CHIMERA

CHIld drone deployment MEchanism and Retrieval Apparatus

Test Readiness Review

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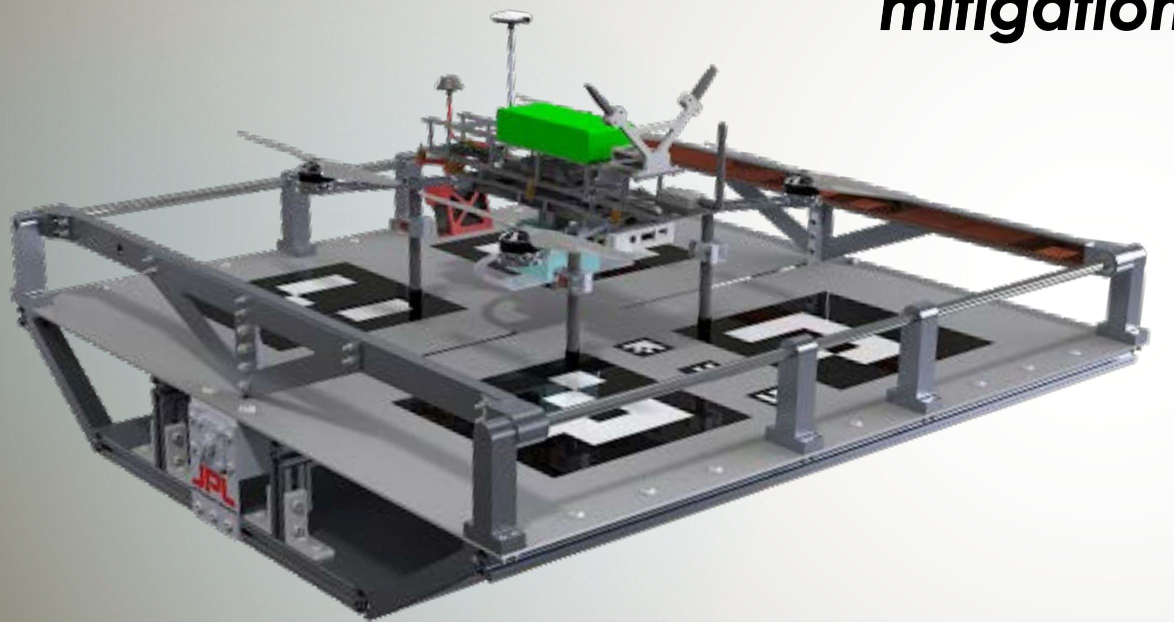
Advisor: Jelliffe Jackson

Agenda

- Project Overview
- System Design and Updates
- Schedule
- Budget
- Testing Update
  - Flight Simulator
  - Image Recognition Verification
  - Autonomous Landing Subsystem Test
  - Automatic Charging Subsystem Test
- Conclusion

Mission Statement

CHIMERA (CHIld drone deployment MEchanism and Retrieval Apparatus) will support the autonomous deployment, landing, and securing of the INFERNO unmanned aerial system and act as a communications relay to assist firefighters in the monitoring and mitigation of wildfires.



Mission Objectives

- Contribute to the overall Fire Tracker mission by designing and building a child drone platform capable of integration with a future mother rover.
- Modify the child drone built by last year's INFERNO senior design team to autonomously land on the platform.
- Design a platform capable of securing and charging a child drone after autonomous landing.
- Design a communication system that facilitates communication between the child drone, the platform and a ground station.

Critical Project Elements

- Autonomous Landing of Child Drone
  - Implements image recognition software for command and control of child drone to land on platform
  - RISK: Commanding the Pixhawk
- Automatic Child Drone Recharging
  - Utilizes conductive contacts to transfer power from platform battery bank to child drone for extended mission duration
  - RISK: Open copper contacts, complex circuitry
- Securing of Child Drone
  - Platform shall capture the child drone and restrict movement over rough terrain
  - RISK: Complex mechanical hardware

Levels of Success

Level 4

- CDS autonomously lands on Platform upon command in correct orientation
- Charging system autonomously charges CDS battery upon command
- Securing system prevents CDS from tipping and positions CDS for charging
- COM system transmits/receives video at 720p and 30 fps according to CONST 1.3
- COM systems transmits/receives telemetry/SPS data according to CONST 1.3

Level 3

- CDS autonomously lands on Platform upon command
- Charging system charges CDS battery with human in-the-loop
- COM system transmits/receives video across a minimum of 200 m
- COM system functions across a minimum of 200 m

Currently on track to achieve Level 4 Objectives

Level 2

- CDS autonomously lands upon command
- Charging system demonstrates charging capability by illuminating LED on platform
- COM system transmits/receives telemetry and SPS data

Level 1

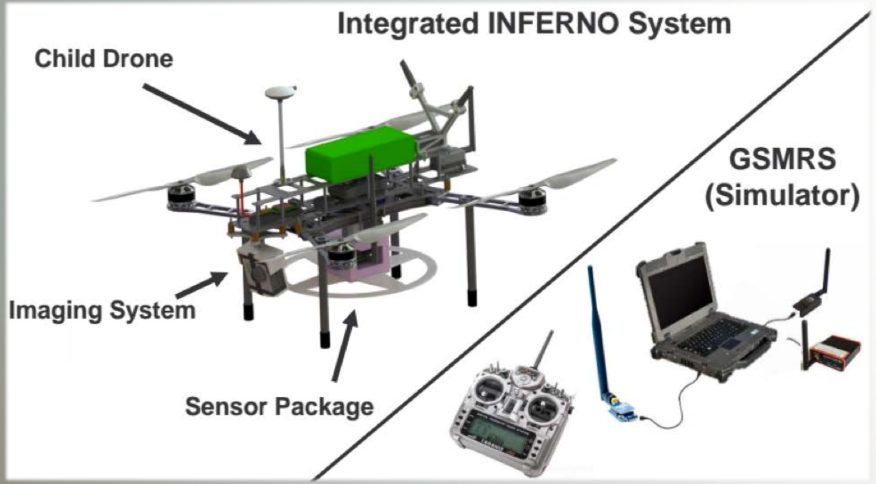
- CDS IRS recognizes platform and initiates landing sequence upon command
- COM system transmits/receives telemetry
- Securing system engages upon command

Inherited Project

INFERNO

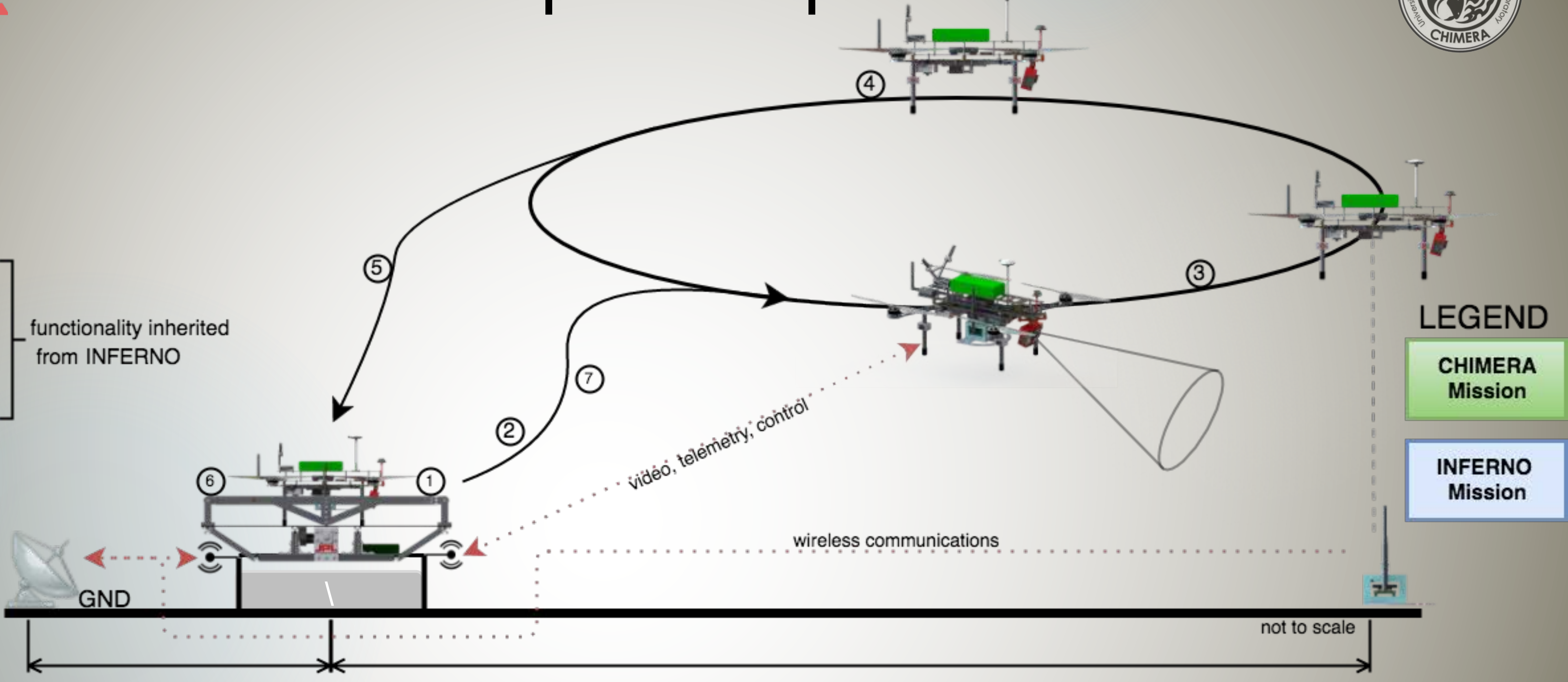
INtegrated Flight Enabled Rover for Natural disaster Observation[2]

- 2015-2016 JPL sponsored senior design project
- Semi-autonomous drone capable of delivering temperature-sensing package to wildfire area of interest
- CHIMERA will utilize existing INFERNO hardware

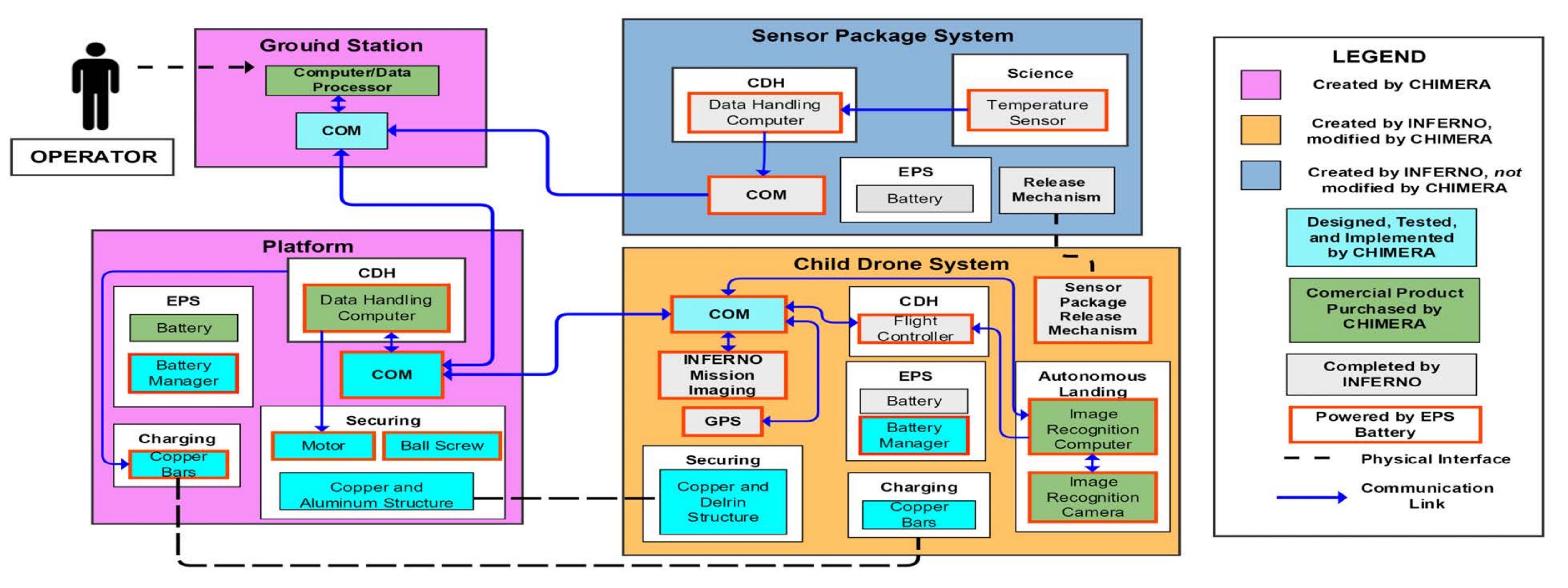


Concept of Operations

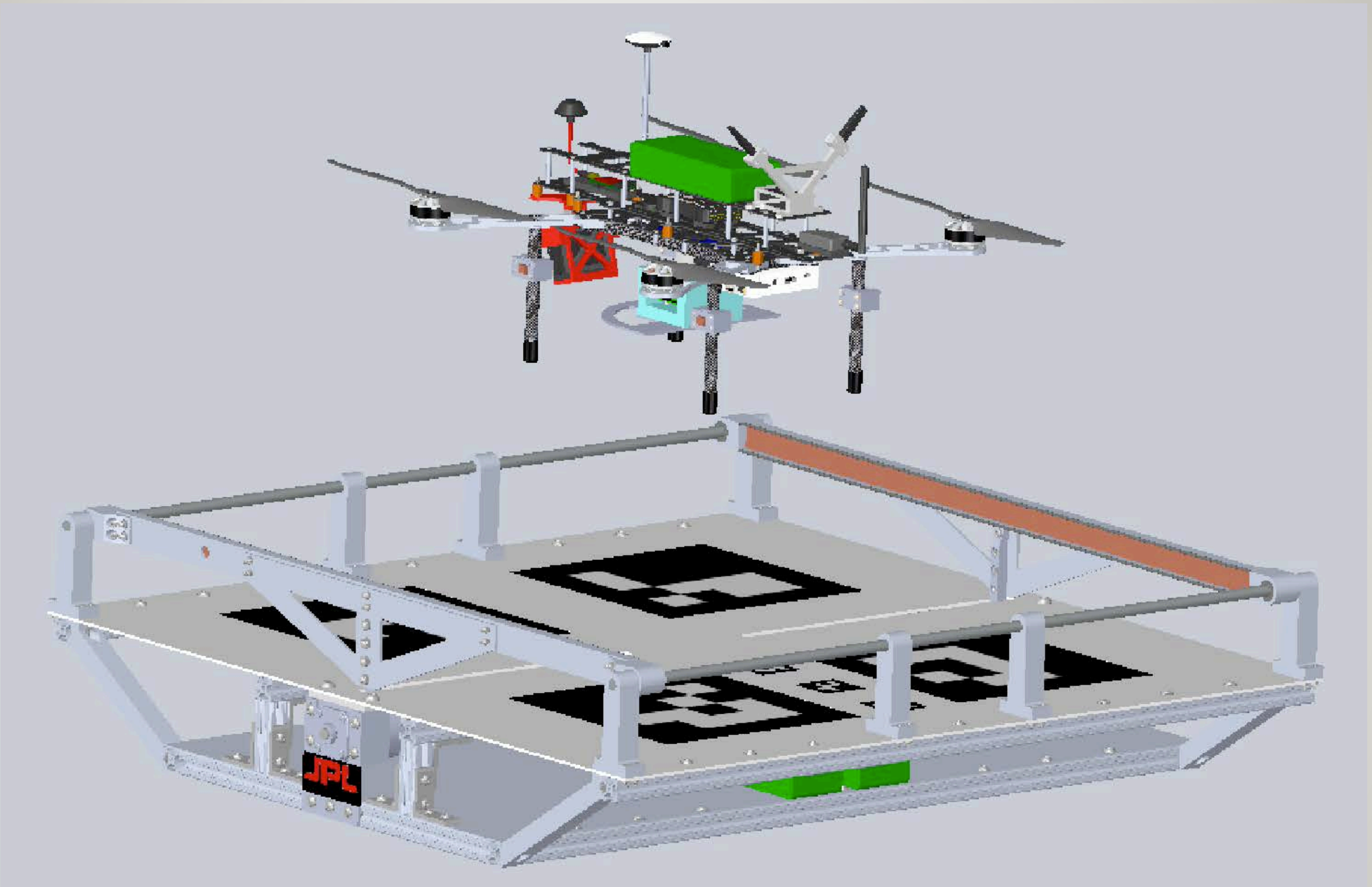
1. Securing Over Sample Environment
2. Deploy CDS (Takeoff)
3. CDS Mission (13.5 Minutes)
4. CDS Return
5. CDS Autonomous Landing
6. CDS Recharge
7. CDS Redeploy



Functional Block Diagram: System Level

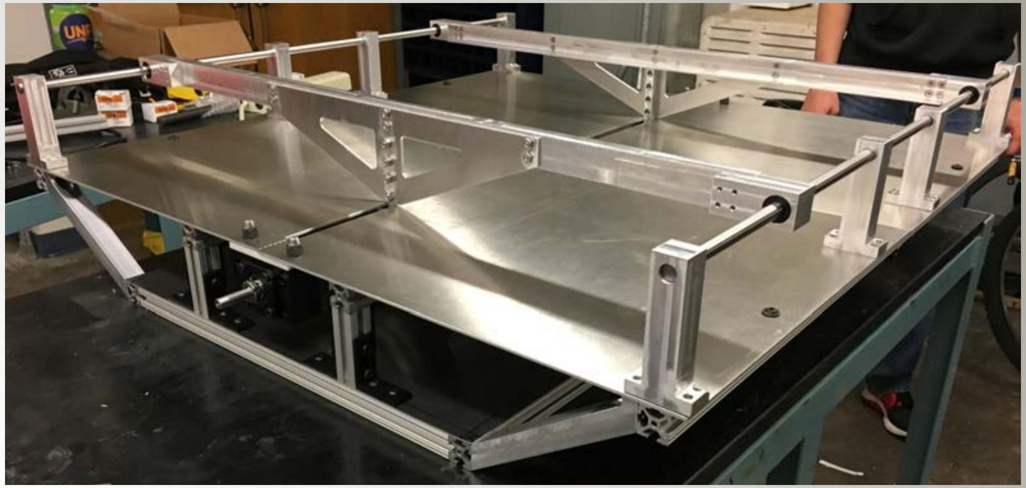


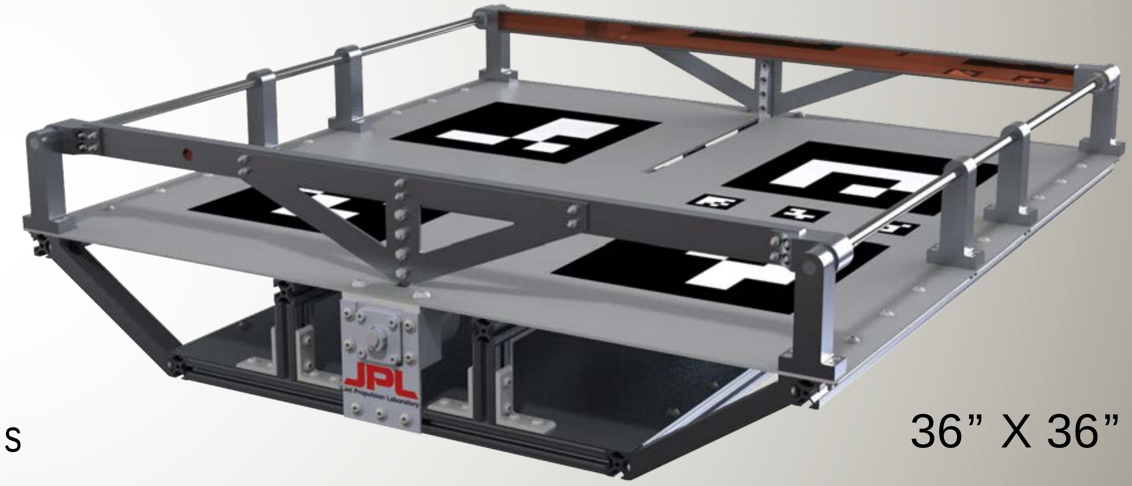
System Design



Hardware Manufacturing

- Hours Estimated to completion at MSR: 180 hrs
- Actual hours worked to complete major manufacturing: 145 hrs
- Outstanding items:
  - Wiring of C-channel brackets
  - Integration of motor to ball screw system
  - Mounting INFERNO charging brackets
  - Powder coating of C-channel brackets
  - Unit testing of securement and charge systems

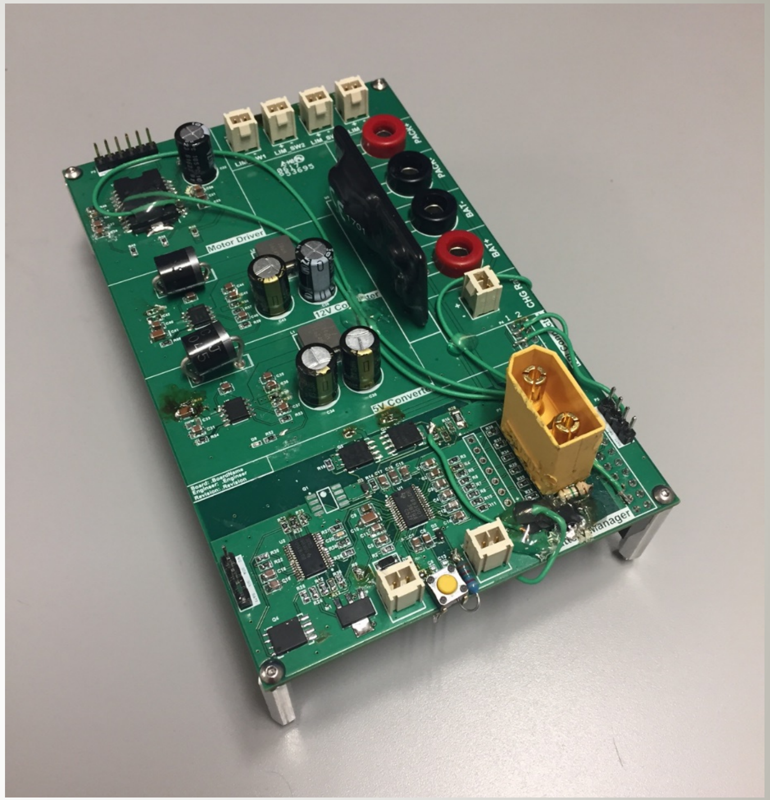




36” X 36”

Electronic Status Update

- Platform PCB
  - Populated
  - Tested
  - Developing Final Software
- INFERNO PCB
  - Populated
  - Developing Software



Platform PCB with all components integrated

PCB Designed → PCB Fabricated → PCB Populated → Pi Integration → INFERNO/Platform Installation

Pixhawk Interface Update

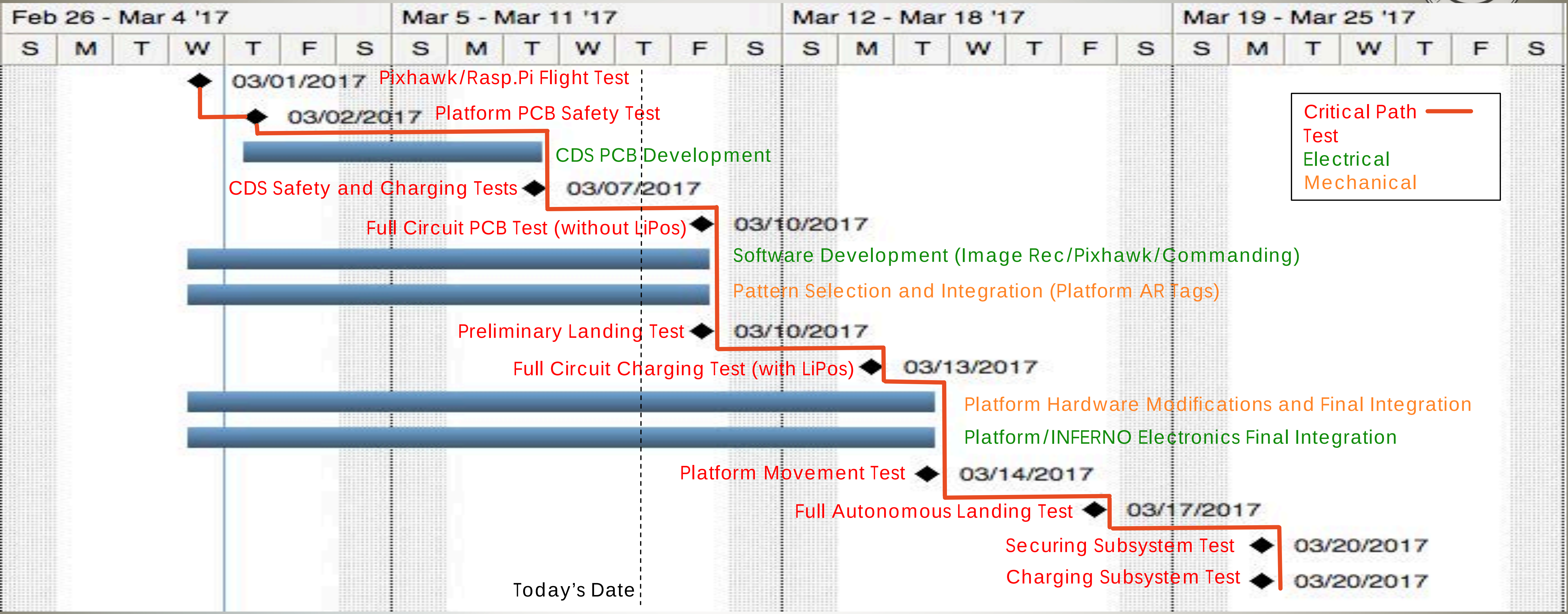
- Initial Problem:
  - Zero Throttle when switching modes caused a crash
- Static Testing – Confident in ability for pilot to take control
- Tethered Testing – Safely Testing bugs in Software and communication between ground station and raspberry pi
- Successful pilot intervention
- Future Work:
  - Test velocity commanding
  - Integrate image recognition with landing script
  - Test full landing sequence

Commanded takeoff with pilot intervention

Schedule Breakdown

Project Overview | **Schedule** | Budget | Test Readiness | Conclusion

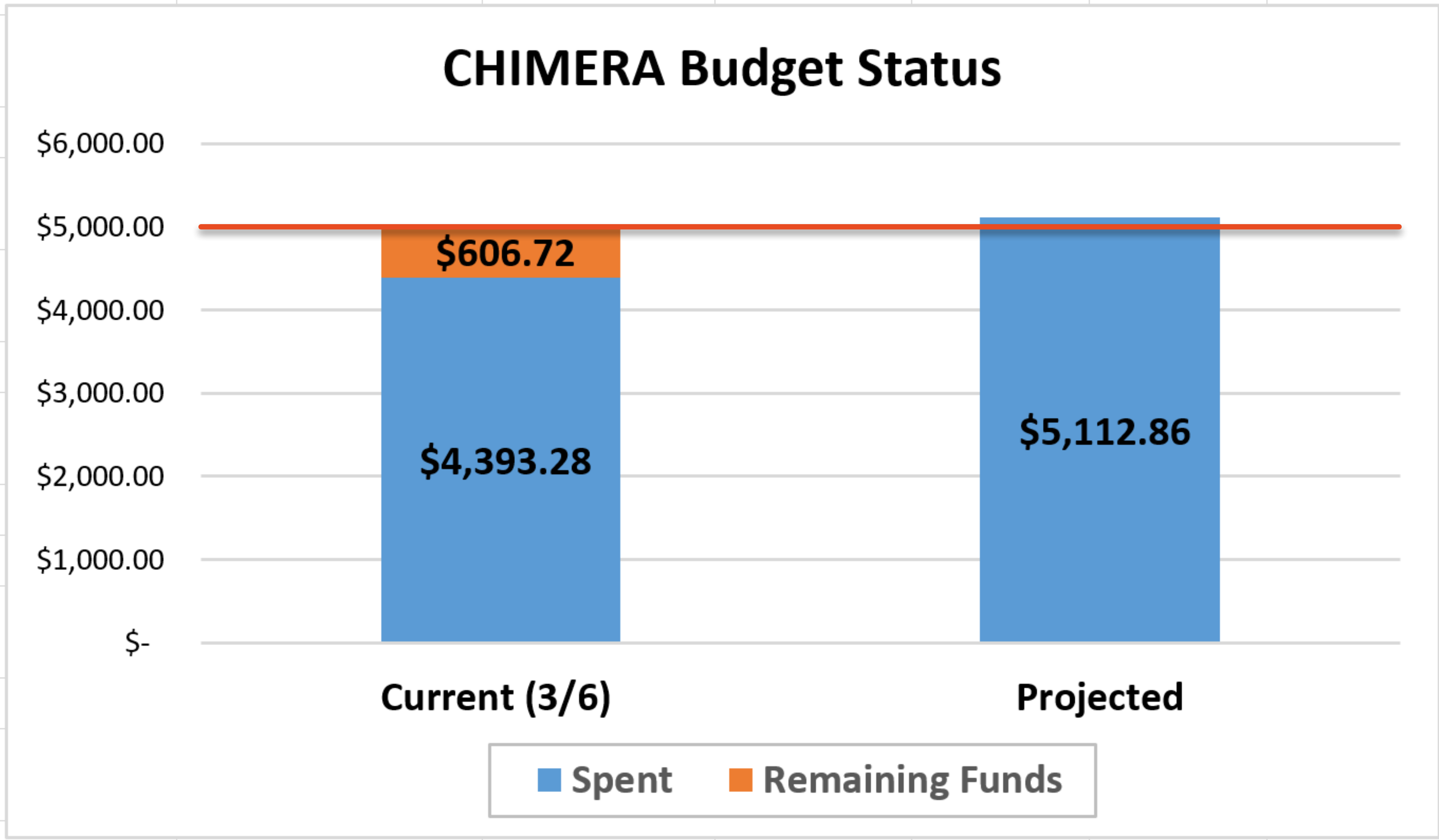
Testing Schedule Highlight



Project Overview | Schedule | Budget | Testing | Conclusion

Budget Status Update

Budget Status



Project Overview | Schedule | **Budget** | Test Readiness | Conclusion

Budget Changes Since MSR

COSTING $

- Second and third PCB revisions, expedited shipping on revision 3
- Additional spare small PCB components
- Decals on platform
- Limit switches
- Symposium poster printing

SAVING $

- Aluminum anodizing → Powder coating
- Worm gear → Bevel gear

Procurement Update

ARRIVED:

- Platform components
- Communication components
- Electronic hardware
- Platform motor
- PCB rev 1
- Lipos
- Spare parts
- Powder coating
- Bevel gear
- Limit switches

PURCHASED, NOT ARRIVED:

- Spare INFERNO GPS

NOT PURCHASED:

- Spare INFERNO legs
- PCB rev 2 and 3
- AR tag decals
- Symposium poster spring report printing

LEGEND

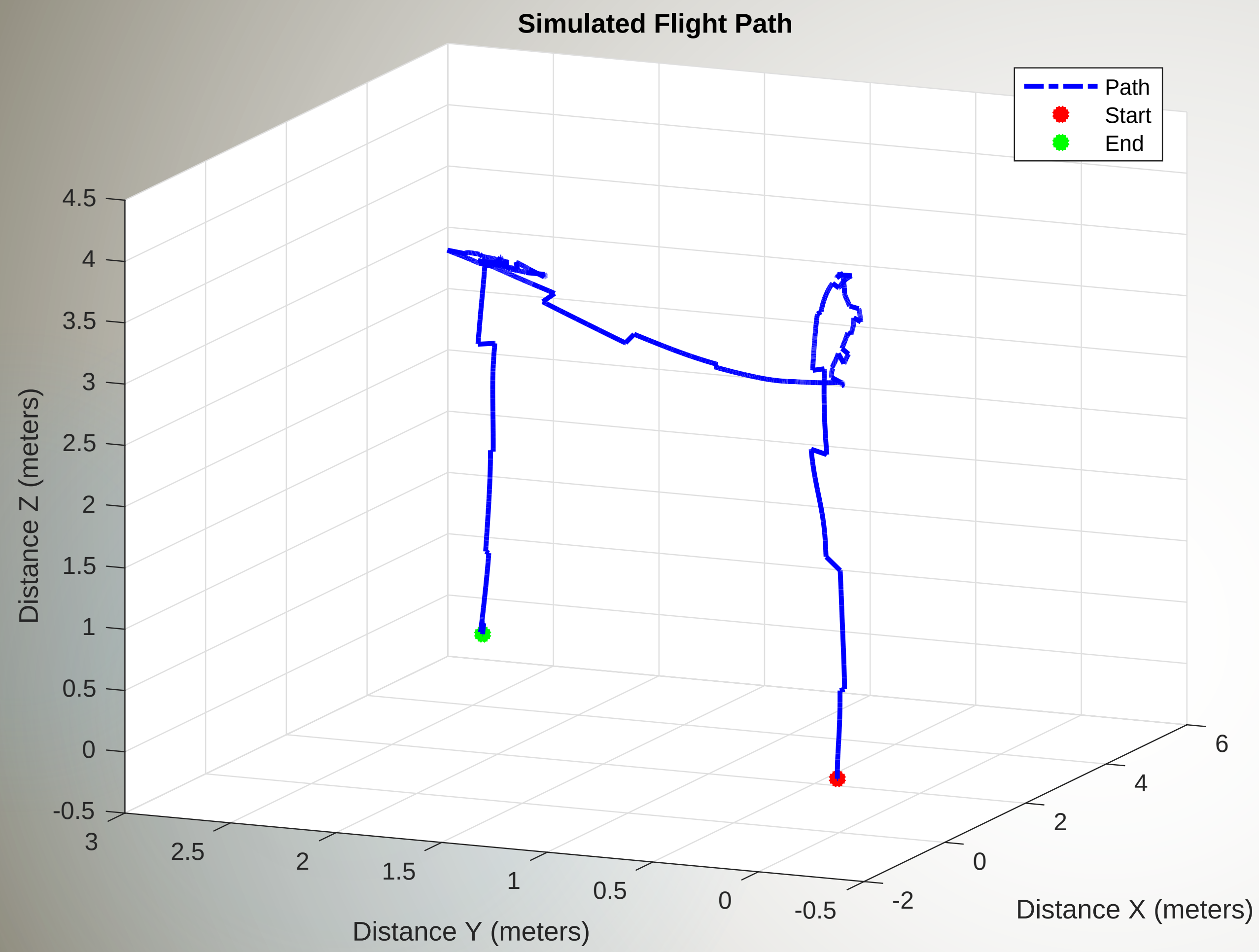
Schedule risk

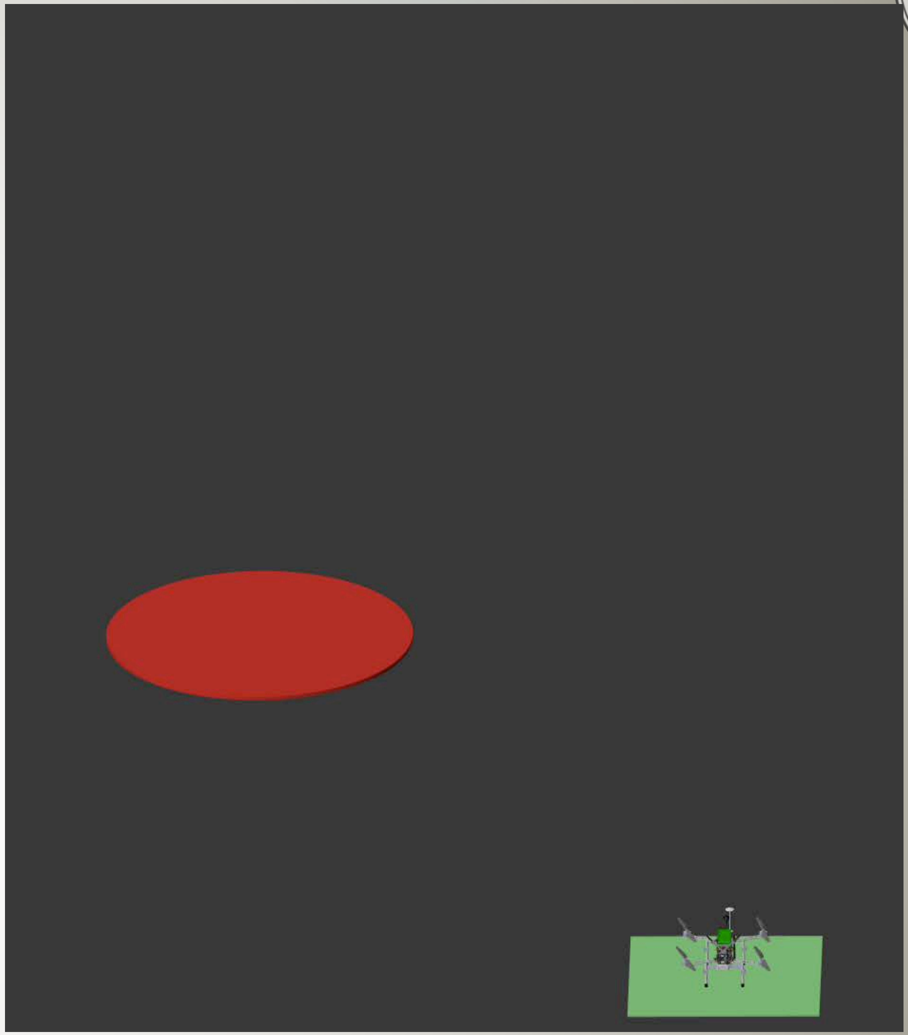
Budget risk

Critical component

Test Readiness

Flight Simulator - Demonstration

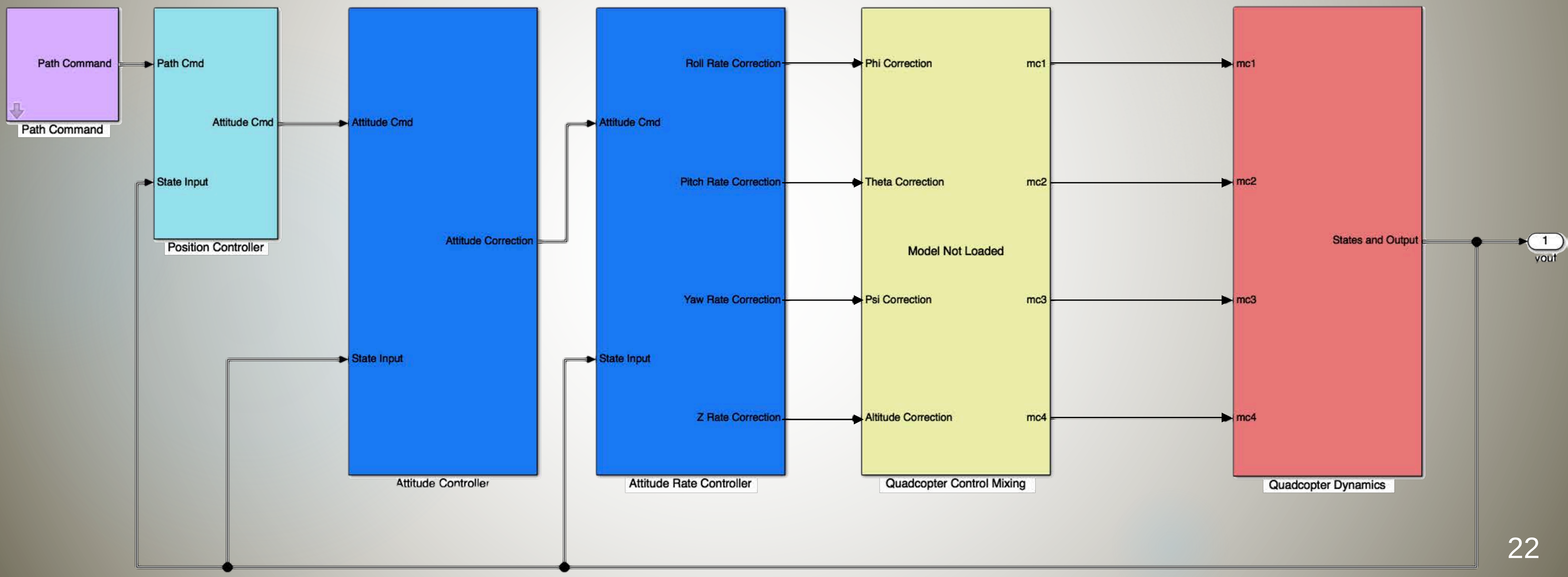




Flight Simulator - Model

- Cascading control system
  - To emulate Pixhawk
- Fully configurable gains

- Utilizes Simscape Multibody Simulink add-in
  - Provided kinetics, calculates kinematics
  - Import Solidworks model of INFERNO for mass and inertia properties

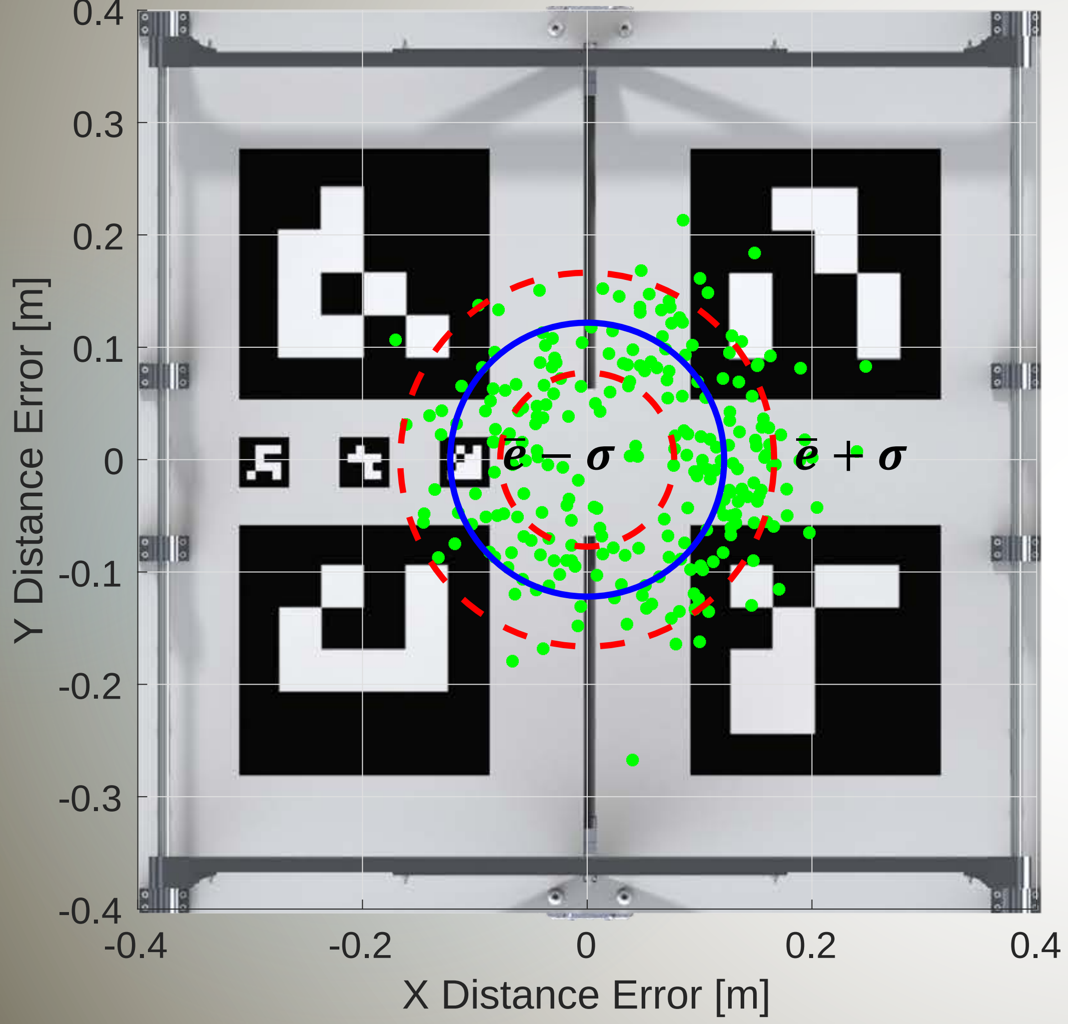


Monte Carlo Simulation

250 Landing simulations run for each case

No Wind or External Forces

- $\bar{e}$ = 0.122 meters
- σ = 0.045 meters



Wind (mean = 20 MPH) +/- Gaussian variance of 2.5 MPH

- $\bar{e}$ = 0.152 meters
- σ = 0.072 meters

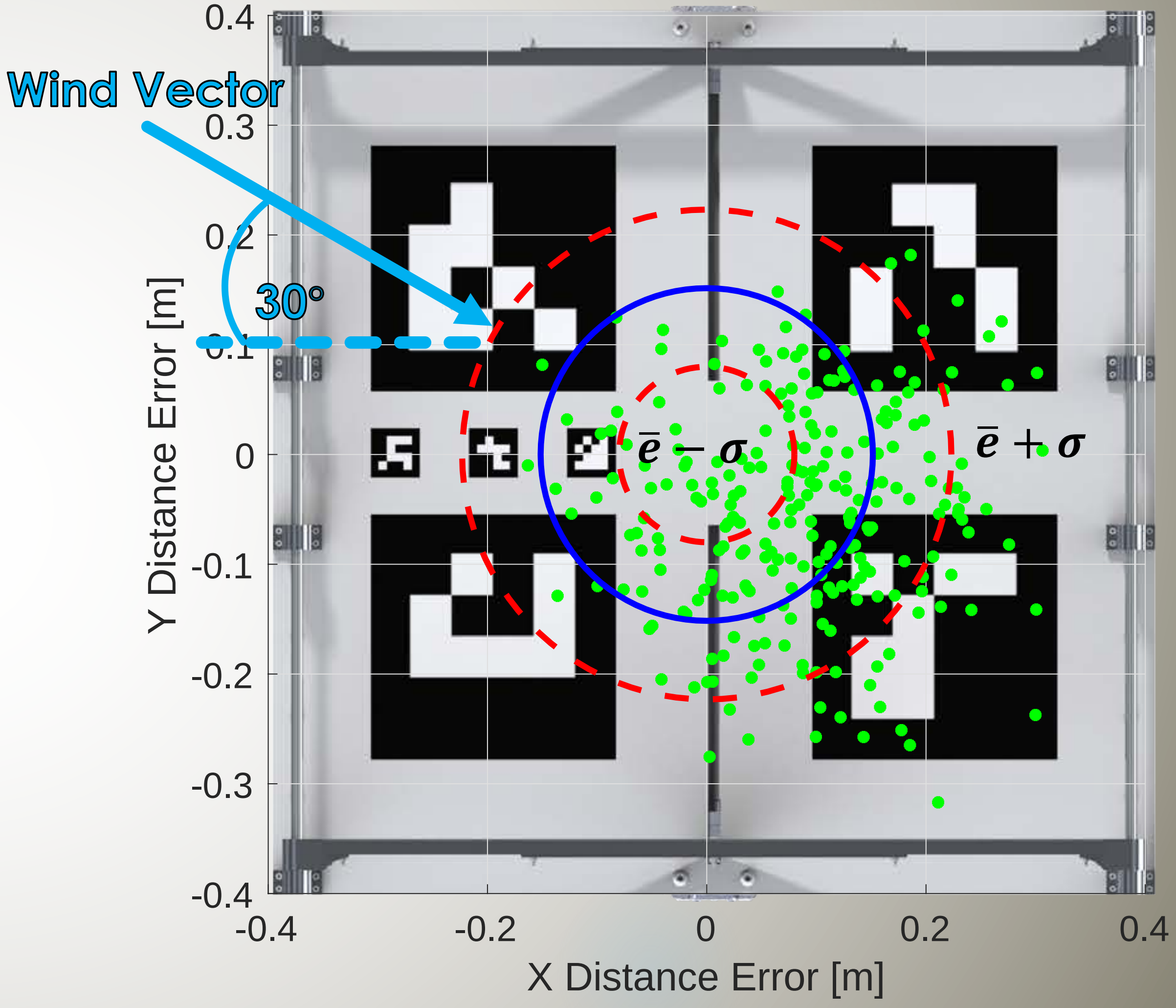


Image Recognition Verification

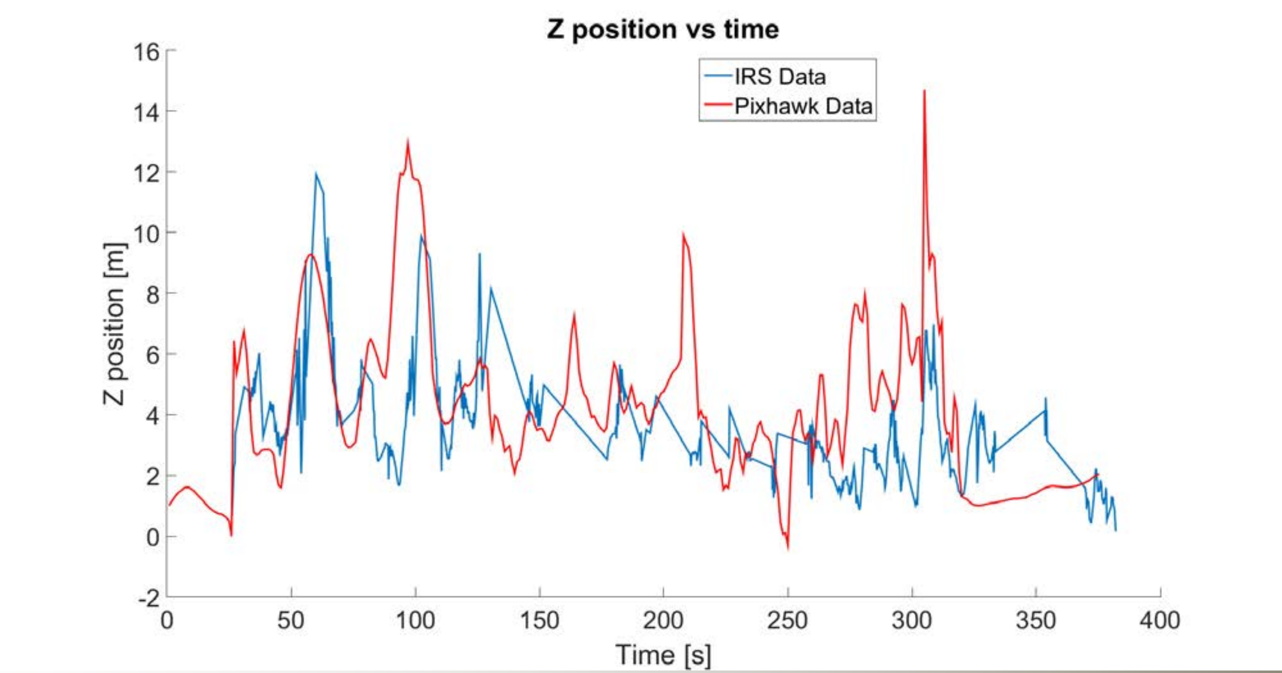
- Requirements Verified:
  - DR 1.1.1, DR 1.1.1.1, DR 1.1.1.2
- Equipment Needed:
  - Previously Recorded Flight Video
  - Image recognition algorithm
- Facilities:
  - South Campus
- Risks Reduced With Testing:
  - 5, 9, 10

Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

Project Overview | Schedule | Budget | Testing | Conclusion

Image Recognition- Procedures

- Procedure:
  - Record Flight video using Raspberry Pi on INFERNO
  - Run flight video through image recognition algorithm
  - Compare mission planner data with Image Recognition Data
- Measurements Taken:
  - GPS - Flight Data From Mission Planner
  - Raspberry Pi Camera- Output Position Vector from Image Recognition Algorithm



Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

Project Overview | Schedule | Budget | **Testing** | Conclusion

Landing Subsystem Test - Motivation

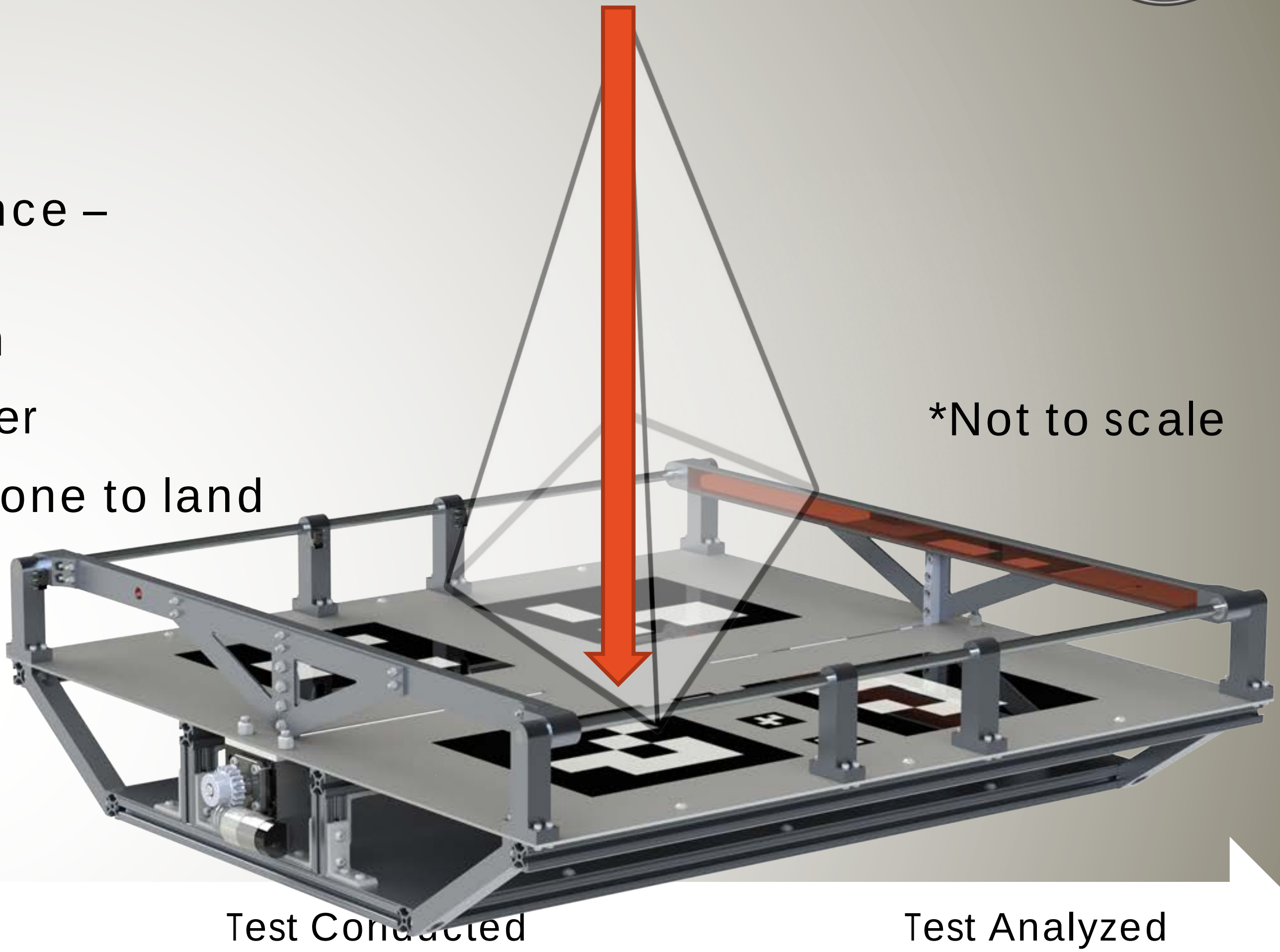
- Requirements Verified:
  - FR 1.0, DR 1.1, DR 1.2, DR 1.3, DR 1.4
  - DR 1.5, DR 1.6
- Equipment Needed:
  - Platform, Child Drone, Ground Station
  - Measuring Tape, Protractor
- Facilities:
  - South Campus
- Risks Reduced With Testing:
  - 8, 9, 10, 11, 12

Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

Landing Subsystem Test - Procedures

- Number of Trials: 20
- Procedure:
  - Ground Station initiates Land sequence – drone "Returns to home" using GPS
  - Image Recognition locks on Platform
  - Algorithm Commands Flight Controller
  - Flight Controller Commands Child Drone to land
- Measurements Taken:
  - Distance From Center of Platform
  - Yaw Angle
- Related Models: Flight Simulator

*Not to scale

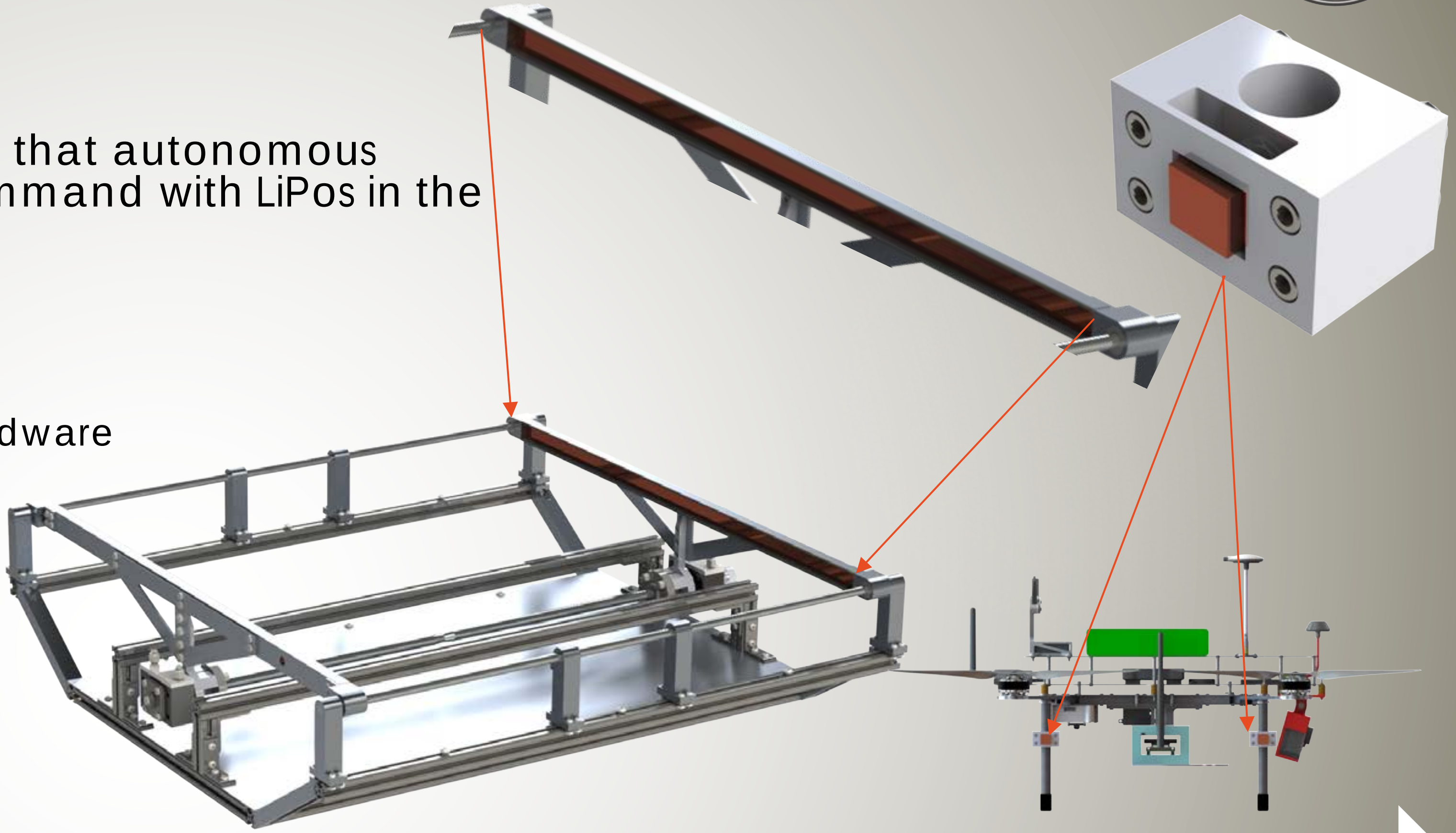


Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

Project Overview | Schedule | Budget | Testing | Conclusion

Charging Subsystem Test - Motivation

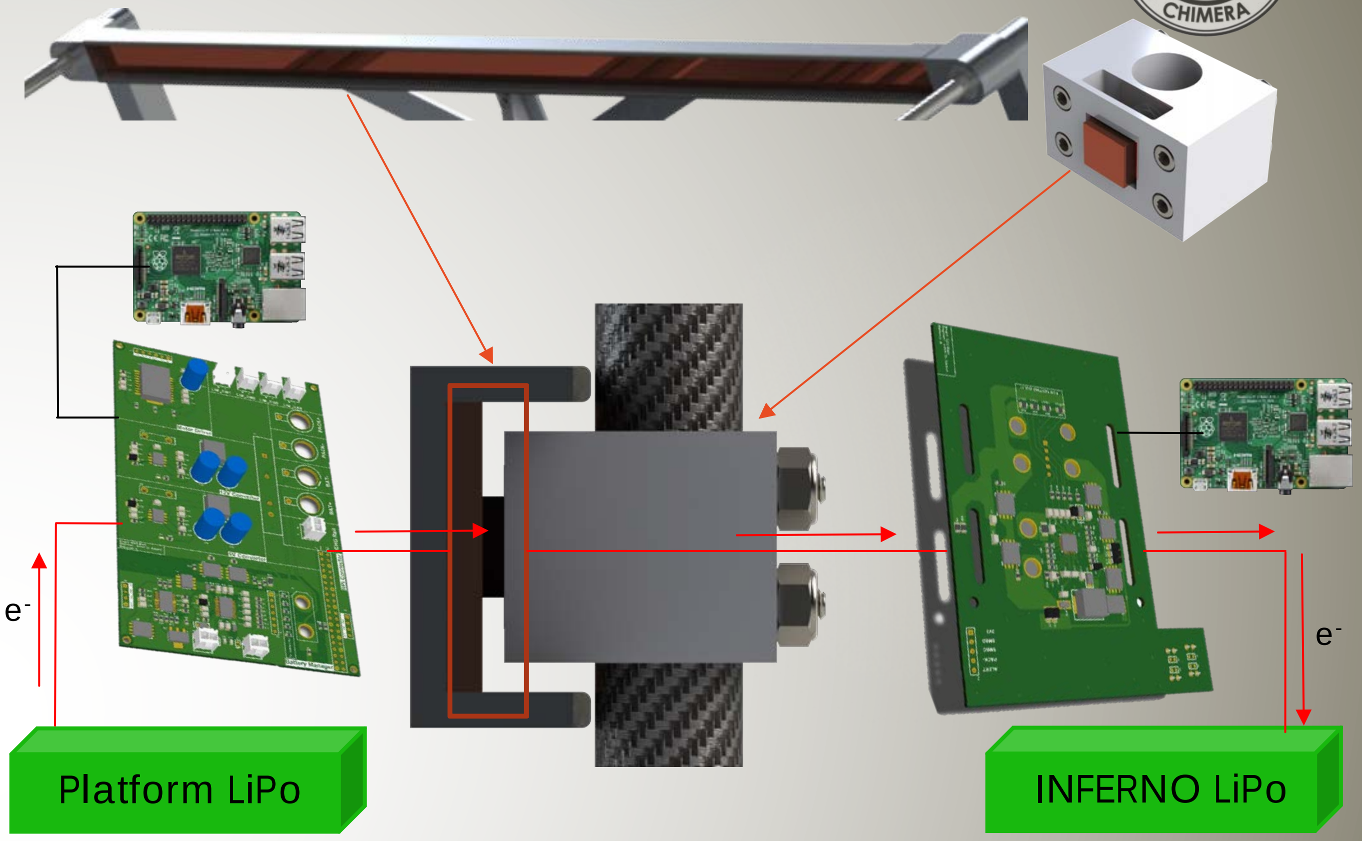
- Requirements Verified:
  - FR 2.0, DR 2.1, DR 2.1.1, DR 2.2, DR 2.3
- Motivation: Full Sub-system test to verify that autonomous charging can be completed upon command with LiPos in the loop
- Component testing in progress
- Equipment:
  - All CHIMERA platform and charging hardware
  - INFERNO Analog
  - Ground station computer
  - Fire Extinguisher/Ammo Can
- Facilities:
  - Electronics Lab



Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

Charging Subsystem Test - Procedures

- 7 Trials
- Procedure:
  - Connect all charging circuitry
  - Connect analog evaluation module to record voltage and current levels throughout the circuit
  - Send command to begin charging sequence to Platform Pi
  - Confirm that voltage on CDS LiPo has increased and then terminate test
- Measurements Taken:
  - Voltage and Current
- Expect to see the CDS battery voltage increase by incremental amount and platform LiPo decrease in voltage



Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

Conclusion

- Changes from MSR: Bevel gear instead of worm gear
- Schedule
  - Machining is complete
- Budget
  - Waiting to hear about EEF Funding
- Testing
  - Successful Communication with Pixhawk: Further work developing Software
  - Image recognition algorithm: Similar trends to Mission Planner Data
  - All Subsystem tests on track for completion

References

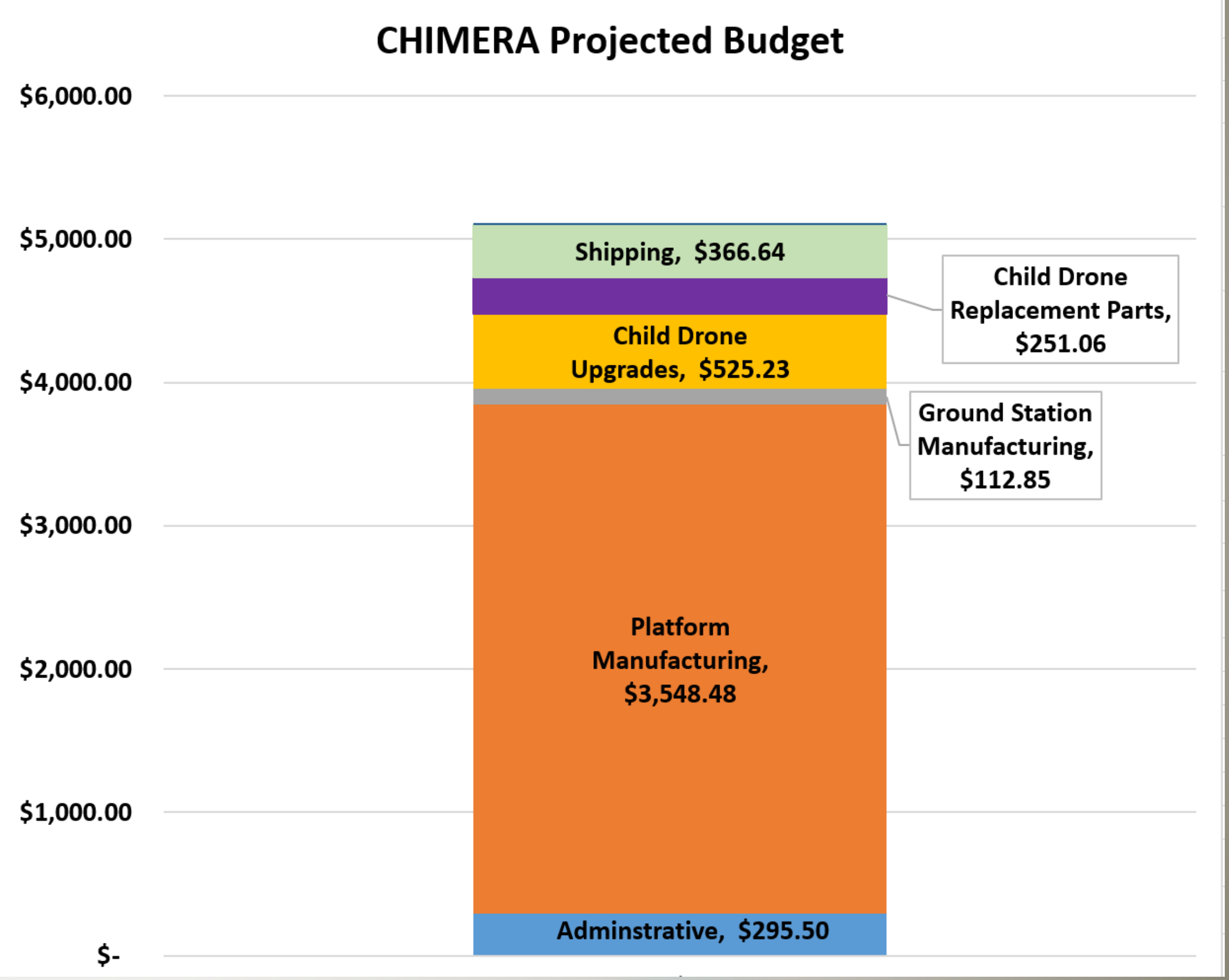
- CHIMERA 1st Semester Content
- INFERNO Project Archive

Budget Backup- What happens if external funding falls through?

- If we *do not* need the third revision of the PCBS…
  - We will end the project under budget by $104
- If we *do* need the third revision of the PCBs…
  - We will need to cut down on printing costs for the final report and symposium poster, currently allotted $200. This includes printing the pages for the report amongst team members and only having it professionally bound, or attempting to get a discount on poster printing via Kinkos.

Budget Backup- System Cost Breakdown

SUMMARY	
System	**Cost**
Adminstrative	$ 295.50
Platform Manufacturing	$ 3,548.48
Ground Station Manufacturing	$ 112.85
Child Drone Upgrades	$ 525.23
Child Drone Replacement Parts	$251.06
Shipping	$ 366.64
Testing and Safety	$ 13.10
Projected Over Budget	**$ (112.86)**
Budget	**$ 5,000.00**



Budget Backup- Procurement Breakdown

Purchasing and Shipping						
Company	**Date Purchased**	**Date Received**	**Description**	**Shipping Cost**	**Parts Cost**	**Total Cost**
CU Bookstore	12-Dec	N/A	FFR Flashdrives	$ -	$13.98	$ 13.98
InkSpot atCU	12-Dec	N/A	FFR Printing	$ -	$81.52	$ 81.52
Arrow	21-Dec	17-Jan	Electronics for Custom PCB	$ -	$16.14	$ 16.14
Mouser Electronics	21-Dec	17-Jan	Electronics for Custom PCB	$ 7.99	$126.97	$ 134.96
McMaster Carr	22-Dec	17-Jan	Raw Materials for INFERNO mods and the Platform	$ 61.12	$865.06	$ 926.18
Nook Industries	23-Dec	31-Jan	Ball screw system for platform	$ 26.39	$1,495.00	$ 1,521.39
Get FPV	1-Jan	7-Feb	Comm antenna, spare INFERNO parts	$ -	$98.95	$ 98.95
DigiKey	5-Jan	17-Jan	Electronics for Custom PCB	$ 6.95	$12.57	$ 19.52
Jameco Electronics	16-Jan	24-Jan	Motor for Platform	$ -	$39.53	$ 39.53
Mouser Electronics (2)	18-Jan	24-Jan	Battery Manager and a spare	$ 7.99	$13.10	$ 21.09
Thomson Linear	20-Jan	30-Jan	Guide rails and bearings	$ 15.21	$161.51	$ 176.72
ITLL	24-Jan	N/A	3D Printing plastic	$ -	$12.00	$ 12.00
Amazon	25-Jan	30-Jan	Raspbery Pis and camera, XT90 connectors, PURCHASED BY JOANIE	$ -	$119.93	$ 119.93
SparkFun	26-Jan	3-Feb	Comm parts- Xbees	$ -	$151.80	$ 151.80
DigiKey (2)	26-Jan	30-Jan	Comm Parts- Xbee adapters	$ 7.40	$99.80	$ 107.20
McMaster Carr (2)	27-Jan	31-Jan	Forgotten spacers	$ 6.30	$1.05	$ 7.35
McMaster Carr (3)	30-Jan	31-Jan	Misc nuts and bolts	$ 13.44	$56.54	$ 69.98
HobbyKing	3-Feb	13-Feb	Batteries for platform and CDS	$ 42.87	$296.12	$ 338.99
McMaster Carr (4)	3-Feb	7-Feb	Spacers AGAIN	$ 6.18	$1.05	$ 7.23
DigiKey (3)	3-Feb	16-Feb	Electronics for Custom PCB	$ 7.40	$26.15	$ 33.55
Advanced Circuits	6-Feb	Picked up: 14-Feb	PCBs, rev 1	$ 20.00	$132.00	$ 152.00
Arrow (2)	7-Feb	9-Feb	PCB Components	$ -	$80.54	$ 80.54
Arrow (3)	9-Feb	13-Feb	Electronics for Custom PCB	$ -	$29.12	$ 29.12
Arrow (4)	18-Feb	22-Feb	Spare components	$ -	$38.58	$ 38.58
Mouser (3)	28-Feb	2-Mar	Limit switches	$ 7.99	$20.80	$ 28.79
McMaster	28-Feb	2-Mar	Powder Coating and bevel gear	$ 12.42	$95.54	$ 107.96
GetFPV	2-Mar		Inferno GPS	$ 2.99	$49.00	$ 51.99
McGuckins	2-Mar	N/A	Washers, set screws, battery straps	$ -	$6.29	$ 6.29
Multicopter Builder			Legs	$ 10.00		
Advanced Circuits (2)			PCBs, rev 2	$ 20.00		
Advanced Circuits (3)			PCBs, rev 3	$ 84.00		
StickerYou			Platform Decals			
			Total Spent			**$ 4,393.28**
			Shipping Costs Total	**$ 366.64**		-
					Total Budget Remaining	$ 606.72

Backup More Testing Procedures

COM Subsystem Test - Motivation

- Requirements Verified:
  - FR 4.0, DR 4.1, DR 4.1.1
  - FR 5.0, DR 5.1, DR 5.1.1, DR 5.2.1
- Equipment Needed:
  - 3 Xbee Antennas
  - Crazy Crosshair Antennas
  - MapMyWalk App to measure distance
- Facilities:
  - South Campus
- Risks Reduced With Testing:
  - 20

Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

Project Overview | Schedule | Budget | Testing | Conclusion

COM Subsystem Test - Procedures

- Number of Trials
- Procedure:
  - Send data between components at 700 m
- Related Models:
  - Link Budget
- What do we Expect?
  - The antennas are rated for these distances, so we expect the antennas to send and receive the information

Environment - Motivation

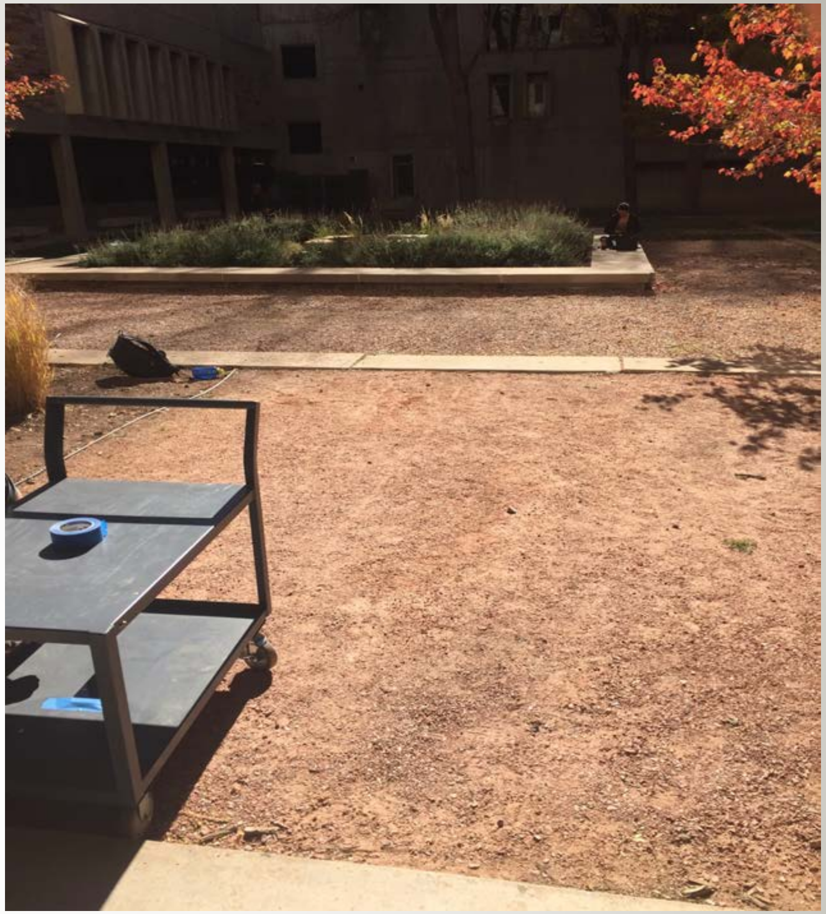
- Environment Verified:
  - ENV: 1.1.2
- Equipment:
  - Accelerometer – Iphone 6+
  - ”VibeSensor” Application
  - Hard Rubber Castor Wheel Cart
- Facilities:
  - Engineering Center Courtyard
- Risks Reduced With Testing:
  - Defines environment

Hard Rubber Castor Wheels

Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

Environment- Procedures

- Number of Trials: Min. 4
- Procedure:
  - Install accelerometer onto cart
  - Traverse rough terrain course
- Measurements Taken:
  - PSD, tilt angle, vibration g level
- Related Models: Bracket Analysis
- Expect: Analyze g level loading to replicate with securing system



Shock Event Course

Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

Securing Subsystem - Motivation

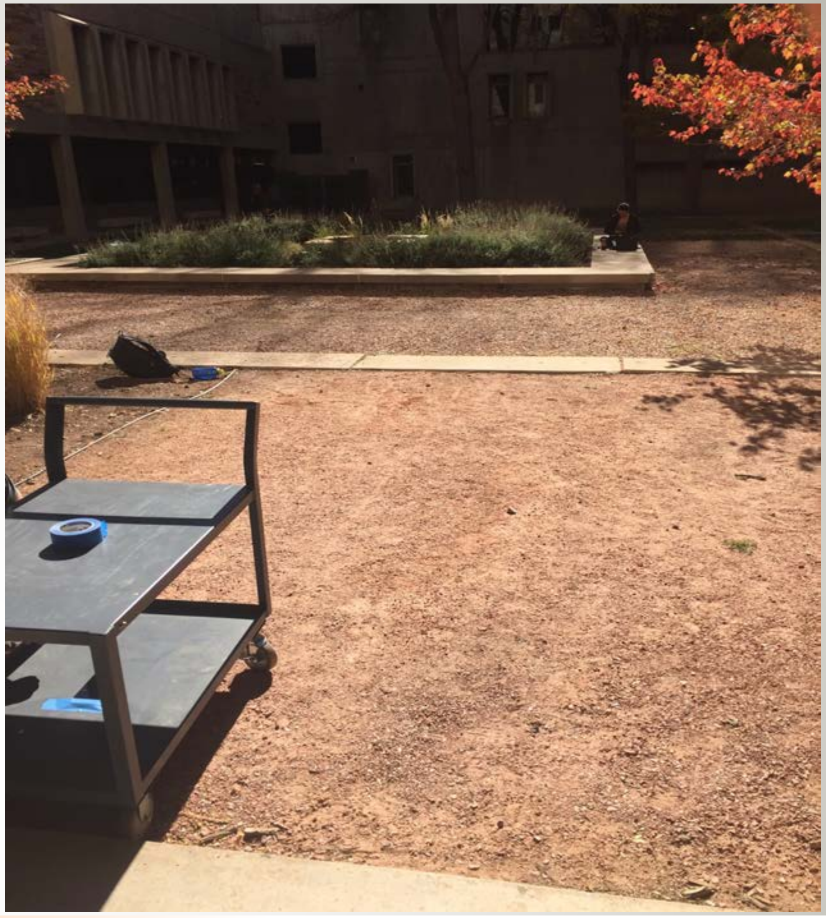
- Requirements Verified:
  - FR 3.0, DR 3.1, DR 3.3, DR 3.4
- Equipment:
  - Accelerometer – Iphone 6+
  - ”VibeSensor” Application
  - Hard Rubber Castor Wheel Cart
  - Platform with INFERNO mounted
- Facilities:
  - Engineering Center: Cobblestone and Courtyard
- Risks Reduced With Testing:
  - 13, 14, 15, 16

Hard Rubber Castor Wheels

Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

Securing Subsystem - Procedures

- Number of Trials: Min. 4
- Procedure:
  - Install accelerometer onto cart
  - Install Platform onto cart
  - Secure INFERNO on Platform
  - Traverse rough terrain course
- Measurements Taken:
  - PSD, tilt angle, vibration g level
- Related Models: Bracket Analysis
- Expect: Visual Confirmation

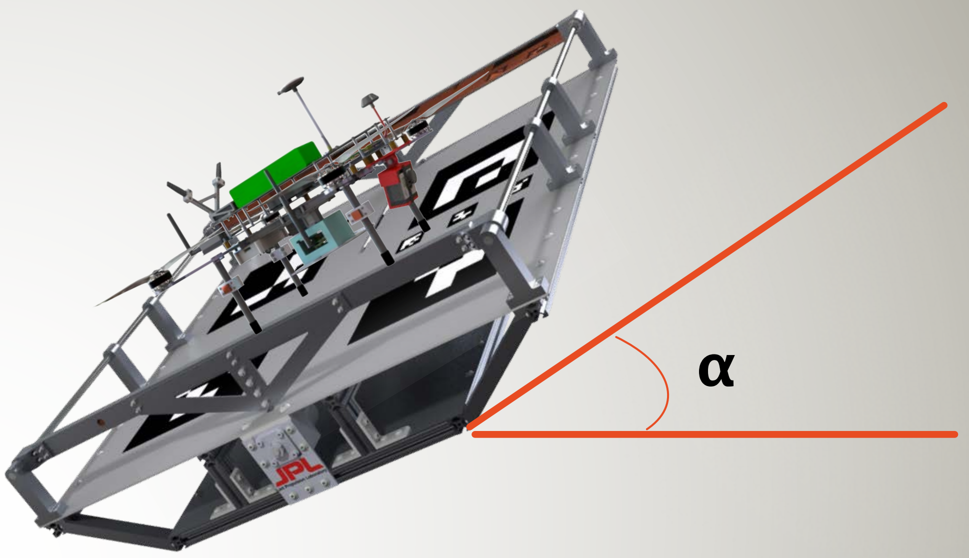


Shock Event Courtyard

Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

Platform Tilt - Motivation

- Requirements Verified:
  - FR 3.0, DR 3.5
- Equipment:
  - Accelerometer – Iphone 6+
  - "VibeSensor" Application
  - Platform securing INFERNO
- Facilities:
  - Engineering Center Courtyard
- Risks Reduced With Testing:
  - 13, 14, 15, 16



Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

Platform Tilt - Procedures

- Number of Trials: Min. 4
- Procedure:
  - Install accelerometer onto cart
  - Install Platform onto cart
  - Secure INFERNO on Platform
  - Traverse rough terrain course
- Measurements Taken:
  - Tilt angle α
- Related Models: Bracket Analysis
- Expect: Visual Confirmation

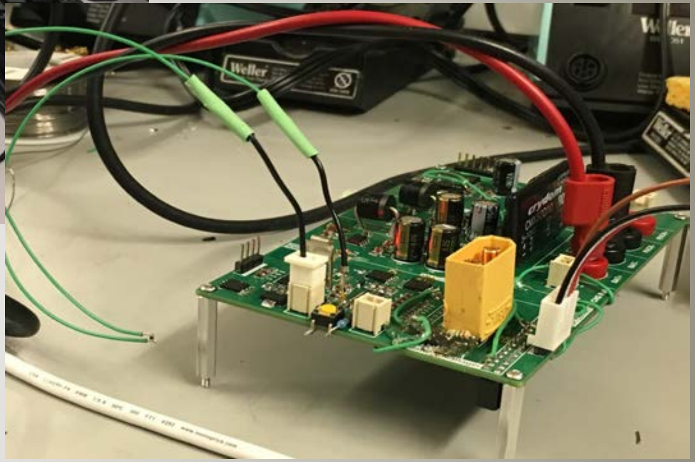
Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

PCB Safety Verification - Motivation

- Requirements Verified:
  - DR 2.2.1, DR 2.2.2
- Motivation: Test PCB Safety Features
- Equipment:
  - CDS and Platform PCBs
  - Power supply, Multimeter, Variable Load Resistor, Analog Evaluation Module
- Facilities:
  - Electronics Lab
- Risks Reduced With Testing:
  - Damage to INFERNO/Equipment
  - Electrical Fires
  - Shock hazards of equipment or team members
  - Burn hazards/Chemical Fires/LiPo combustion

Test Setup

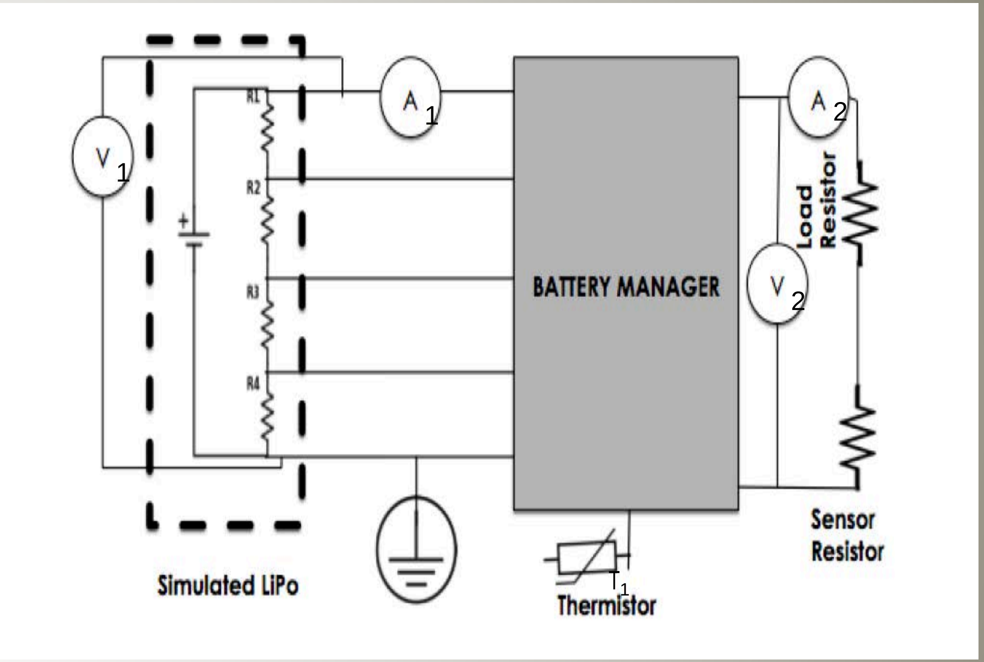
Platform PCB



Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

PCB Safety Verification - Procedures

- 9 Trials
- Procedure:
  - Under-Voltage: Static load of 100 Ohms. Initial voltage of 25 V. Cell under-volt set point: 19.2V (3.2V/cell)
  - Over-Current: Initial Voltage: 20V, Amp limit: 1 A, decreased load resistance until current achieved 1A limit.
  - Over-Temperature: Heat gun aimed at thermistor. Over-tem limit: 140F (60C)
- Measurements Taken:
  - V_1, A_1, T_1
- Related Models: ????
- Results: Battery manager broke the circuit when pre-programmed limits were achieved.

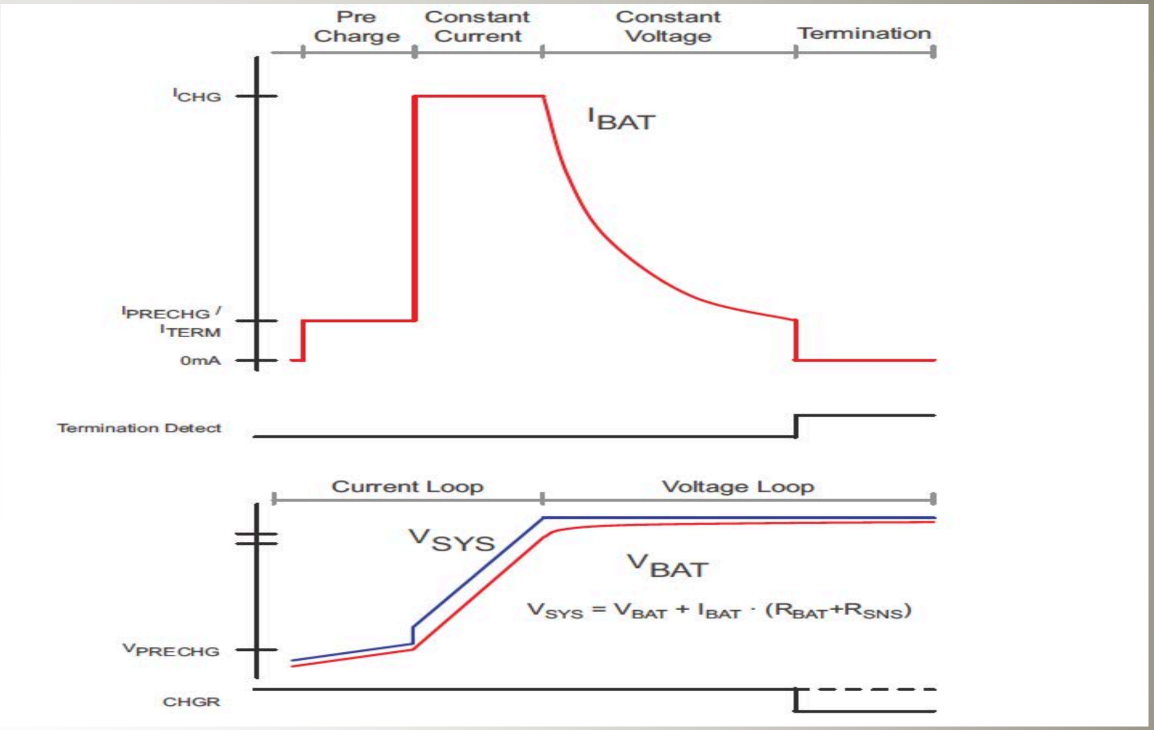


Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

Project Overview | Schedule | Budget | **Testing** | Conclusion

CDS PCB Charging Test - Motivation

- Requirements Verified:
  - FR 2.0, DR 2.1, DR 2.1.1, DR 2.2, DR 2.3
- Motivation: Test charging functionality of CDS PCB and reproduce expected charging profile (see figure)
- Equipment:
  - CDS PCB
  - 2 Power supplies, Analog evaluation module
  - Multimeter, Desktop computer
- Facilities:
  - Electronics Lab
- Risks Reduced With Testing:
  - Charging circuitry malfunctions
  - Characterizes charging capabilities to prevent equipment damage
  - Demonstrates charging profile to reduce fire risks



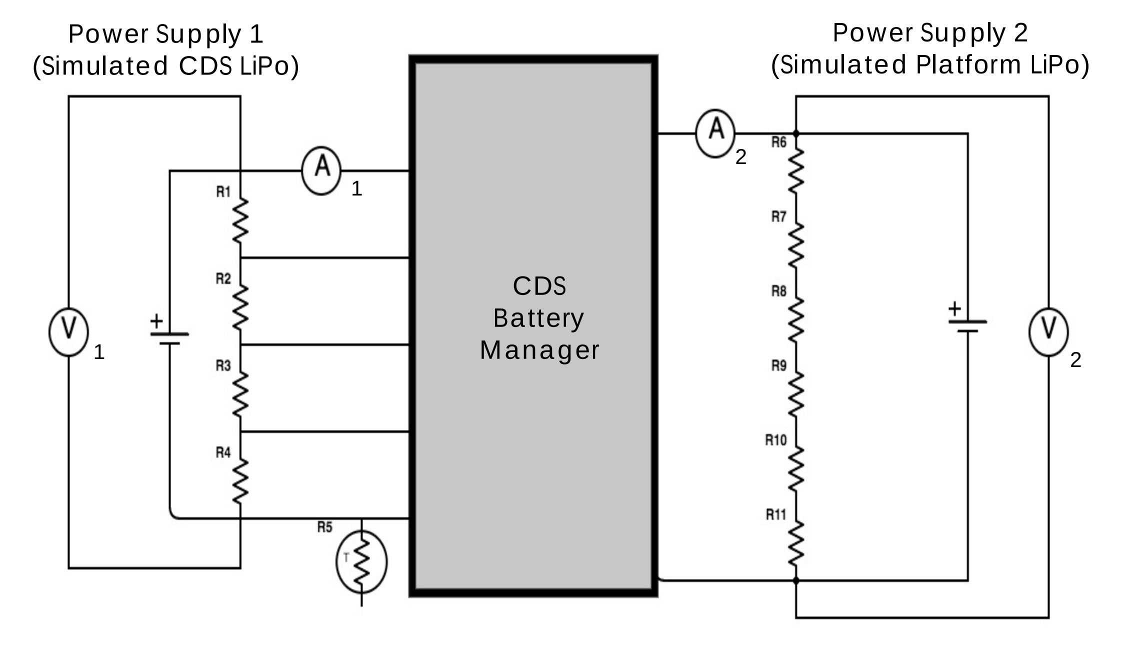
Expected Charge Profile

Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

Project Overview | Schedule | Budget | Testing | Conclusion

CDS PCB Charging Test - Procedures

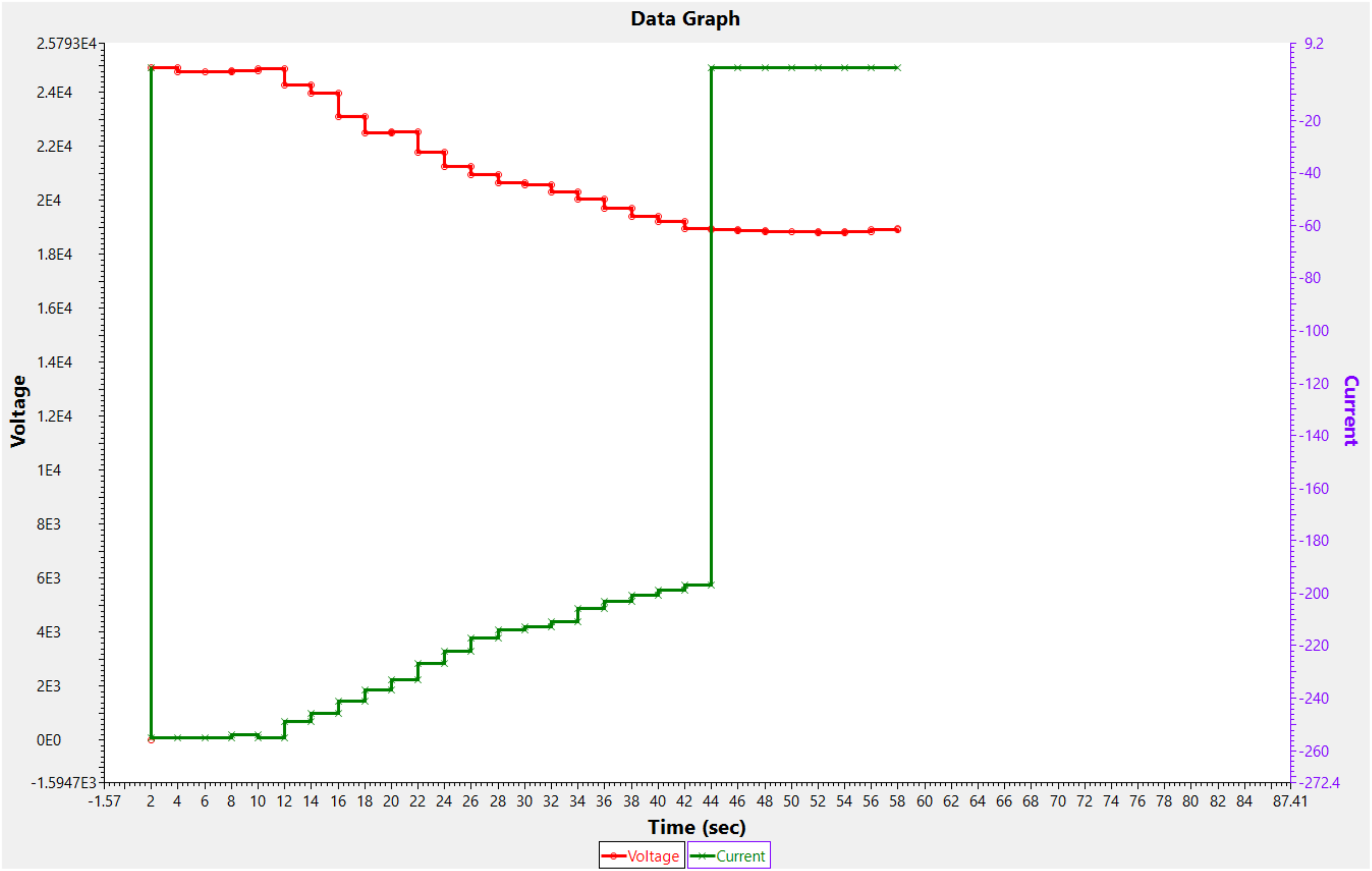
- 10 Trials
- Procedure:
  - Connect CDS PCB to two power supplies
  - Increase voltage on PS 1 incrementally up to max voltage of battery (16.8V)
  - Observe current reduction on PS 2 as max voltage on PS 1 is achieved
- Measurements Taken:
  - V_1, A_1, V_2, A_2, Charge Profile
- Related Models: ???
- Expect to see charge profile described in previous slide as voltage is increased on PS 1



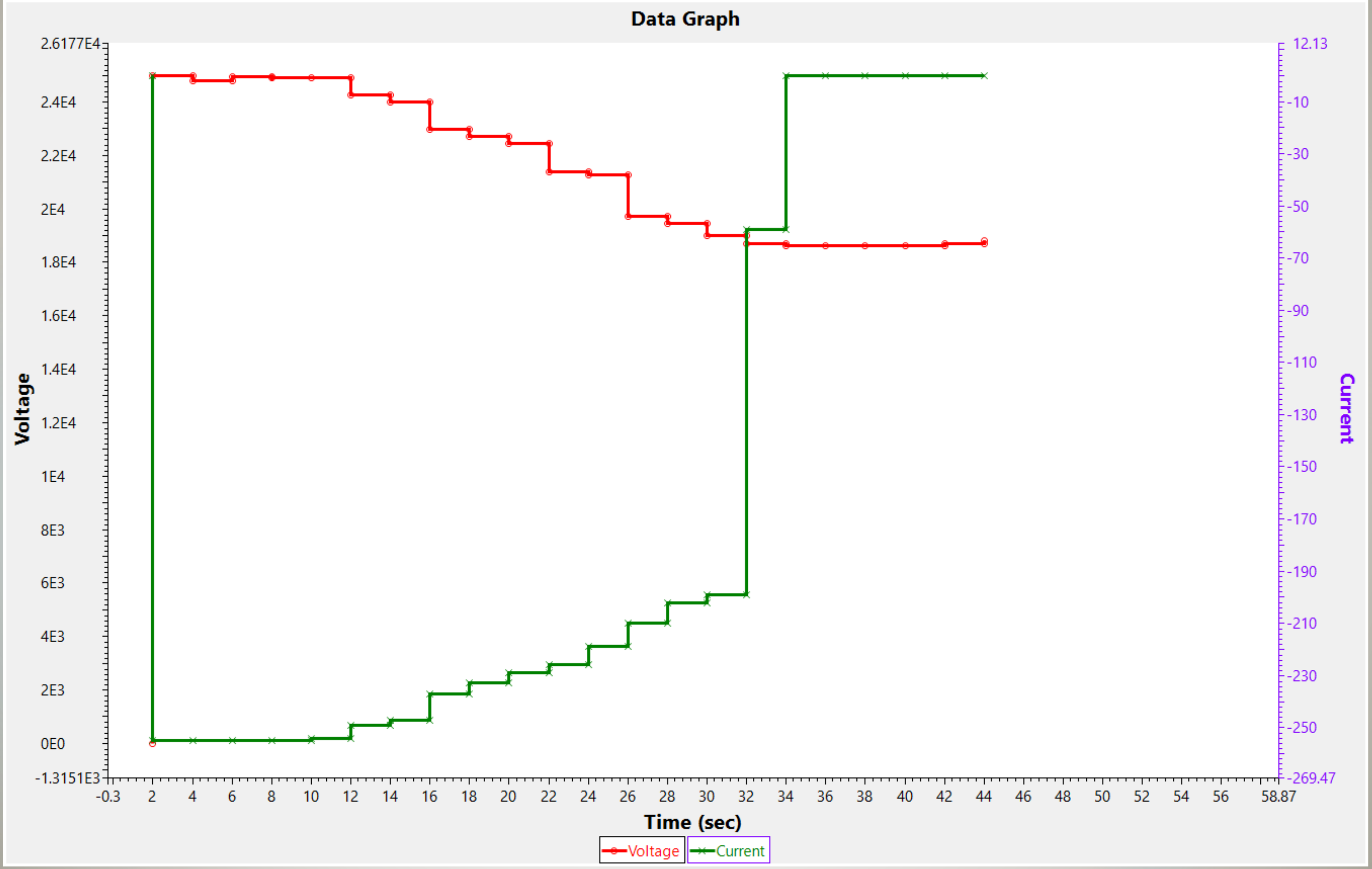
Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

Project Overview | Schedule | Budget | Testing | Conclusion

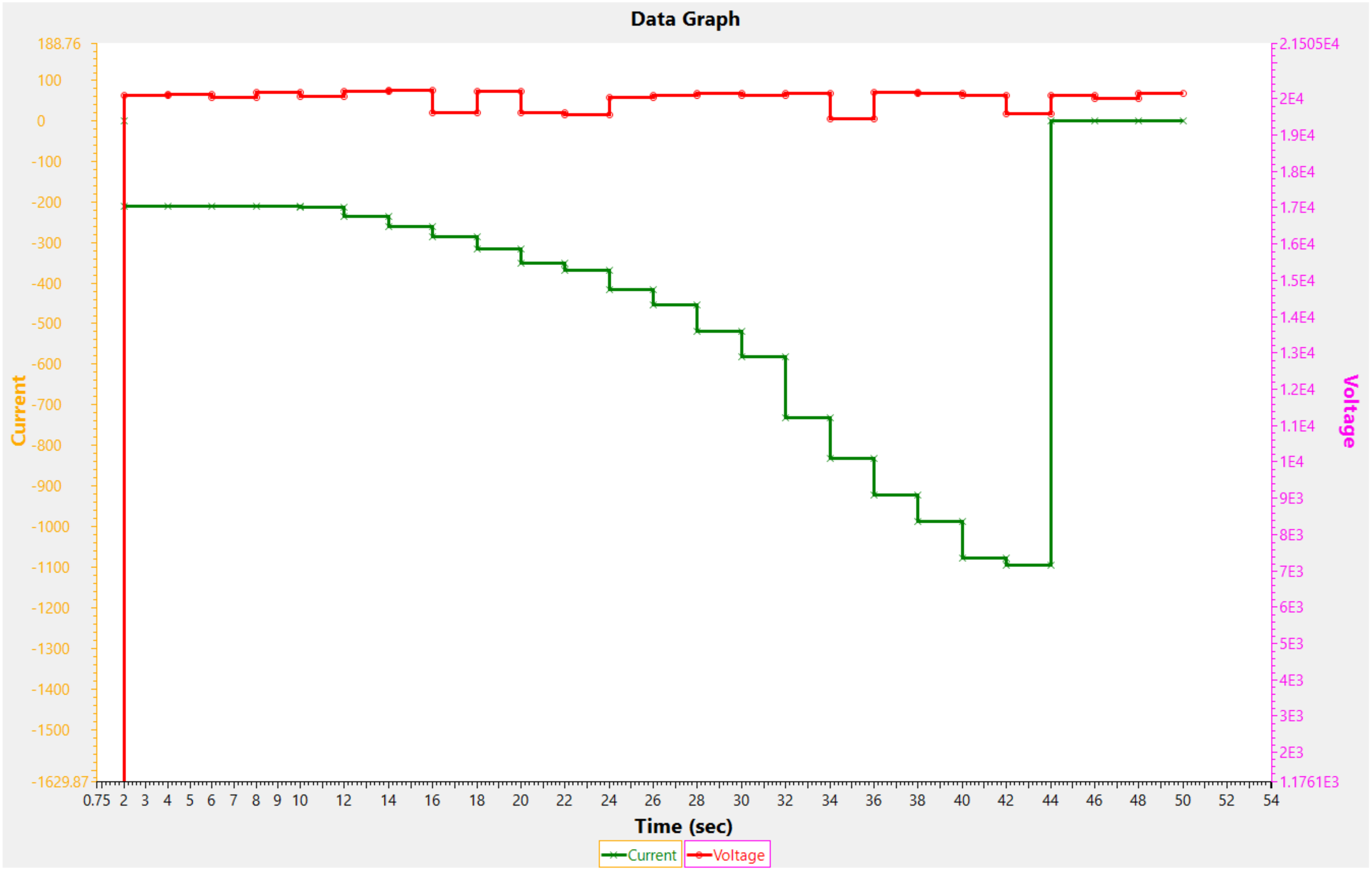
Charging Backup



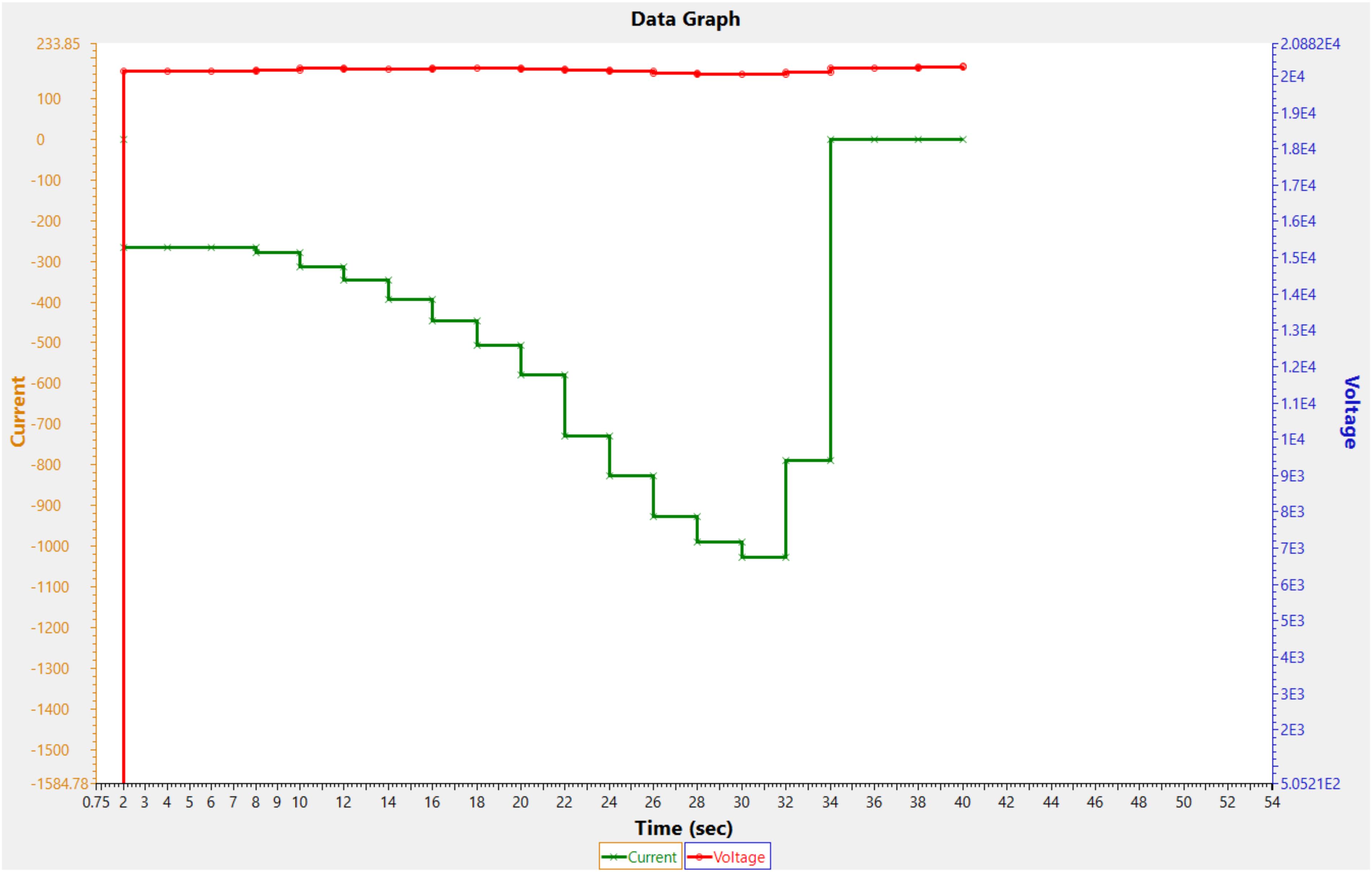
Charging Backup



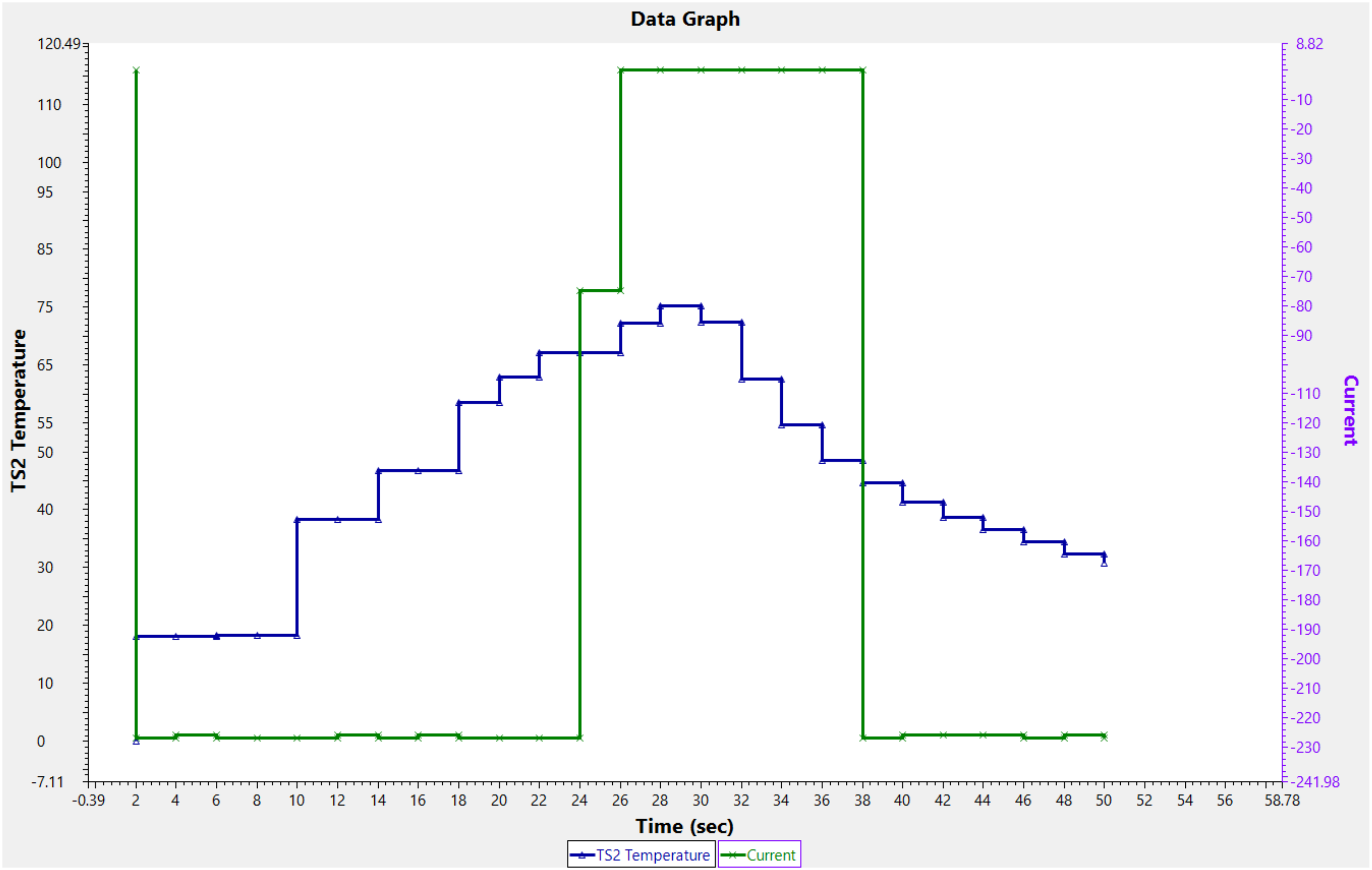
Charging Backup



Charging Backup



Charging Backup



Charging Backup

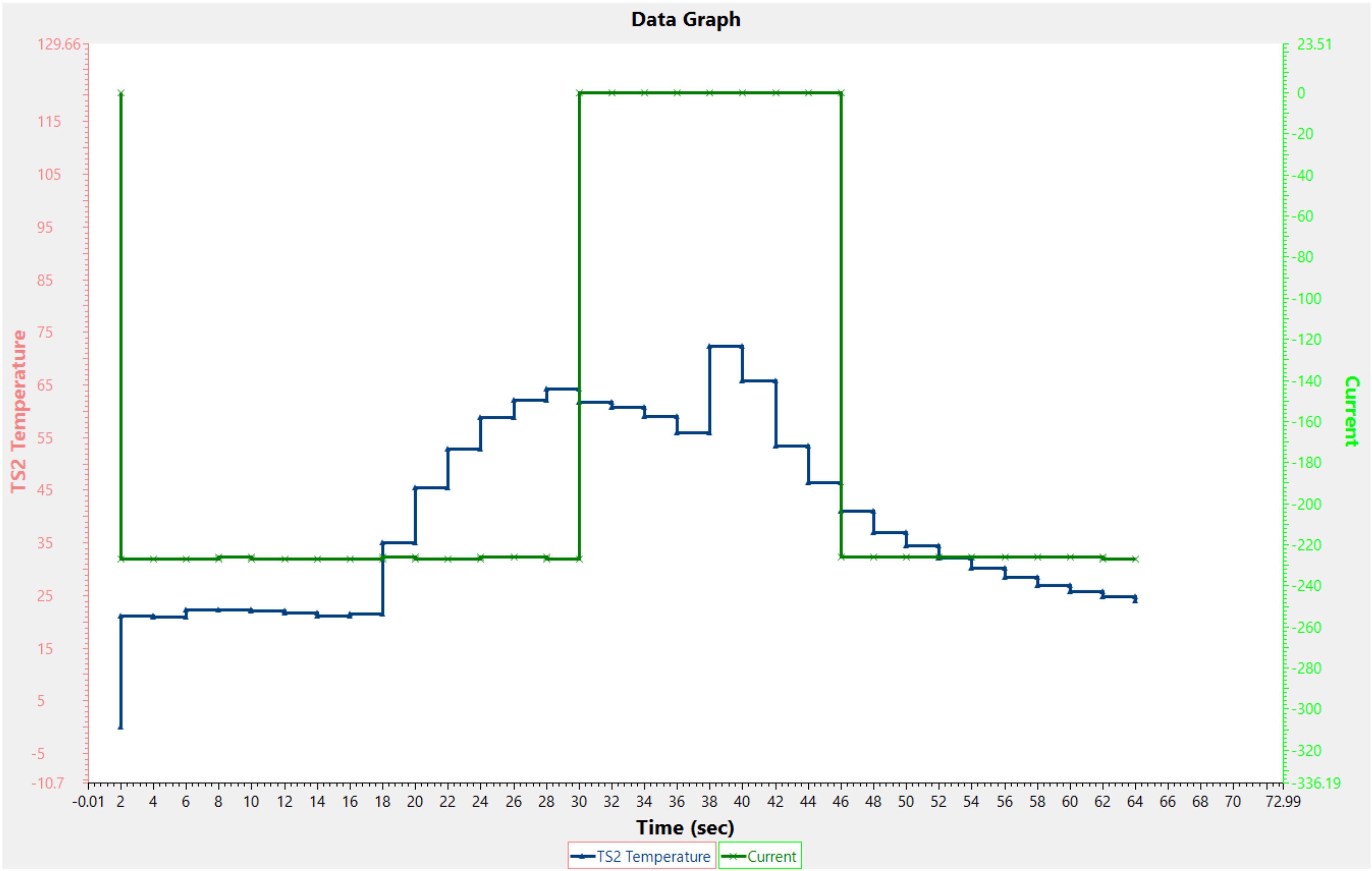


Image Recognition Errors

- GPS error +/- 5 m
  - No knowledge of platform location
- Image Recognition Algorithm Error – difficult to characterize
  - Loses data when platform is out of sight of the camera
- Why compare sensors?
  - While the GPS has known errors, it is the best way to safely validate the image recognition algorithm.

Requirements Backup

Functional Requirements

Functional Requirement	Description
FR 1.0	The child drone shall autonomously land on the platform upon command in the environment specified by ENVI.1.2.
FR 2.0	The platform shall charge the child drone.
FR 3.0	The platform shall secure the child drone by preventing motion according to CONST 1.1 and ENVI 1.1
FR 4.0	The ground station shall communicate with the sensor package according to ENVI1.5 and CONST1.3.3
FR 5.0	The platform shall communicate with the ground station according to ENVI1.5 and CONST1.3.2.

FR 1.0

- FR 1.0 – The child drone shall autonomously land on the platform upon command in the environment specified by ENVI.1.2.

  Motivation: Customer Requirement

  Verification: Flight test

  - DR 1.1 – The child drone shall autonomously land using an image recognition system

    Motivation: Trade study result

    Verification: Demonstration

    - DR 1.1.1 - The child drone shall have a camera with a minimum resolution of 5 MP

      Motivation: IRS system requirements to achieve specified landing accuracy

      Verification: Visual Inspection

      - DR 1.1.1.1 The camera shall not interfere with the deployment of the sensor package
      - DR 1.1.1.2 The camera shall have a minimum field of view of 41 degrees
    - DR 1.1.2 The platform shall have a pattern with maximum dimensions of 0.8 m by 0.8 m
    - DR 1.1.3 The image recognition system shall land the child drone on the platform from a maximum horizontal distance of 5 m from the geometric center of the platform
    - DR 1.1.4 The child drone shall have a maximum descent rate of 1 m/s
    - DR 1.1.5 The image recognition system shall send position commands to the child drone flight controller at a minimum rate of 2 Hz

FR 1.0

- DR 1.2 - The platform shall communicate with the child drone according to CONST1.3.1 and ENVI1.5

  Motivation: Communication system must be in place to send/receive commands and data

  Verification: Demonstration

  - DR 1.2.1 The platform shall wirelessly send commands to the child drone
  - DR 1.2.2 The platform shall wirelessly receive data from the child drone

- DR 1.3 - The child drone shall wirelessly transmit video at 720p and 30fps to the ground station according to CONS1.3.1 and ENVI1.5

  Motivation: Inherited capability to be incorporated in CHIMERA design

  Verification: Test

  - DR 1.3.1 The child drone shall have a transmitter capable of transmitting 600 mW of power

- DR 1.4 The child drone shall wirelessly transmit telemetry to platform
- DR 1.5 The child drone shall wirelessly receive commands from the platform
  - DR 1.5.1 The child drone shall have a receiver gain of 2.1 dB

FR 2.0

- FR 2.0 - The platform shall charge the child drone.

  Motivation: Enable future capability to re-deploy the child drone

  Verification: Test and Demonstration

  - DR 2.1 - The platform shall demonstrate charging capability upon command by providing visual confirmation that the charging circuit is complete under conditions specified by ENVI1.3.

    Motivation: Indicate charging capability

    Verification: Test and Demonstration

    - DR 2.1.1 - The platform shall visually indicate charging capability by illuminating an LED when the circuit is completed and current is flowing.

  - DR 2.2 The platform shall charge the child drone battery with a child drone analog upon command under conditions specified by ENVI1.4.
    - DR 2.2.1 A cell balancer shall be used to ensure LiPo battery cells are evenly charge
    - DR 2.2.2 A battery manager shall be used during all circuitry testing to ensure LiPo battery is operating within COTS safety limits
  - DR 2.3 The platform shall include a circuit breaker capable of interrupting the flow of current from the platform to the LiPo battery upon command.

FR 3.0

- FR 3.0 - The platform shall secure the child drone by preventing motion according to CONST 1.1 and ENVI 1.1

  Source: Customer Requirement

  Verification: Test and Demonstration

  - DR 3.1 - The securing system shall prevent motion of the child drone under vibrational loading specified by CHIMERA-TEST1.

    Motivation: Ensure that child drone does not fall off of platform under specified conditions

    Verification: Demonstration

  - DR 3.2 - The securing system shall not obstruct the child drone landing platform surface or interfere with landing operations

    Motivation: Image recognition landing requirement

    Verification: Test

  - DR 3.3 The securing system shall secure the child drone upon command
  - DR 3.4 The securing system shall release the child drone upon command

FR 4.0

- FR 4.0 - The ground station shall communicate with the sensor package according to ENVI1.5 and CONST1.3.3

  Motivation: Inherited capability to be incorporated in CHIMERA design

  Verification: Test and Demonstration

  - DR 4.1 - The ground station shall receive data from the sensor package.

    Motivation: Must receive sensor package temperature data at the ground station

    Verification: Demonstration

    - DR 4.1.1 - The ground station shall have a receiver gain of 2.1 dB.

  - DR 4.2 The ground station shall command the platform and child drone while retaining the ability to land the child drone via manual piloting.

    Motivation: Piloted capability ensures drone safety in the event of a software failure

    Verification: Demonstration

FR 5.0

- FR 5.0 - The platform shall communicate with the ground station according to ENVI1.5 and CONST1.3.2

  Motivation: Customer Requirement

  Verification: Test and Demonstration

  - DR 5.1 - The platform shall wirelessly receive commands from the ground station.

    Motivation: Must receive commands in order to command/secure child drone

    Verification: Test and Demonstration

    - DR 5.1.1 - The platform shall have a receiver antenna gain of TBD dB.

      Motivation: Needs this gain in order to receive commands across required distance

      Verification: Visual Inspection

  - DR 5.2 The platform shall wirelessly transmit data to the ground station.

    Motivation: Transmit telemetry in order to interpret heath and status of system

    Verification: Test and Demonstration

    - DR 5.2.1 The platform shall have a transmitter capable of transmitting X watts of power

      Motivation: Needs this transmitter power in order to transmit across required distance

      Verification: Test and Demonstration

Risk Backup

Risk Summary

Risk #	Description	Reason for Identification
1	Lithium polymer battery damage	Harmful to team members and equipment
2	High current draw through exposed copper plates	Harmful to team members
3	High current draw from source battery on platform	Harmful to equipment
4	Inadequate copper contact between child drone and platform charge plates	Does not fulfill FR 2.0
5	Child drone lands with a yaw error greater than 45 ° and prevents charging	Does not fulfill FR 2.0
6	Manufacturing defects in PCB prevent successful charging	Does not fulfill FR 2.0
7	Battery manager malfunctions causing damage to child drone or harming team members	Harmful to team members and equipment
8	Raspberry Pi loses communication with Pixhawk while child drone is in flight, it cannot land	Does not fulfill FR 1.0, could be harmful equipment
9	Poor landing accuracy causes child drone to fall off platform	Harmful to equipment
10	Child drone loses lock on platform before it can make final descent	Does not fulfill FR 1.0
11	Piloting error could result in child drone damage	Harmful to equipment
12	Refresh rate between the Pixhawk and Raspberry Pi could lead to position lag between commands, creating unstable flight conditions	Harmful to equipment

Risk Summary continued…

13	Child drone legs disengage upon hard landing, not able to secure and charge	Does not fulfill FR 3.0
14	Charging/securing bars fail to disengage and damage the child drone	Harmful to equipment
15	Manufacturing errors in child drone charging/securing bars do allow the parts to fit together, charging cannot take place	Does not fulfill FR 3.0
16	Securing system does not restrain child drone in specified environment	Does not fulfill FR 1.0 and could be harmful to equipment
17	Mass added to child drone prevents it from completing the inherited INFERNO mission	Does not fulfill FR 1.0
18	The ball screw that drives the charging/securing bars on the platform fails, cannot charge child drone	Does not fulfill FR 3.0 and could harm equipment
19	Platform does not fit into University CNC machine	Delays schedule
20	Communication system failure	Does not fulfill FRs 4.0 and 5.0
21	Platform has too high of a coefficient of friction for the child drone to slide without tipping	Does not fulfill FR 3.0, could damage equipment
22	High lead time on outsourced parts	Delays schedule
23	Inclement weather during spring testing	Delays schedule
24	Large budgetary expenses from child drone replacement	Inflates budget

Risk Analysis

Risk 1: Lithium polymer battery damage

- Severity: 5 Likelihood: 4 TOTAL: 20
- Description: LiPo batteries are known to swell and explode if damaged or if used or stored improperly.
- Mitigation options:
  - Use a cell balancer to ensure even charge distribution between LiPo battery cells
  - Seek PAB expertise when designing and testing charging circuitry
  - Run simulation tests without the LiPo battery in the circuit and gradually incorporate more risk once previous steps are verified
- Response if risk occurs:
  - Contact fire department
  - Attempt to extinguish with CO2 fire extinguisher
  - Attempt to place in ammunition can or LiPo sack
  - Evacuate lab and make sure everyone is safe

Post-Mitigation Risk Analysis

- Severity: 5 Likelihood: 1 TOTAL: 5

Risk Analysis

Risk 2: High current draw through exposed copper plates could harm team members

- Severity: 5 Likelihood: 3 TOTAL: 15
- Description: While charging, current is flowing through exposed copper plates that could pose a potential shock risk to team members.
- Mitigation options:
  - Design Delrin overhangs on copper plates to prevent inadvertent contact
  - Smaller copper plates on the child drone brackets
  - Master kill switch to immediately break the circuit in case of emergency
- Response if risk occurs:
  - Power off the system
  - Ensure team safety
  - Call 911 if necessary

Post-Mitigation Risk Analysis

- Severity: 5 Likelihood: 1 TOTAL: 5

Risk Analysis

Risk 3: High current draw from source battery could damage platform electronics or child drone

- Severity: 4 Likelihood: 3 TOTAL: 12
- Description: While charging, a power surge could cause damage to the sensitive electrical hardware on both the platform and the child drone
- Mitigation options:
  - Use battery manager while testing
  - Incremental sub-system testing
  - Final system test with batteries in the circuit
- Response if risk occurs:
  - Unplug circuit and test components individually for damage
  - Replace components with discretionary budget funds if necessary

Post-Mitigation Risk Analysis

- Severity: 4 Likelihood: 1 TOTAL: 4

Risk Analysis

Risk 4: Inadequate charging contact between charging plates and circuit is not completed

- Severity: 3 Likelihood: 4 TOTAL: 12
- Description: Charging contact is insufficient between the child drone charging brackets and the securing system charging bars to allow charging to commence. This would result in failing to meet requirement FR 2.0.
- Mitigation options:
  - Spring/copper design to ensure adequate contact
- Response if risk occurs:
  - Adjust materials selected and positioning
  - Re-design

Post-Mitigation Risk Analysis

- Severity: 3 Likelihood: 3 TOTAL: 9

Risk Analysis

Risk 5: Child drone lands in poor landing configuration and prevents charging

- Severity: 3 Likelihood: 3 TOTAL: 9
- Description: Child drone could potentially land perpendicular to the charging bars and therefore prevent the charging bars from making contact with the brackets on child drone. Does not fulfill FR 2.0.
- Mitigation options:
  - Pixhawk yaw gain adjustment
  - Improve IRS landing accuracy
  - Modeling from PDR proved this risk is negligible
- Response if risk occurs:
  - Re-attempt landing sequence and tweak software parameters

Post-Mitigation Risk Analysis

- Severity: 3 Likelihood: 2 TOTAL: 6

Risk Analysis

Risk 6: PCB manufacturing defects that prevent charging circuit completion

- Severity: 3 Likelihood: 2 TOTAL: 6
- Description: Manufacturing defects could prevent charging circuitry from working as intended, not fulfilling FR 2.0.
- Mitigation options:
  - Find reputable vendors
  - Test circuit board components prior to PCB integration
- Response if risk occurs:
  - Diagnose broken component and attempt to fix
  - Return to manufacturer

Post-Mitigation Risk Analysis

- Severity: 3 Likelihood: 1 TOTAL: 3

Risk Analysis

Risk 7: Battery manager malfunctions causing damage to child drone or harming team members

- Severity: 5 Likelihood: 2 TOTAL: **10**
- Description: The battery manager used to ensure that charging is being completely properly could malfunction causing the LiPo to explode, potentially damaging hardware or injuring team members.
- Mitigation options:
  - Sub-system incremental testing with components
  - Use component only after testing that it will regulate voltage properly
- Response if risk occurs:
  - Power system off
  - Ensure no team members are injured
  - Place LiPo in LiPo sack or ammo can
  - Test circuit components to ensure they still function properly

Post-Mitigation Risk Analysis

- Severity: 5 Likelihood: 1 TOTAL: **5**

Risk Analysis

Risk 8: Raspberry Pi loses communication with Pixhawk

- Severity: 4 Likelihood: 3 TOTAL: 12
- Description: The Raspberry Pi onboard the child drone could lose communications with the onboard flight controller, ultimately preventing landing on the platform and not fulfilling FR 1.0.
- Mitigation options:
  - Communication testing prior to flight
  - Implement system redundancy to have a back-up system if loss of communication occurs
- Response if risk occurs:
  - Switch Pixhawk to manual flight mode from Ground Station if possible

Post-Mitigation Risk Analysis

- Severity: 4 Likelihood: 2 TOTAL: 8

Risk Analysis

Risk 9: Poor landing accuracy causes child drone to fall off platform resulting in damage

- Severity: 4 Likelihood: 2 TOTAL: **8**
- Description: Child drone could potentially land with 2 or more legs off of the platform, causing it to topple and fall of the platform and causing damage.
- Mitigation options:
  - Use AR tags instead of color recognition for increased landing accuracy
  - Indoor flight testing with mats/nets beneath platform to catch drone if it falls off the platform
- Response if risk occurs:
  - Cut throttle
  - Assess child drone for damage
  - Replace damaged parts from discretionary spending budget

Post-Mitigation Risk Analysis

- Severity: 4 Likelihood: 1 TOTAL: **4**

Risk Analysis

Risk 10: Child drone loses lock on platform before it can make final descent

- Severity: 4 Likelihood: 3 TOTAL: 12
- Description: Child drone image recognition system could lose a lock on the platform image and be unable to land on the platform resulting in failure to meet FR 1.0.
- Mitigation options:
  - Software algorithms that command the drone to start landing sequence over again if image is lost
  - Use AR codes to assist with landing accuracy
- Response if risk occurs:
  - Switch to manual mode and piloted landing

Post-Mitigation Risk Analysis

- Severity: 3 Likelihood: 2 TOTAL: 6

Risk Analysis

Risk 11: Piloting error could result in child drone damage

- Severity: 4 Likelihood: 2 TOTAL: 8
- Description: In order to verify various software capabilities, the child drone must be flown by a pilot in some test flights. A piloting error could lead to costly and even irreparable damage.
- Mitigation options:
  - Pilot training and certification
- Response if risk occurs:
  - Assess environmental factors
  - Review flight data
  - Require that pilot receive additional training

Post-Mitigation Risk Analysis

- Severity: 4 Likelihood: 1 TOTAL: 4

Risk Analysis

Risk 12: Position lag time between commands

- Severity: 4 Likelihood: 2 TOTAL: 8
- Description: The refresh rate between the Pixhawk and the Raspberry Pi camera could lead to a significant lag time between commands resulting in unstable flight conditions.
- Mitigation options:
  - Do not send position vector data faster than the Pixhawk can process
- Response if risk occurs:
  - Adjust command frequency

Post-Mitigation Risk Analysis

- Severity: 4 Likelihood: 1 TOTAL: 4

Risk Analysis

Risk # 13: Child drone legs disengage upon hard landing

- Severity: 2 Likelihood: 2 TOTAL: 4
- Description: The child drone is equipped with a leg-detaching feature to prevent splintering. This would prevent the drone from re-charging and thus would not meet functional requirement 3.0.
- Mitigation options:
  - Adjust the descent rate of the drone to safe levels to ensure the legs would not splinter and epoxy the legs to the child drone frame
- Response if risk occurs:
  - Retry the mission after reattaching and adjusting the descent rate

Post Mitigation Analysis

- Severity: 2 Likelihood: 1 TOTAL: 2

Risk Analysis

Risk # 14: Charging/securement bars fail to disengage and damage the child drone

- Severity: 3 Likelihood: 1 TOTAL: 3
- Description: The bars could damage the drone by squeezing it and bending the legs.
- Mitigation options:
  - Use a motor controller to stop the bars once they have completed a specific number of RPMs correlating to a safe distance
  - Design a mechanical fail-safe, such as a barrier, to ensure that the bars cannot harm the child drone
- Response if risk occurs:
  - Stop the test immediately and administer necessary repairs

Post Mitigation Analysis

- Severity: 2 Likelihood: 1 TOTAL: 2

Risk Analysis

Risk # 15: Manufacturing errors in child drone charging/securement bars

- Severity: 2 Likelihood: 3 TOTAL: **6**
- Description: If the copper and delrin are not manufactured to the necessary tolerances, the additions to child drone will not fit into the bars. Charging can not occur and functional requirement 3.0 is not met
- Mitigation options:
  - Allow for a design margin of 1/10 inch on either side of the delrin additions to child drone
- Response if risk occurs:
  - Stop the test to prevent damage and sand down the delrin before testing again

Post Mitigation Analysis

- Severity: 2 Likelihood: 2 TOTAL: **4**

Risk Analysis

Risk # 16: Securement system does not secure child drone in specified environment

- Severity: 4 Likelihood: 3 TOTAL: 12
- Description: If the securement system cannot secure the child drone in environment 1.1, functional requirement 1.0 is not met. The child drone could also be damaged if it falls off of the platform.
- Mitigation options:
  - Characterize the environment and design the securement system for the worst case with a safety factor
  - Create a restraining system such that if the child drone becomes unsecured it will not fall and incur damage
- Response if risk occurs:
  - Add a mild adhesive to the delrin sides of the charging/securement panels on the child drone

Post Mitigation Analysis

- Severity: 4 Likelihood: 2 TOTAL: 8

Risk Analysis

Risk # 17: Mass added to child drone prevents it from completing its mission

- Severity: 3 Likelihood: 2 TOTAL: 6
- Description: The INFERNO mission is inherited and the additions made this year are not to infer with the child drone mission. The charging/securement panels and the image recognition system will both add mass to the child drone and could impede its mission duration.
- Mitigation options:
  - Analyze the mass specifications provided in INFERNO's spring final report. Design around these specs and do not exceed the mass detailed for a 13.5 minute mission.
- Response if risk occurs:
  - Redesign the components added to the child drone to make them more mass efficient.

Post Mitigation Analysis

- Severity: 3 Likelihood: 1 TOTAL: 3

Risk Analysis

Risk # 18: The ball screw on the platform fails

- Severity: 5 Likelihood: 2 TOTAL: **10**
- Description: The ball screw drives the charging/securement bars. If this mechanism fails requirements # and # will not be met.
- Mitigation options:
  - Buy a commercial off the shelf ball screw to minimize manufacturing error
- Response if risk occurs:
  - Explore other commercial retailers

Post Mitigation Analysis

- Severity: 5 Likelihood: 1 TOTAL: **5**

Risk Analysis

Risk # 19: Platform does not fit into University CNC machine

- Severity: 4 Likelihood: 3 TOTAL: 12
- Description: If the platform material does not fit into the University CNC machine, manufacturing will take much longer than anticipated and set back the project schedule.
- Mitigation options:
  - Discuss platform dimensions with machine shop staff
  - Outsource the machining to Colorado Waterjet Company for $150
- Response if risk occurs:
  - Outsource the machining

Post Mitigation Analysis

- Severity: 4 Likelihood: 1 TOTAL: 4

Risk Analysis

Risk # 20: Communication system failure

- Severity: 3 Likelihood: 3 TOTAL: **9**
- Description: If a communication link between the ground station, platform, or child drone breaks, functional requirements 4 and/or 5 are not met.
- Mitigation options:
  - Conduct link budget analysis to determine the strength of components that is needed
- Response if risk occurs:
  - Purchase higher powered antennas

Post Mitigation Analysis

- Severity: 2 Likelihood: 2 TOTAL: **4**

Risk Analysis

Risk # 21: Platform has too high a coefficient of friction for the child drone to slide

- Severity: 3 Likelihood: 3 TOTAL: 9
- Description: If the child drone does not land exactly centered on the platform, the charging/securement bars will need to push it into place. If the coefficient of friction is too high, the drone could topple and would not be able to charge, not fulfilling functional requirement 3.0.
- Mitigation options:
  - Grease the platform
- Response if risk occurs
  - Change/polish the rubber material on the child drone feet

Post Mitigation Analysis

- Severity: 3 Likelihood: 2 TOTAL: 6

Risk Analysis

Risk # 22: High lead time on outsourced parts

- Severity: 3 Likelihood: 4 TOTAL: 12
- Description: Some parts, in particular the platform ball screw have a known high lead time. If this gets pushed back any further than anticipated it could impede the spring semester schedule.
- Mitigation options:
  - Begin ordering parts after CDR
  - Do not buy from any source outside the US
- Response if risk occurs:
  - Investigate alternate purchasing sources

Post Mitigation Analysis

- Severity: 3 Likelihood: 2 TOTAL: 6

Risk Analysis

Risk # 23: Inclement weather during spring testing

- Severity: 2 Likelihood: 5 TOTAL: **10**
- Description: Several of the tests need to occur outdoors. If there is inclement weather the tests cannot be completed and it will push back the schedule.
- Mitigation options:
  - Have indoor spaces booked as a back up, plan for alternate testing dates
  - Design tests that can still prove functionality but can be completed indoors
- Response if risk occurs:
  - Test indoors. If this is not a viable option (test needs GPS location) the test must fall on an alternate date

Post Mitigation Analysis

- Severity: 1 Likelihood: 5 TOTAL: **5**

Risk Analysis

Risk # 24: Large budgetary expenses from child drone replacement

- Severity: 3 Likelihood: 3 TOTAL: 9
- Description: The budget accounts for some of the smaller parts of the child drone being replaced, but does not allow for an entire system replacement. Should the entire child drone become irreparably damaged, it must be replaced.
- Mitigation options:
  - Test system by system and do not involve the child drone until certain that the electronics are not in danger
  - Follow testing and safety protocol when flight testing
- Response if risk occurs:
  - Apply for external funding (EEF, UROP) in the spring

Post Mitigation Analysis

- Severity: 2 Likelihood: 3 TOTAL: 6