High Power System Test	Power	4
IRISS Drone Test	Structures	1, 2
Data Downlink Radio Test	Data Transmission	7
Latch Command Test	Communication and Control	2
Induction Charging Test	Power	5
Manual Connection and Disconnection	Structures	1, 2

Test 1: Heavy Lift UAV Test - Model Details

Periscope Thrust-to-Weight Ratio Specs → Expected forces/accelerations → FEA Modeling → Stress concentrations/deformation



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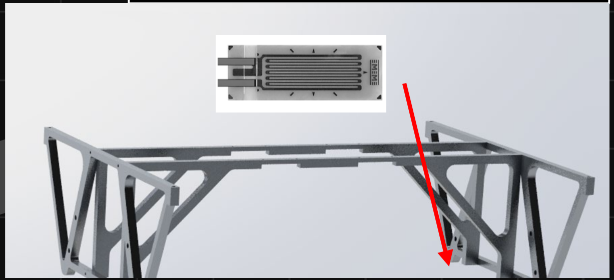
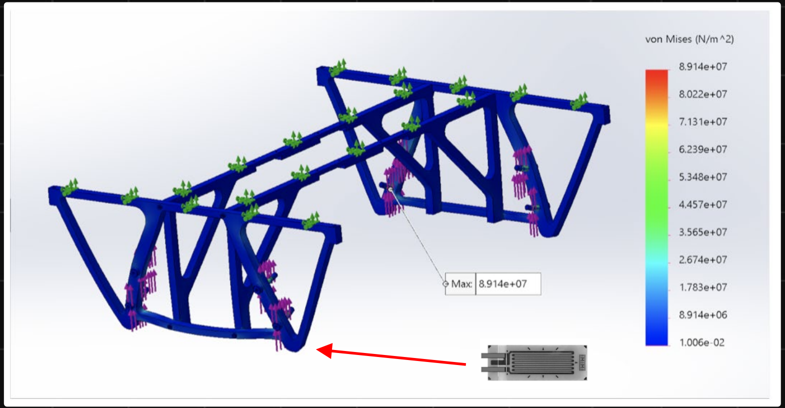
Strain Gauge Placement

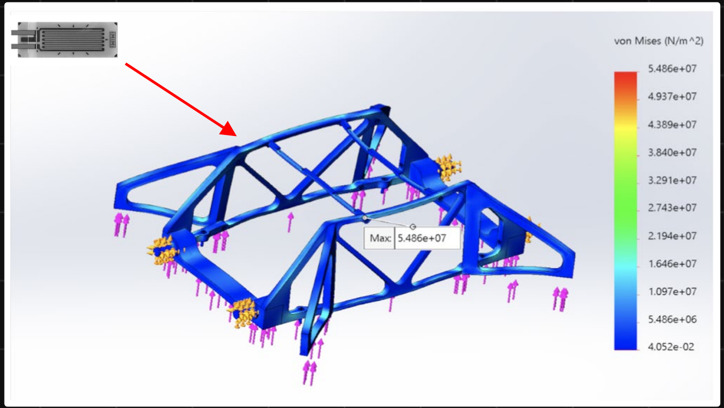


→ UAV Flight Test → Actual forces/deformation ↔ Periscope Thrust-to-Weight Ratio Specs

Test 1: Heavy Lift UAV Test

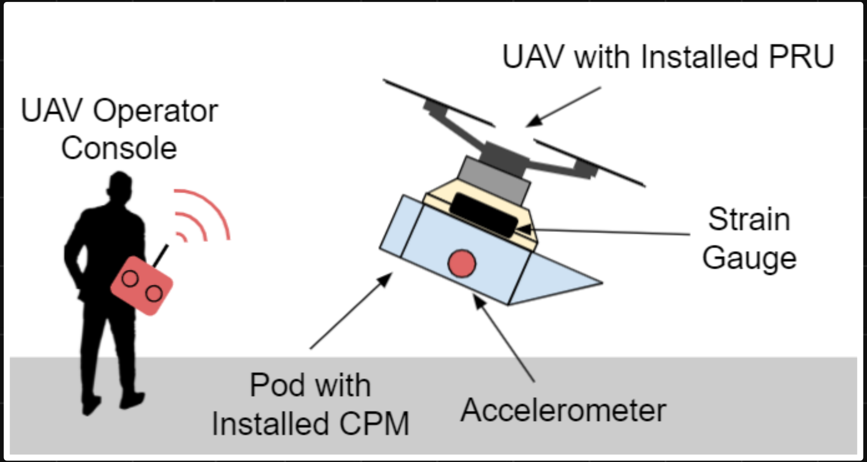
Goals	1. Fly the Pod with the drone and detach with remote operator 2. Dress rehearsal for Army event (AEWE)
Models verified	CPM FEA, PRU FEA (landing)
Data Collected	3 axis acceleration data Expected Values: < 25.4 m/s^2 vertical, 7 m/s^2 lateral Strain gauge data Expected Values at selected strain gauge location: 7.01 e-2 mm (PRU), 1.35e-2 mm (CPM)





Test 1: Heavy Lift UAV Test

Facilities	Periscope facility
Steps	1. Pod manually connected to drone 2. Drone flys with Pod recording accel. and strain data 3. Drone lands 4. Pod remotely detached 5. Drone flies away
Requirements Closed	FR 4, level 2 and 3 performance requirements



Test 2: High Power System Test - Model Details

Copper 145 Alloy Specs:

K [W/m*K]	386
ρ [Ohms]	$1.678 * 10^{-8}$

Voltage and Current:

Constant Voltage [V]	44.4
Constant Current Per Pad [A]	50

Pad Model Results:

Power Loss Per Pad [W]	$1.13 * 10^{-4}$
Temp. Increase Per Pad [K]	$7.88 * 10^{-7}$

Pad Power Loss Equations:

$$R_{Pad} = \frac{\rho t}{wh}$$

$$V_{Drop} = I * R_{Pad}$$

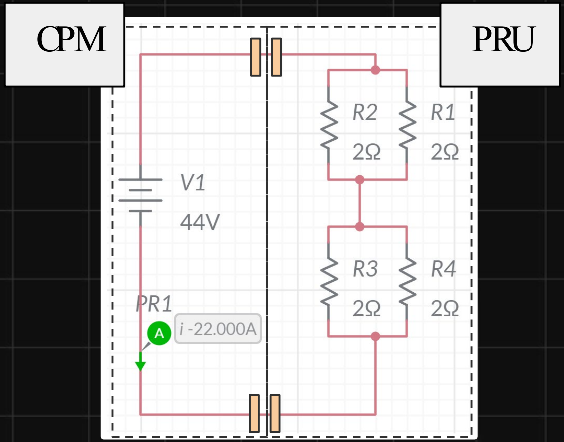
$$P_{Loss} = I * (44.4 - V_{Drop})$$

Pad Temperature Change Equation:

$$T_{Change} = P_{Loss} \frac{t}{whk}$$

Test 2: High Power System Test

Goal	Test the system can supply 22 Amps of current at the PRU terminal cables.
Models verified	1. Power pass through layout (Battery Input/Output and Pads) 2. Power and temperature losses with contact pads
Data Collected	Electrical Current through the High Power System (Expected: ~22 A) Voltage differential at PRU end (Expected: ~44 V) Copper PADs temperature (Expected: Room Temperature, Delta T << 1C)

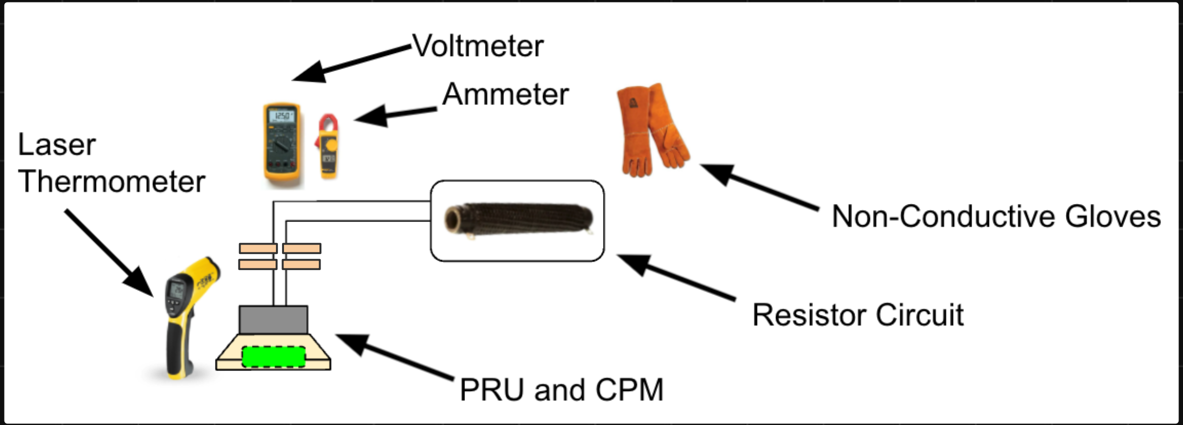


Test Circuit Modeling Results:

Est. Voltage at Input:	44 V
Test Current Desired:	20-25 A
Total Resistance Required:	2 Ohm
Resistor Power Rating:	300 W
Resistor Rating Tolerance:	5-10 %
Est. Dissipation Per Unit:	242 W
Safety Margin:	< 50 W / 20 %

Test 2: High Power System Test

Facilities	N200 Projects Space
Steps	1. Measure/Record PADS temperature 2. Connect testing circuit to PRU 3. Place PRU on CPM and turn power on 4. Measure/Record Current and Voltage 5. Turn power off, remove PRU 6. Measure/Record PADs temperature
Requirements	FR 4, performance level 2



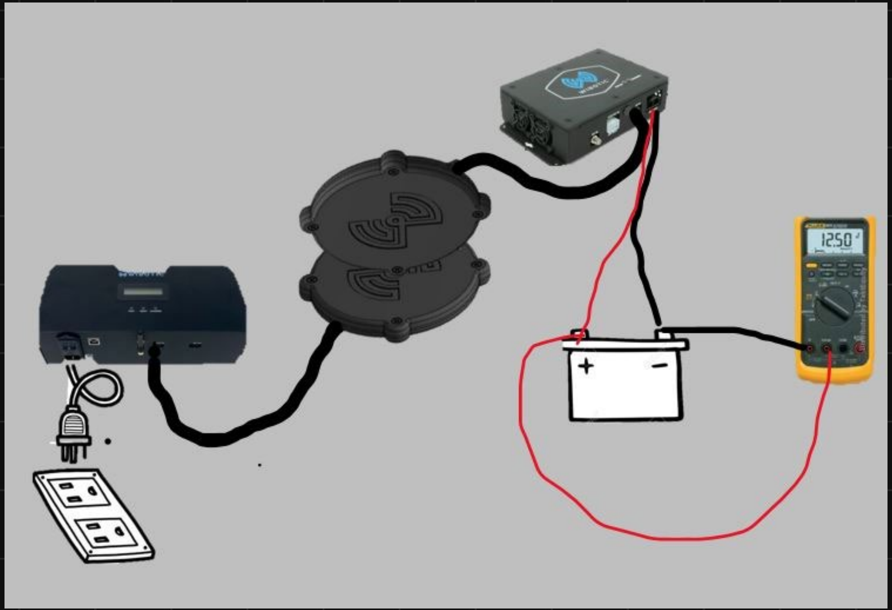
Small Scale Testing

Induction Charging Test

Battery Charging/Discharging

- Test Plan: Induction Charging Test
  - Materials:
    - Wibotics Charging System
    - Voltmeter
    - Battery
    - Glenair Wires
    - Ring joints
- Safety Checklist:
  - High Power circuit inspected
  - LiPo Bag ready
  - LiPo Fire bucket ready
- Date: 1/22/2021
- Location for this test
  - N200 not great per email yesterday
  - Engine test cell good location?

Testing Setup:



Induction Charging Test - Procedures Overview

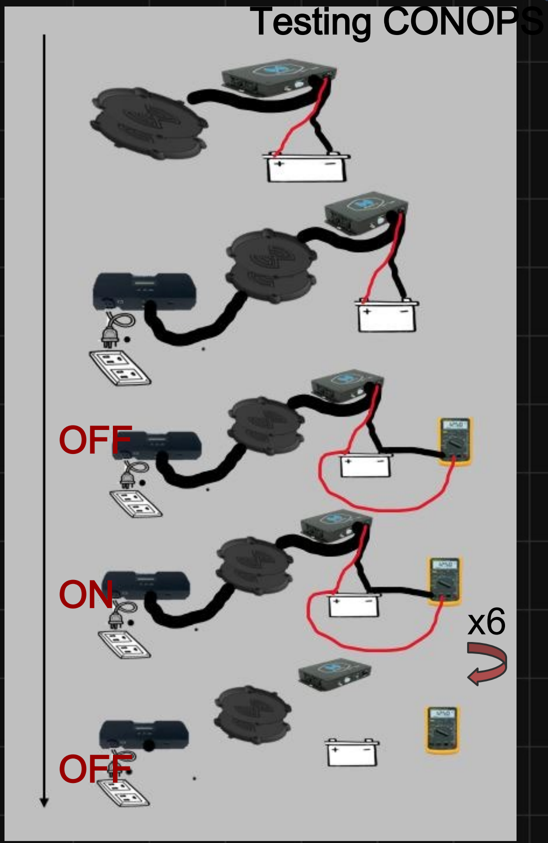
- Connect the onboard charger to the batteries and receiver coil.

- Connect the transmitter coil to the wall transmitter and plug to the wall power outlet.

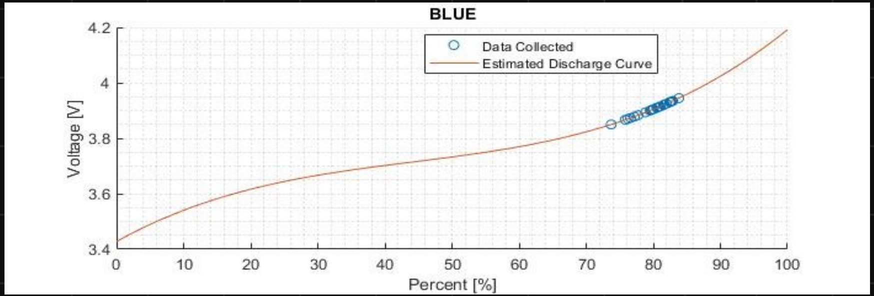
- Measure the starting battery voltage and record it.

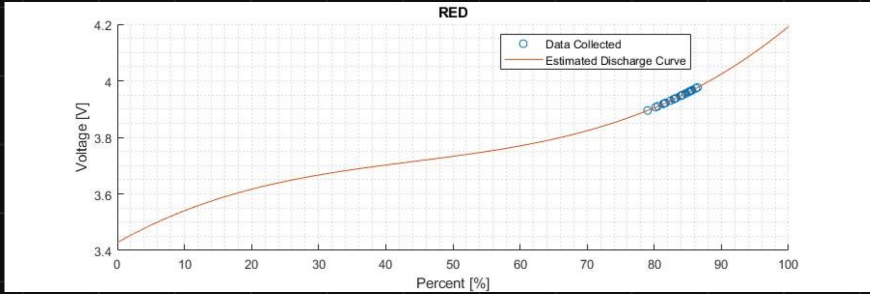
- Turn power on and wait for 10 minutes. Repeat measurement until one hour has passed. There should be a total of 7 measurements.

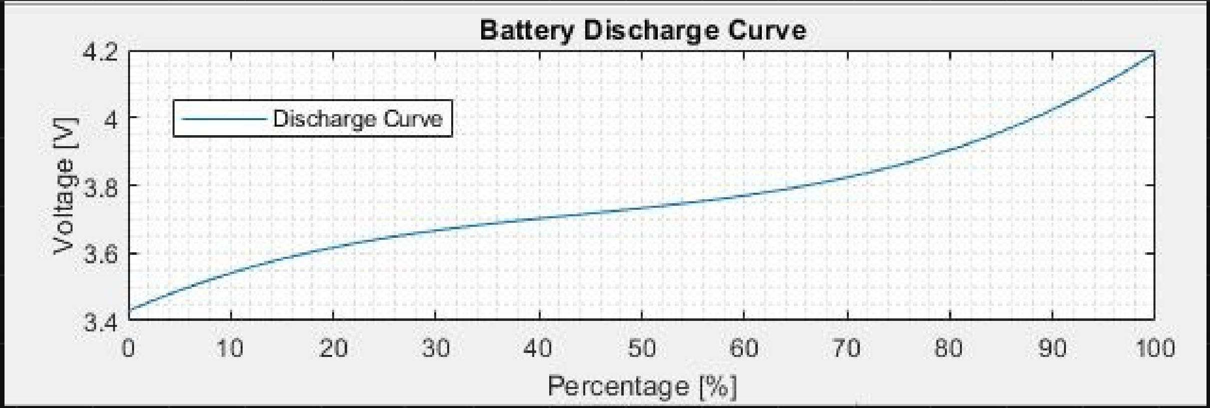
- End of the test. Turn power off. Disconnect everything.



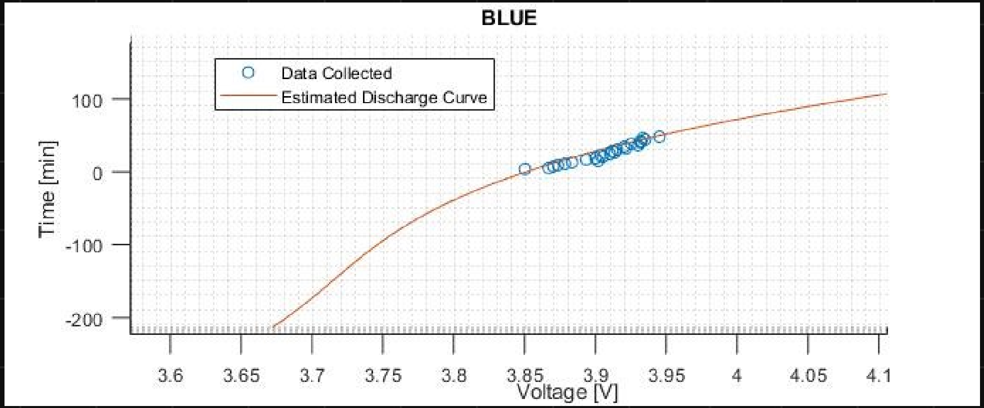
Detailed induction test details

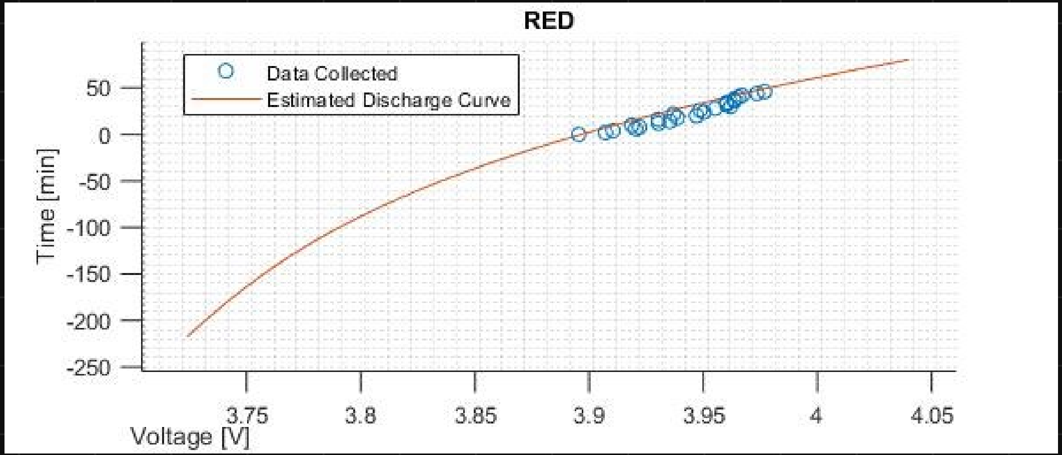




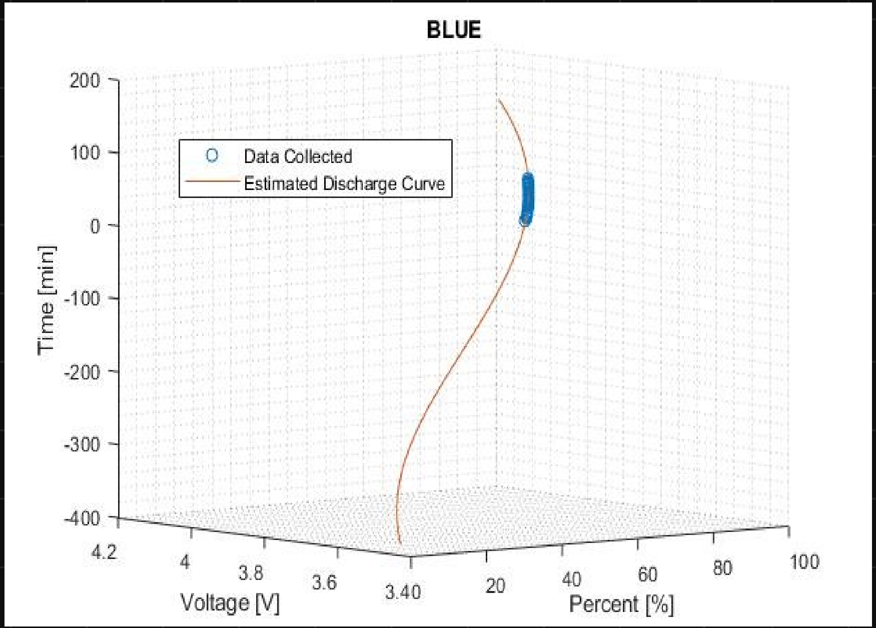


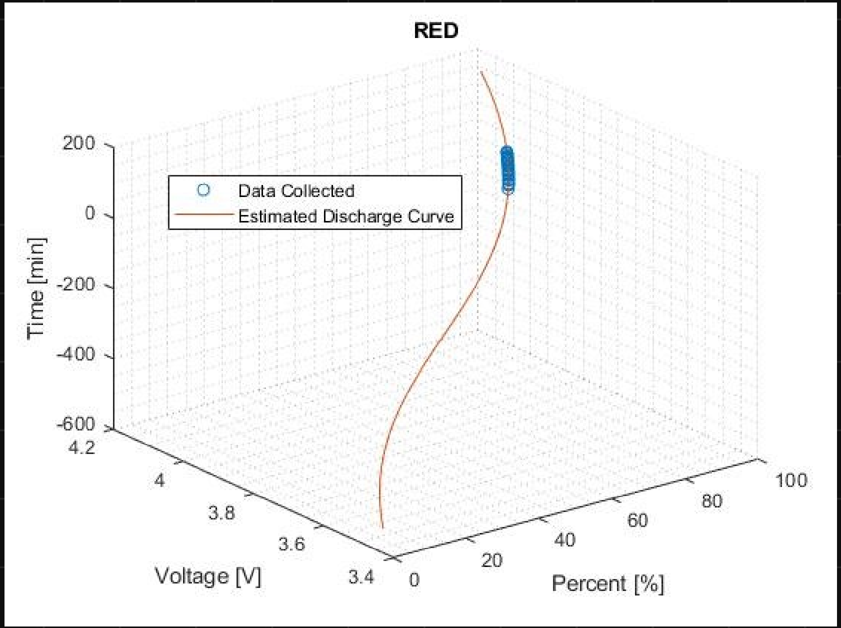
Detailed induction test details





Detailed induction test details





Detailed induction test details