CHIMERA

CHIld drone deployment MEchanism and Retrieval Apparatus

Spring Final Review

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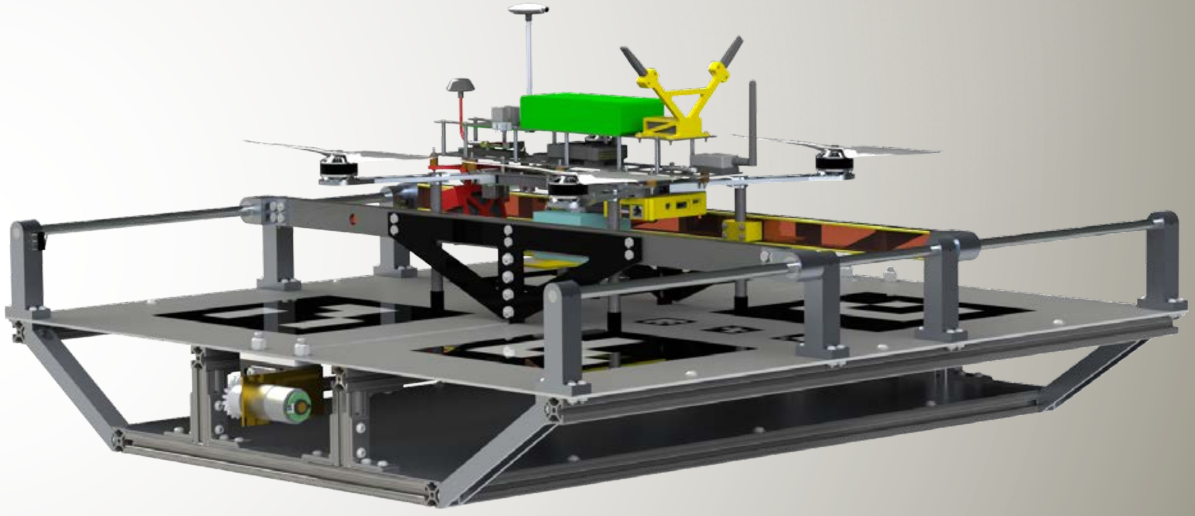
Agenda

- Project Purpose and Objectives
- Autonomous Landing
  - Design Description
  - Test Overview
  - Test Results
- Securing
  - Design Description
  - Test Overview
  - Test Results
- Automatic Charging
  - Design Description
  - Test Overview
  - Test Results
- Systems Engineering
- Project Management

Project Purpose and Overview

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

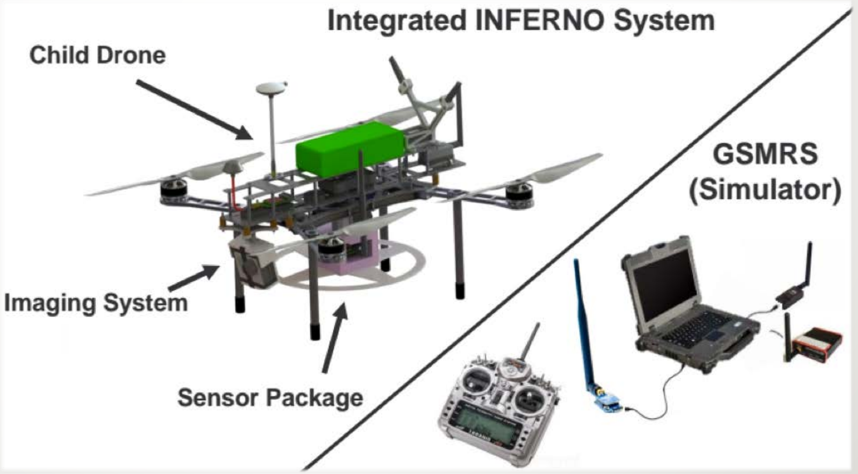
- Contribute to the overall Fire Tracker mission by designing and building a child drone platform capable of integration with a future mother rover.
- Modify the child drone using hardware and software to autonomously land on the platform.
- Design a platform capable of securing and charging the child drone after autonomous landing.
- Design a communication system that facilitates transfer of commands and data between the child drone, platform, and ground station, <u>will be discussed within other project elements</u>.

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
- Nominal mission time 12.5 minutes



CHIMERA System CONOPS

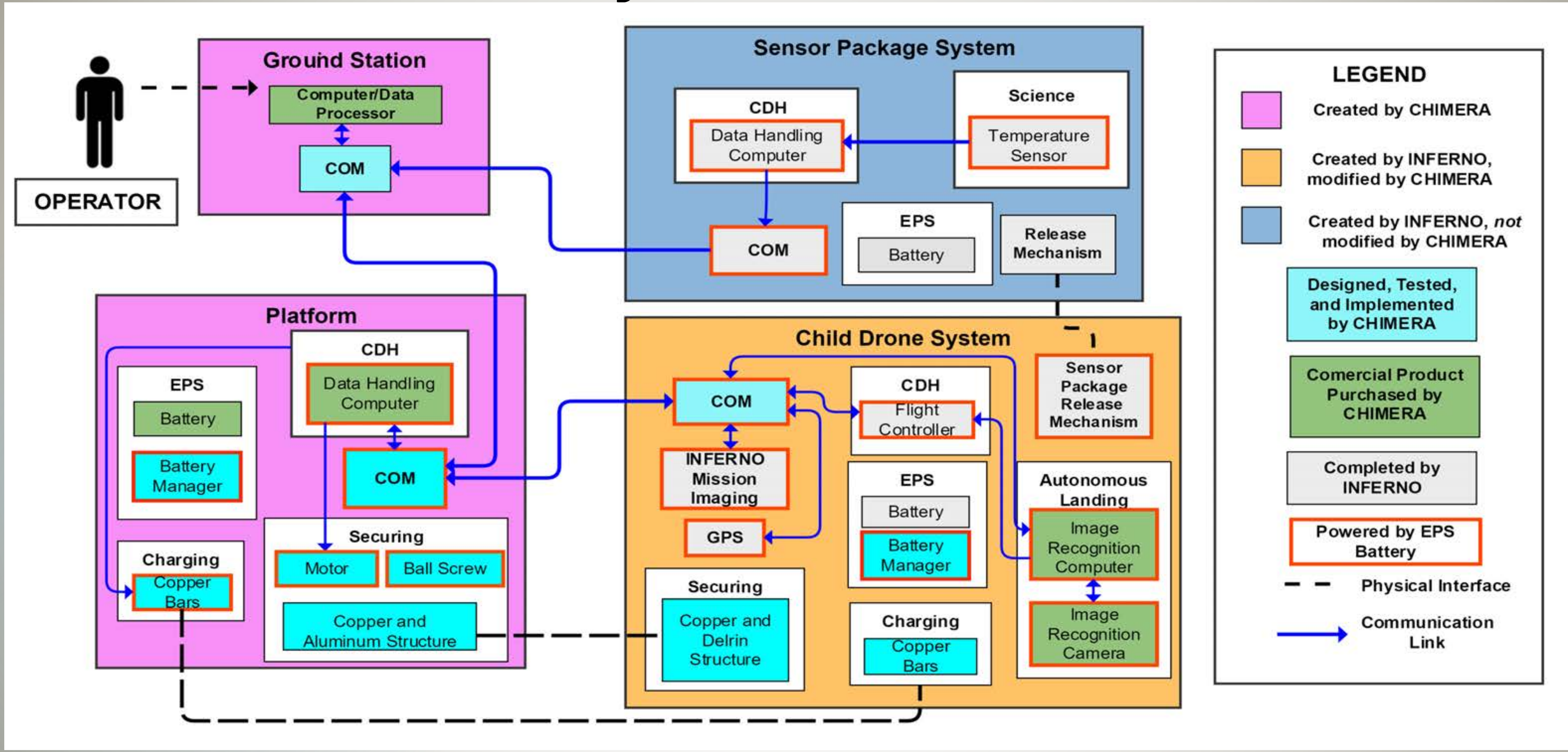
Release Child Drone	Operator Command
Deploy Child Drone	Automated
Child Drone Mission (12.5 Minutes)	
Land Child Drone	Automated
Secure Child Drone	Operator Command
Recharge Child Drone	Operator Command
End CHIMERA Mission	

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
  - Challenge: Presents a difficult software challenge, high risk of child drone damage
- Securing of Child Drone
  - Platform shall capture the child drone and restrict movement over rough terrain
  - Challenge: Complex mechanical hardware requiring precision machining
- Automatic Child Drone Recharging
  - Utilizes conductive contacts to transfer power from platform battery bank to child drone for extended mission duration
  - Challenge: Complex circuitry, open copper presents risk to team members and equipment

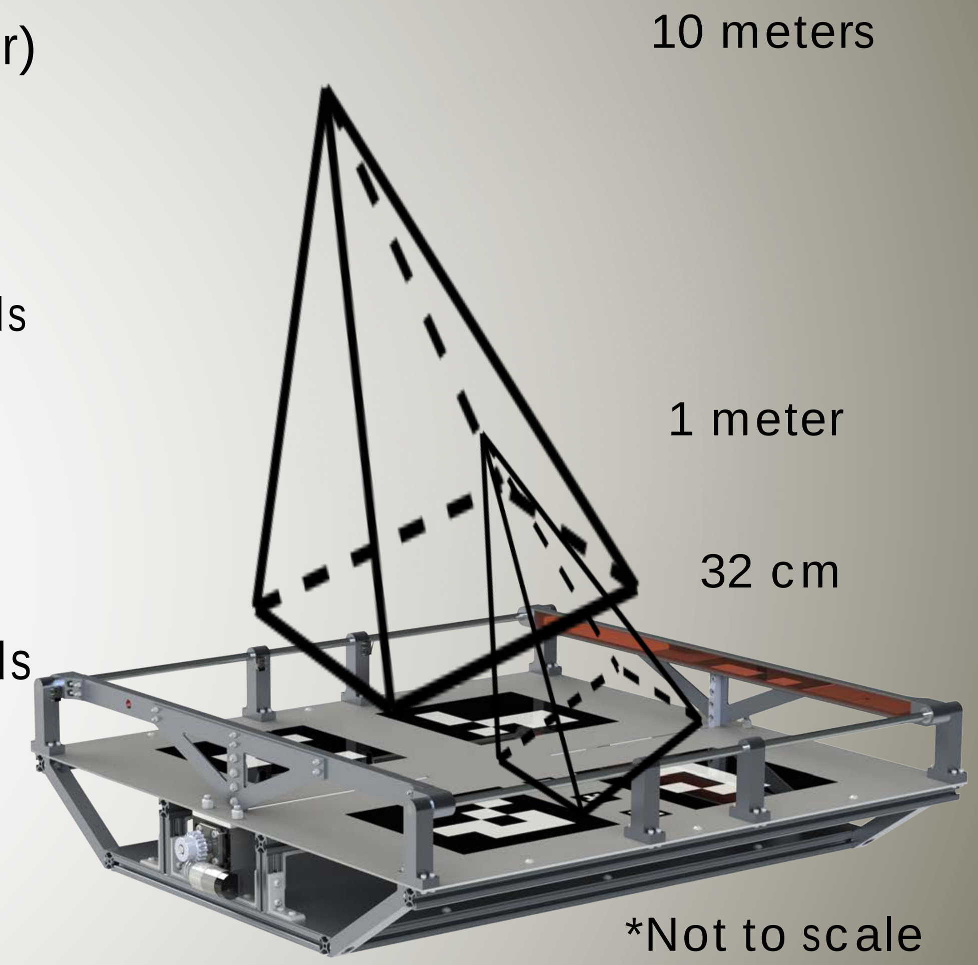
Functional Block Diagram: System Level



Autonomous Landing System

Landing Subsystem CONOPS

- Ground Station initiates Land sequence – drone "Returns to home" using GPS (5 meter error)
- Image Recognition locks on Platform
- Algorithm Commands Flight Controller
  - If child drone is within decent threshold, it descends
  - If not, child drone re-centers
- At 1 meter, child drone switches to small markers
  - Same descent threshold
- At 32 cm, drone switches to land mode and lands
- If lock is lost, child drone executes square search pattern

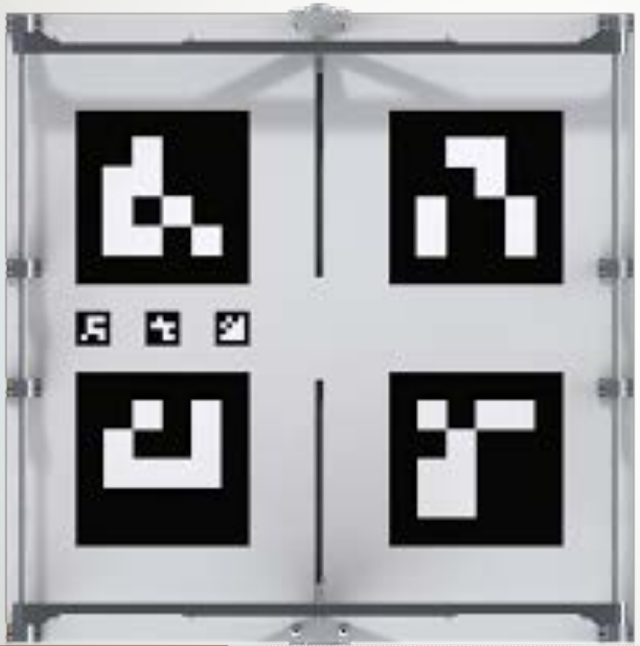


Autonomous Landing

Image Recognition

Image Recognition Objective:

Transform an image into a velocity vector and yaw rotation that can be used to navigate the child drone to a landing platform



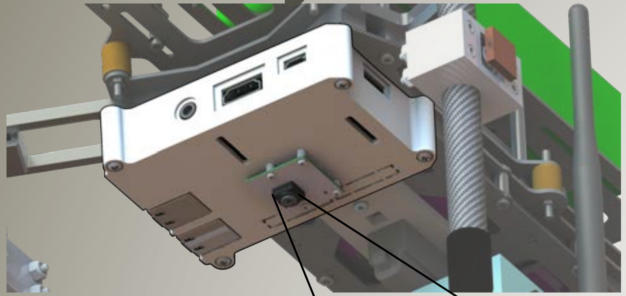
Landing Platform with AR Tags

Solution:

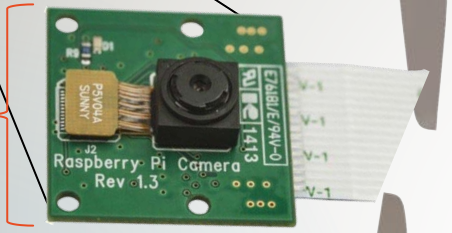
- Robust lighting variation immunity, i.e. does not get washed out in sunlight
- Numerous pattern combinations
- Lock only requires one target

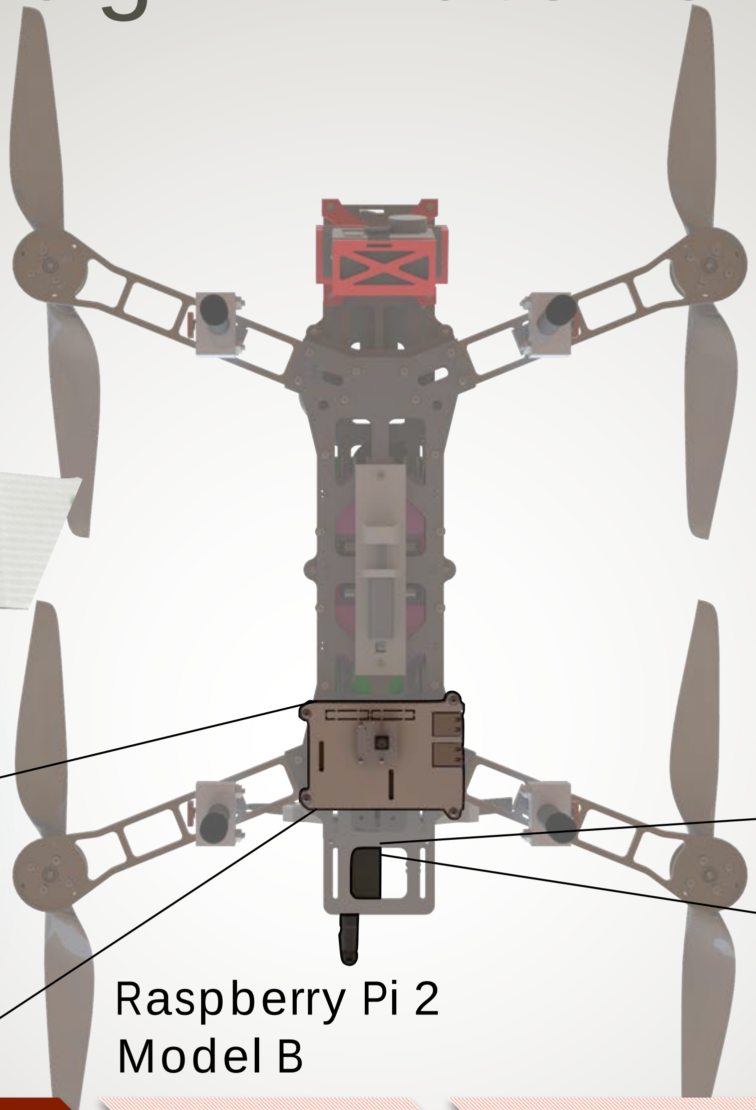
System Design – Autonomous Landing

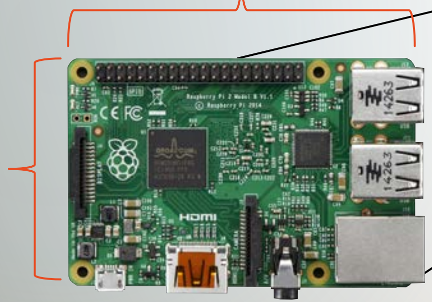
Attribute	Value
Camera Resolution	- 5 Megapixels - 2592 x1944 pixels
Camera Field of View	- Horizontal: 53.5º - Vertical: 41.4º
Mass Added to Child Drone	Raspberry Pi: 45 g Camera: 3 g Xbee: 6 g



Raspberry Pi Camera Board Module

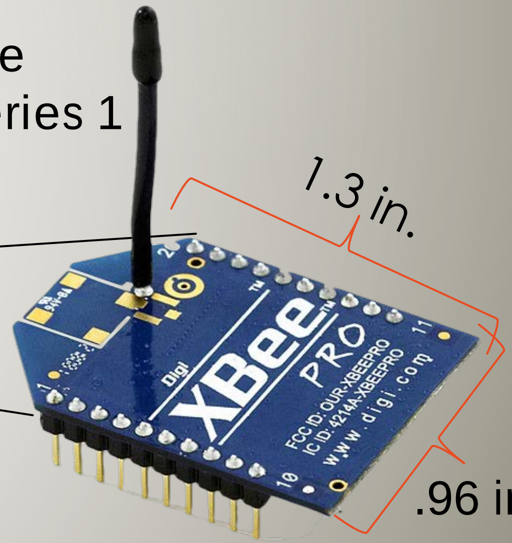




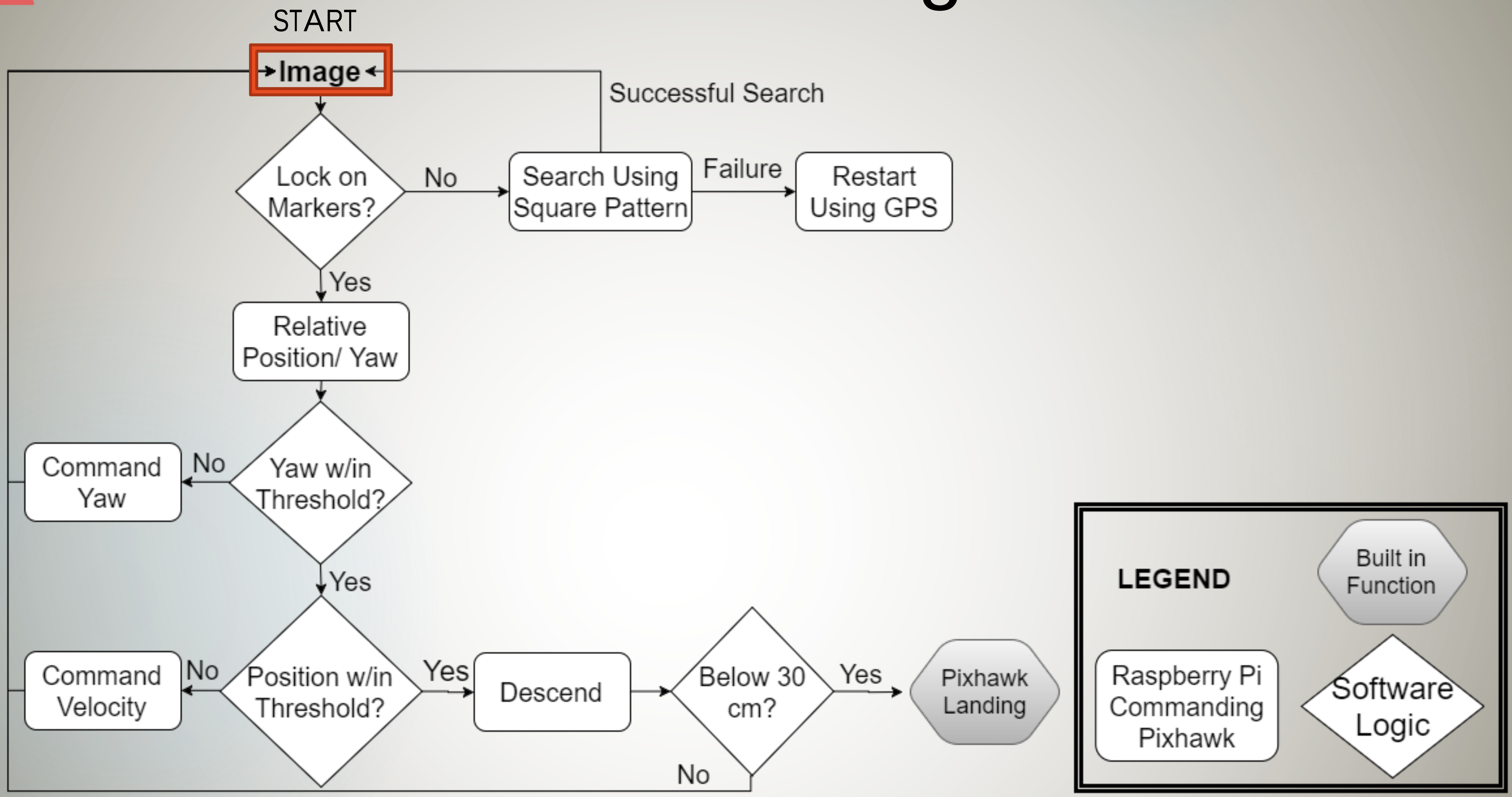


Raspberry Pi 2 Model B

XBee Pro Wire Antenna - Series 1 2.4 GHz



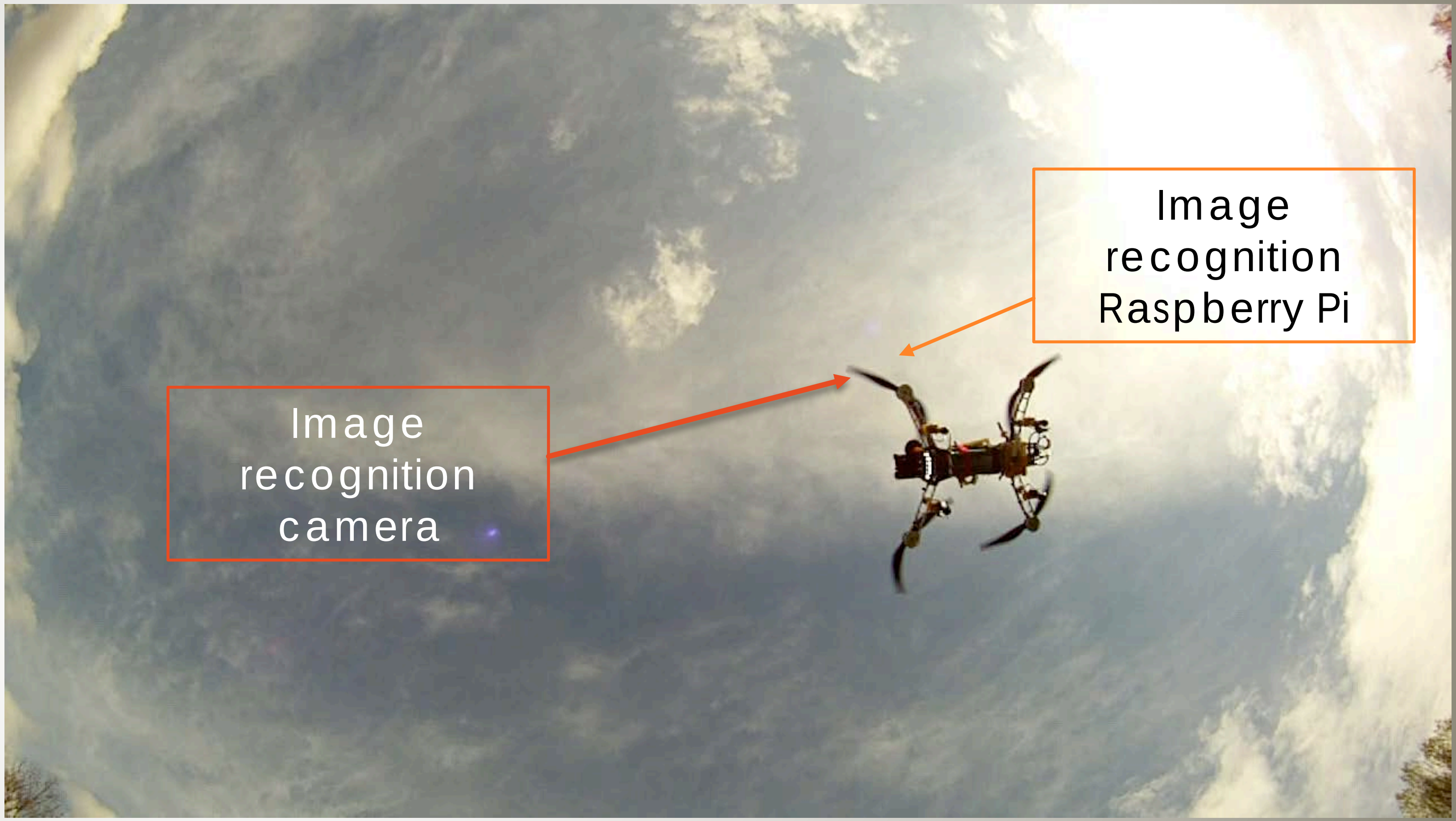
Autonomous Landing - Software



Autonomous Landing Subsystem

- Image Recognition System with AR Tags

Attribute	Value
Refresh Rate	5-8 FPS
Command Rate	0.67-1.6 Hz
Inputs	AR Tag Dimensions
Outputs	- Velocity Command - Yaw Command



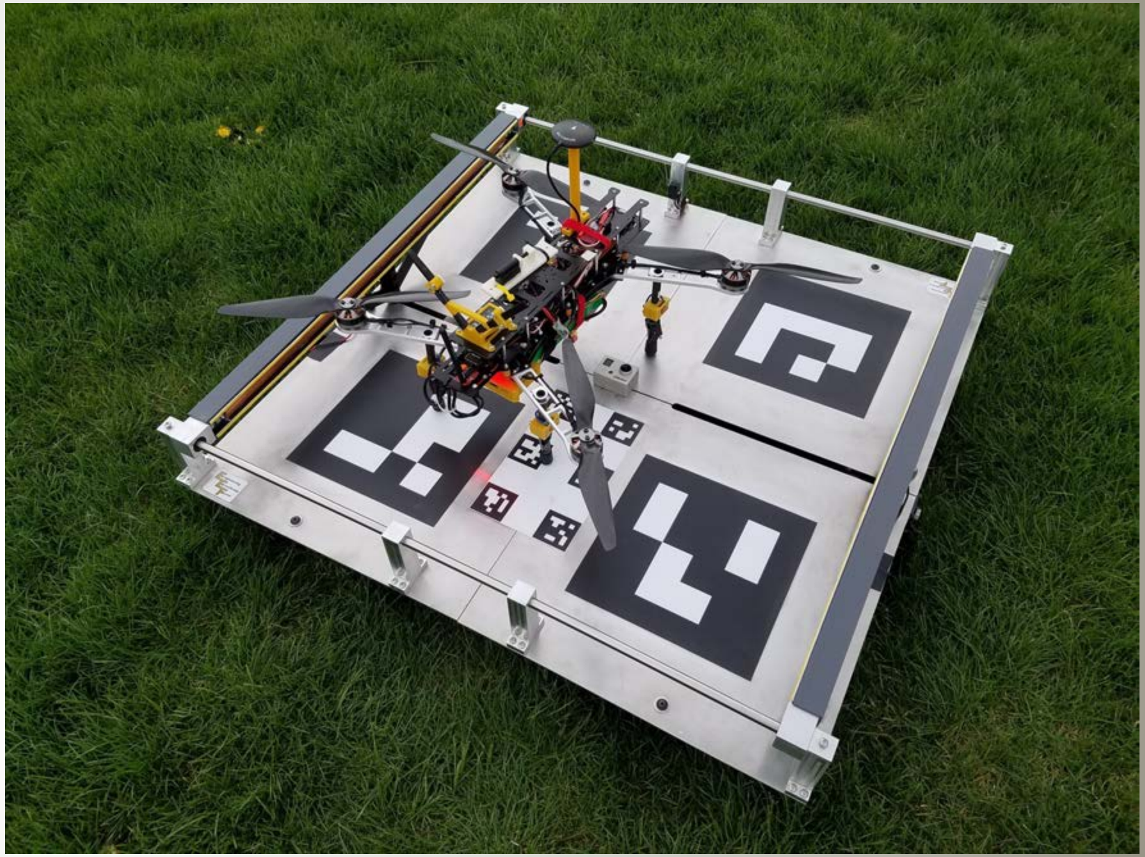
Autonomous Landing Subsystem Test

- Purpose: Determine the success of the autonomous landing subsystem

Requirement Verified	Description
FR 1.0 ✓	Autonomously land on platform
DR 1.1 ✓	Land using an image recognition system
DR 1.2 ✓	Platform landing area of 0.8 m by 0.8 m
DR 1.3 ✓	Platform communicates with child drone
DR 1.4 ✓	Ground station receives video from child drone
DR 1.5 ✓	Child drone sends telemetry to the platform
DR 1.6 ✓	Child drone receives commands from the platform

Autonomous Landing Test Results

- Number of trials completed: 10
- Number of successful landings: 2
  - Mean distance from center: 15.9 cm
- Number of indeterminate trials: 8
  - Due to pilot take over
- Future Work:
  - Additional trials to increase confidence levels



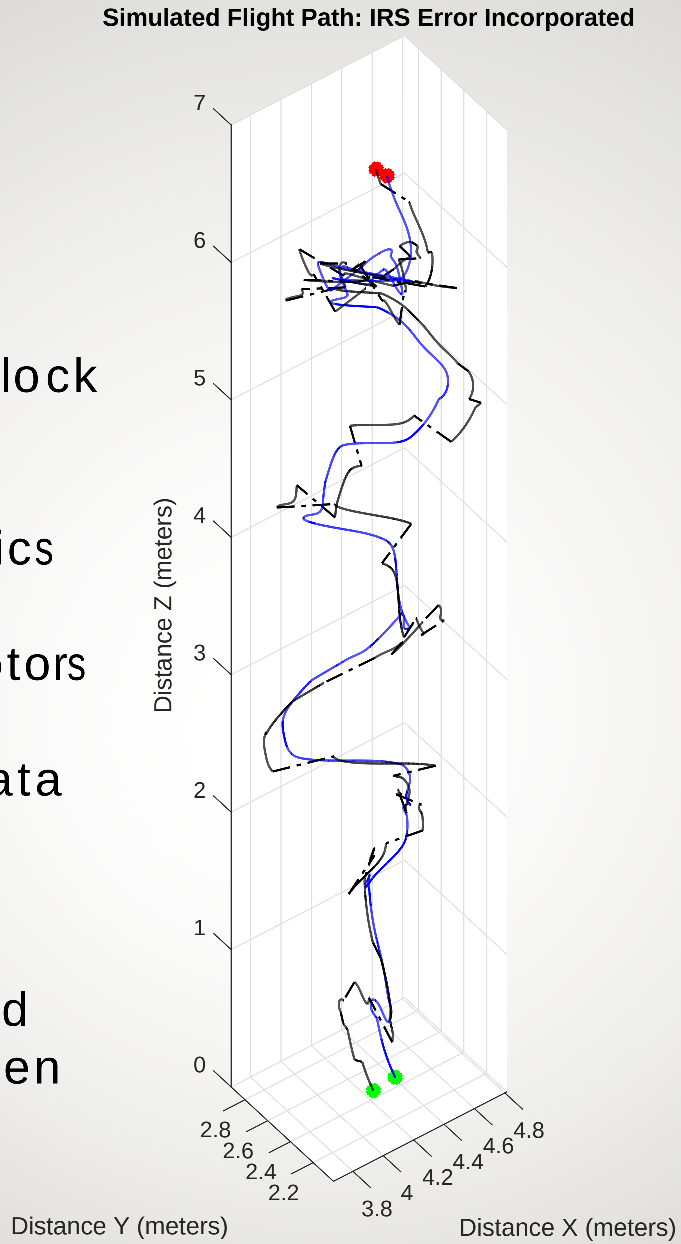
Flight Simulator

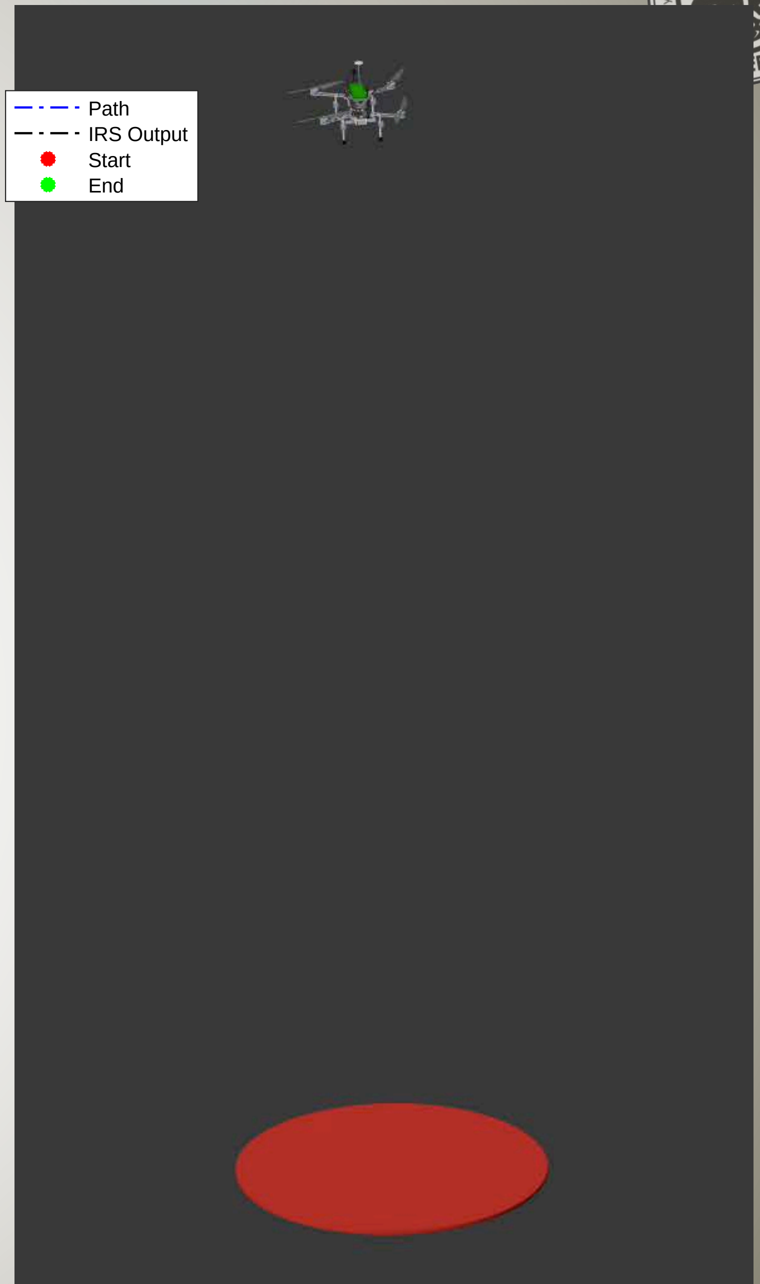
Assumptions:

- Simulator estimates for error:
  - In Image Recognition
  - Due to environmental conditions
- Assumes Image Rec always has lock

Differences from Physical System:

- Control → How it affects dynamics not exact
  - Throttle to thrust that the motors and propellers supply
  - Second order fit to online data tables
- Flight software logic not fully captured in simulator
  - Hyperbolic descent threshold
  - Square search algorithm when loss of lock





Monte Carlo Simulation

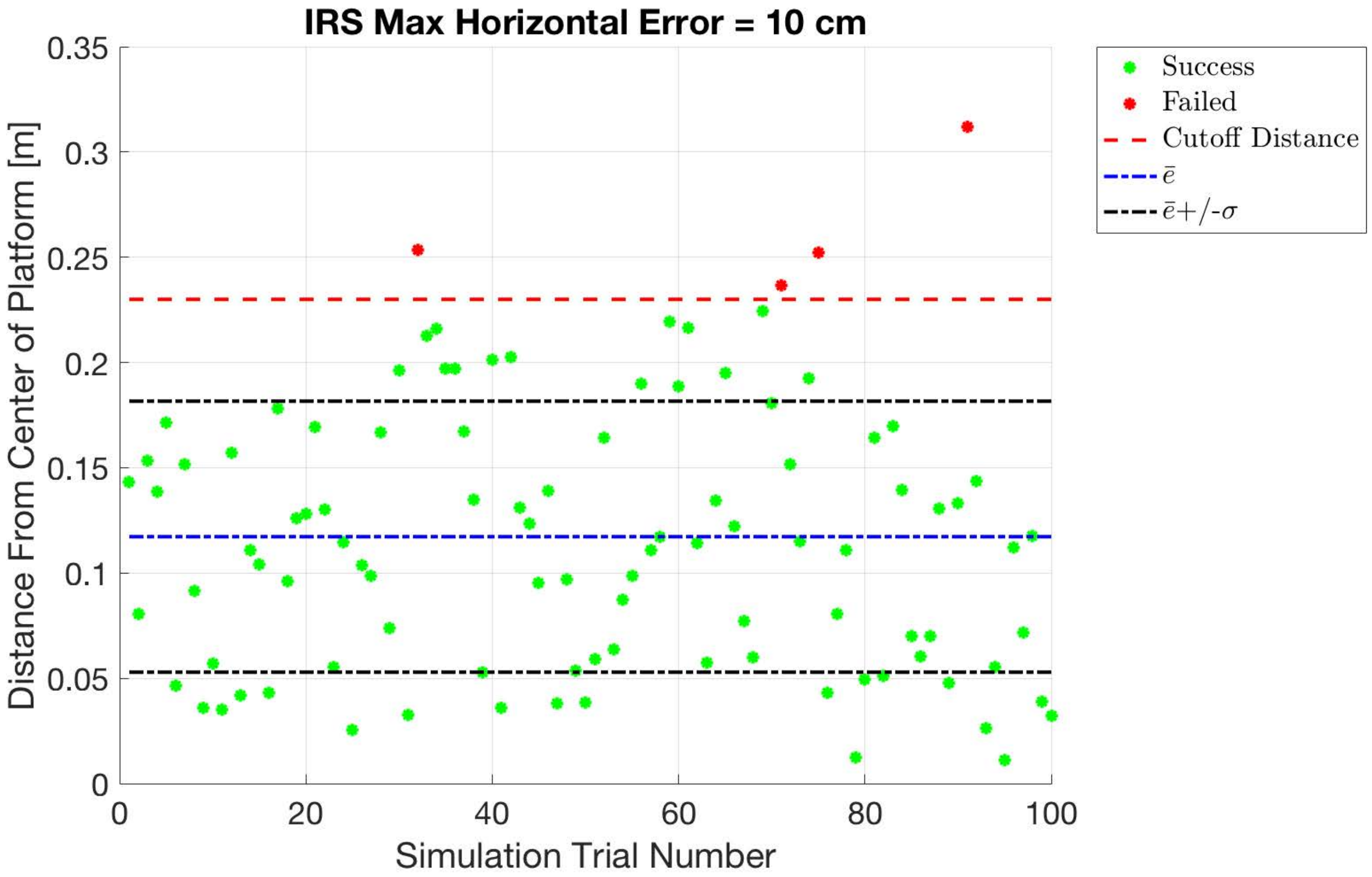
100 Landing simulations run for each case

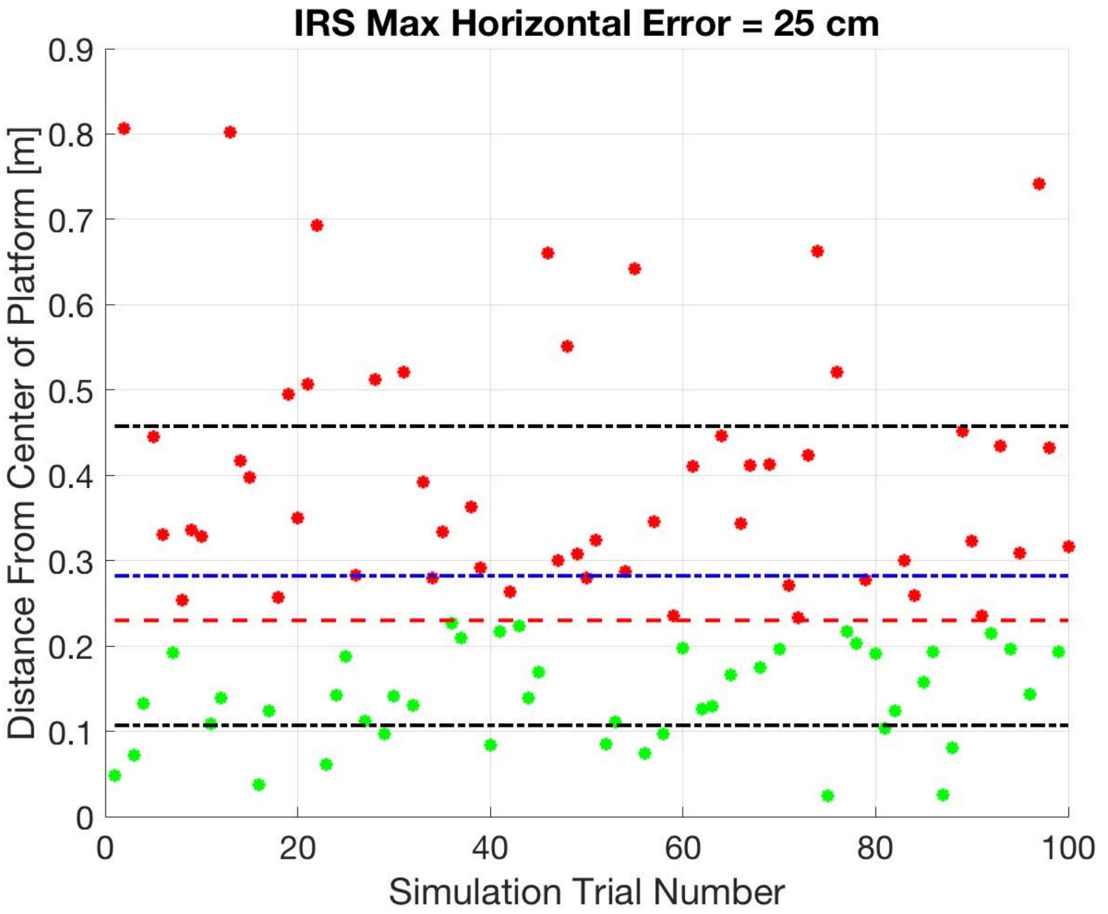
IRS Estimated Error +/- 10 cm in horizontal plane

- $\bar{e}$ = 0.117 meters
- σ = 0.064 meters
- Success Rate = 96%

IRS Estimated Error +/- 25 cm in horizontal plane

- $\bar{e}$ = 0.282 meters
- σ = 0.175 meters
- Success Rate = 46%





Levels of Success
Autonomous Landing

Level 1	Command child drone with onboard Raspberry Pi
Level 2	Autonomously lands on platform in incorrect orientation
Level 3	Autonomously lands on platform

Future Work:

- Conduct more trials in order to quantify confidence of autonomous landing system

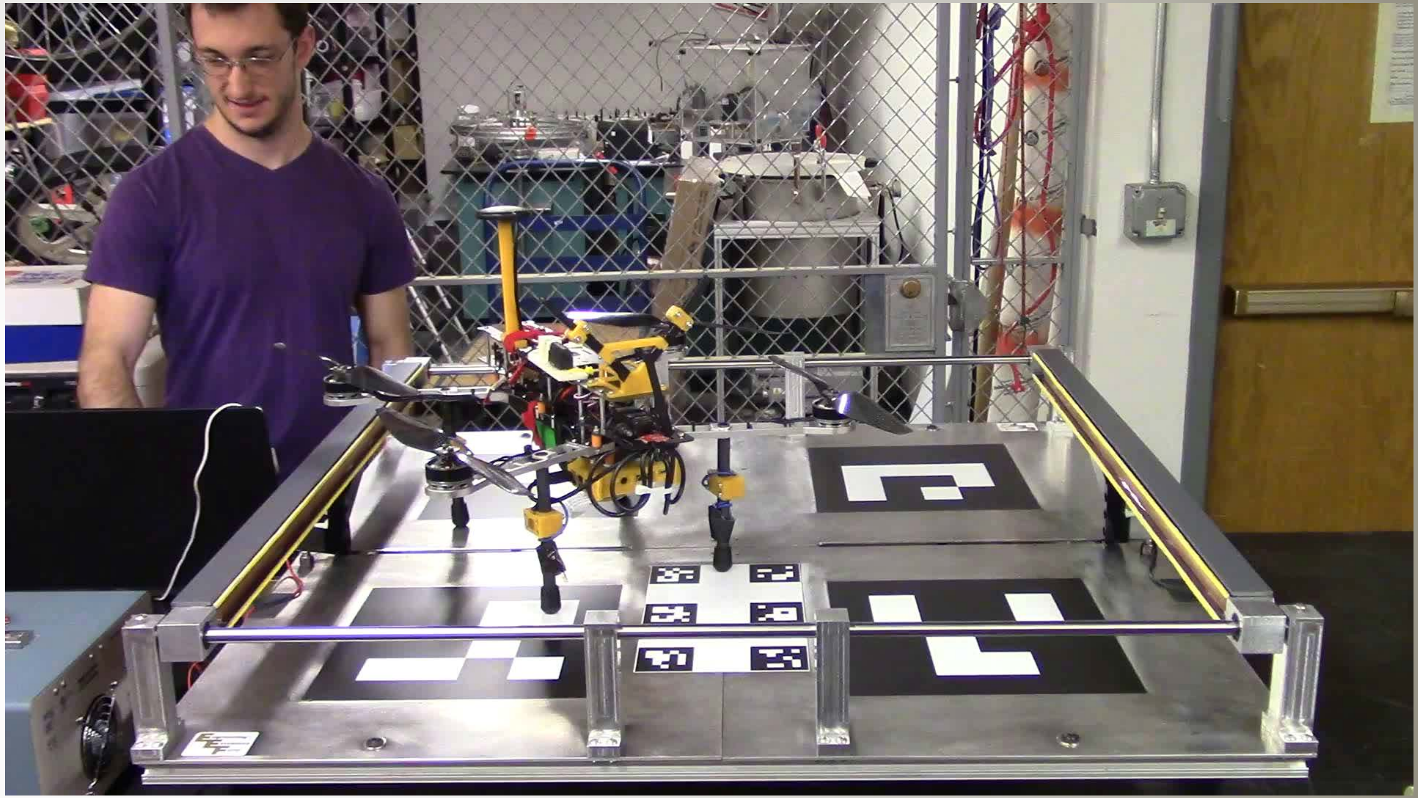
Legend

Full Success
Partial Success

Securing System

Securing Subsystem CONOPS

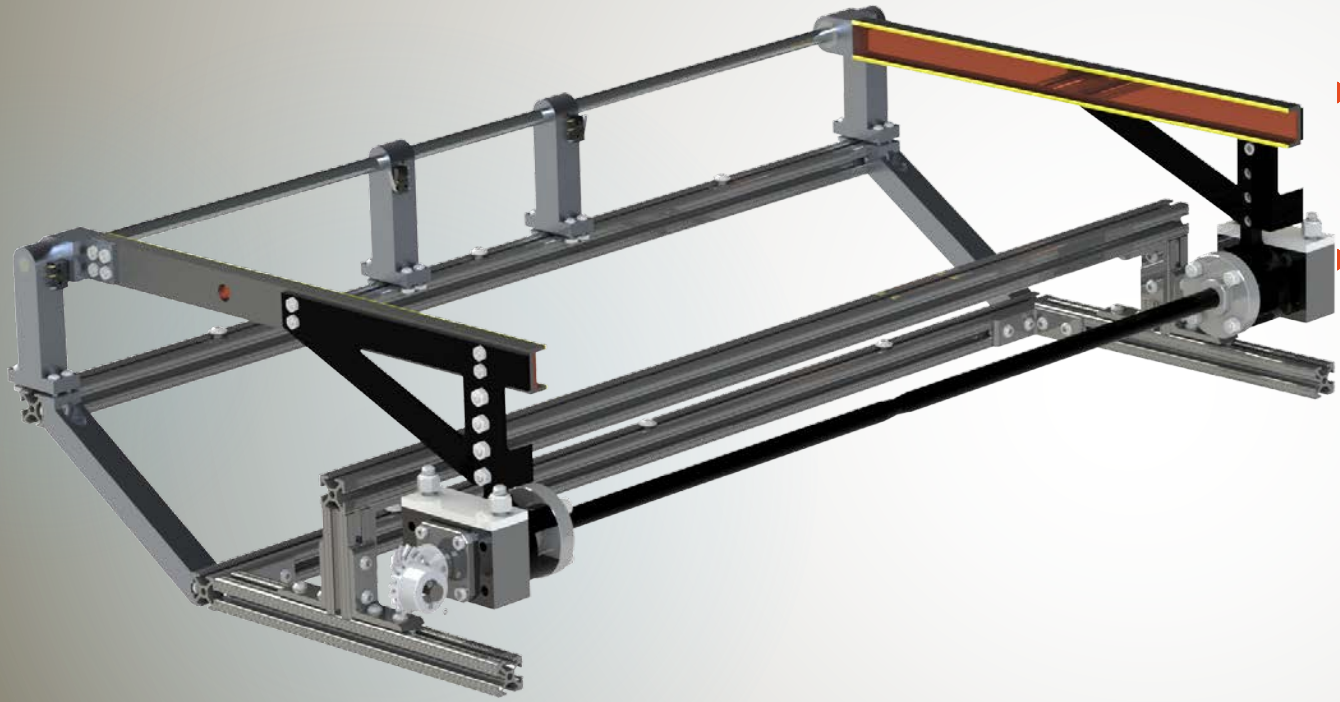
- Step 1: Landing is verified
- Step 2: Operator sends command to begin securement
- Step 3: Platform PCB provides power to DC motor and C-channels push drone to center
- Step 4: C-channel reorient drone to correct for yaw error
- Step 5: C-channels trigger limit switch and power to motor is cut



Securing Subsystem Objective

Securing System Objective:

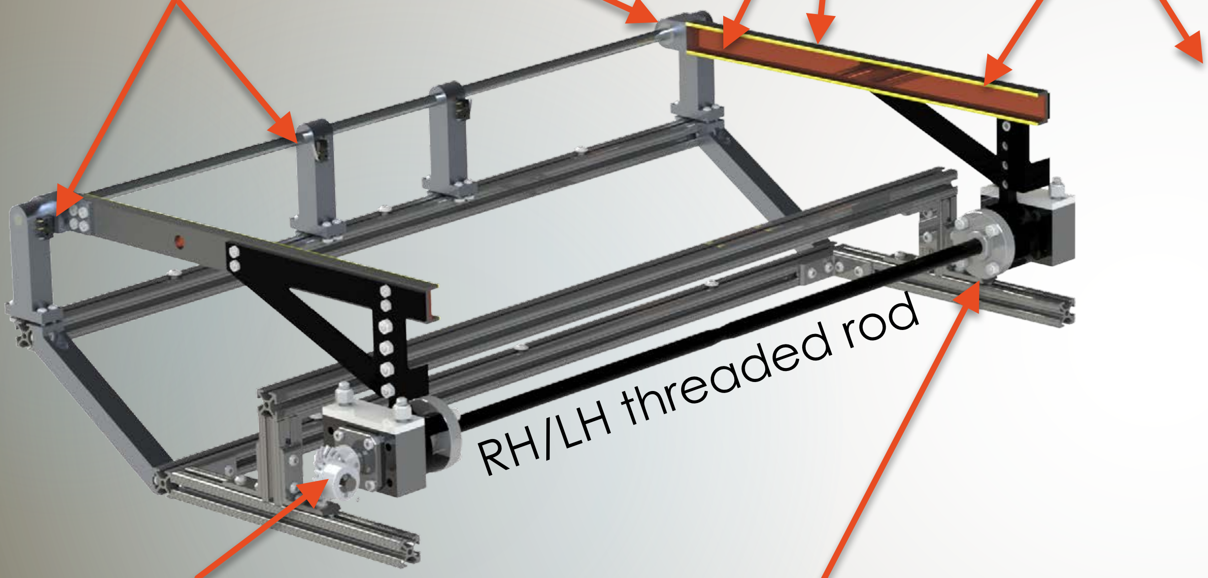
To support and secure the Child Drone through defined tilt, shock, and vibration environments.

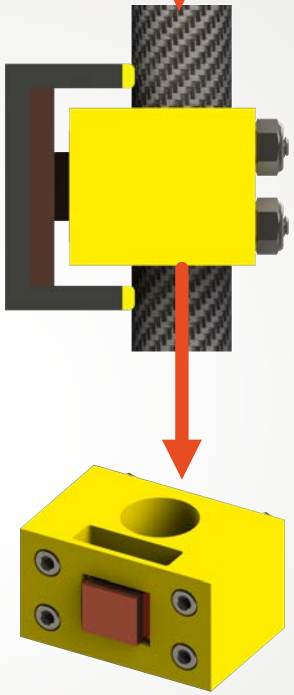


Solution:

- 91cm x 91cm Aluminum platform with structural supports
  - 80cm x 80cm available landing area
- DC motor to drive a ball screw securing system
- Retractable Aluminum c-channels with rubber grips to prevent Child Drone movement in all axes

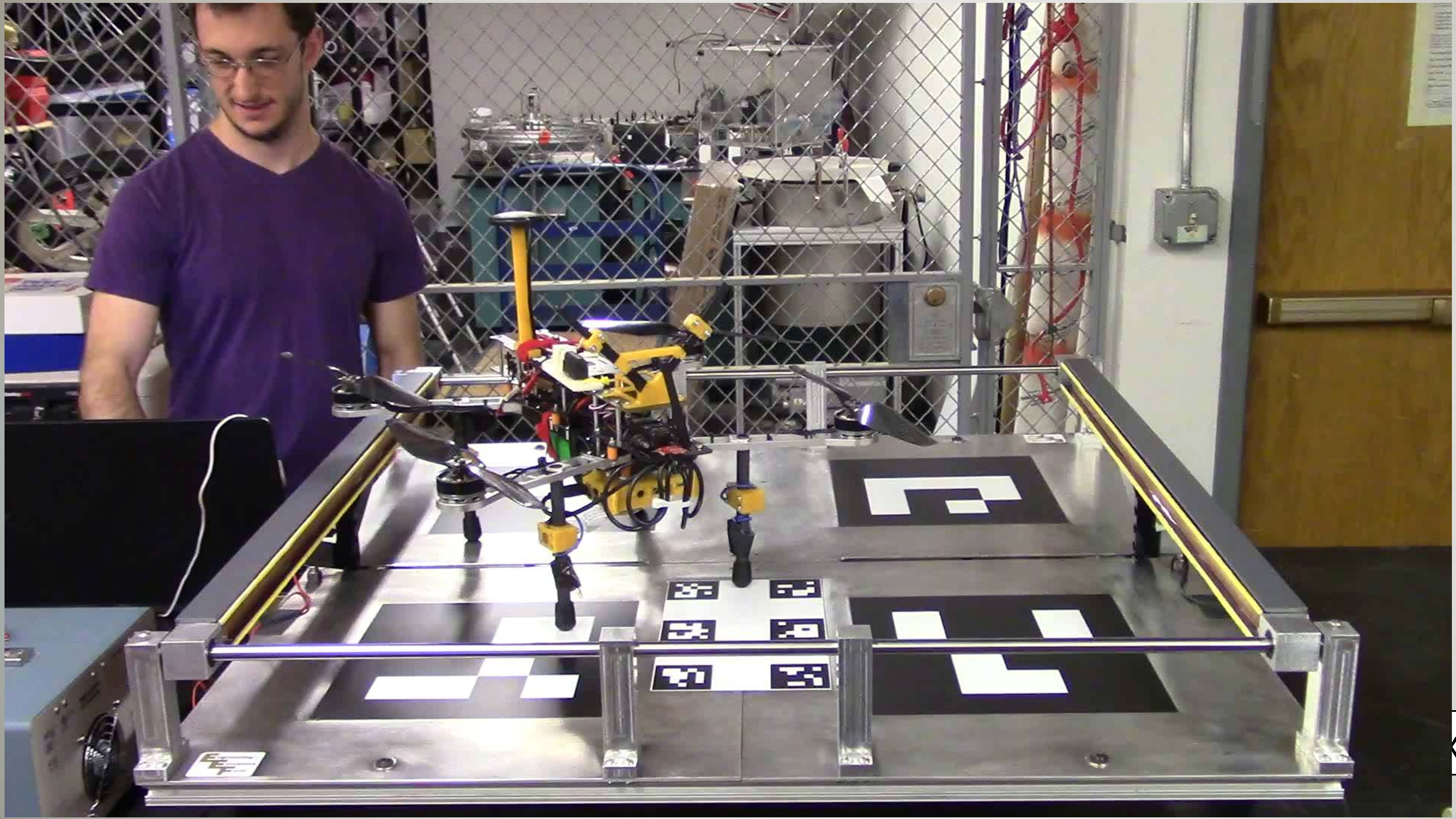
Securing Subsystem Design





Attribute	Value
Size of platform	91.44cm x 91.44cm x 23.70cm
Added mass to Child Drone	239 g
Time to Secure	~ 1 minute
Maximum tested tilt angle	90°

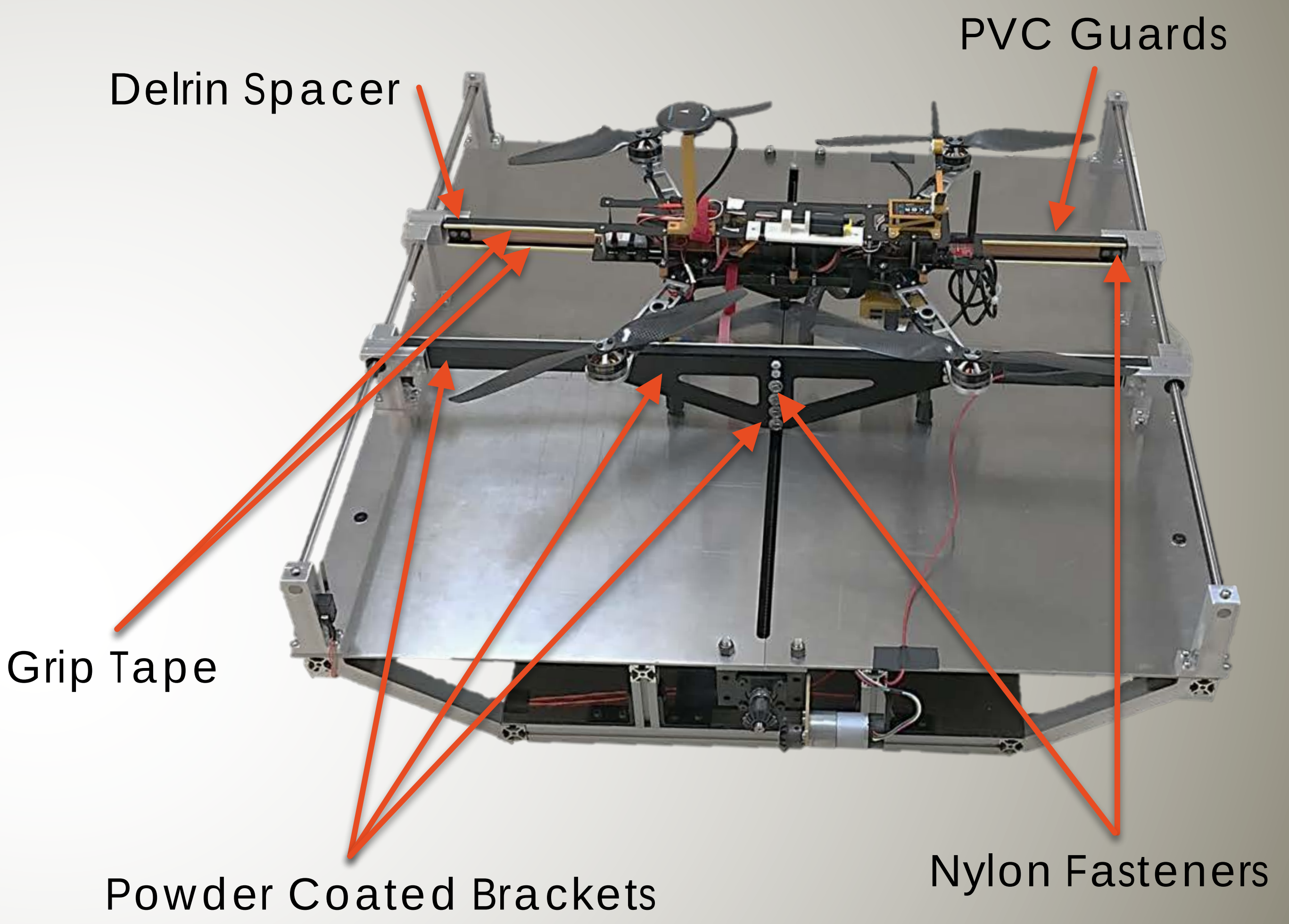
System Design – Securing



x2.5 speed

Changes Since TRR

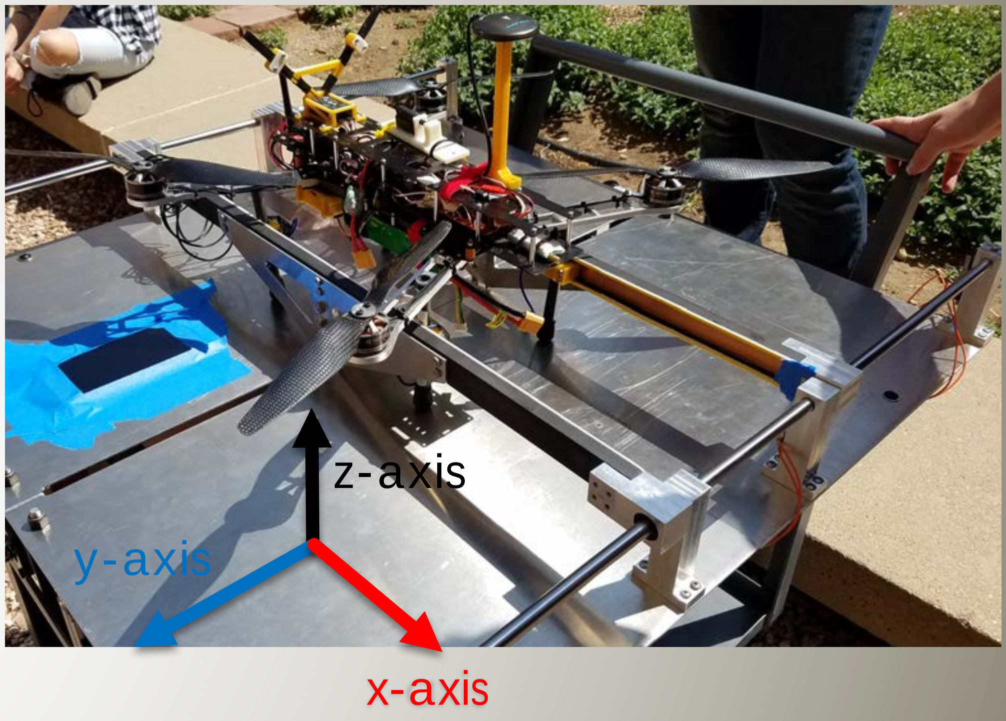
- Changes made for safety
  - Powder coated brackets connecting C-channel to ball screw system
  - Delrin spacers added between bearing bracket and C-channel
  - Nylon fasteners and washers add
  - PVC guard added to C-channel
- Grip tape added to C-channel to aid in child drone securement



Securing Subsystem Test

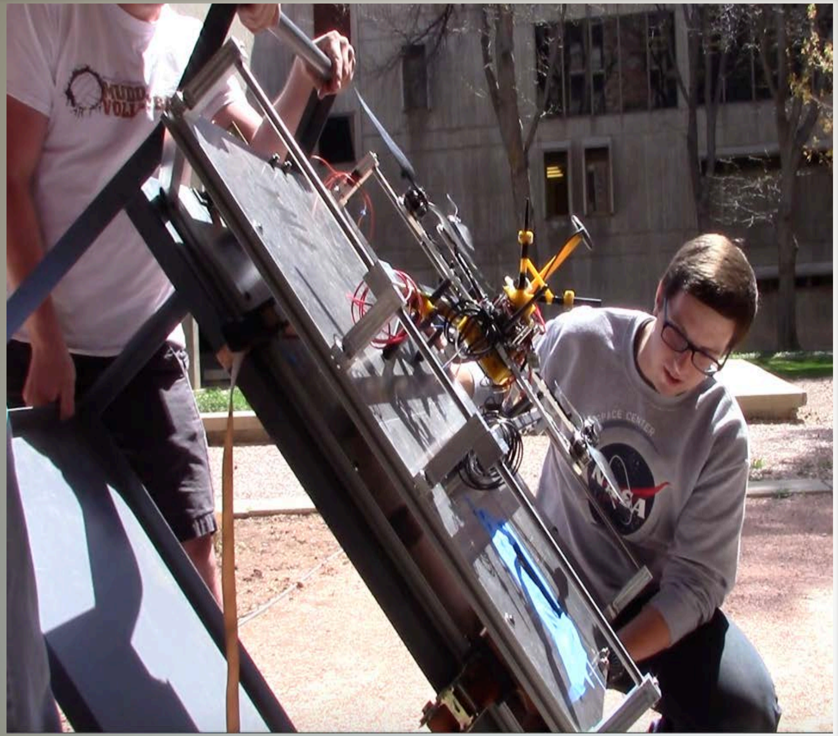
- Purpose: Ensure drone stays secured to platform over "rough terrain" specified in requirements

Requirement Verified	Description
FR 3.0 ✓	Platform secures the child drone
DR 3.1 ✓	Platform secures child drone under rough terrain specified in sample environment
DR 3.3 ✓	Platform secures the child drone upon command
DR 3.4 ✓	Platform releases the child drone upon command
DR 3.5 ✓	Platform secures the child drone at an angle of 3.5 degrees
FR 5.0 ✓	The platform shall communicate with the ground station at 500 m distance



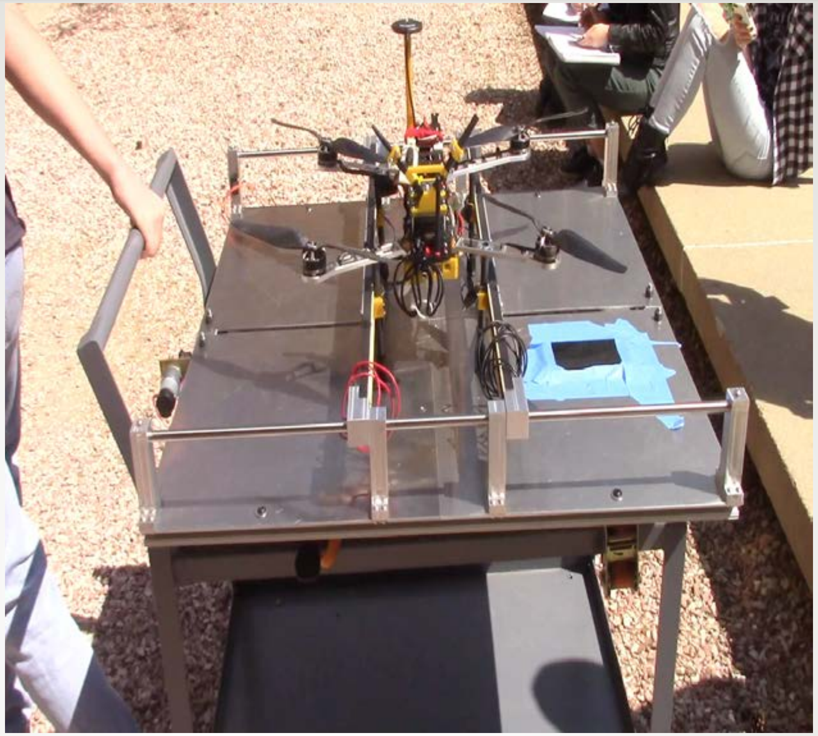
Securing Test Results

Tilt Testing



Requirement: 3.5 Degrees
Test: 50 Degrees
Confidence: 99%

Shock Testing



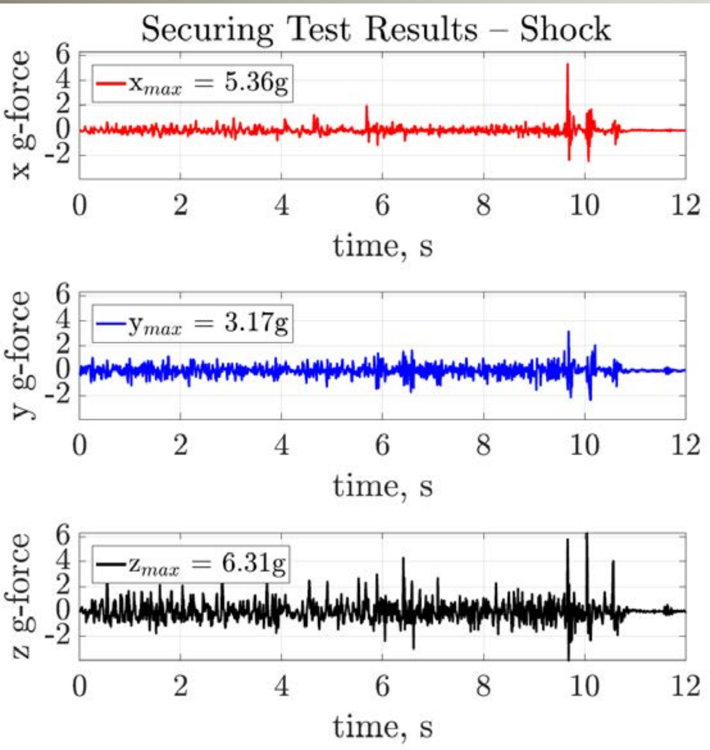
Test: 6.3g
Confidence: 99%

Vibration Testing

Test: 3.5g
Confidence: 99%

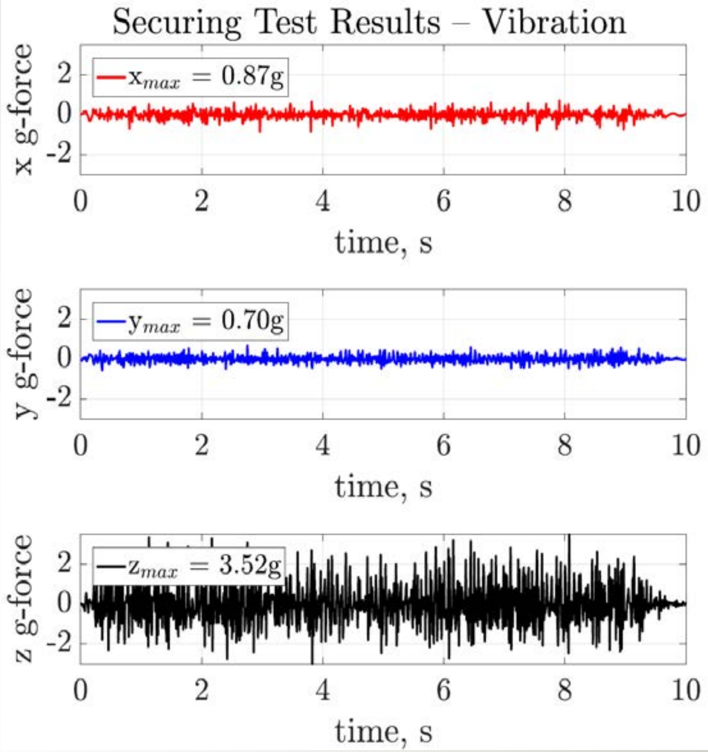
Securing Test Results

Shock Testing



Requirements:
Secure over rough terrain sample environment
Results:
Withstand shock load of 6.3 g
Rough Terrain:
Drop off 3 inch ledge, packed dirt and ½ inch gravel

Vibration Testing



Requirements:
Secure over rough terrain sample environment
Results:
Withstand sustained vibration load of 3.5 g
Rough Terrain:
Cobblestone

Levels of Success Securing

Level 1	Restricts child drone movement and does not allow tipping
Level 2	Secures child drone in sample rough terrain environment
Level 3	Securing system works at a distance of 500m (Communication link strong at 100 m, partial connection at 200 m.)

<u>Future Work:</u>

- Will raise antenna in order to determine if ground interference caused inter-connectivity
- Install a higher gain antenna on ground station and platform(Next Year)

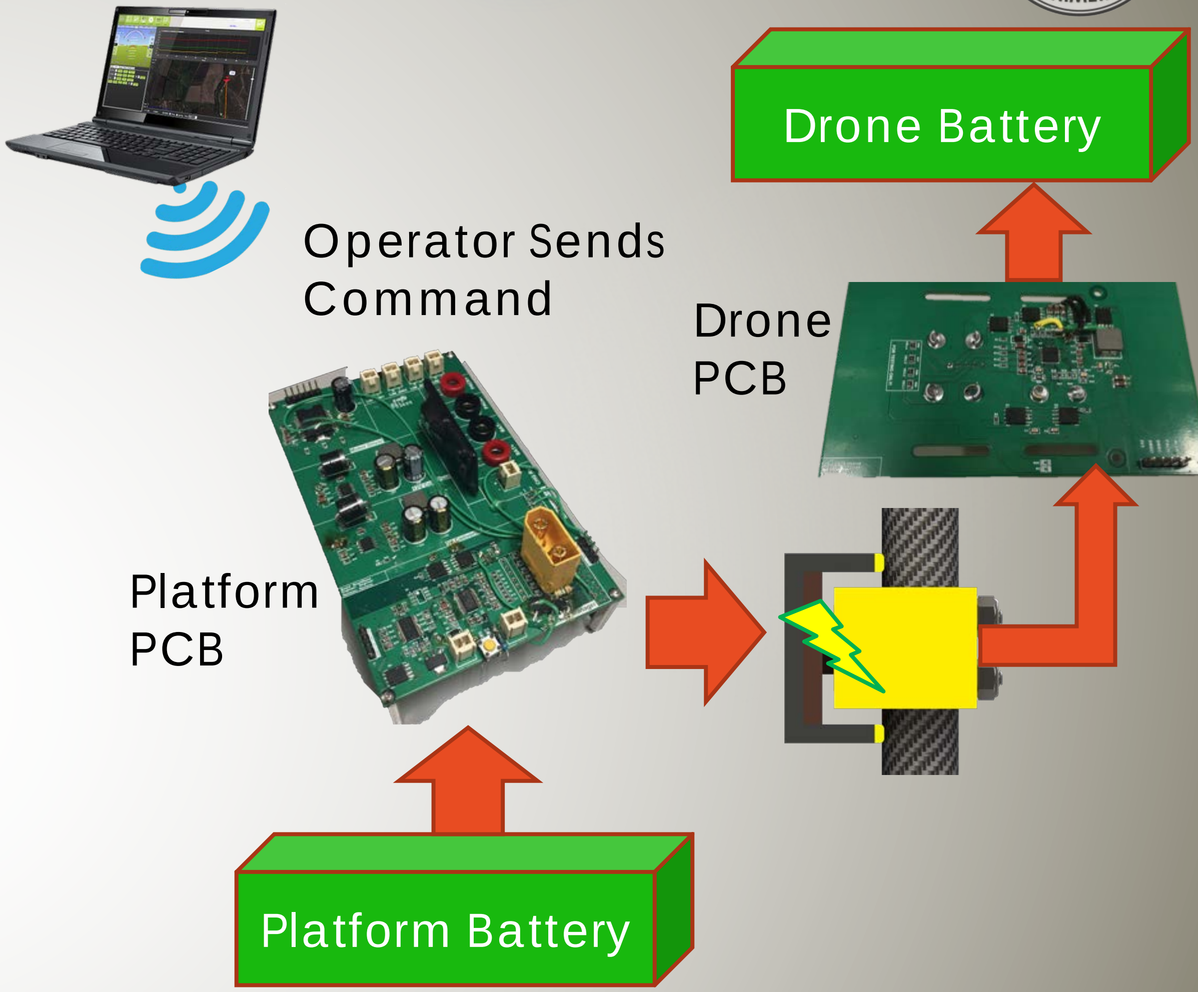
Legend

Full Success
Partial Success

Automatic Charging System

Automatic Recharging CONOPS

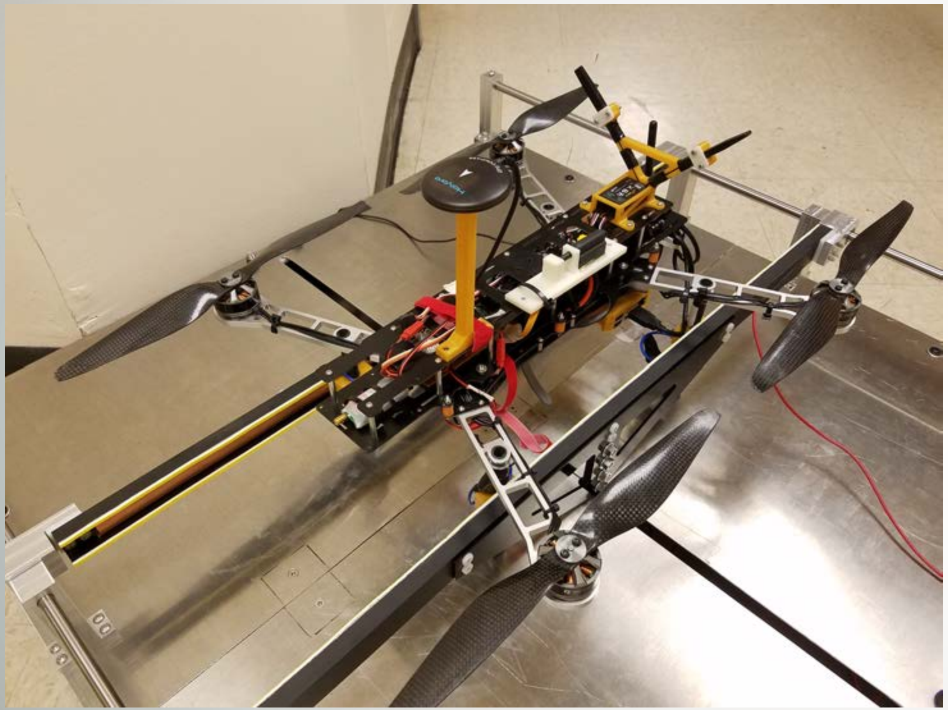
- Step 1: Securement is verified
- Step 2: Operator command sent to being charging
- Step 3: Platform PCB enables charging of C-channel
- Step 4: Drone PCB regulates power to drone battery



Child Drone Recharging

Recharge System Objective:

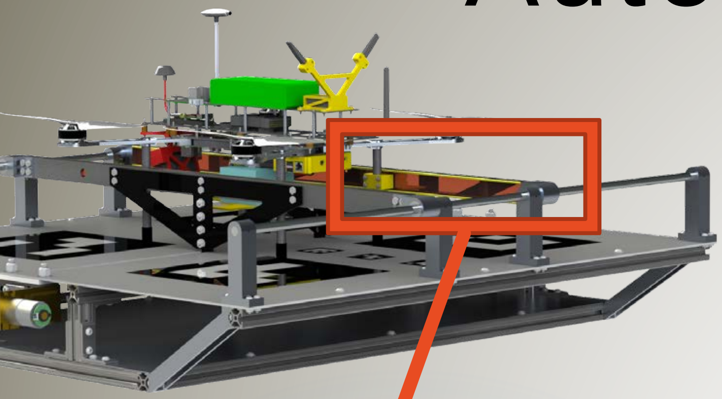
To provide additional power to the Child Drone battery after landing, creating the opportunity for multiple flights.



Solution:

- Custom child drone PCB
  - Battery manager
  - Balancing port
- Custom platform PCB
  - Battery manager
- 3D printed brackets with contact points on the child drone's landing gear
- Retractable copper plates on the platform which utilize the securing system

Automatic Recharging Design



Attribute	Value
Drone LiPo	4s1p 10 AH 1C
Drone Battery Manager	BQ40Z60
Platform LiPo	6s1p 10AH 1C
Platform Battery Manager	BQ78350

Electrical Attributes

Attribute	Value
Charging Levels	26 mV 215 mA
Added Mass to Child Drone	239 g
Output Commands	Amperage, Time

Physical Attributes

Automatic Charging Test Overview

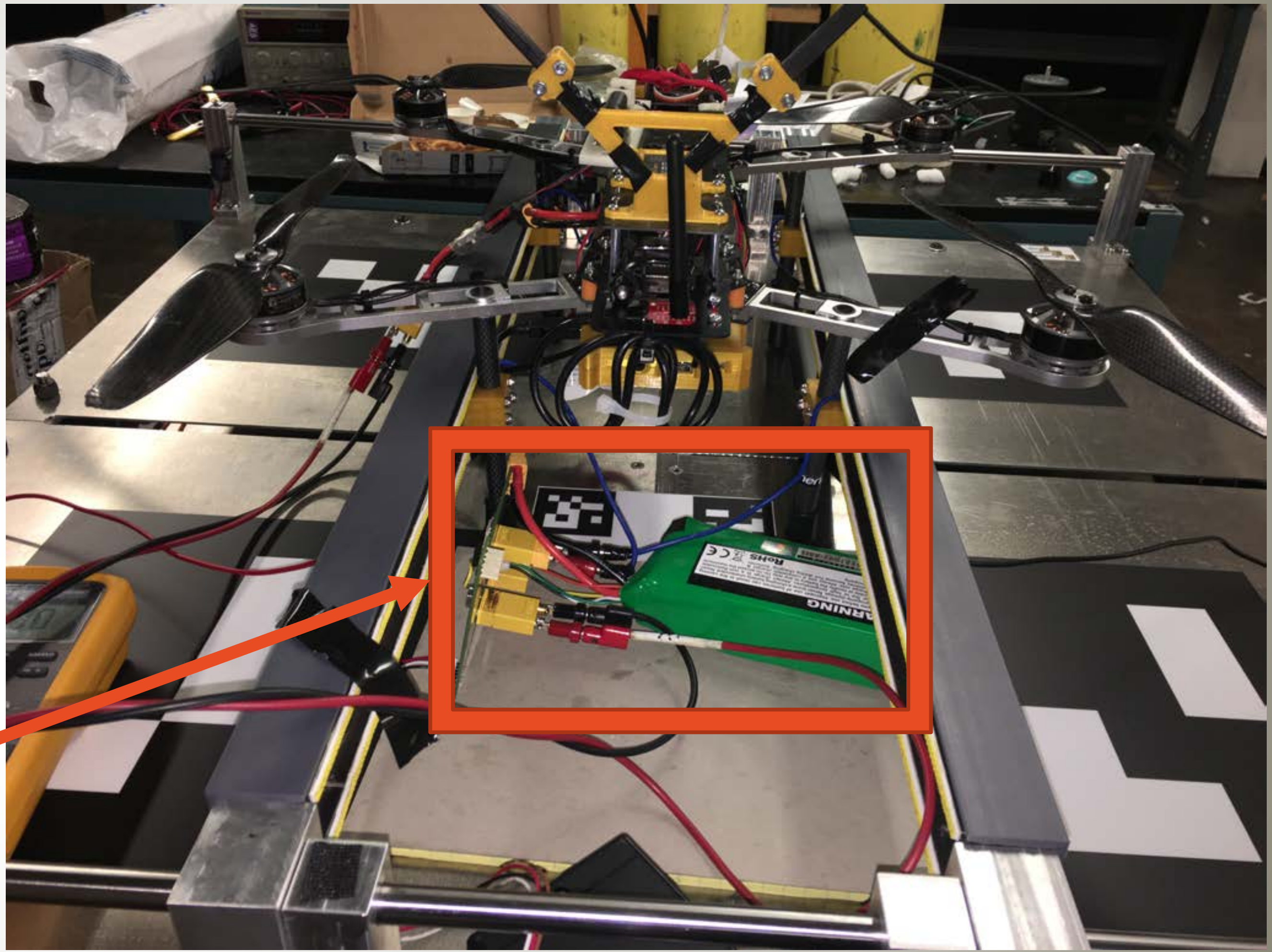
Step 1: Secure child drone

Step 2: Command automatic recharging from platform

Step 3: Monitor child drone battery health and status

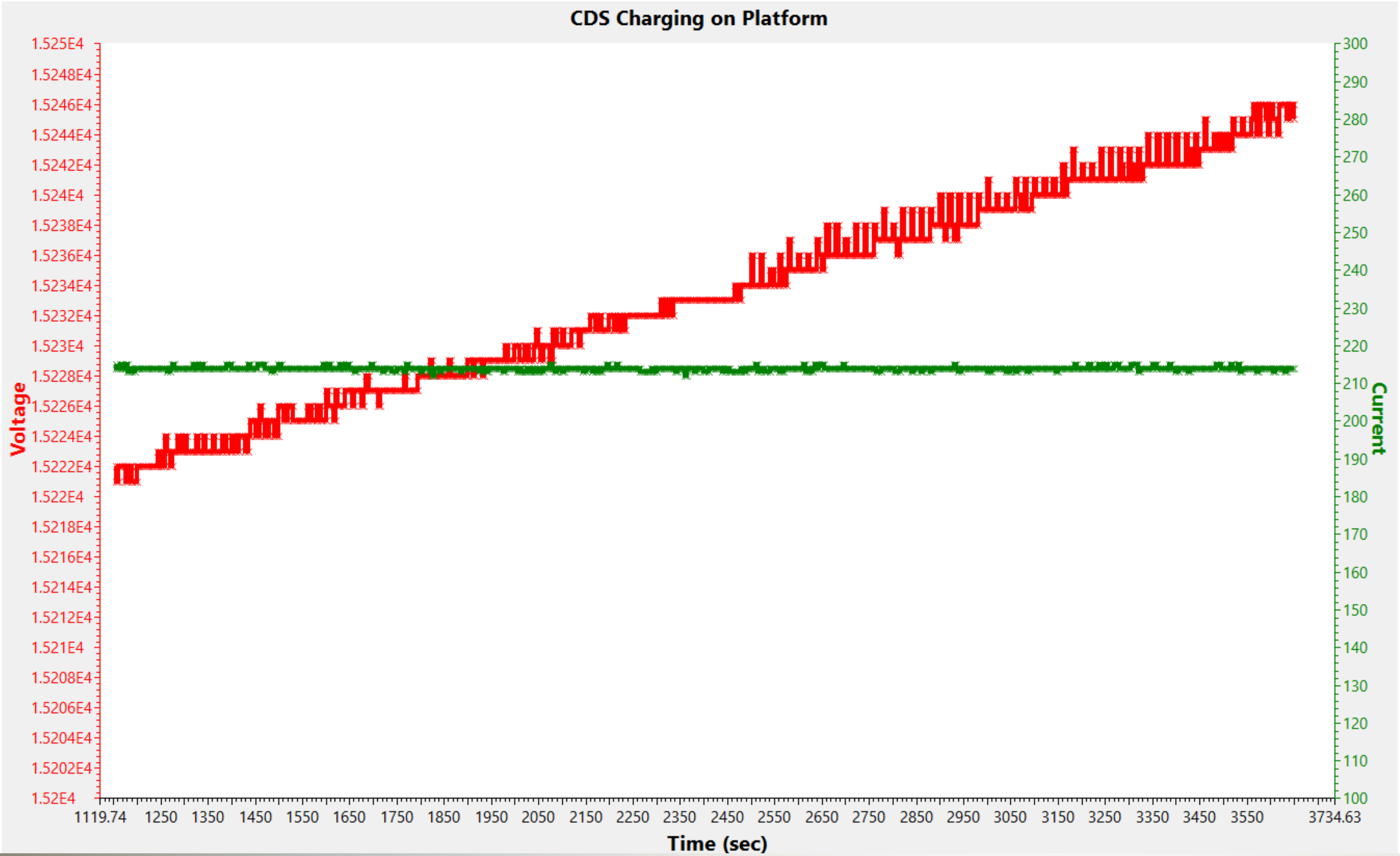
Step 4: Command off automatic charging

Child drone battery and PCB manager



Automatic Charging Test Results

Charging: No Applied Load



- Constant Current: ~215 mA
- Voltage Increase: 26 mV
- Time: ~ 40 min
- All requirements satisfied

Legend:

Current

Voltage

Levels of Success
Automatic Recharging

Level 1	Custom PCB components and safety features work
Level 2	Can charge LiPo with LiPo outside physical interfaces
Level 3	Full recharging system successful (Transferred power to drone)

Future Work:

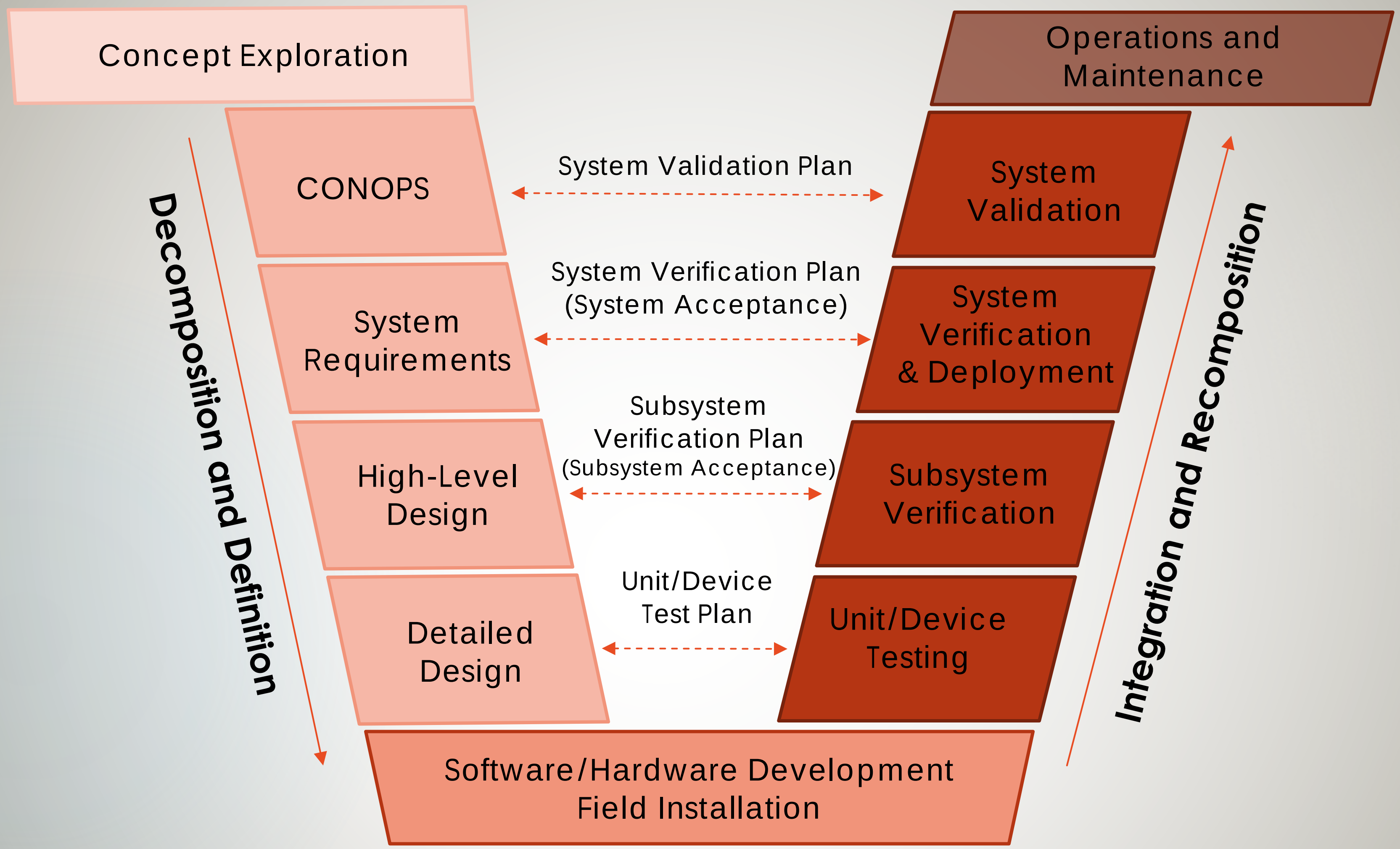
- Will raise antenna in order to determine if ground interference caused inter-connectivity
- Install a higher gain antenna on ground station and platform(Next Year)

Legend

Full Success
Partial Success

Systems Engineering

Systems Engineering V



Project Planning

Concept Exploration

CONOPS

System Requirements

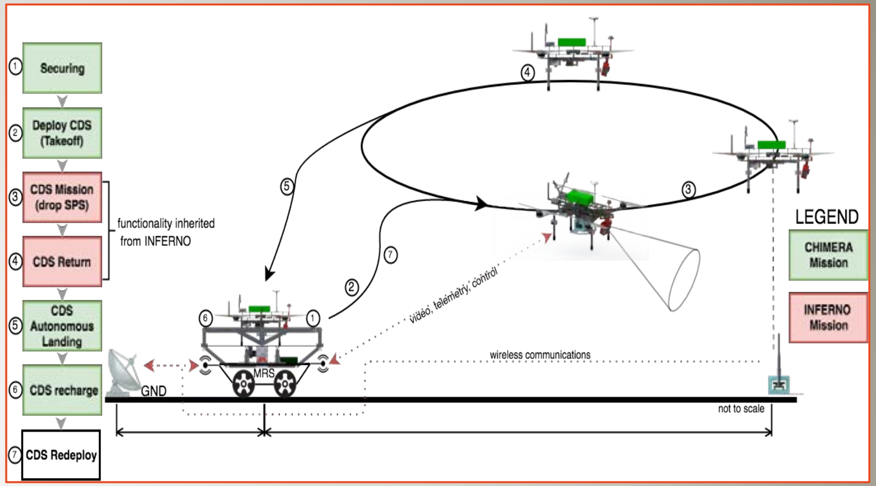
High-Level Design

Detailed Design

Decomposition and Definition

Overview

- CONOPS critical to project definition
- Clear Project Scope
- Requirements Development
  - Design choices
  - Trade spaces
  - Derived requirements



Challenges

- Defining project scope
- Writing verifiable requirements

Lessons Learned

- Time, money and personnel planning
- Scope Management
- Stakeholder input and concurrence

Project Implementation

Overview

- Software/ Hardware Development
- Manufacturing
- Verifying subsystem functionality
- Integration

Challenges

- Software Testing – Weather, Team member availability
- Pixhawk Control – Crashes, RPi communicating with Pixhawk
- Hardware breaking – PCB components breaking

Lessons Learned

- Have spares ordered ahead of time

Operations and Maintenance

System Validation

System Verification & Deployment

Subsystem Verification

Unit/Device Testing

Software/Hardware Development Field Installation

Integration and Recomposition

Risk Analysis

Severity

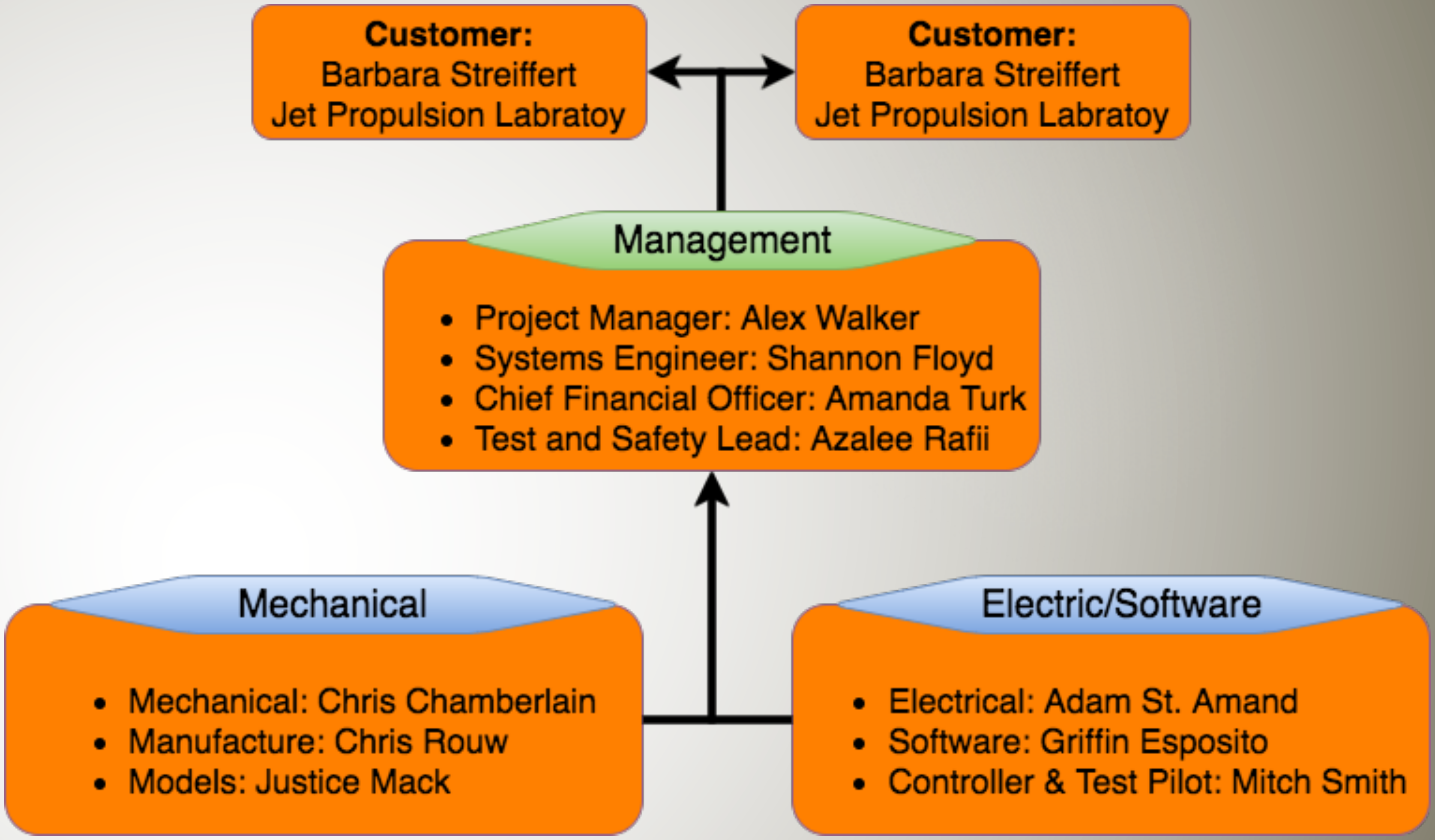
	1	2	3	4	5
5		(18)	(2)	(1)	
4		(9,12)	(3,8,19)		
3		(6,15)	(5,10,20,21) 4	(4,16,22)	
2		15, 20, 23,24	(17,24) 5, 10, 21, 22	(11) 8, 16	(7,23)
1		13, 14	(14) 6, 17	(13) 3, 9, 11, 12, 19	1, 2, 7, 18

Risk	Description	Solution
10	Child drone loses lock on platform	Search pattern/vibration isolators
11	Piloting error resulting in drone damage	Static testing and order replacements
15	Manufacturing errors in child drone charge bars	Electrically isolate charge bars
19	Platform doesn't fit in CNC machine	Cut into 4 pieces
20	Communication failure	Decrease distance
23	Inclement weather during testing	Multiple test windows

Project Management

Project Management Approach

- Management Approach
  - Three sub teams:
    - Management
    - Electrical & Software
    - Mechanical
  - Weekly Status Meetings
    - Allocate work
    - Tracking deadlines
  - Individual responsibility
    - Taking ownership



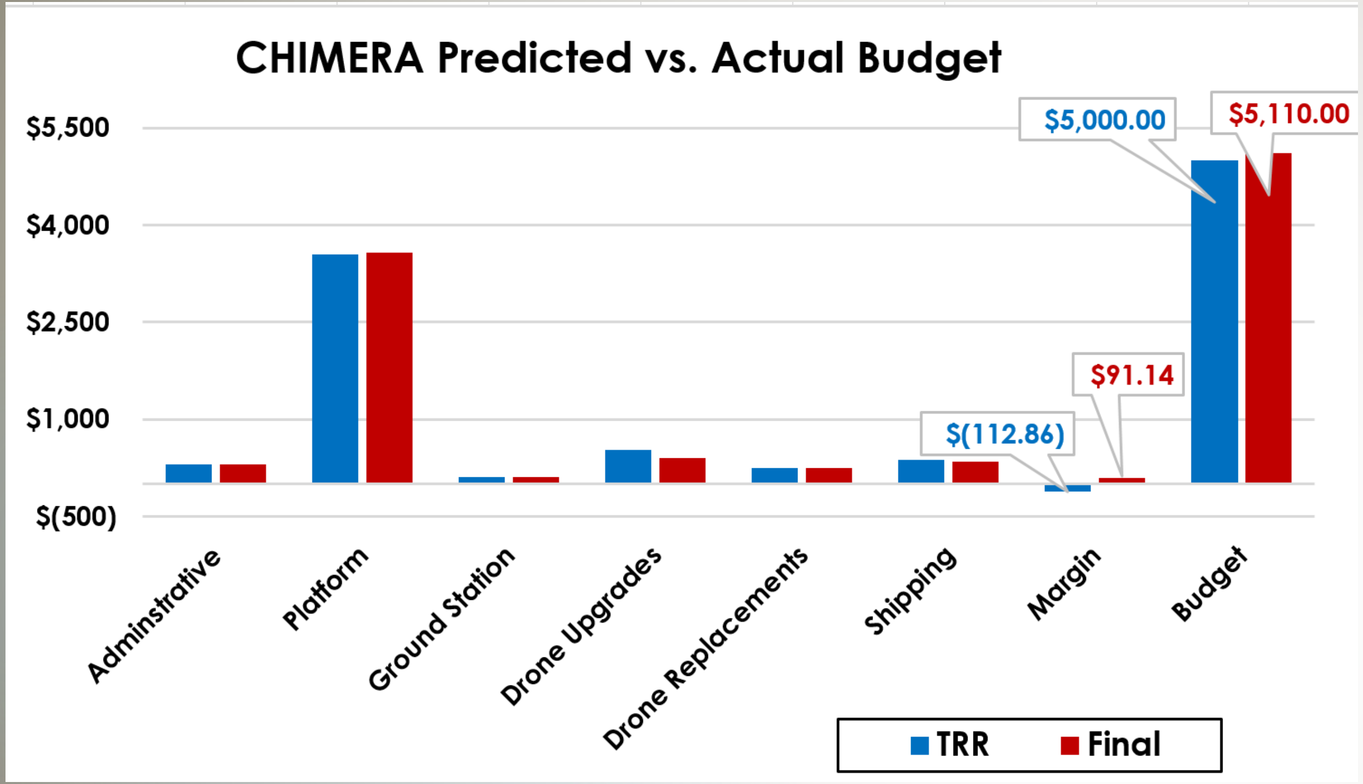
Project Management Success and Challenges

Success	Challenges
Finished work early to allow for PAB edits	Coordinating efforts across a team for large deliverables
Met all class deliverable deadlines – Start early	Agreeing on path forward Multiple solution options
Had fun along the way – Enjoy the journey	Was a long arduous year

Lessons Learned

- Autonomous Landing
  - Necessary to have multiple testing days
    - Weather
    - Dead batteries
    - Software glitches
  - Automatic Recharging
    - Order spare parts from the start
    - Acquire PAB help
  - Securing
    - Understand tolerances
    - Ordering vs. Making tradeoff

Budget Comparison



CHANGES FROM TRR

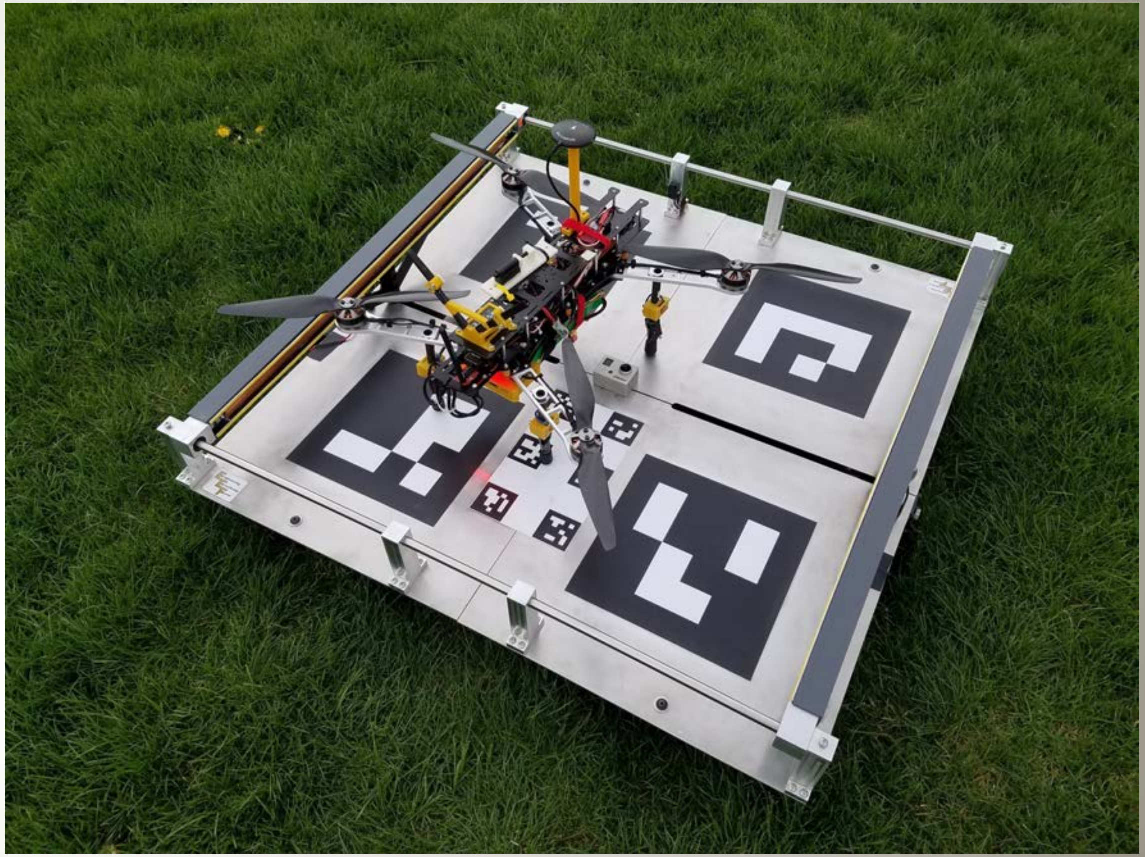
- EEF funding request accepted
- Did not need additional PCB revisions
- Unexpected costs incurred during charging bar integration
- $90 remaining for child drone spare parts

Industry Cost of Project

Item	Hours	Rate	Total Cost
Engineering Work	4712.5	$ 31.25/hour	$ 147,265.63
Project Materials	–	$ 5,110.00	$ 5,110.00
Table Mountain Flight Space Access	–	$ 5,000.00 for 1 year	$ 5,000.00
Drone Pilot	50	$ 40.00/hour	$ 2,000.00
		Subtotal	$ 159,375.63
Overhead	–	200% of subtotal	$ 318,751.28
		Total Cost	$ 478,126.89

Project Conclusion

- Full success for autonomous landing
- Partial success for securing
- Full success for automatic recharging
- Future work:
  - Additional trials for autonomous landing
  - Ground station to platform communication link improvement



REFERENCES

- First semester content.
- INFERNO Archive

Backup Slides - Subsystems

Decomposition and Definition

Concept Exploration

CONOPS

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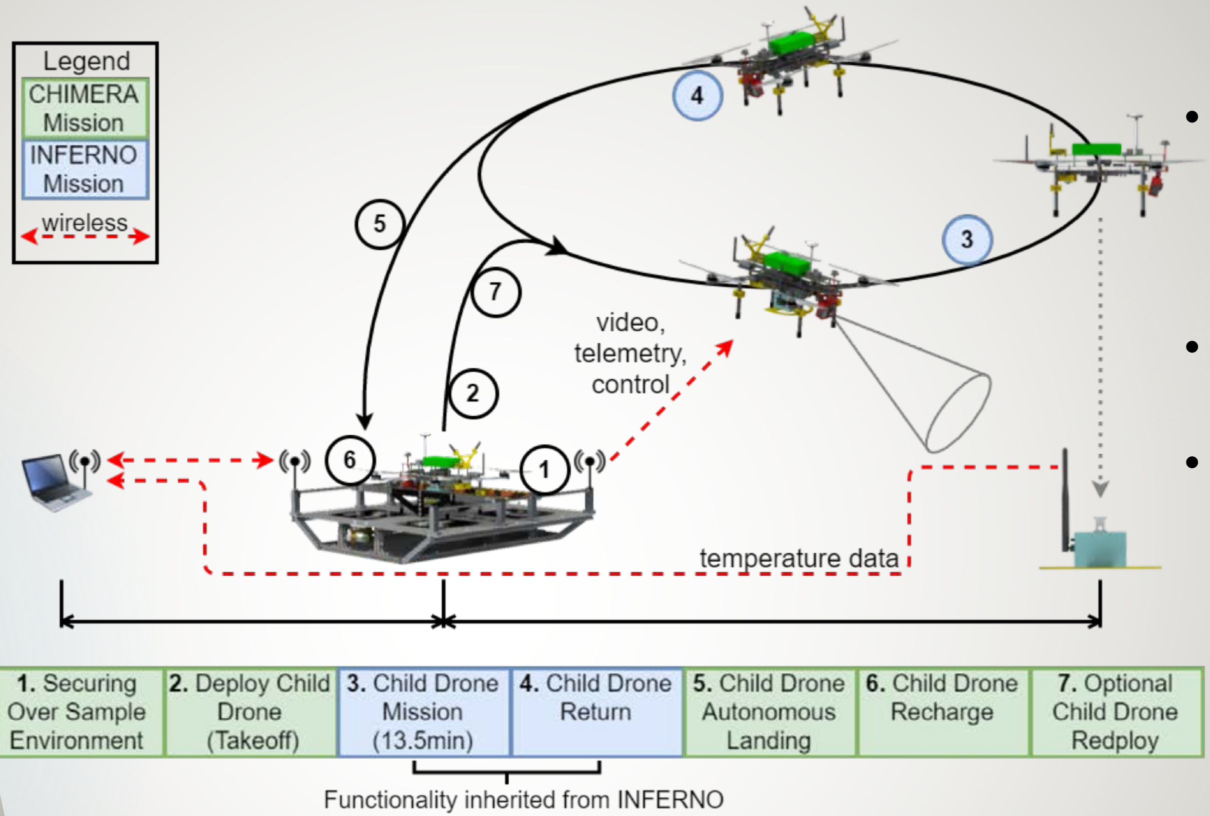
Detailed Design



Lessons Learned

- Manage team, customer and faculty expectations (watch for scope creep)
- Requirements flow from established CONOPS
- Clear project definition

Decomposition and Definition

Concept Exploration
CONOPS
System Requirements
High-Level Design
Detailed Design

System Requirements Development:

- Automatic charging expectations
- Operational Environments established
- Project constraints defined based upon previous year's project and this year's primary objectives
- Securing definitions: What defines a "secured" child drone?

Challenges:

- Managing customer/PAB expectations and Project Scope
- Writing verifiable requirements that guide project development
- Writing requirements that don't restrict the design space

Lessons Learned:

- Expect to make multiple revisions of the requirements
- Use the CONOPS to define what the project MUST accomplish and write requirements based on these tasks
- Don't write requirements that constrain design or add complexity

Decomposition and Definition

Concept Exploration

CONOPS

System Requirements

High-Level Design

Detailed Design

High-Level Design

Key Trade Studies:

Autonomous Landing:

1) Sonar – Highly complex, intensive algorithm development, questionable reliability
2) Image Recognition – Affordable, reliable, complex control problem, IR software available
3) Differential GPS – Poor accuracy, unreliable in remote coverage areas, simple to execute
4) Lidar – Complex for object detection, expensive, time-intensive image processing required

Auto Charging:

1) Conductive – Inexpensive, needs high landing accuracy, hardware easily mounted
2) Electromagnetic Induction – Expensive, cumbersome, inefficient

Challenges:

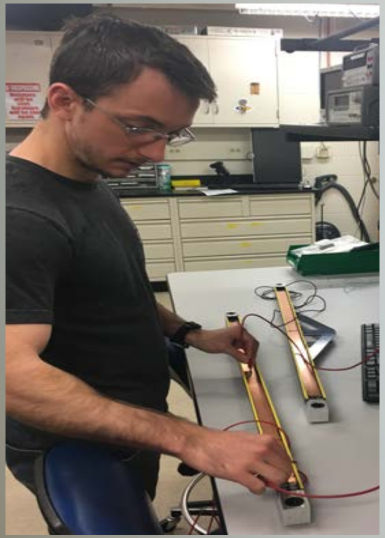
- Minimize added weight to INFERNO
- IR pattern wash-out in sunlight
- LiPo to LiPo Battery Charging
- Interfacing with the Pixhawk

Lessons Learned:

- Don't "over-design" and create unnecessary additional work
- Manage team and customer expectations, especially when they conflict
- Choose design solutions that allow for budget and time constraints

Software/Hardware Development

System Development:
- Clear communication between sub-system teams is a must
- Well-developed integration plan is helpful to ensure component manufacturing is completed on schedule
- Schedule margin allows for last-minute hardware modifications (charging bar copper trimming and nylon bolt install)



Challenges:
- Pixhawk/Rasp. Pi Communication
- PCB testing with LiPo transient effects/unknown risks
- Unexpected INFERNO flight anomalies (eg: GPS issues indoors, drift)
- Safely testing with LiPo batteries
- Charging hardware continuity issues
- Ball-screw system binding

Lessons Learned:
- Tethered/static test flights are a good idea when testing new software
- Ample time margin is key during testing of hardware and software
- Budget extra funds for spare parts – development can be (unintentionally) destructive
- Check twice, glue ONCE!

Operations and Maintenance

System Validation

System Verification & Deployment

Subsystem Verification

Unit/Device Testing

Software/Hardware Development Field Installation

Integration and Recomposition

Unit/Device Testing:

- Flight testing
  - IRS Software
  - IRS/Rasp. Pi Communication
  - Pixhawk Commanding
  - Whole landing sequence
- Charging
  - Battery managers
  - PCB functionality (individual)
- Securing
  - Motor functionality
  - Ball-screw system
  - PCB integration
  - Limit switches
- Communication
  - Xbee short-range testing
  - Xbee long-range testing

Challenges:

- Fried PCB components when LiPos were attached
- GPS/Compass calibration errors during flight testing
- Ball-screw binding during securing
- Xbee antenna issues over desired range

Lessons Learned:

- Budget for spare parts
- Budget extra time to troubleshoot unexpected issues
- Develop a well-formulated test plan to maximize team and hardware resources
- Document all unit tests thoroughly for future reference

Operations and Maintenance

System Validation

System Verification & Deployment

Subsystem Verification

Unit/Device Testing

Software/Hardware Development Field Installation

Integration and Recomposition

Subsystem & System Verification:

- Verified securing system functionality
- Verified Communication functionality at short range distances
- Verified autonomous landing functionality upon command from ground station
- Verified charging system can charge the CDS LiPo battery upon command

Challenges:

- Long-range Xbee commanding of the platform securing system over 200m
- Loss of lock on AR tag pattern at about 12 in (?) above platform surface
- Slugging command rates to the Pixhawk from IR software

Lessons Learned:

- Efficient team resource management prevents wasted time in the lab
- Develop test plan with contingency and margin to account for unforeseen issues

Operations and Maintenance

System Validation

System Verification & Deployment

Subsystem Verification

Unit/Device Testing

Software/Hardware Development Field Installation

Integration and Recomposition

Full System Validation:

- Autonomous landing completed
  - Command sent from ground station from 500m
  - INFERNO landed on platform
- Securing system
  - Secured INFERNO under defined environmental conditions
  - Secured upon command from 200m
- Charging system
  - Charged INFERNO LiPo upon command
  - All platform charging circuitry performed as expected
- Communication system
  - Telemetry received at 500m distance
  - Difficulties with commanding from 500m

Risk	Mitigated	Occurred
LiPo damage causing fire	✖	
High current draw through copper plates	✖	
Landing yaw error prevents charging	✖	
Raspberry Pi loses comm w/ Pixhawk during flight		✖
Platform doesn't fit into CNC machine		✖

Operations and Maintenance

System Validation

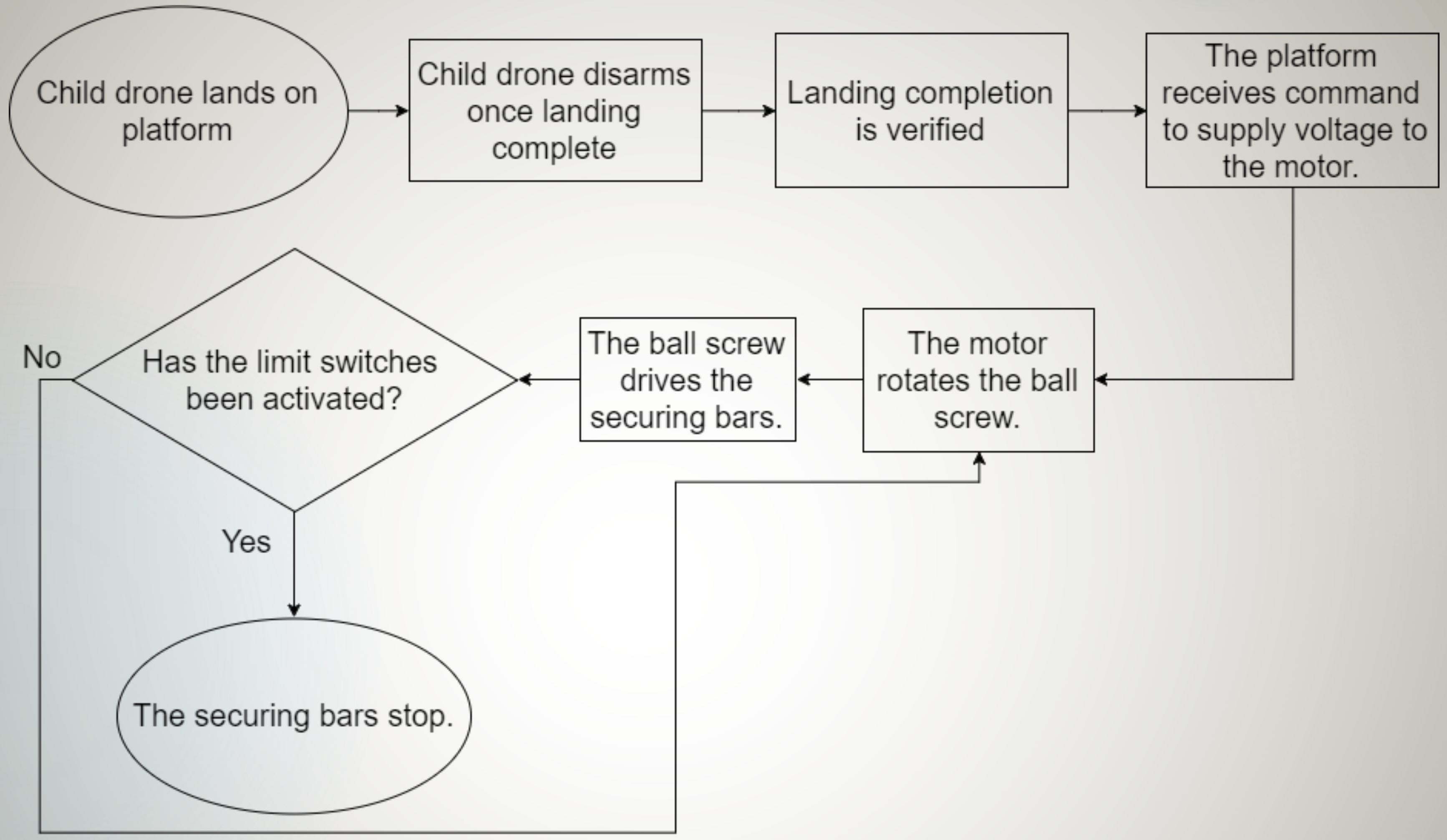
System Verification & Deployment

Subsystem Verification

Unit/Device Testing

Software/Hardware Development Field Installation

Securing Subsystem Flowchart

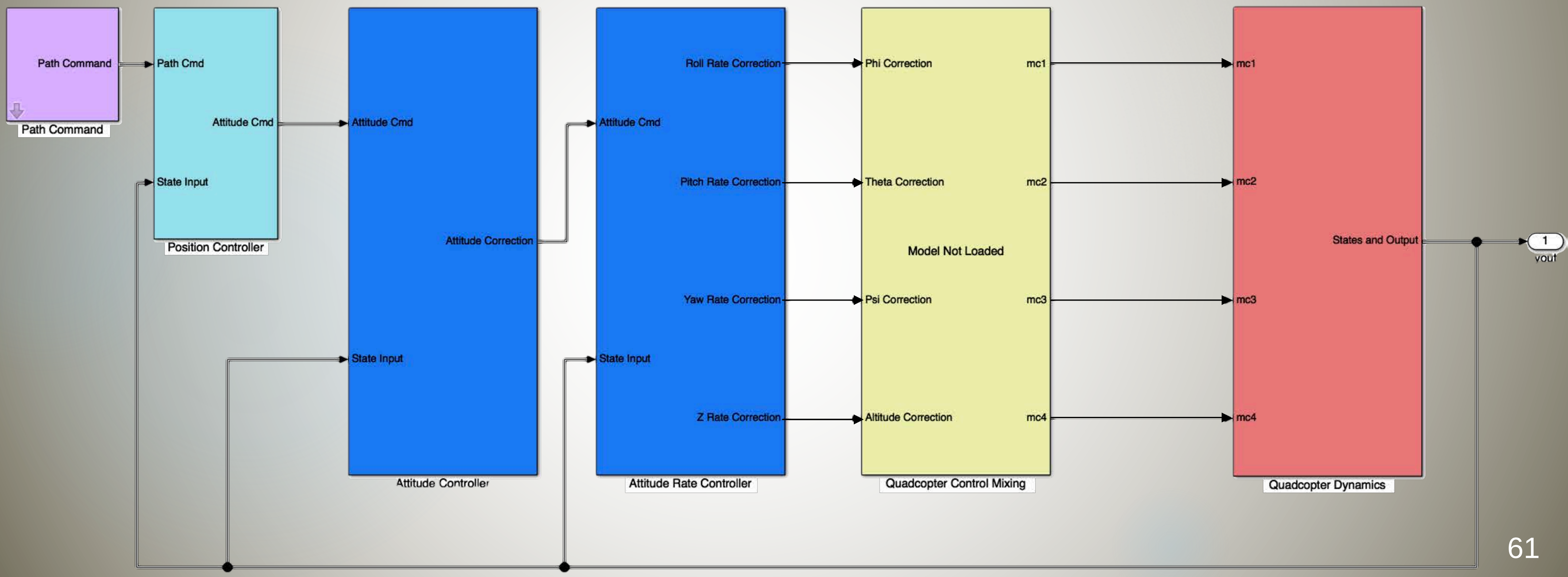


Backup Slides – Flight Simulator Backup

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



BACK UP SLIDES – SUBSYSTEM TESTS

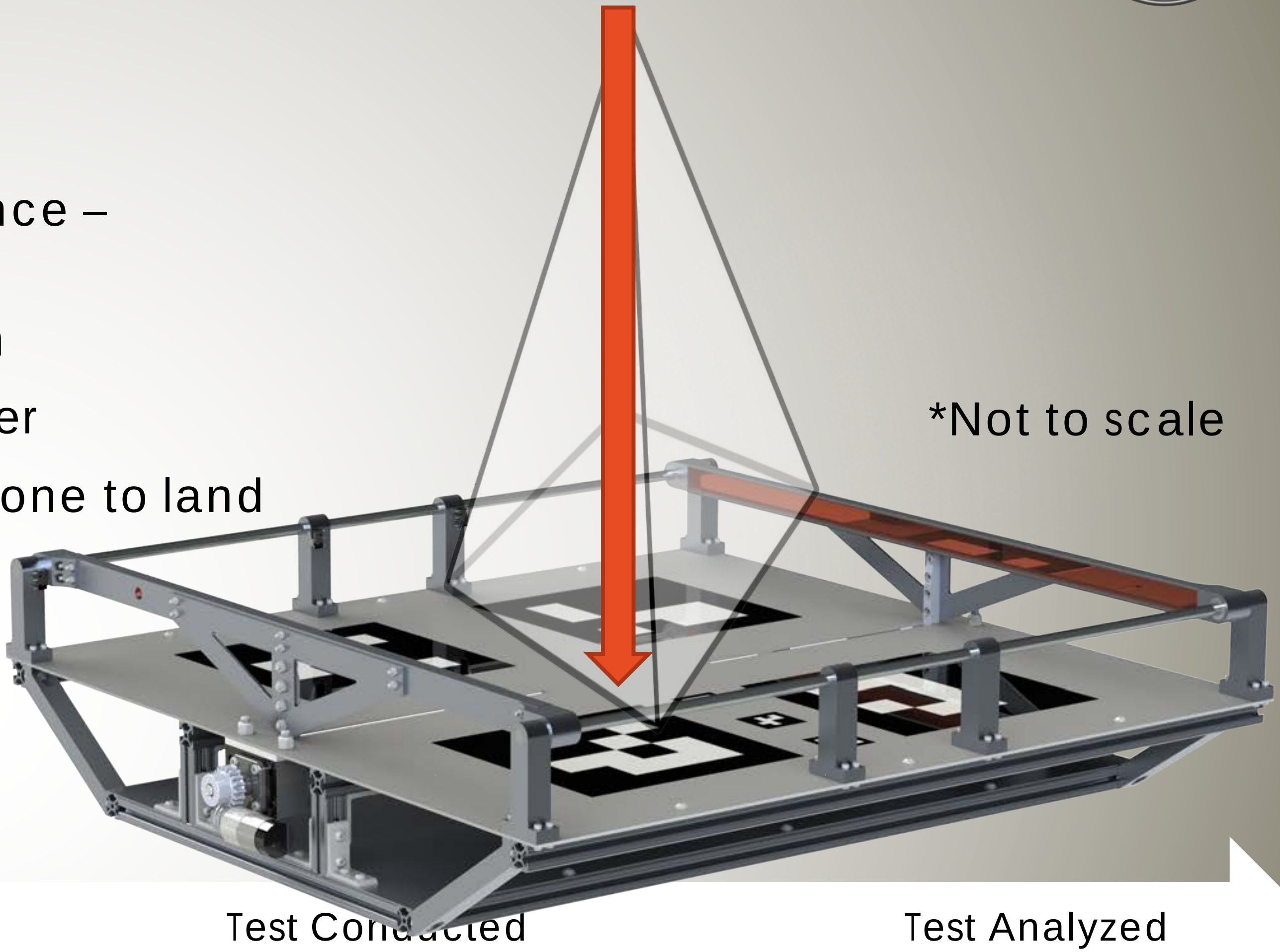
Landing Subsystem Test - Motivation

- 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



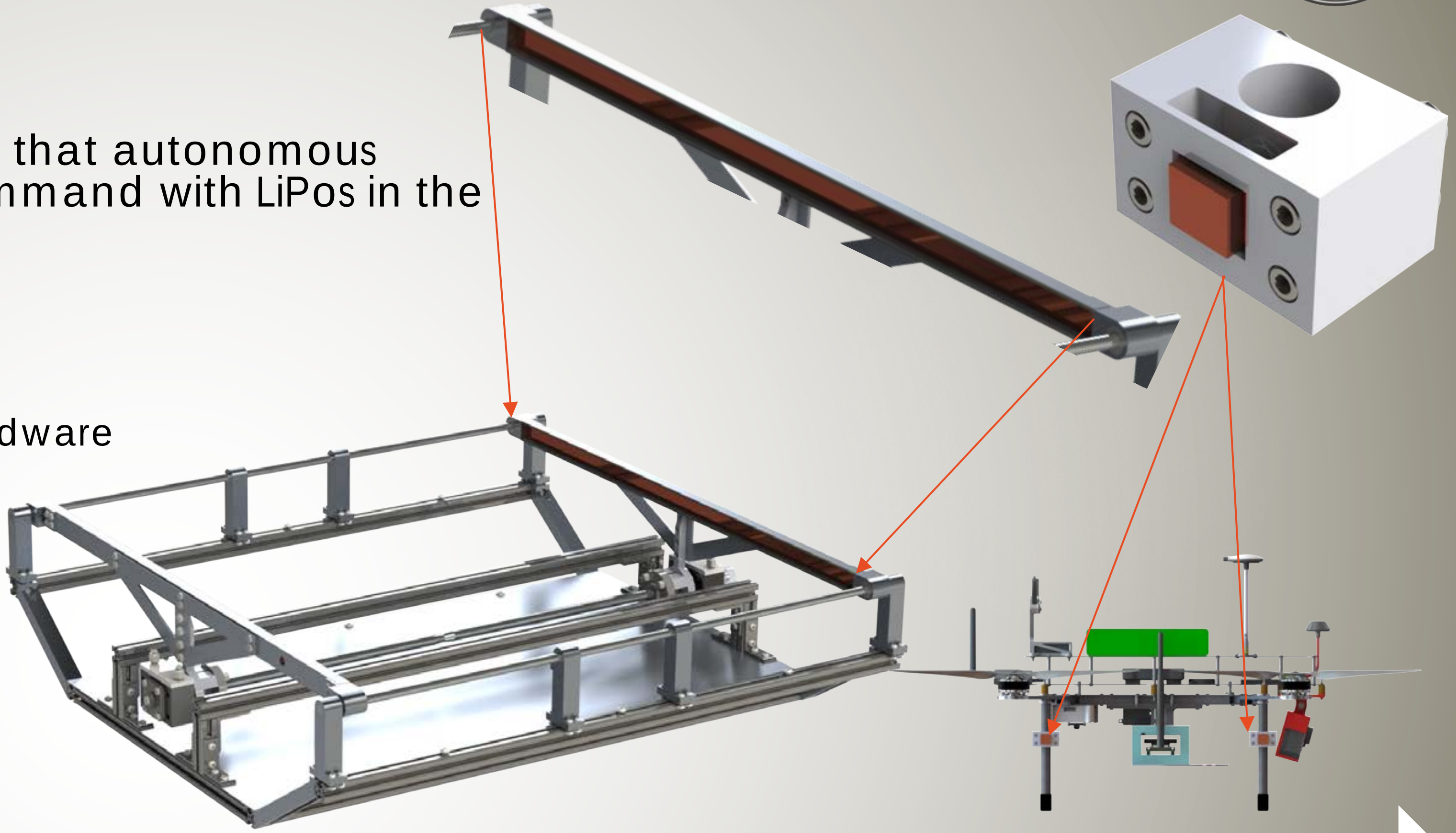
*Not to scale

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

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

Charging Subsystem Test - Motivation

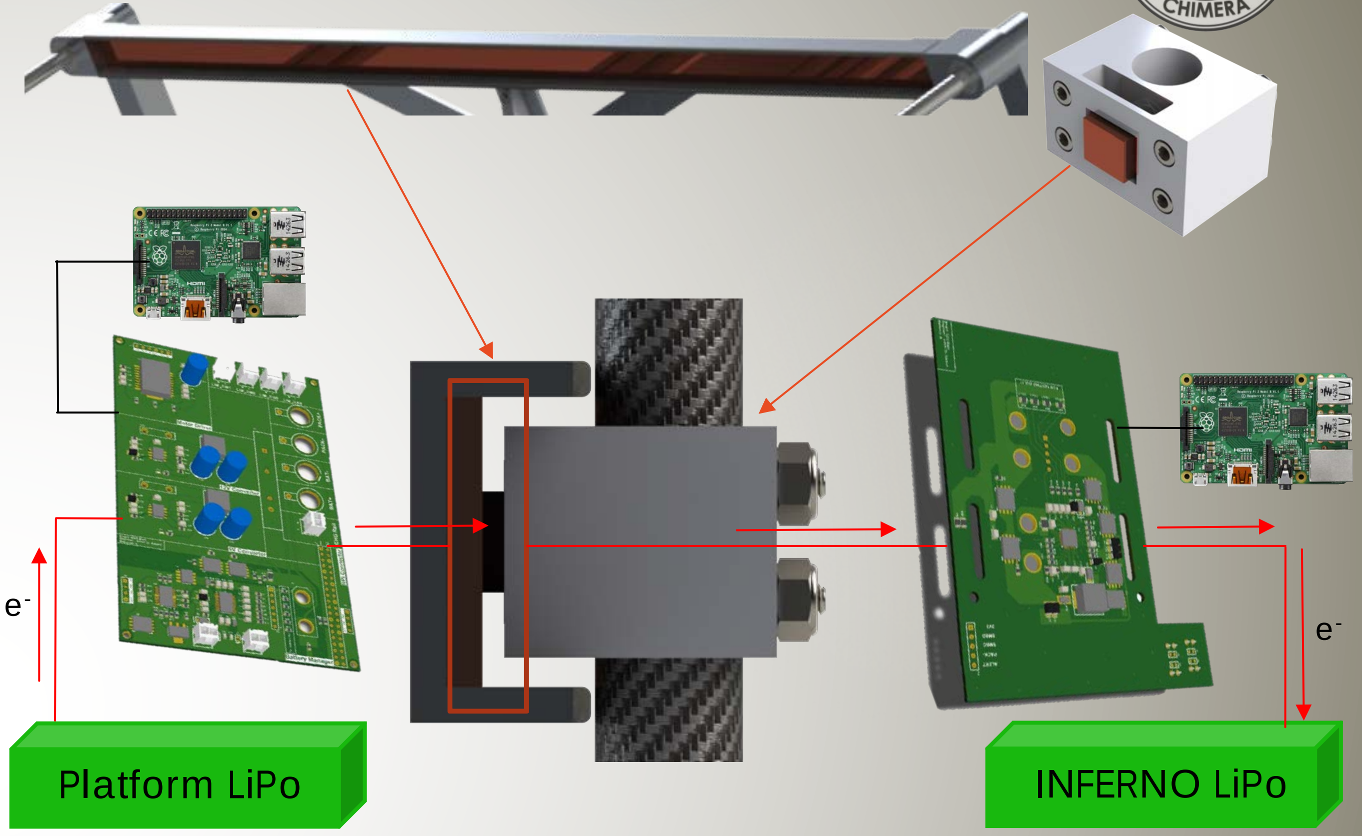
- Requirements Verified:
  - FR 2.0, DR 2.1, DR 2.1.1, DR 2.2, DR 2.3
- Motivation: Full Sub-system test to verify that autonomous charging can be completed upon command with LiPos in the loop
- Component testing in progress
- Equipment:
  - All CHIMERA platform and charging hardware
  - INFERNO Analog
  - 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

Budget Back Up

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

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

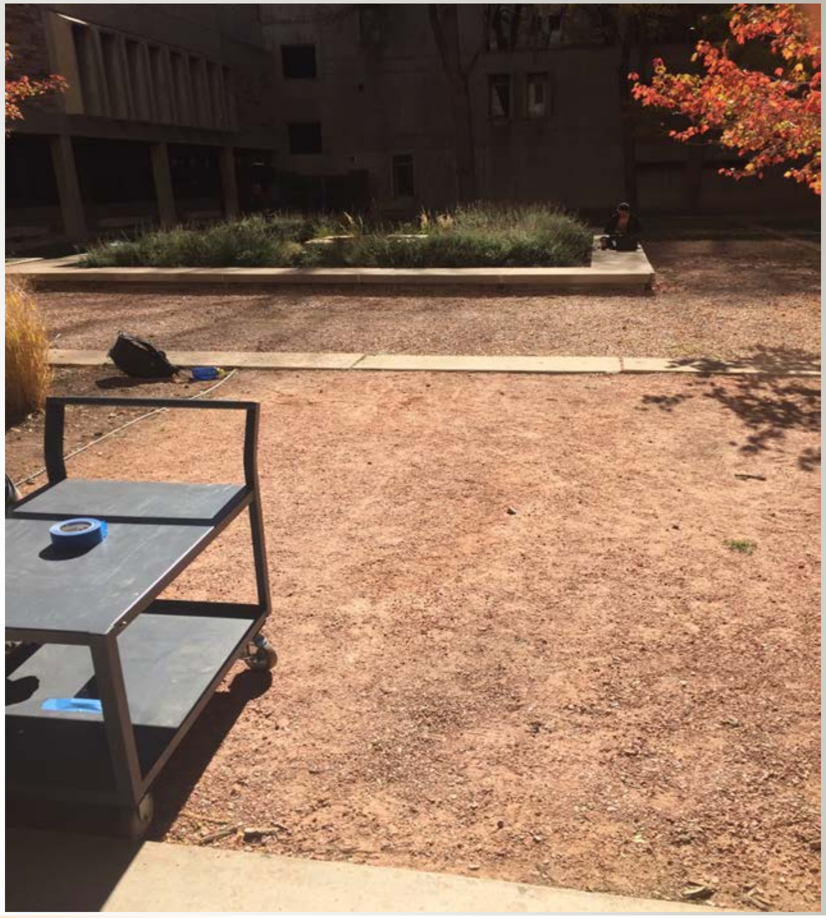
Hard Rubber Castor Wheels

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

Project Overview | Schedule | Budget | Testing | Conclusion

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

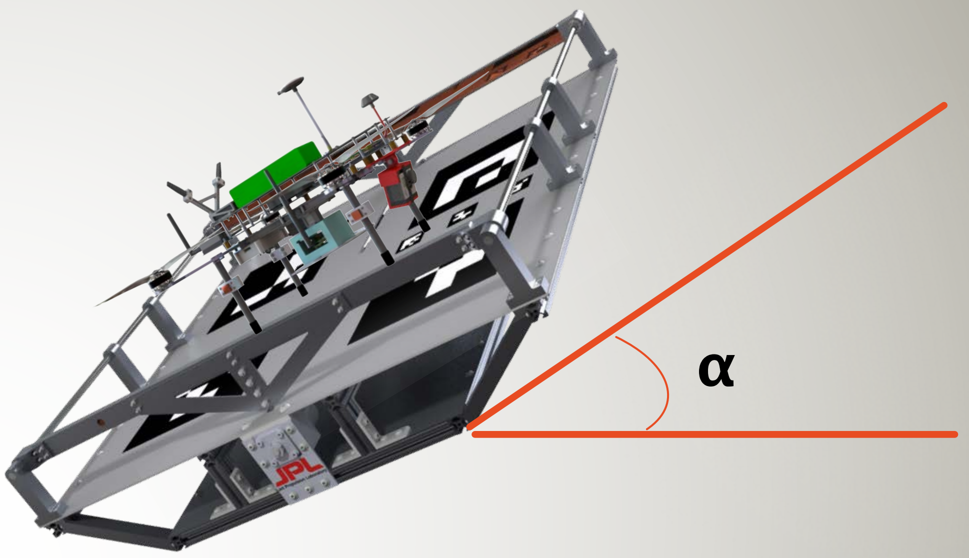


Shock Event Courtyard

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

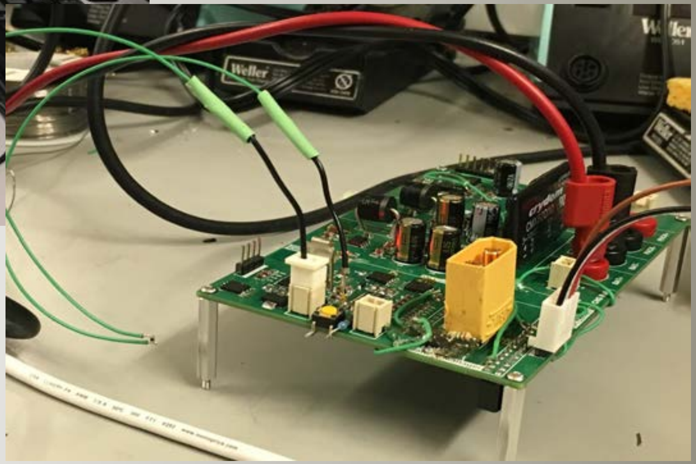
Test Plan Created → Test Scheduled → Test Conducted → Test Analyzed

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

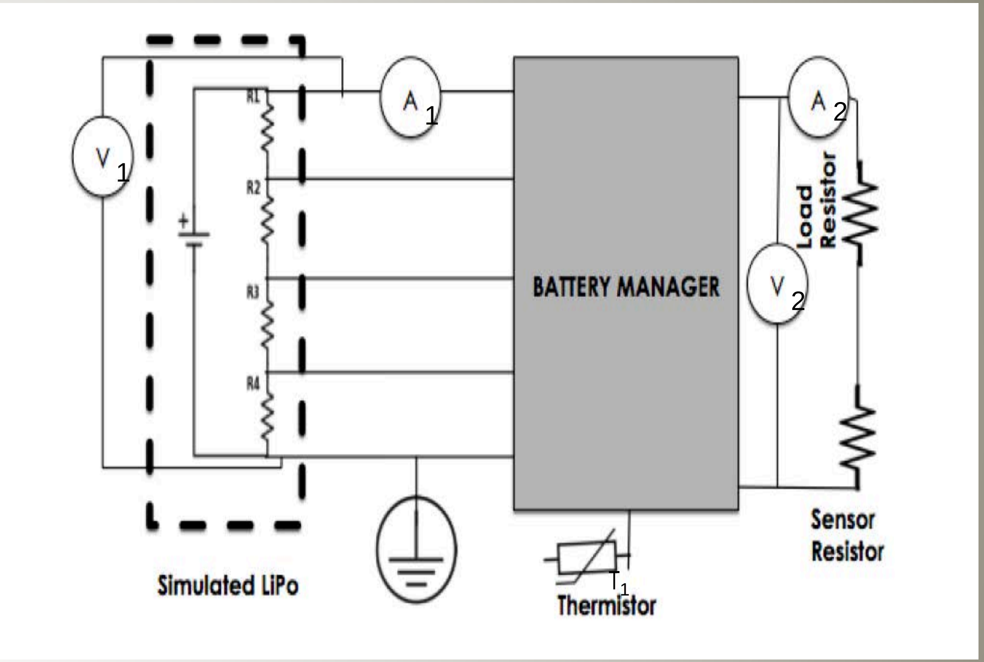
Platform PCB



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.

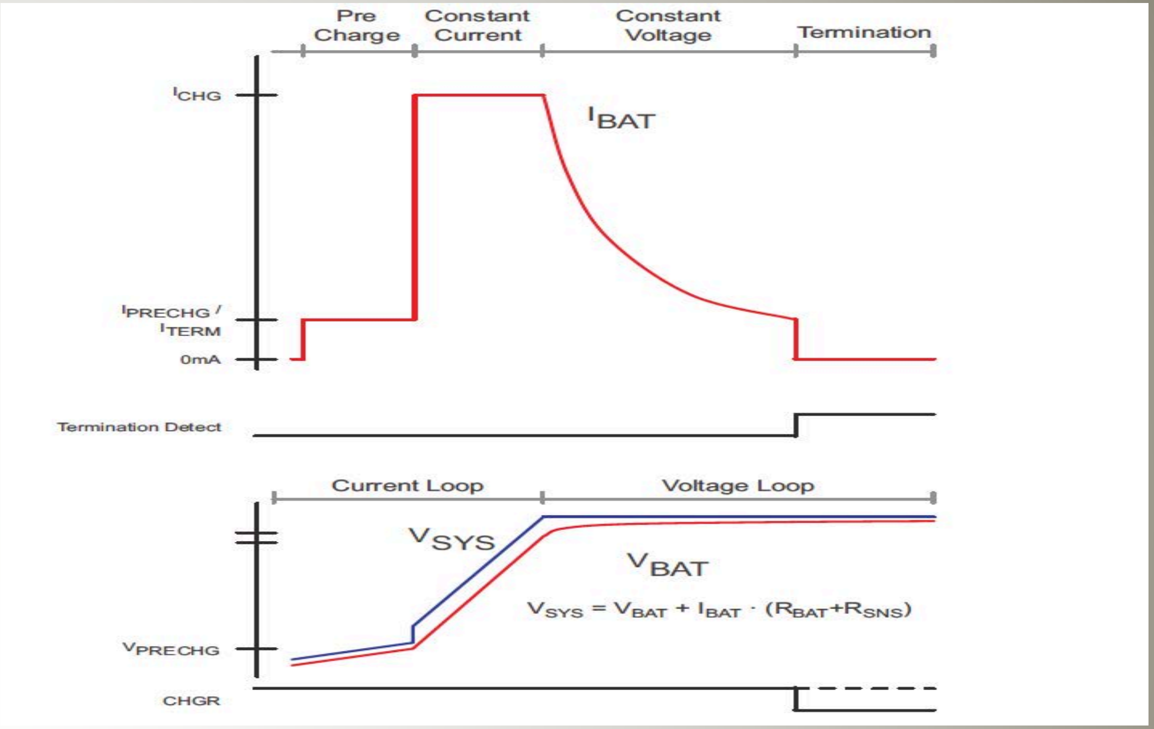


Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

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



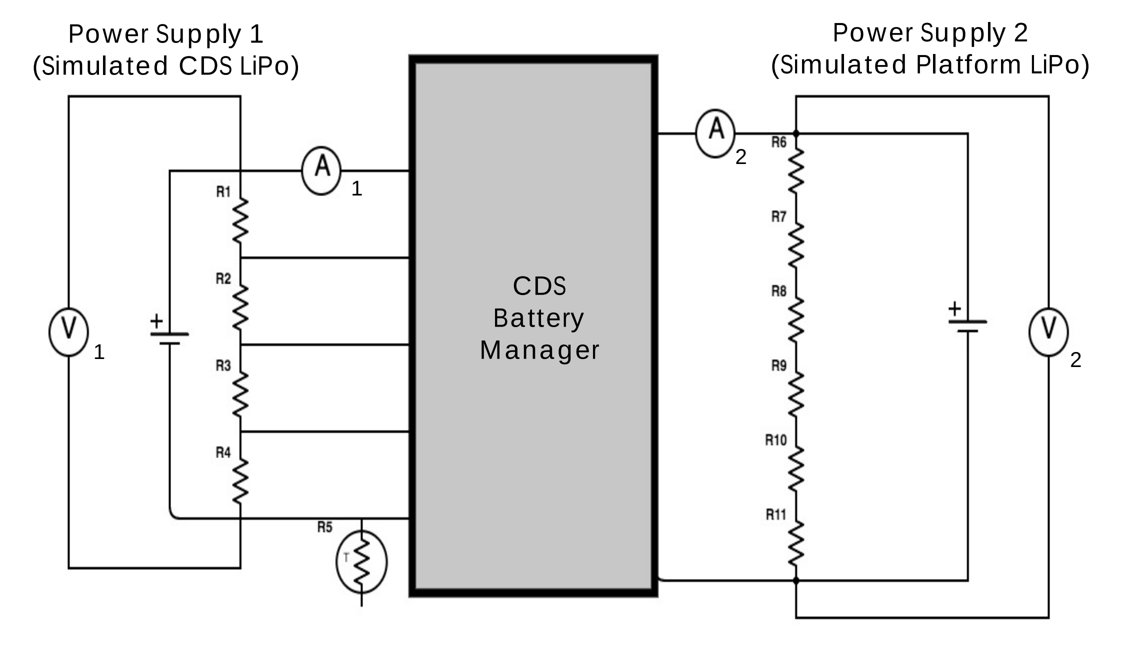
Expected Charge Profile

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

Project Overview | Schedule | Budget | Testing | Conclusion

CDS PCB Charging Test - Procedures

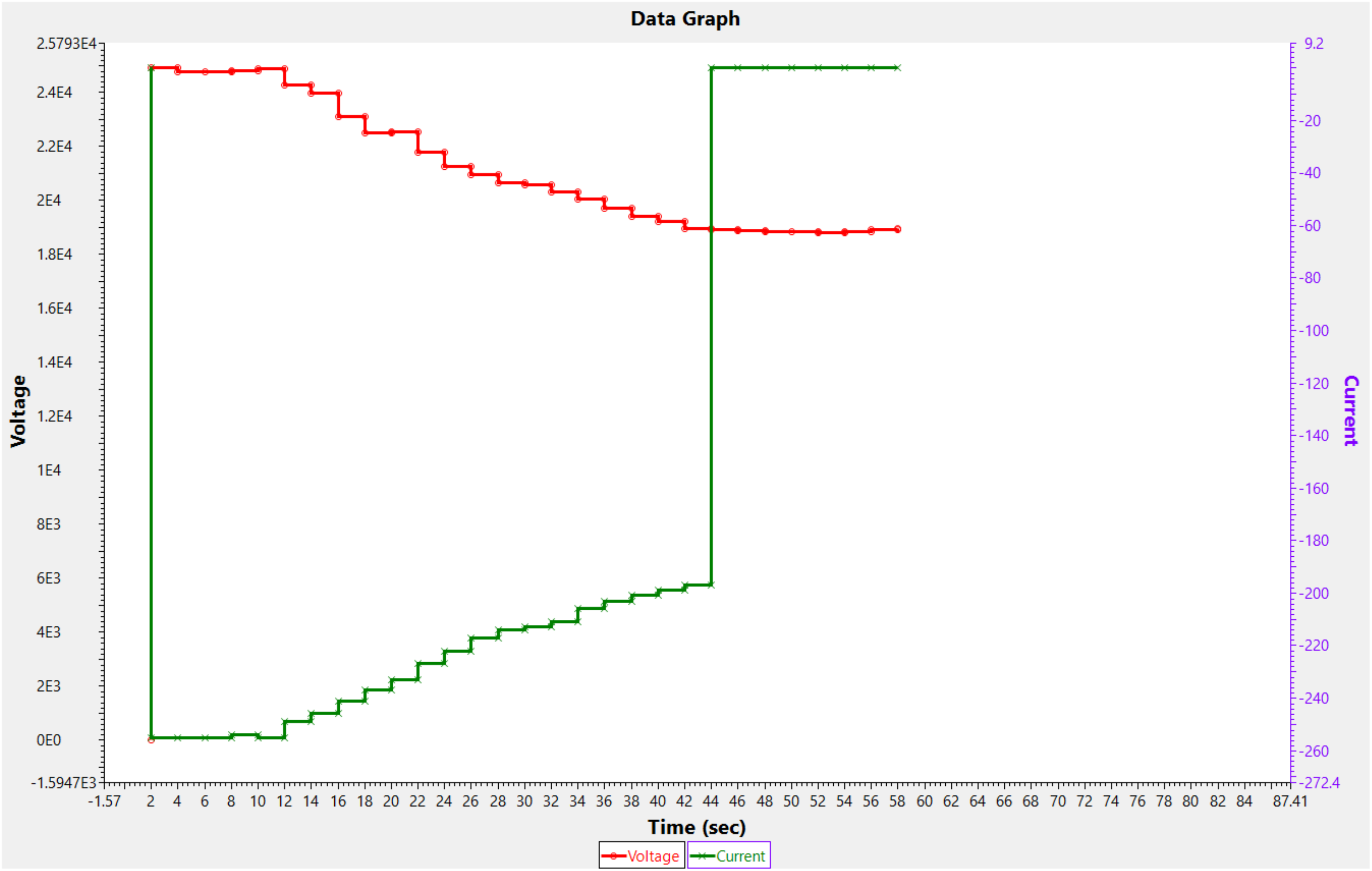
- 10 Trials
- Procedure:
  - Connect CDS PCB to two power supplies
  - Increase voltage on PS 1 incrementally up to max voltage of battery (16.8V)
  - Observe current reduction on PS 2 as max voltage on PS 1 is achieved
- Measurements Taken:
  - V_1, A_1, V_2, A_2, Charge Profile
- Related Models: ???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



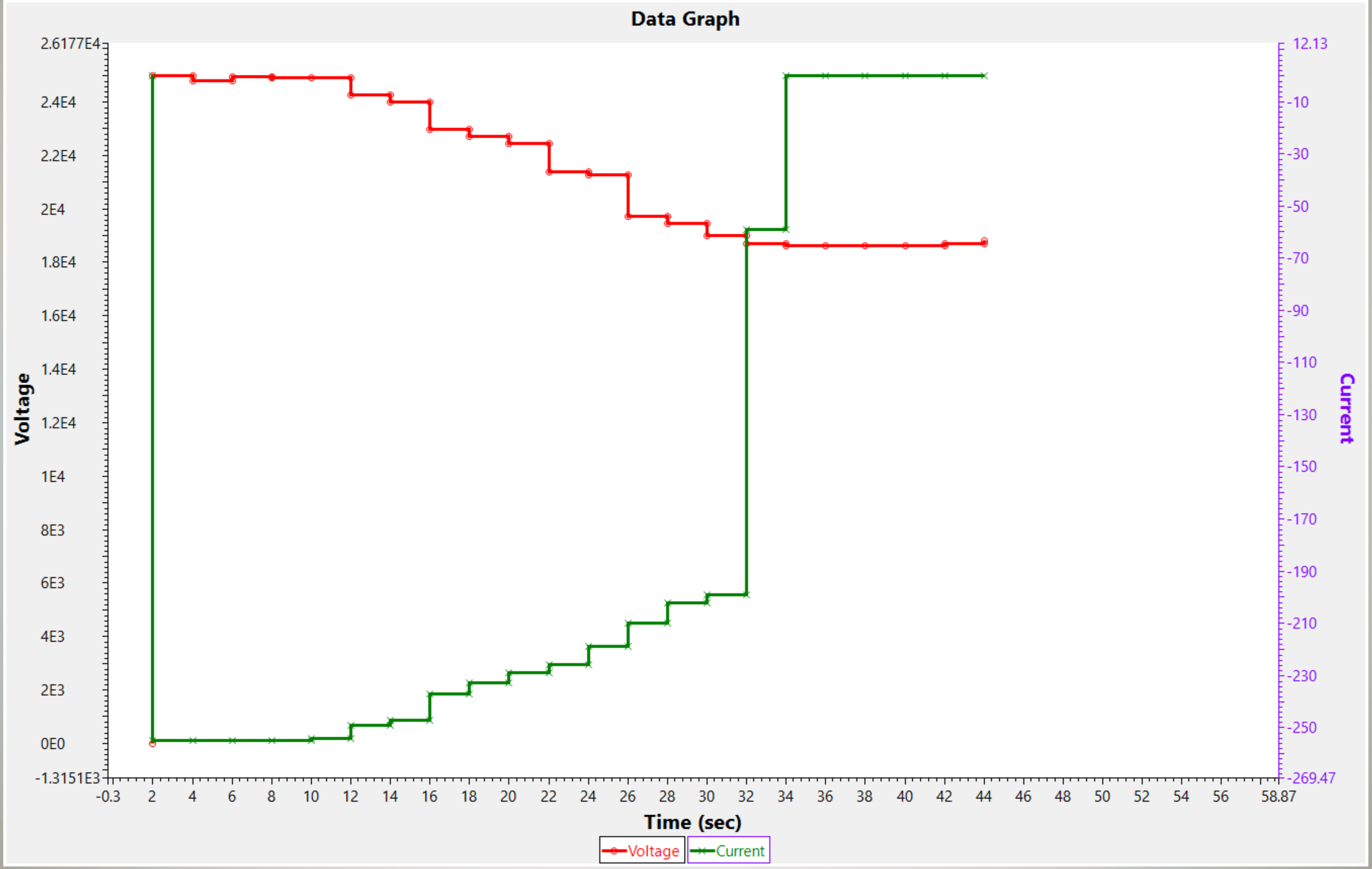
Test Plan Created | Test Scheduled | Test Conducted | Test Analyzed

Project Overview | Schedule | Budget | Testing | Conclusion

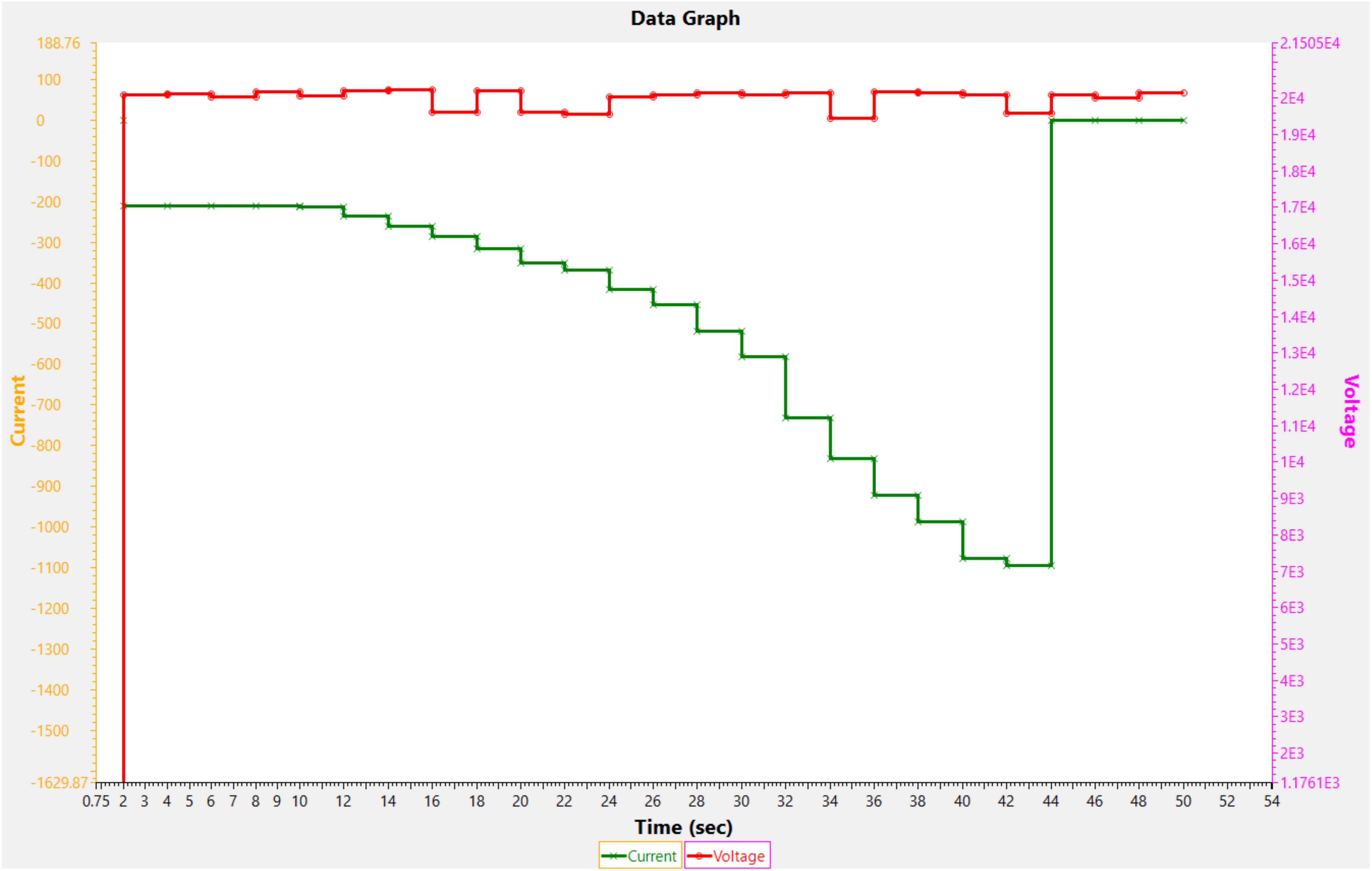
Charging Backup



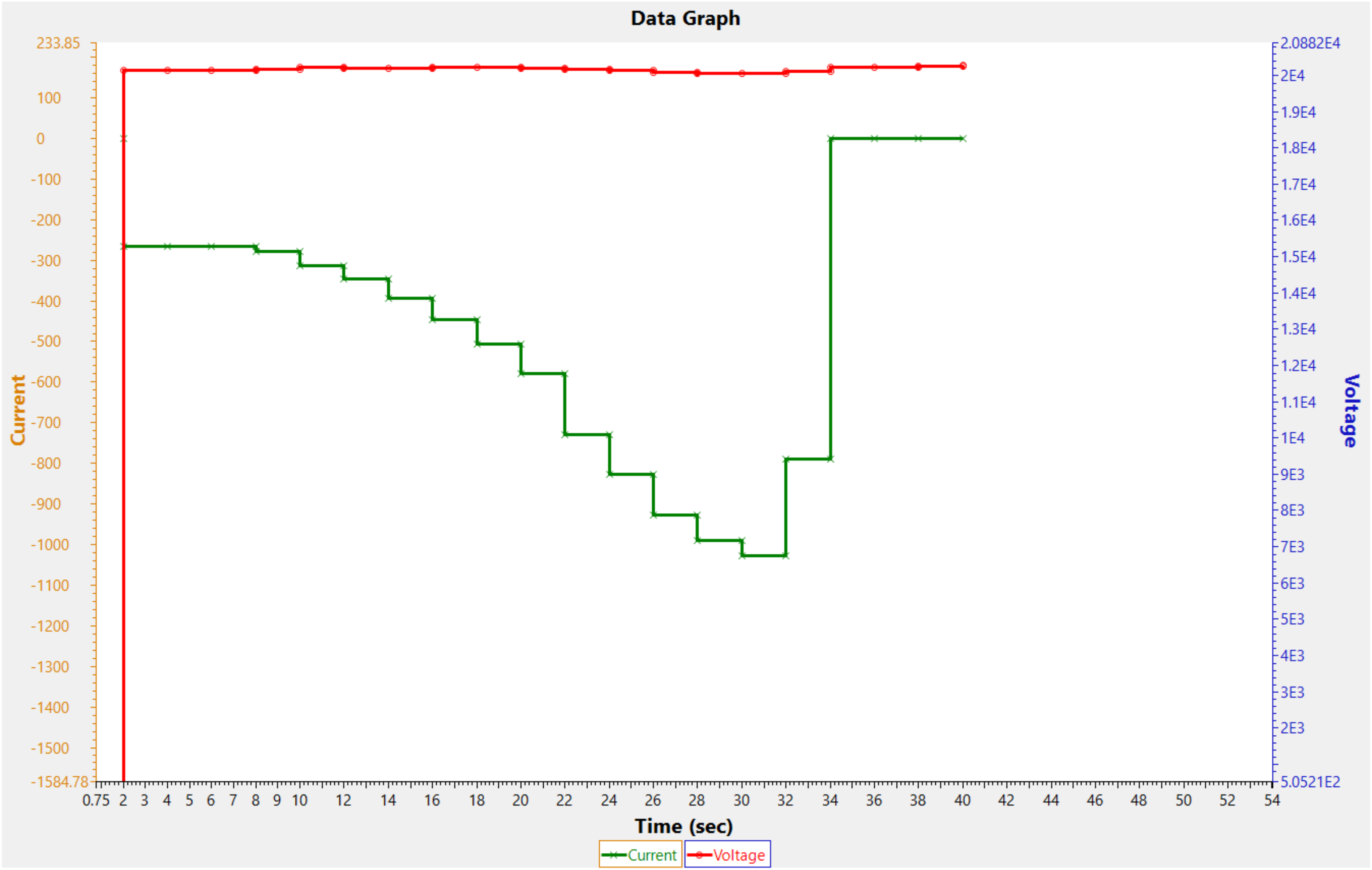
Charging Backup



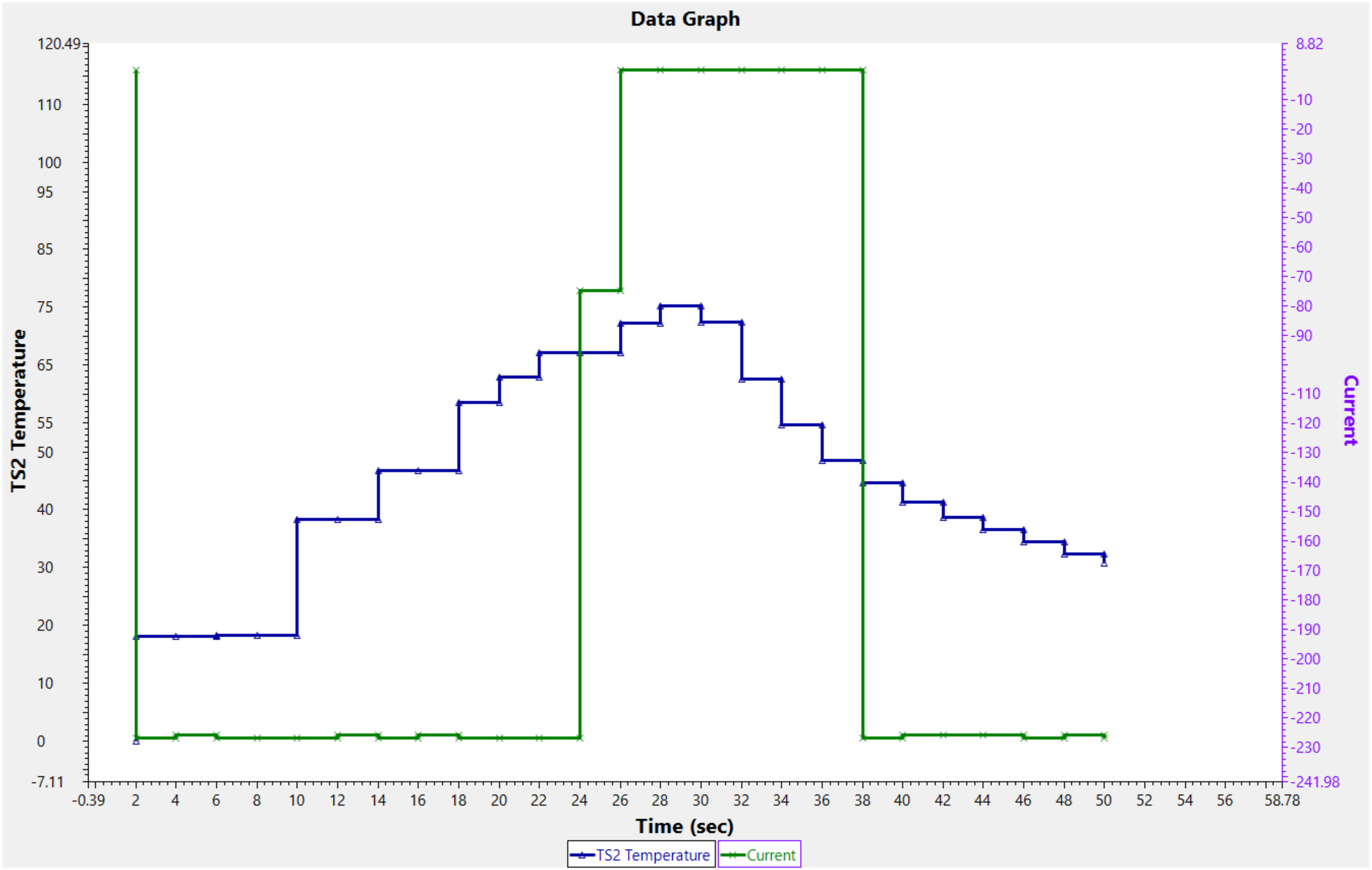
Charging Backup



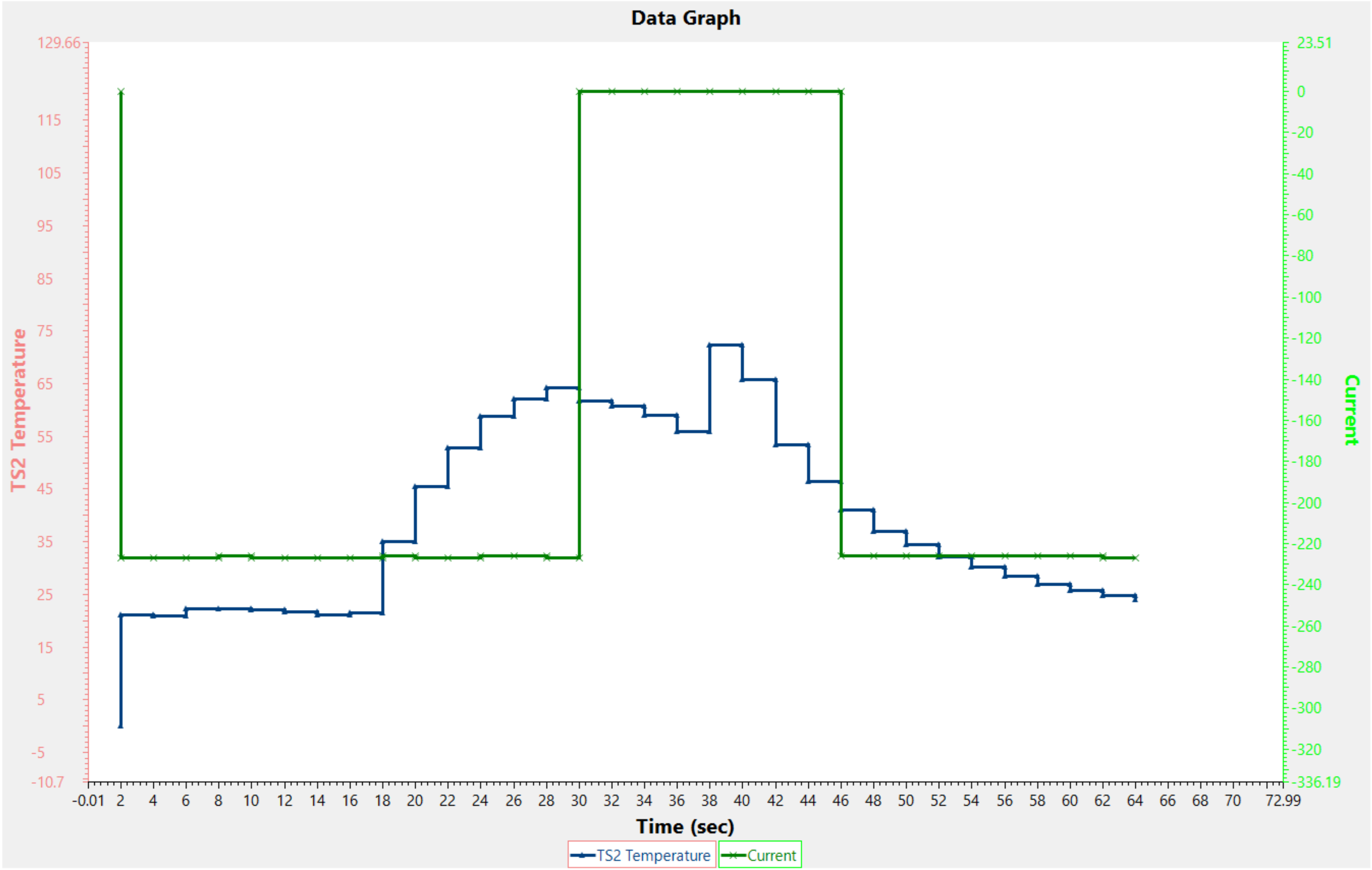
Charging Backup



Charging Backup

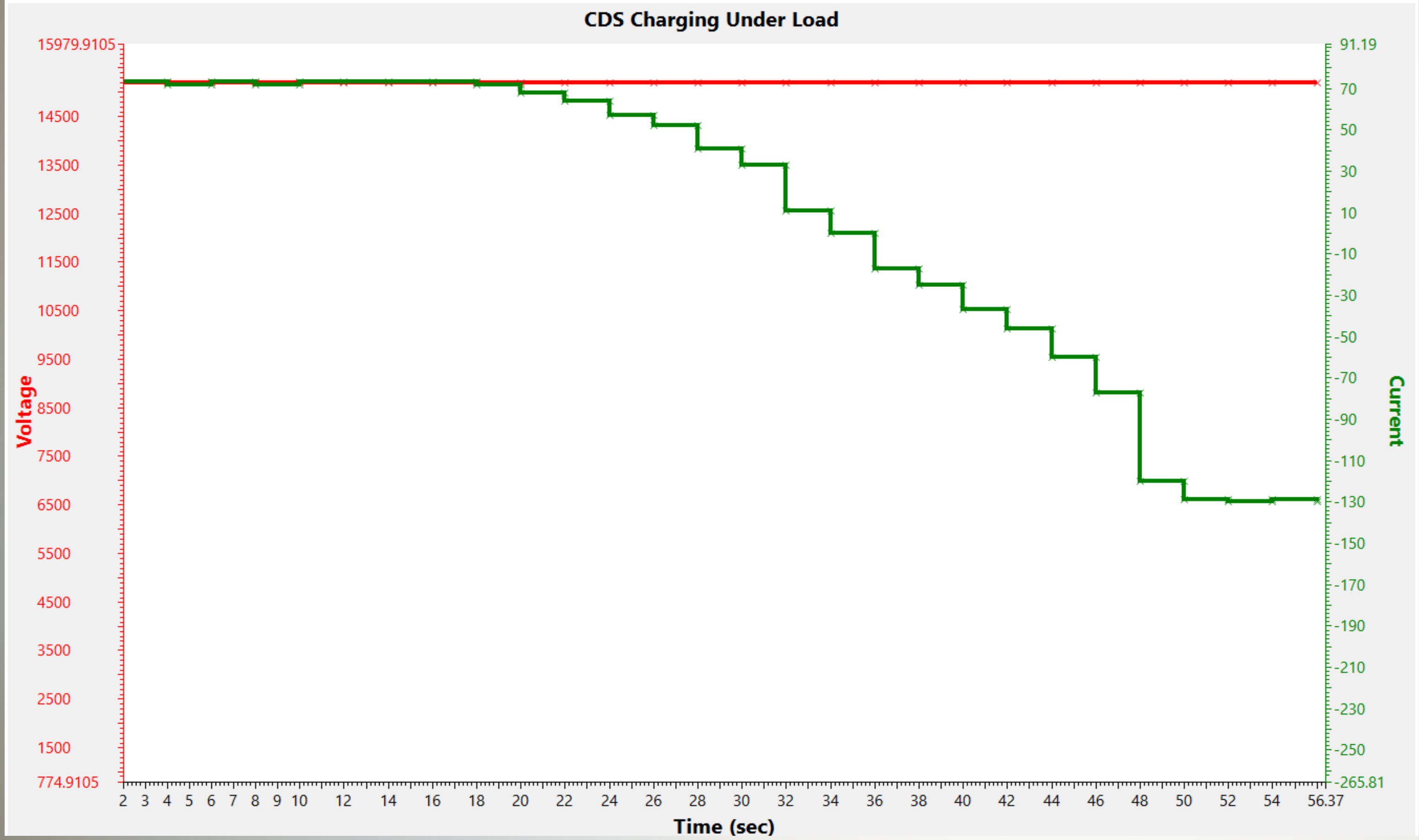


Charging Backup



Automatic Charging Test Results

Charging: Applied Load



- Applied Loads: Pixhawk and Rasp. Pi
- Charging not currently possible with Pi and Pixhawk powered
- Once a load is applied, current is drawn from child drone battery preventing charging
- Not a requirement to charge child drone battery while drone is powered

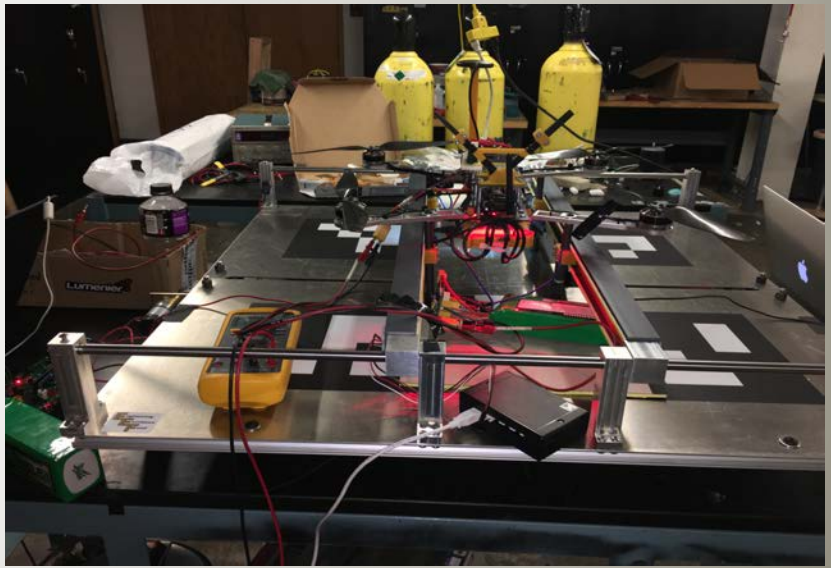


Image Recognition Errors

- 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 5

- Severity: 1 Likelihood: 5 TOTAL:

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