Test Readiness Review

Drone-Rover Integrated Fire Tracker

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Advisor: Dr. Jelliffe Jackson

Agenda

- Project Overview
- Mother Rover Design
- Test Readiness Review
  - Software and Electronics Testing
  - Model Verification
  - Integrated Testing
- Schedule
- Budget
- Conclusion

Project Overview | Test Readiness | Schedule | Budget | Conclusion

Mission Statement

Drone-Rover Integrated Fire-Tracker (DRIFT)
will develop a mother rover to secure, carry, and level an Unmanned Aerial Vehicle (UAV) for the purposes of gathering pertinent environmental data regarding locations at risk of or exposed to a wildfire.

Project Overview

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

Project Overview: Fire Tracker System

- As a result of climate change, wildfire seasons are becoming hotter and longer
  - This allows for a wildfire to easily ignite and rapidly spread
  - United States Forest Service is consistently increasing its budget for wildfire mitigation, rising from 16 to 50% of the Forest Service Budget since 1995[1]
- A deployable **mother rover** and **autonomous drone** provide a low cost means of long-range reconnaissance for early detection of wildfires
- These systems can assist firefighters in investigating areas sometimes impassible by ground-based methods alone

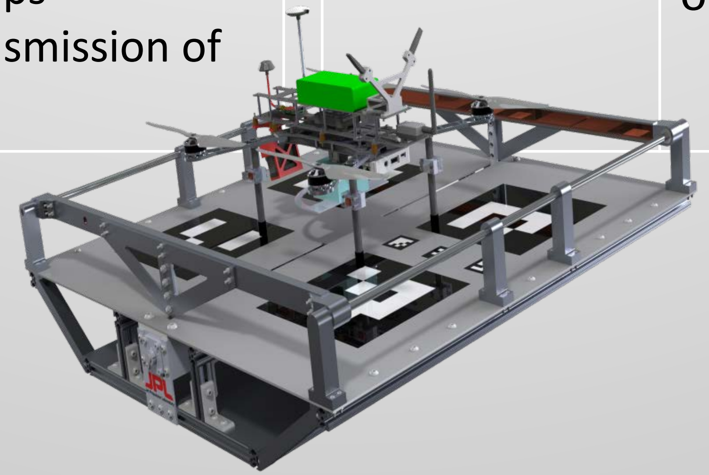
[1]The Rising Cost of Wildfire Operations: Effects on the Forest Service's Non-Fire Work." United States Department of Agriculture: Forest Service, 4 Aug. 2015.

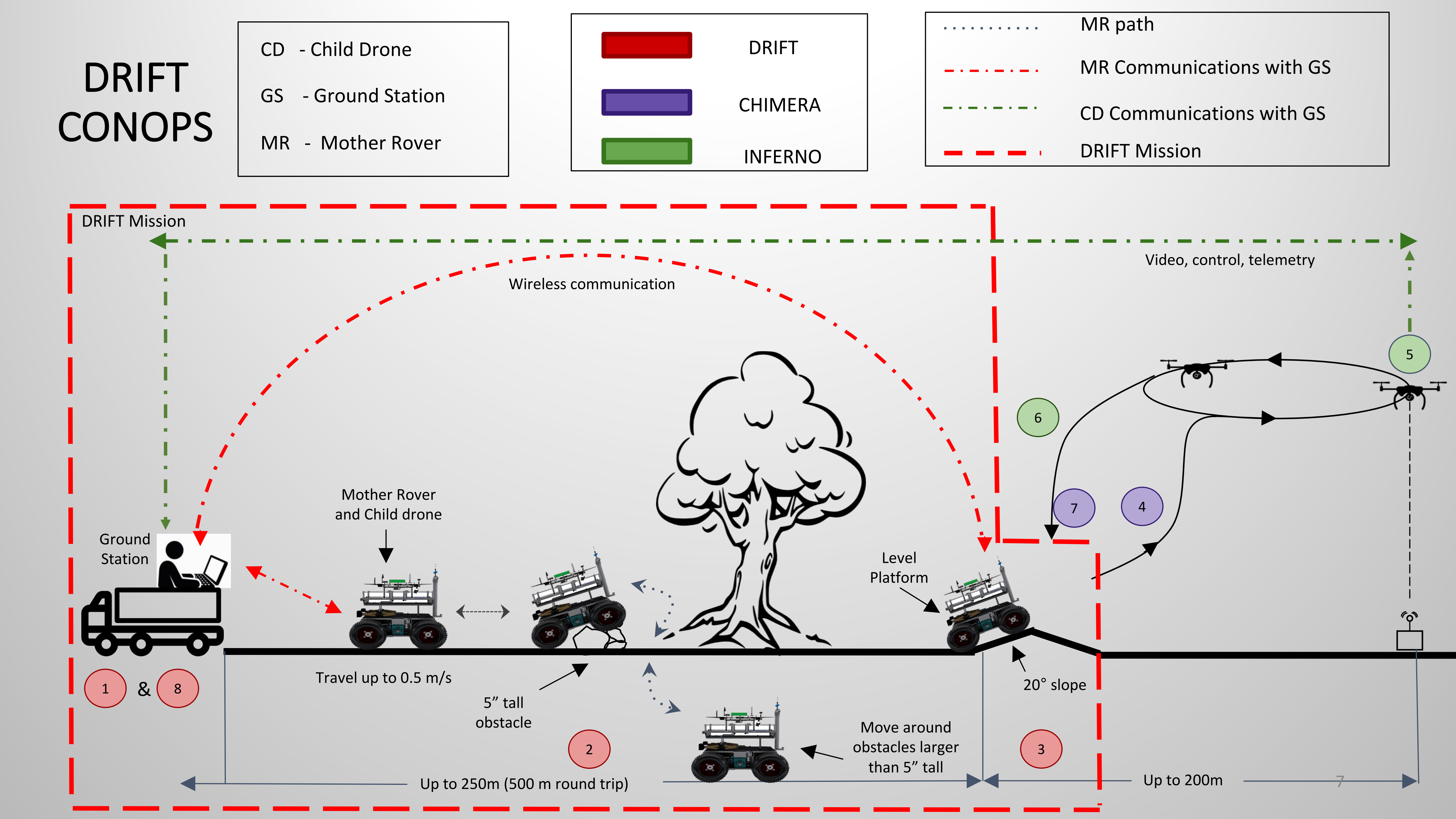
Project Heritage

DRIFT will utilize both the **INFERNO** and **CHIMERA** hardware and software shown below:

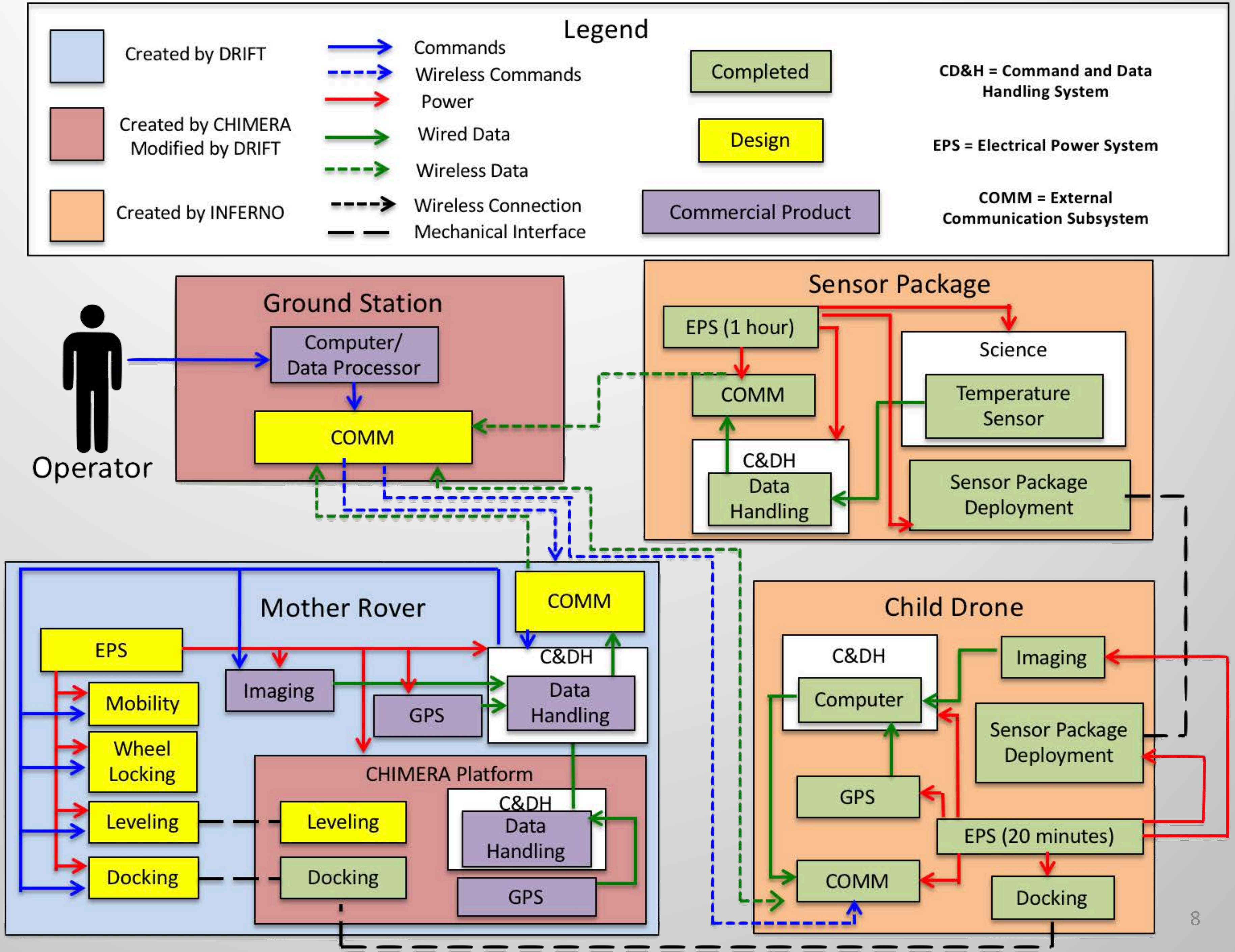
Project Name	INFERNO **IN**tegrated **F**light **E**nabled **R**over for **N**atural disaster **O**bservation
Timeline	2015-2016
Overview	Semi-autonomous **Child Drone** capable of transporting and deploying a temperature sensor package to a location of interest
Capabilities	o Mission Duration: 13.5 min o Fully Autonomous Takeoff at inclinations < 3.5 degrees o 10 m/s Translational Flight o Video/Imaging: 720p at 30fps o Sensor Package: > 90% transmission of SPS data

Project Name	CHIMERA **CHI**ld drone deployment **ME**chanism and **R**etrieval **A**pparatus
Timeline	2016-2017
Overview	The landing, securing, and deployment system for the autonomous drone inherited from INFERNO (**Landing Platform**)
Capabilities	o Capable of securing CD up to 200m from GS o Drone recharging system can charge the CDS LiPo battery upon command o Autonomous landing functionality utilizing image recognition upon command from ground station




DRIFT
CONOPS
CD - Child Drone
GS - Ground Station
MR - Mother Rover
DRIFT
CHIMERA
INFERNO
MR path
MR Communications with GS
CD Communications with GS
DRIFT Mission
DRIFT Mission
Video, control, telemetry
Wireless communication
Mother Rover
and Child drone
Ground
Station
Level
Platform
1
&
8
Travel up to 0.5 m/s
5” tall
obstacle
2
Move around
obstacles larger
than 5” tall
3
20° slope
4
5
6
7
Up to 250m (500 m round trip)
Up to 200m

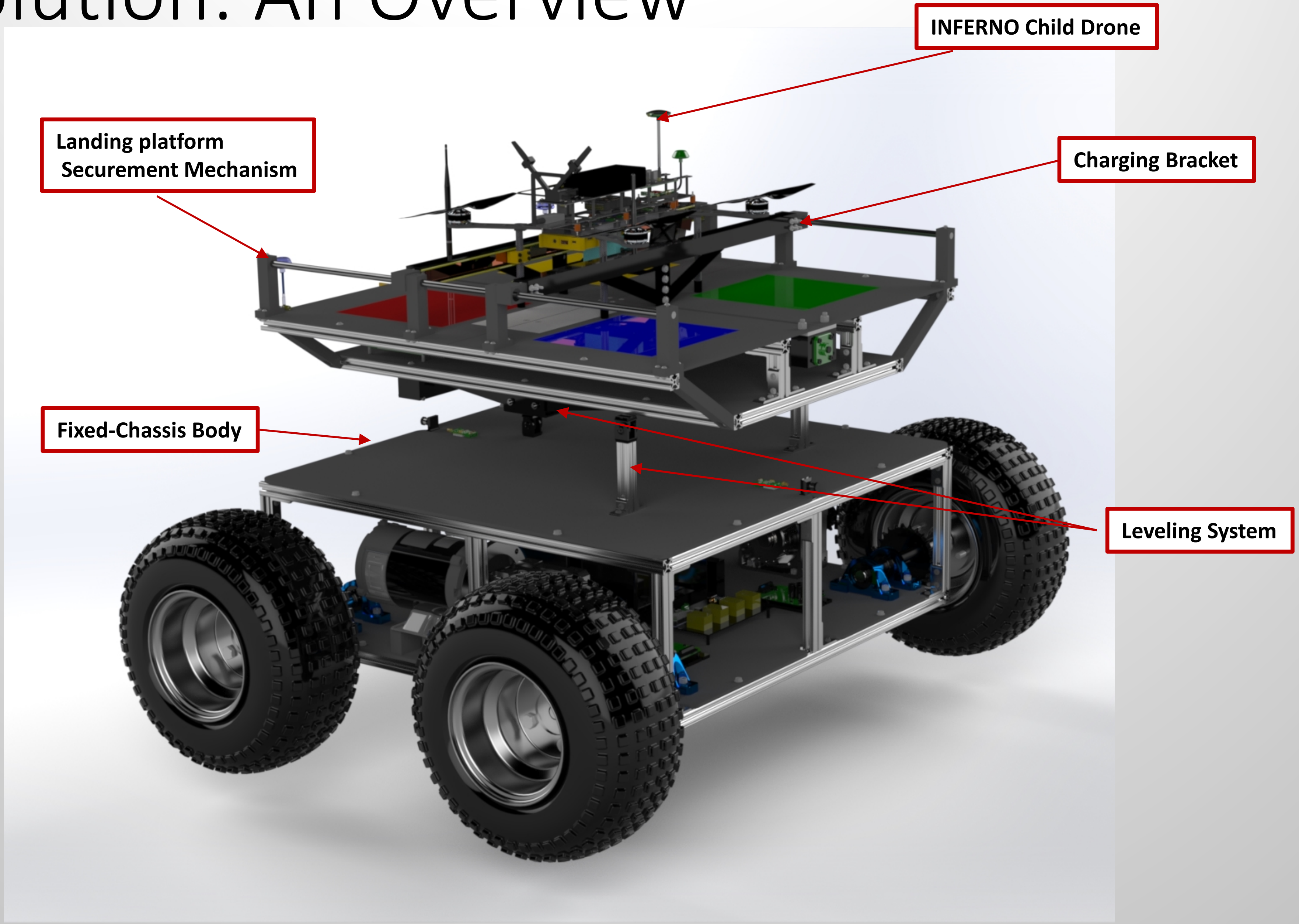
Functional Block Diagram



Design Solution

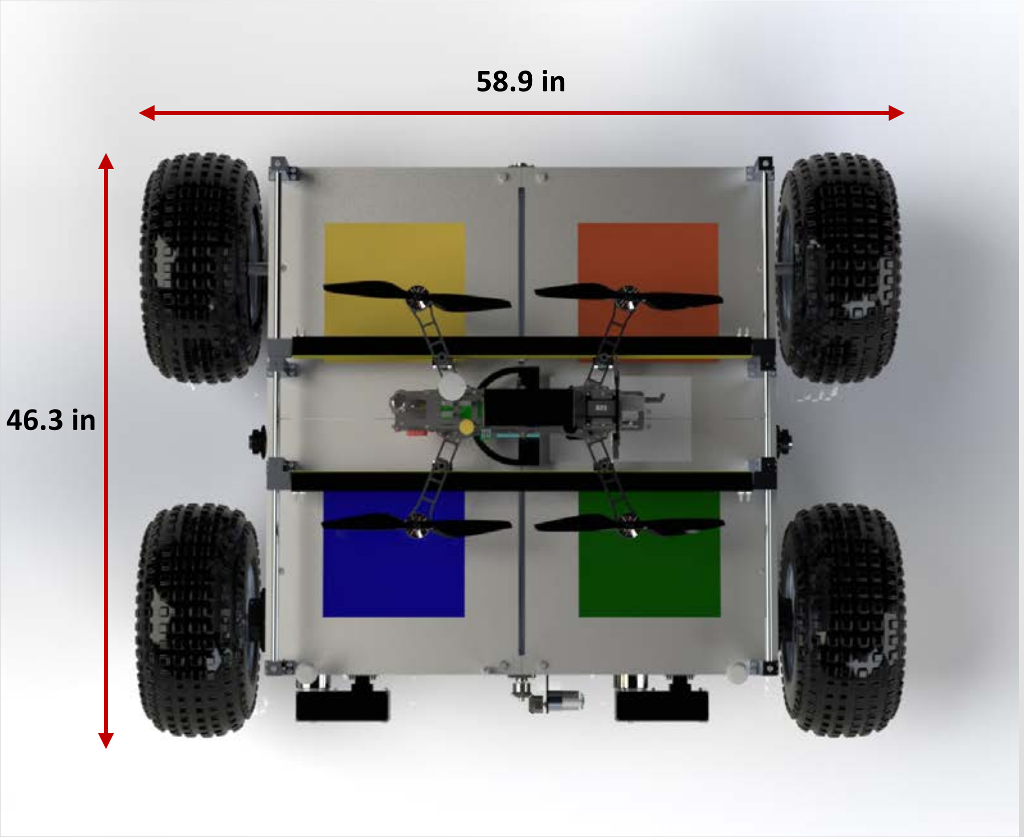
Project Overview | Test Readiness | Schedule | Budget | Conclusion

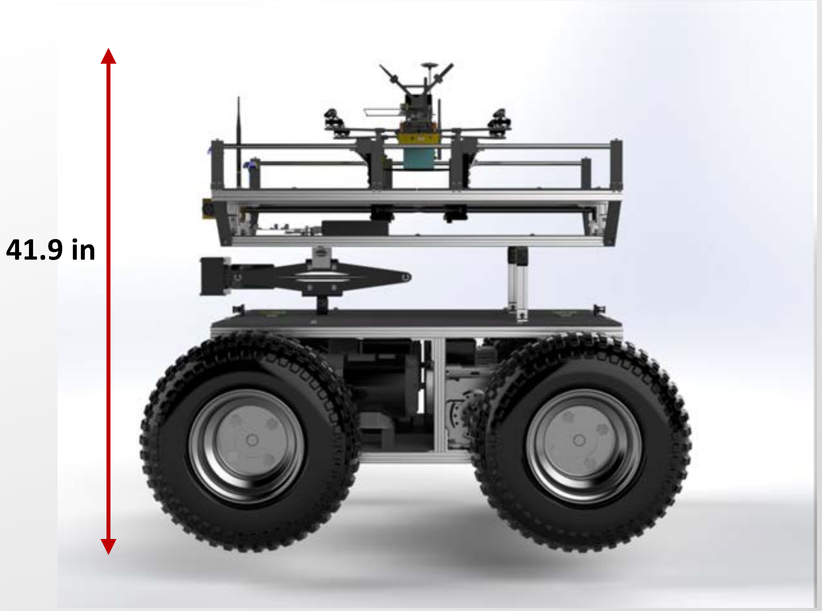
Design Solution: An Overview



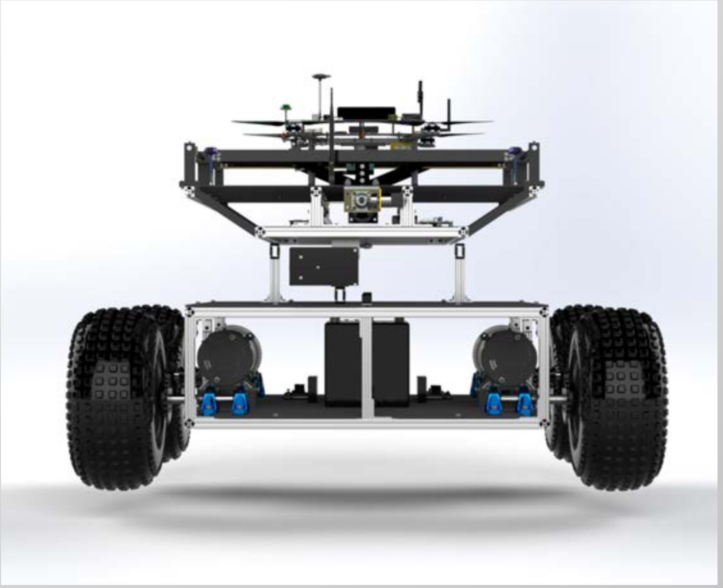
Design Solution: An Overview

Top View





Side View



Front View

Total Weight : **383.77 lbs**

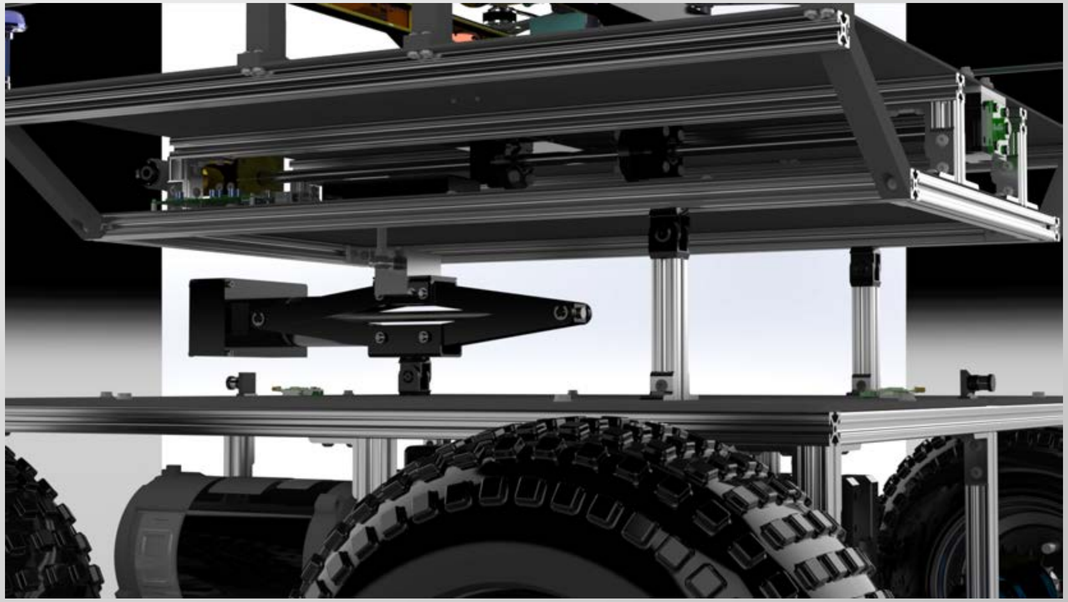
Design Modifications from MSR

Leveling

- Previous multi-directional system shown by models to be dynamically unstable
- One-directional leveling system prototype built and successfully demonstrated
- Paired with our skid steering capability, this change does not impact our ability to meet our requirements or achieve our third level of success
- Budget – Saves $165.25
- Schedule – Saves approximately 12.5 hours of machining

Design

- Single scissor jack
- Two forward points topped with one-directional pivot joint
- Bottom of jack connected to rover with pivot joint
- Jack remains topped with single ball joint.



Critical Project Elements

- **Translational System**
  - **Fixed Chassis design** enables the mother rover to traverse rough terrain including fine dirt, small gravel, and lawn grass.
- **Leveling System**
  - Utilizes **internal leveling jack design** to level the landing platform to the required 3.5^0 necessary for the child drone to deploy and autonomously land safely.
- **Electronics and Communication**
  - Necessary for communication between Ground Station and Mother Rover
    - Commands leveling system
    - Provides live video feed for operator
    - Commands Mother Rover for Translational motion
- **$5000 Budget**
  - Currently only $322.36 margin, improved from MSR $ 163.31 margin
  - Applied for an additional $675.00 through Engineering Excellence Fund (EEF)

Levels of Success

Level 3

- MR can overcome slopes $\leq$ 20 degrees at speeds up to 0.5 m/s
- MR can maneuver around obstacle over 5 inches tall while the CD and LP remains securely fixed to the MR
- MR can level the platform to $\mathbf{0}° \pm \mathbf{3.5}°$ to take off and land on a 20 degrees slope
- MR can relay live video feed and location at least at 5Hz for a distance of 250 m to the GS
- MR can be powered to achieve a round trip mission of 500 m

Level 2

- MR can overcome slopes $\leq$ 10 degrees at speed up to 0.5 m/s
- MR can traverse a path that has obstacles less than or equal to 5 inch tall while the CD and LP remain securely fixed to MR
- MR can level the platform to $\mathbf{0}° \pm \mathbf{3.5}°$ for the CD to take off and land on a 10 slope
- MR can be driven by an operator at GS via live video feed to desired location
- MR can relay live video feed and location at least at 5 Hz for a distance of 150 m to the GS
- MR can be powered to achieve a round trip of 300 m

Level 1

- MR can traverse over a flat dirt path while supporting the size and the weight of the attached LP and CD
- MR can be driven by operator to the desired location (and back) while operator walks alongside
- MR can relay location at least at 5 Hz at a distance of 100 m back to GS
- MR can be powered to achieve a round trip of 100 m

Test Readiness Review

- Software and Electronics Testing
- Model Verification
- Integrated Testing

Test Breakdown

Software and Electronics Testing
- Leveling System Test
- Motor Driver-Motor Integration Test
- Electronics System Unit Testing
- Camera Testing
- Battery Depletion Test

Model Verification
- Torque Model Verification
- Drop Test
- Tipping Model/COM Verification
- Traction Model Verification

Integrated Testing
- Communications Test
- Maneuverability Test
- Slope Capability and Leveling Test
- Obstacle Clearance Test
- Distance Test
- GPS Test
- Full Mission Simulation

Discussed in this presentation: Leveling System Test, Motor Driver-Motor Integration Test, Torque Model Verification, Drop Test, Communications Test, Maneuverability Test, Slope Capability and Leveling Test

Other tests to be completed: Electronics System Unit Testing, Camera Testing, Battery Depletion Test, Tipping Model/COM Verification, Traction Model Verification, Obstacle Clearance Test, Distance Test, GPS Test, Full Mission Simulation

Facilities and Transportation

Locations

- Switzerland Trail (Pending Trailer Access)
- Chautauqua (Tests only using components not full rover body)
- Backup indoor methods provided weather restrictions

Transportation

- Locally around Engineering Center
  - Pallet Jacks
  - Rolling Carts
- Switzerland Trail Access
  - Trailer

Switzerland Trail

Chautauqua

Trailer

Software & Electronic Testing

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

Leveling System

Software and Electronics Testing

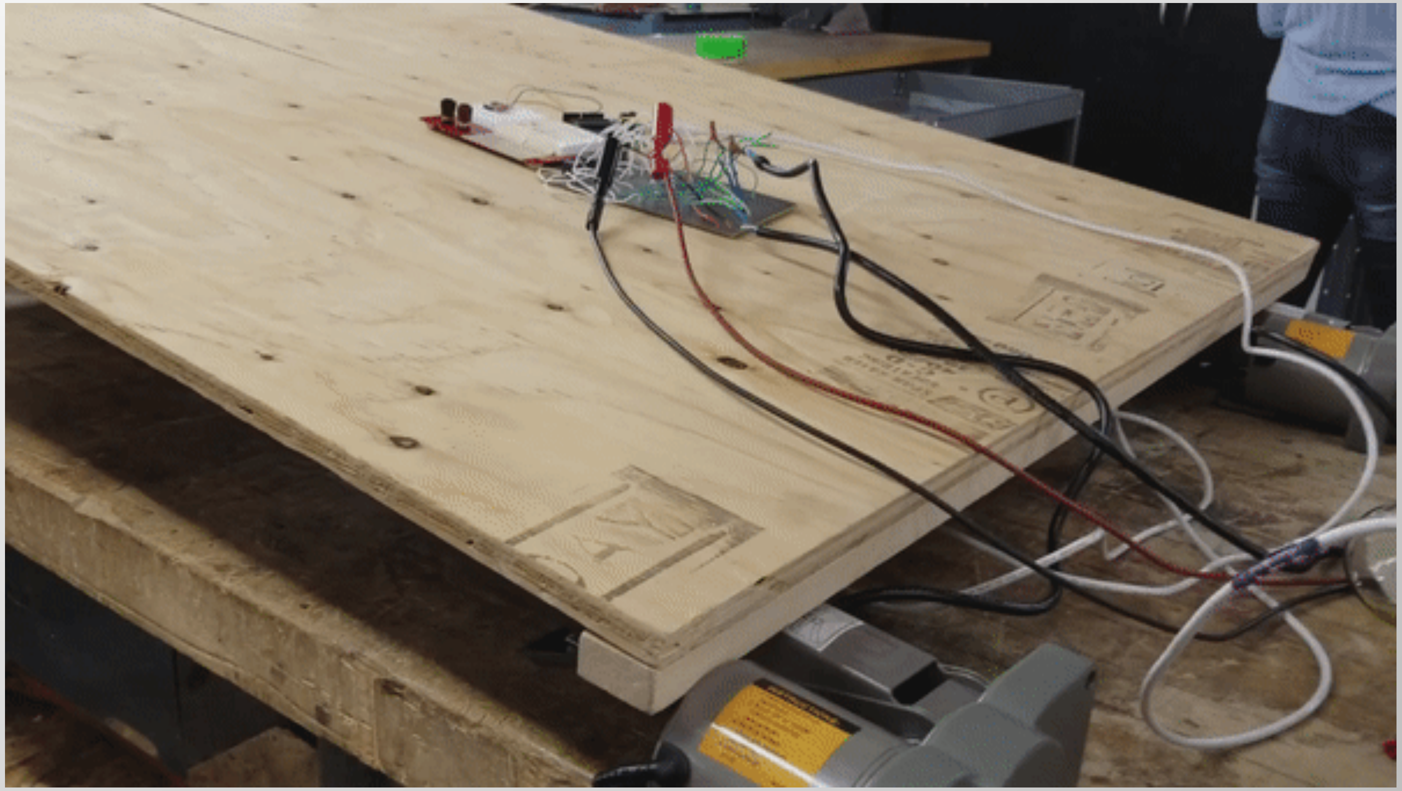
Requirements Verified

Functional Requirement	Description
FR5.0	The MR shall position itself for the CD to take-off and land safely such that it is able to be secured by the MR's securement mechanism
DR5.1	The MR must ***level itself to 0° +/- 3.5°*** *of the gravitational normal on a slope up to 20°* after coming to a complete stop.
DR5.1.1	The MR will ***use an accelerometer to measure the angle of the LP*** with respect to level ground.

Leveling System

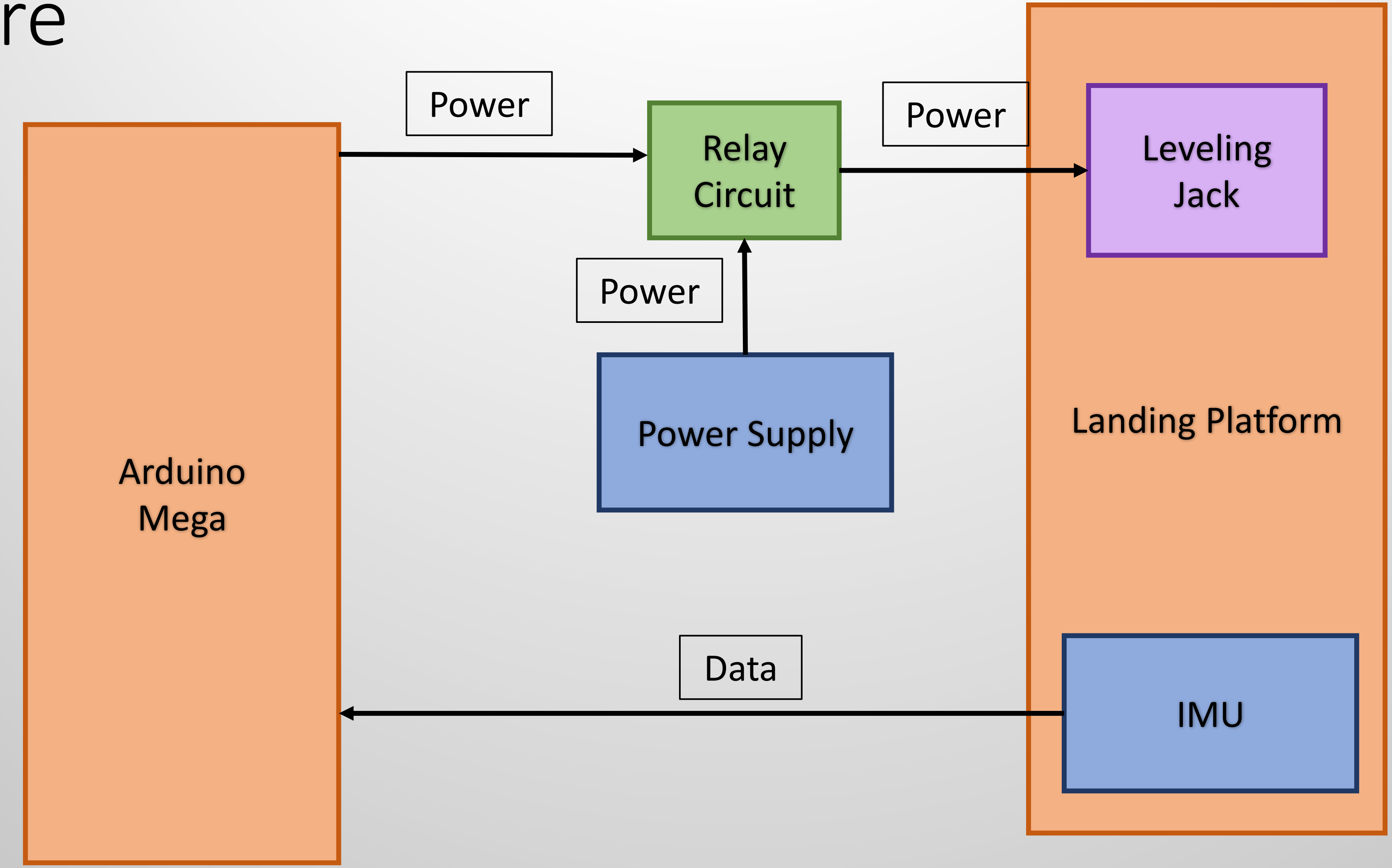
Software and Electronics Testing

- **Overview**
  - Verify the functionality of the complete leveling system with leveling, resetting, and calibration commands with the Arduino.
- **Test Equipment**
  - **Leveling Jack**
  - **Leveling Relay Circuit**
  - Arduino Mega
  - 12V Power Supply
  - IMU
- **Results**
  - **Success** for both jacks operating – able to level using two jacks
  - In progress for operating one jack system – software has been tested using IMU, the leveling, resetting, and calibration commands are functional, waiting on jack to run full demonstration
- **Risk Reduction**
  - Fixing the issues with wiring, and editing relay circuit



Leveling System-Integration Test

Software and Electronics Testing Procedure



Ground Station & Full Software

Software and Electronics Testing

Requirements Verified

Functional Requirement	Description
FR1.0	The MR shall integrate with the attached landing platform such that it is permanently fixed and securely carries the CD without tipping while traversing the defined rough terrain.
FR2.0	The MR shall ***receive commands from the GS at a rate of at least 5 Hz***.
FR3.0	The MR shall ***transmit data to the GS at a rate of 30 HZ***.
FR4.0	The MR shall ***traverse*** 250 meters away from the GS ***to a specified GPS location*** over rough terrain defined by varying slopes and obstacles which require the MR to ***navigate*** over and around them. The MR shall ***return to the GS*** after the mission is complete.
FR5.0	The MR shall ***position itself*** for the CD to take-off and land safely such that it is able to be secured by the MR's securement mechanism.

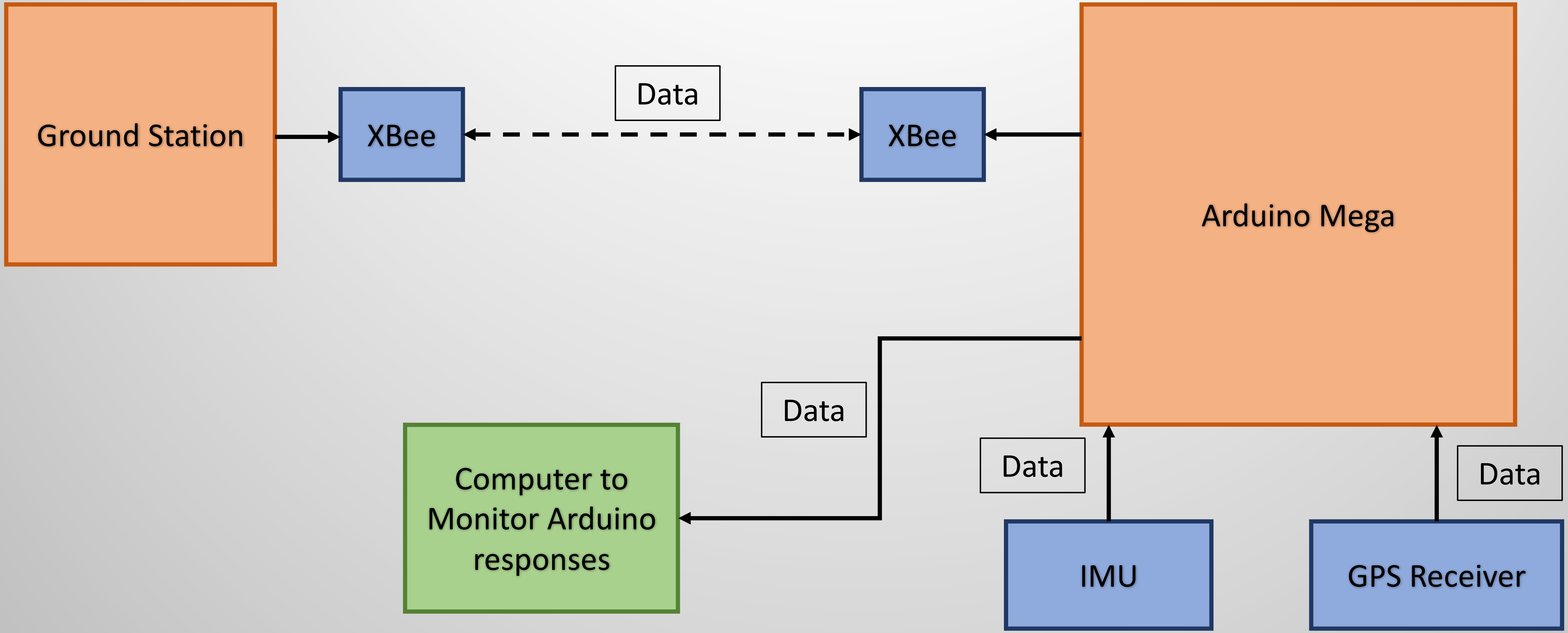
Ground Station & Full Software

Software and Electronics Testing

- **Overview**
  - Verify the functionality of the ground station's ability to send commands and display data, and the rover's ability to respond to commands
- **Test Equipment**
  - IMU
  - XBees
  - Arduino Mega
  - GPS receiver
  - GS computer
- **Results**
  - **Success** for two jack leveling system – able to level using two jacks
  - **Success** for motor control – able to control motor driver via Arduino Mega with DIO pins
  - In progress for operating one jack system – software has been tested using IMU, the leveling, resetting, and calibration commands are functional, waiting on jack to run full demonstration
  - In progress with communication system – ground station control under construction
- **Risk Reduction**
  - Fixing the issues with wiring, and editing relay circuit
  - Place a fuse between the battery and the motor driver to limit peak current through the motor driver

Ground Station-Integration Test

Software and Electronics Testing Procedure



Motor Driver-Motor Integration Test

Software and Electronics Testing

Requirements Verified

Rough Terrain

- Materials: lawn grass, small gravel, and fine dirt
- Varying slopes from 0 to 20^0
- Traversable obstacles up to 5 in tall
- Non-traversable obstacles at least 10 feet apart.

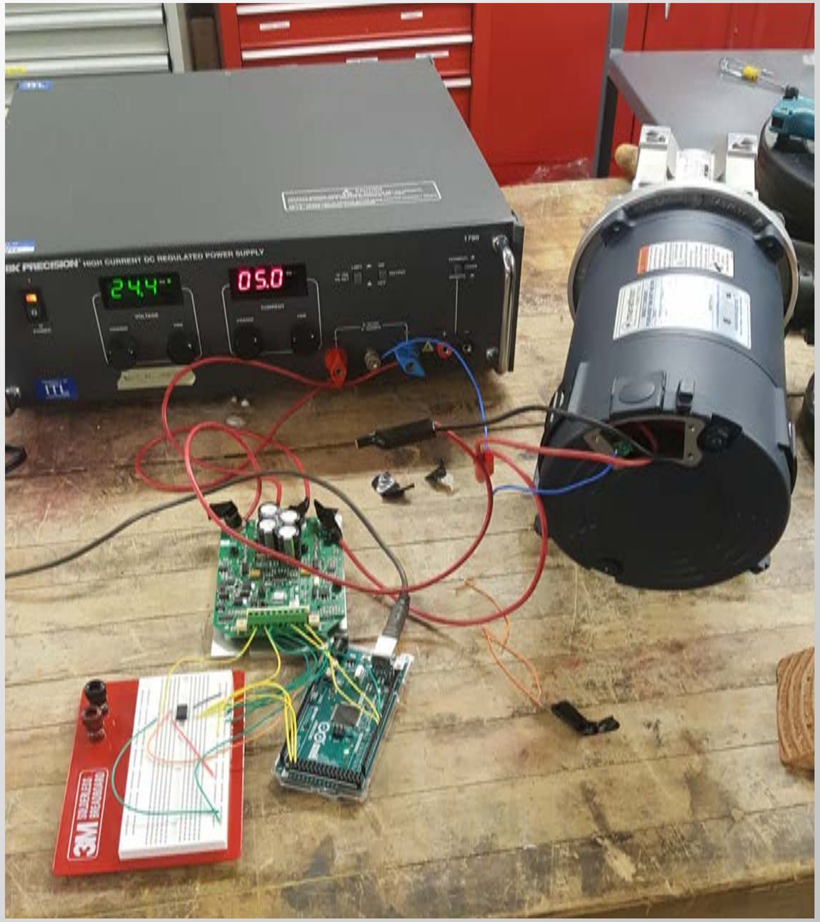
Functional Requirement	Description
FR4.0	**The MR shall traverse over rough terrain up to 250 meters away from the GS to a specified location of interest.**
DR4.1	The MR shall travel ***at a speed within the range of 0 to 0.5 m/s in forward and reverse***.
DR4.2.1	The batteries shall have enough power available to provide to the motors and motor drivers such that the MR is able to traverse the defined rough terrain
DR4.5	The MR shall traverse up and down a 20^0 slope.
DR4.5.1	The MR ***motors shall provide enough torque*** to traverse up and down the defined slope.

Motor Driver-Motor Integration Test

Software and Electronics Testing

Completed: 1/23/2018

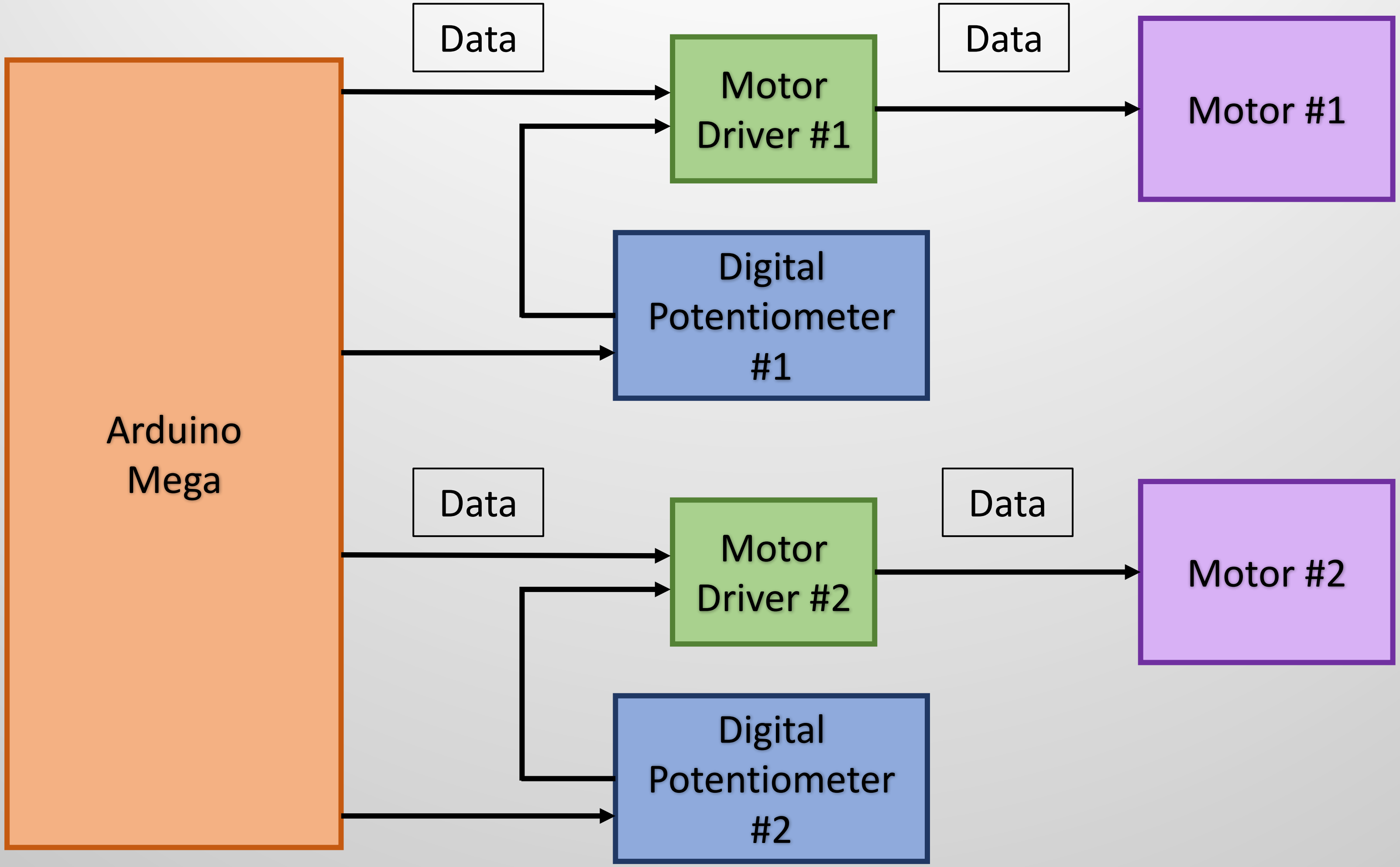
- **Overview**
  - Verify the functionality between the motor drivers and motors with speed, stop, and direction control with the Arduino Mega.
- **Test Equipment**
  - DC60-12/24-4Q **Motor Driver**
  - **Digital Potentiometer Circuit**
  - Marathon Electric DC Brushed **Motor**
  - Arduino Mega
  - 24V Power Supply
- **Results**
  - **Success** for both motors – able to control motor driver via Arduino Mega with DIO pins
- **Risk Reduction**
  - Place a fuse between the battery and the motor driver to limit peak current through the motor driver



Motor Driver-Motor Integration Test

Software and Electronics Testing

Procedure



Model Verification

Model Validation

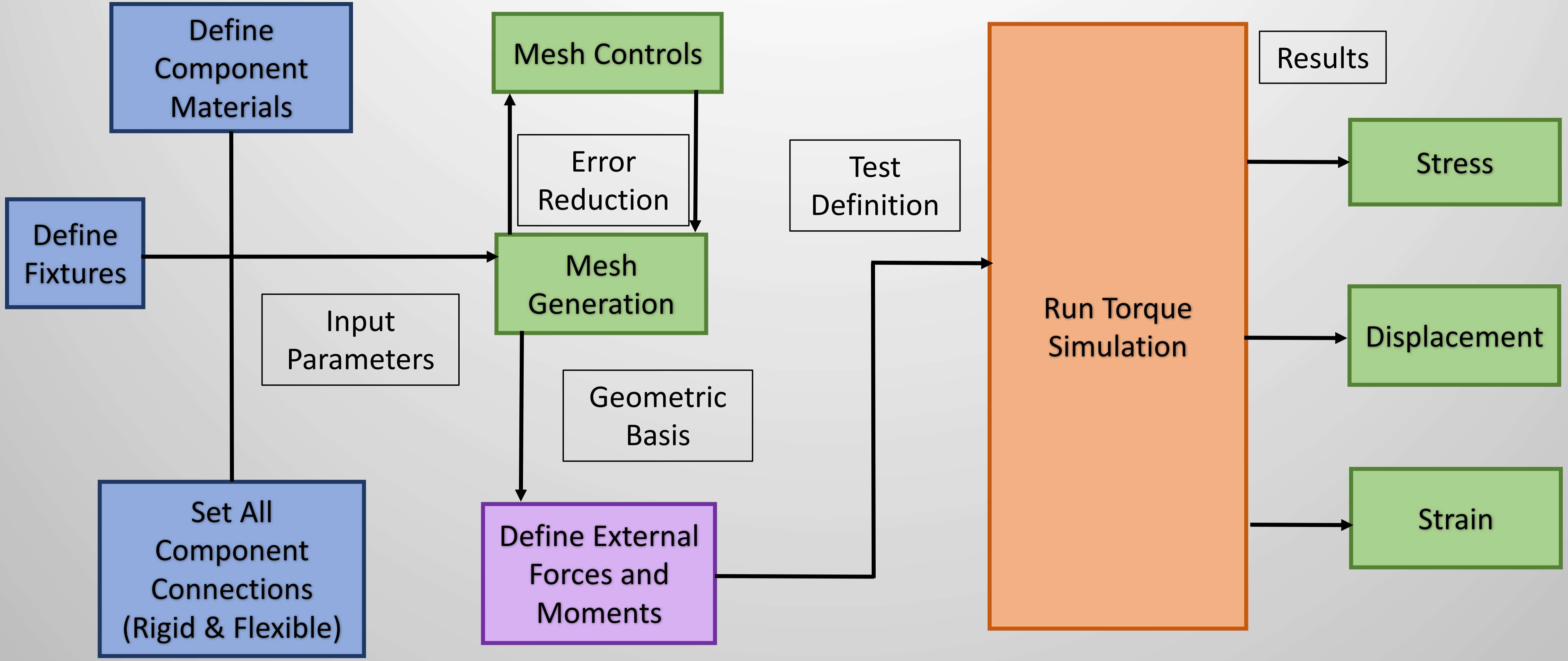
Torque Model Verification

- **Overview**
  - Verify that the drive shaft and respective components will be structurally capable of driving the rover when subject to forces and torques during full mission.
- **Test Equipment**
  - CAD Model of Completed Mother Rover
- **Results Expected**
  - Von-Mises stress contours
  - Displacements
  - Strains
- **Risk Reduction**
  - SolidWorks models to ensure success before physical testing

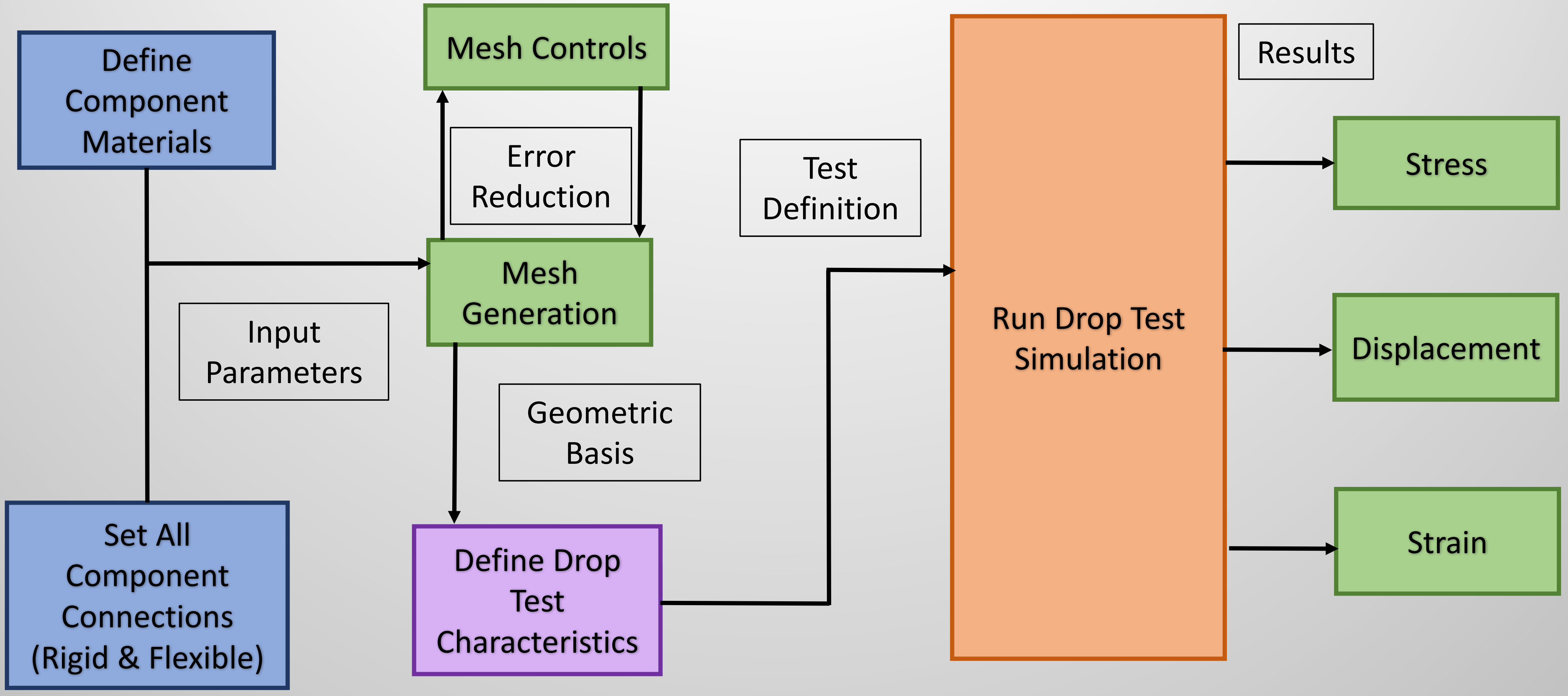
Drop Test

- **Overview**
  - Verify that all rover components (I.e. CHIMERA Landing Platform, leveling system, rover housing, and translational system) remain structurally sound after dropping from a height of 5 inches
- **Test Equipment**
  - Solidworks model simulation
- **Results Expected**
  - Von Mises stress contours
  - Displacements
  - Strains
- **Risk Reduction**
  - SolidWorks models complete to ensure success before physical testing

Torque Model Test
Model Validation Procedure



Drop Test
Model Simulation Procedure



Integrated Testing

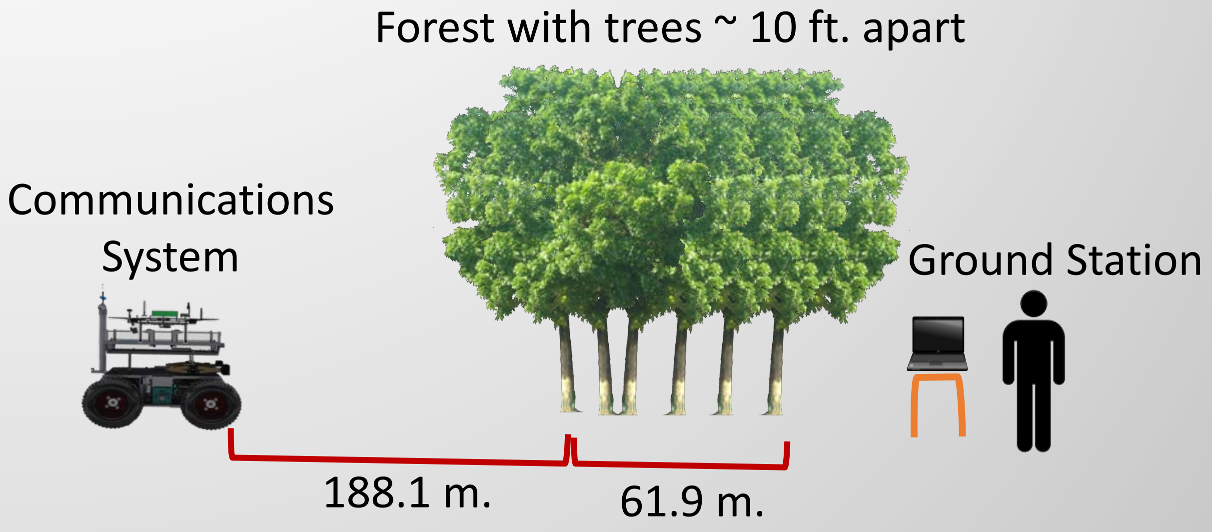
Communications Test Requirements

Functional Requirement	**Description**
FR2.0	The MR shall ***receive commands from the GS at 5 Hz***.
Design Requirement	Definition
DR2.1	The MR shall record a ***log*** of received commands from the GS detailed in DR2.4.
DR2.2	The MR shall receive signals with a ***signal to noise ratio of at least 6 dB-Hz*** (industry standard).
DR2.3	The MR shall receive commands at a ***distance of 250 meters***.
DR2.4	The commands to be received by the MR from the GS include: forward/backward translational motion, turning motion, to turn on/off the MR video feed, opening/closing the CD securement mechanism, and to level the LP.

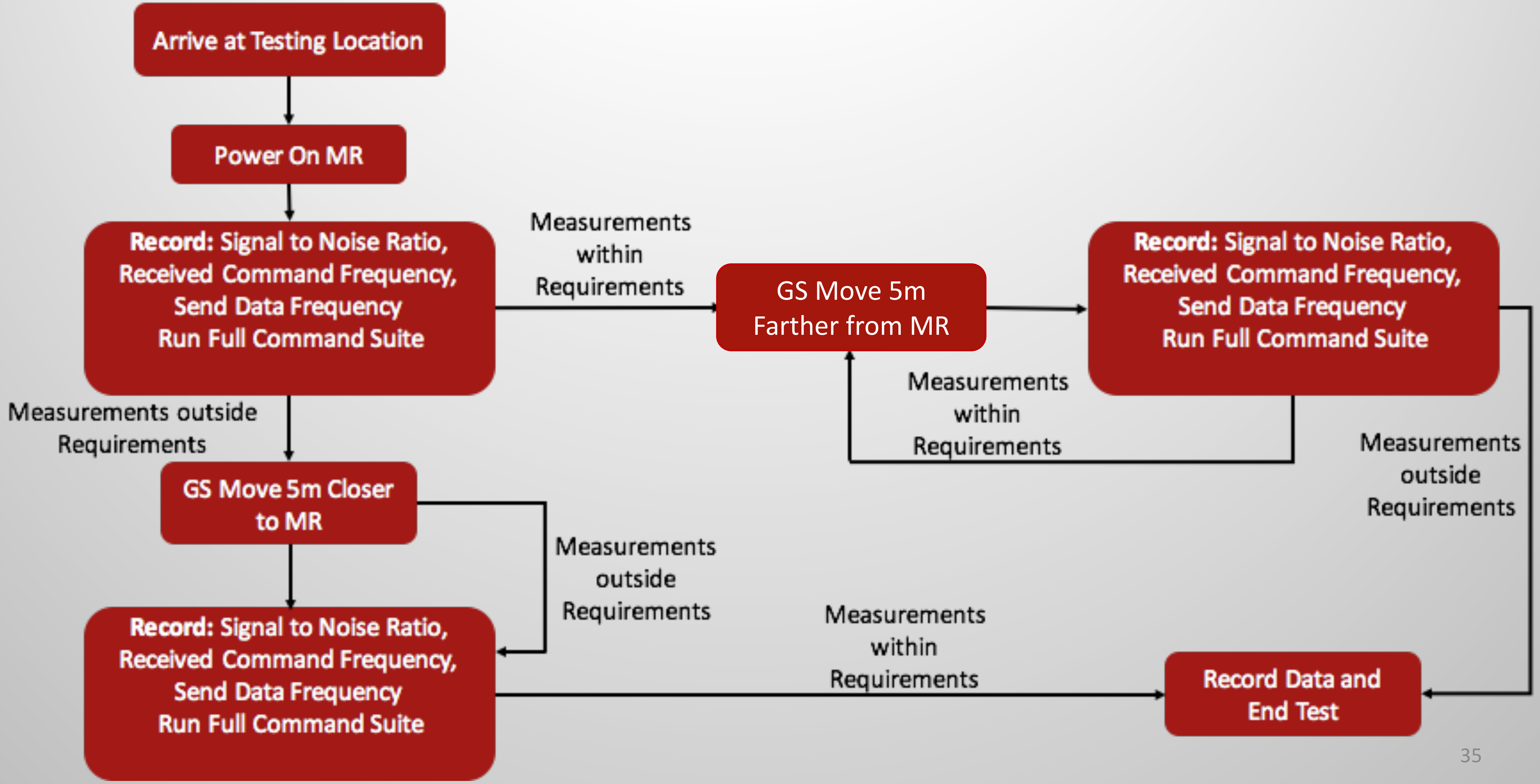
Functional Requirement	**Description**
FR3.0	The MR shall ***transmit specified data to the GS at 30 Hz***.
Design Requirement	Definition
DR3.1	The MR shall transmit its ***current GPS location*** to the GS with an ***accuracy of 5 m***.
DR3.2	The MR shall transmit ***live video feed*** at 1080p at 30 fps to the GS

Communications Test
Integrated Testing

- **Overview**
  - Measure whether the MR can transmit desired data in specified environments at specified rates
- **Test Equipment**
  - Full Communications System
    - Including XBees and cameras and corresponding antennas
  - Ground Station
  - Chatauqua Mountain Park
- **Results Expected**
  - Signal to Noise Ratio
  - Frequency of data received
  - Frequency of data sent
  - Latency
  - Max distance in trees capable of communicating.
- **Risk Reduction**
  - Only using suite to prevent moving whole rover and making data collection easier



Communications Test
Integrated Testing

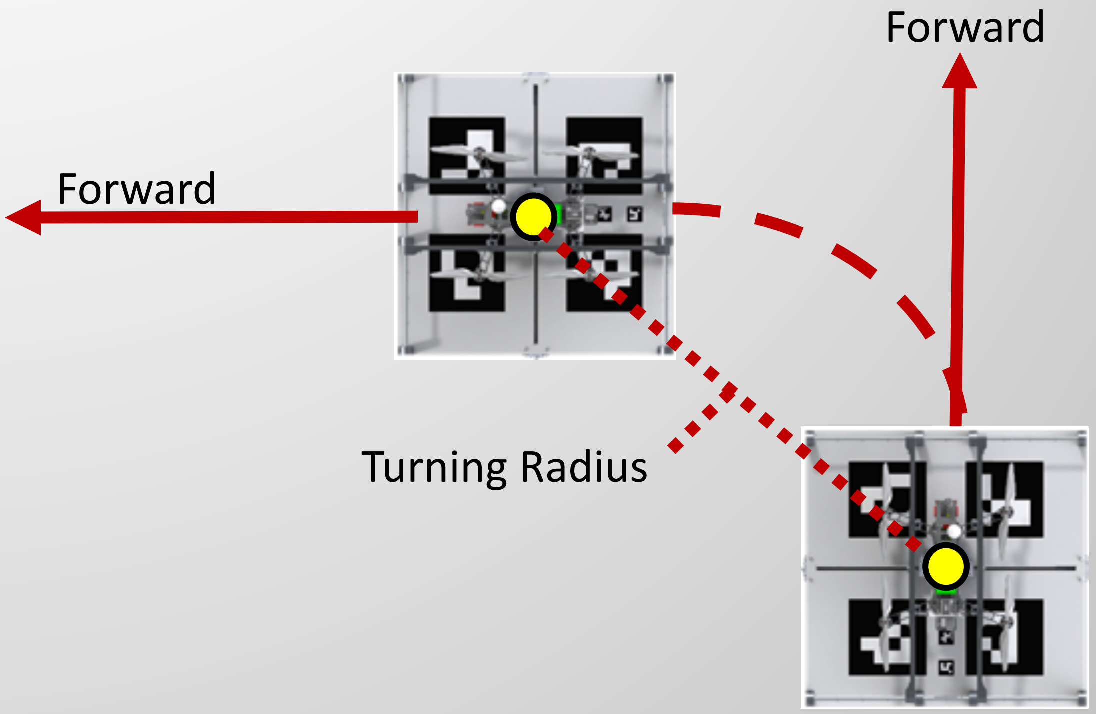


Maneuverability Test Requirements

Functional Requirement	**Description**
FR4.0	The MR ***shall traverse 250 meters away from the GS*** to a specified GPS location over ***rough terrain*** defined by varying slopes and obstacles which require the MR to navigate over and around them. The MR shall return to the GS after the mission is complete.
Design Requirement	Definition
DR4.3	The MR shall ***turn 90 degrees in a 10 ft. radius***

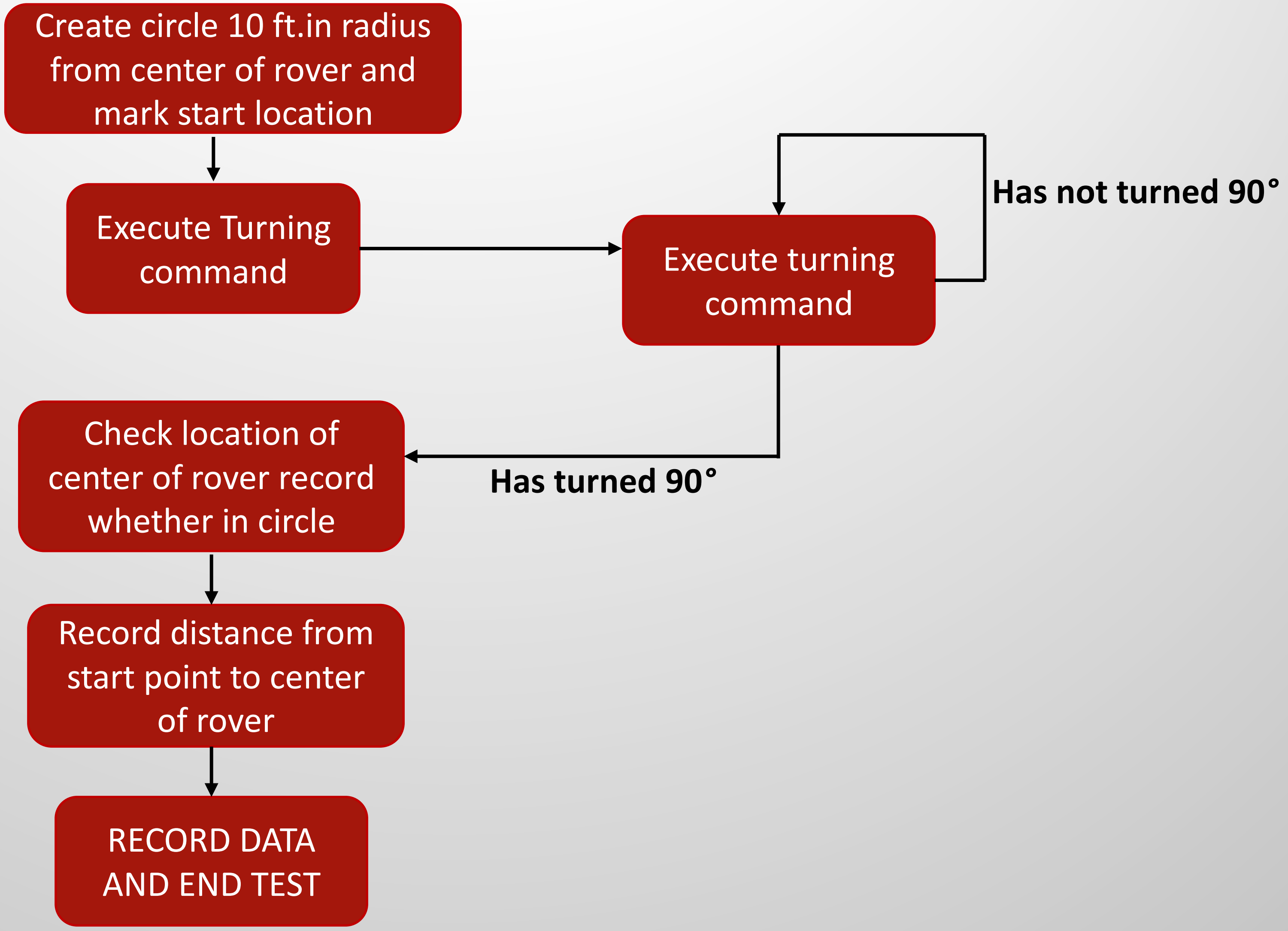
Maneuverability Test
Integrated Testing

- **Overview**
  - Verifies that rover can execute a 90 degree turn ending at most 10 ft from beginning position of the rover
- **Test Equipment**
  - Full Rover
  - Ground Station
  - Marker
  - Tape Measure
- **Results Expected**
  - Distance in between center of rover before and after 90 degree turn
- **Risk Reduction**
  - Test in clear area. Observing turn carefully and make sure no danger to rover.



Maneuverability Test

Integrated Testing



Translational System Requirements

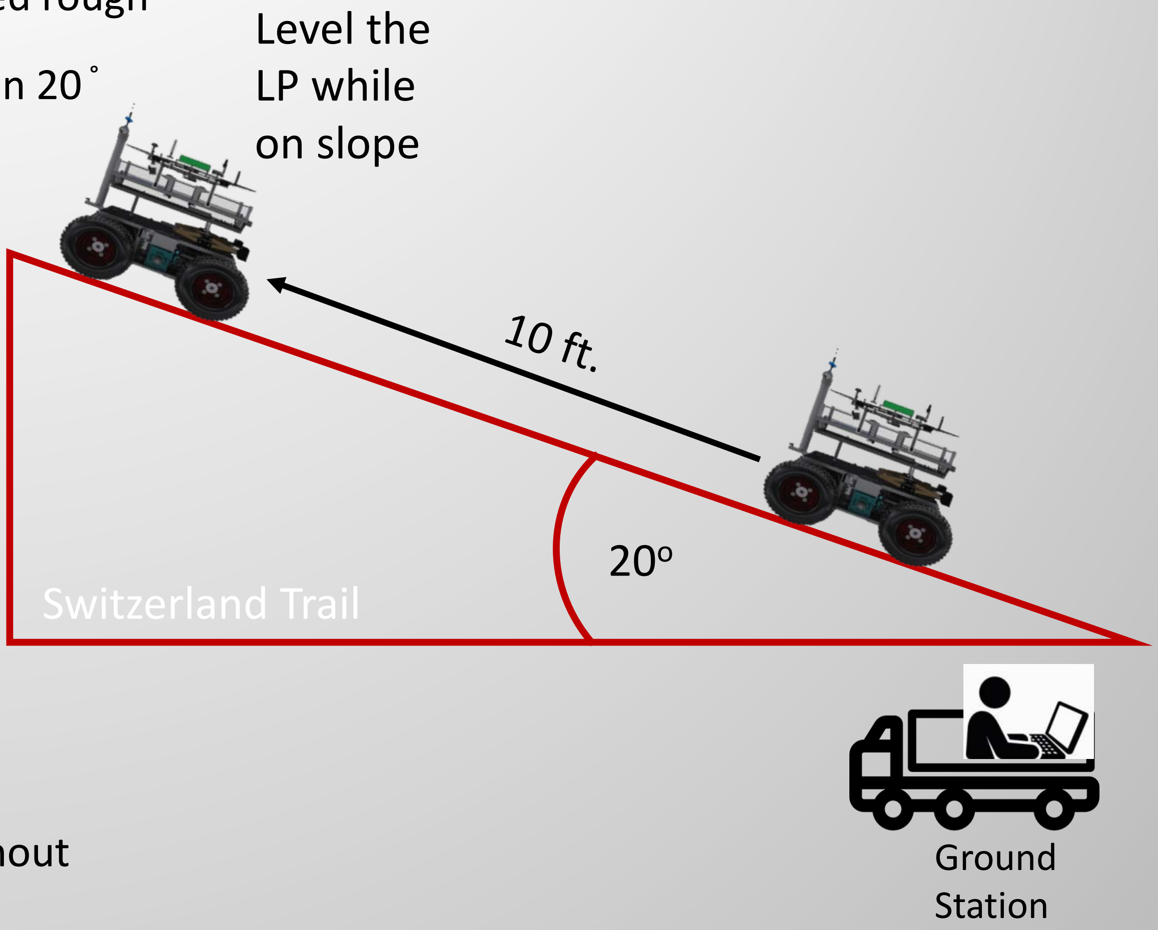
Functional Requirement	Description
FR4.0	The MR shall traverse ***250 meters away from the GS*** to a specified GPS location over ***rough terrain*** defined by varying slopes and obstacles which require the MR to navigate over and around them. The MR shall return to the GS after the mission is complete.
Design Requirement	Definition
DR4.5	The MR shall ***traverse up and down a slope of 20 degrees***.

Functional Requirement	Description
FR5.0	The MR shall position itself for the CD to take-off and land safely such that it is able to be secured by the MR's securement mechanism
Design Requirement	Definition
DR5.1	The MR ***shall level itself within 3.5 degrees after coming to a complete stop***.
DR5.2	The MR shall hold a completely stopped position on a slope of 20 degrees

Slope Capability and Leveling Test

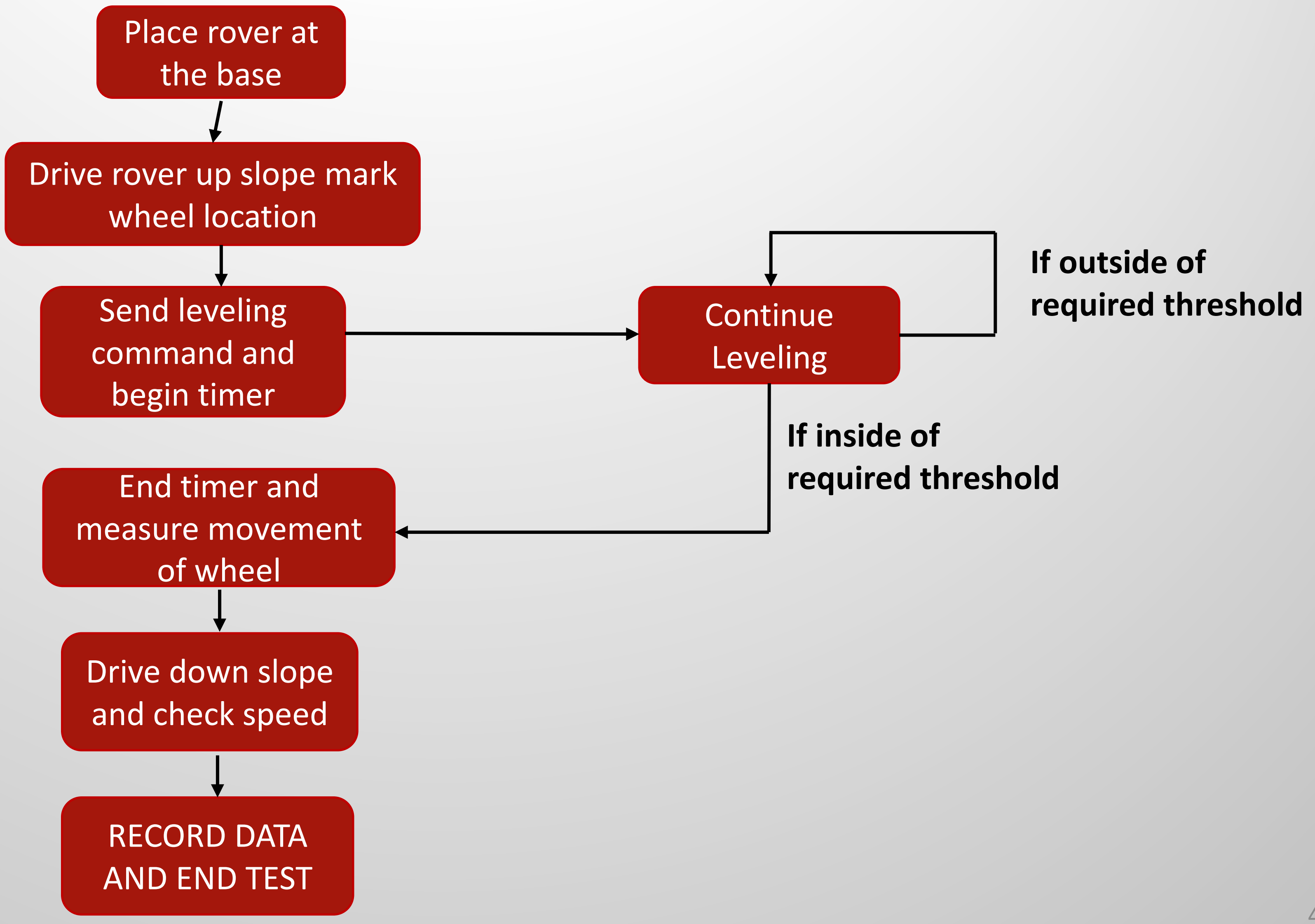
Integrated Testing

- **Overview**
  - Verifies the MR is capable of traversing a 20˚ slope up the defined rough terrain.
  - Verifies MR is capable of leveling LP within 3.5˚ when stopped on 20˚ slope
- **Test Equipment**
  - Slope of 20 degrees (Switzerland Trail)
  - Full rover
  - Ground Station
  - Tape Measure
  - Stopwatch
- **Results Expected**
  - Maximum slope capable
  - Time to level
  - Distance rover travels during leveling
  - Verification or failure of 20 degree slope
- **Risk Reduction**
  - Utilize center of gravity model to constrain maximum slope without tipping
  - Have many team members at hand in case of emergency.
  - Moniter battery for in field tests to facilitate loading and unloading.



Slope Capability and Leveling Test

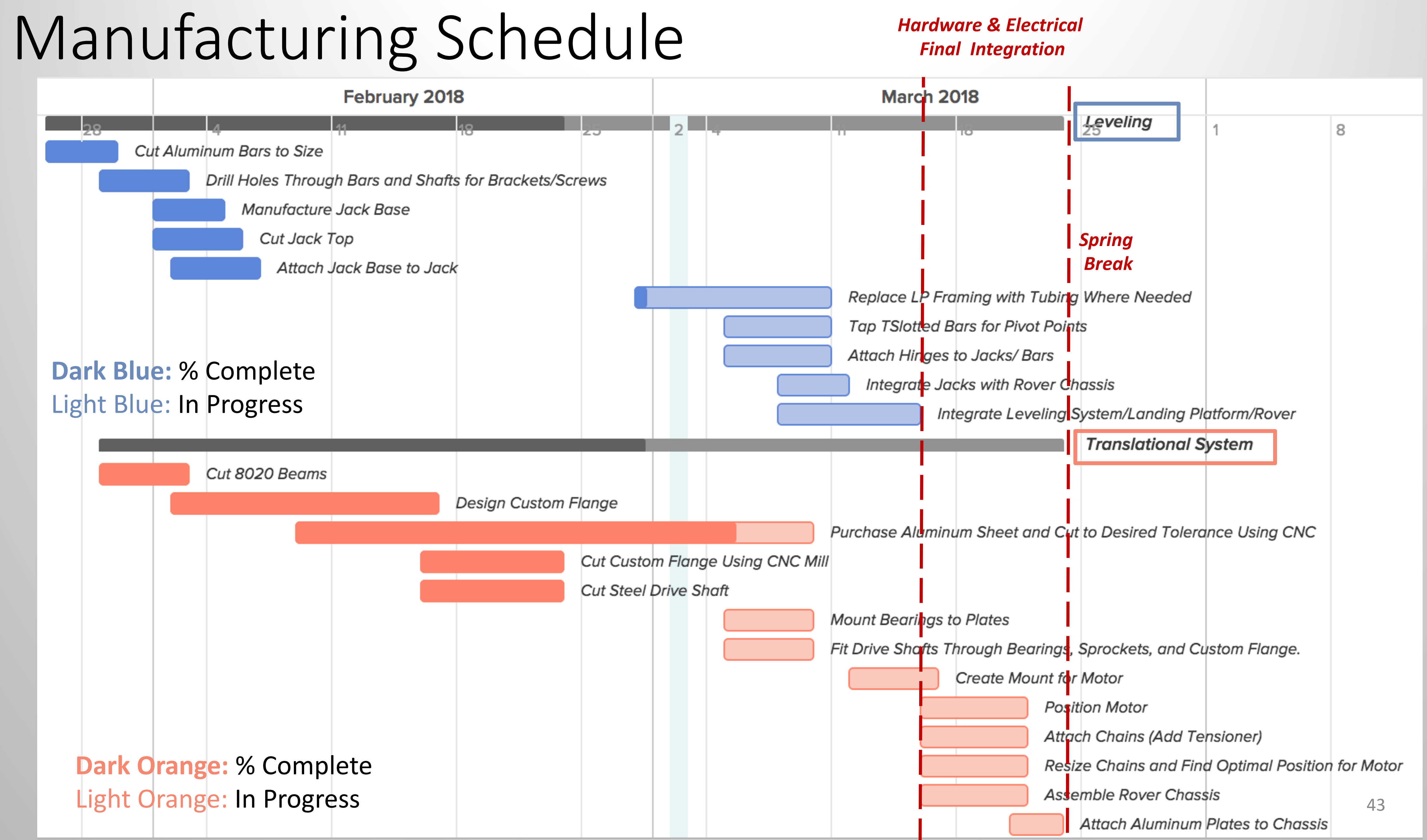
Integrated Testing



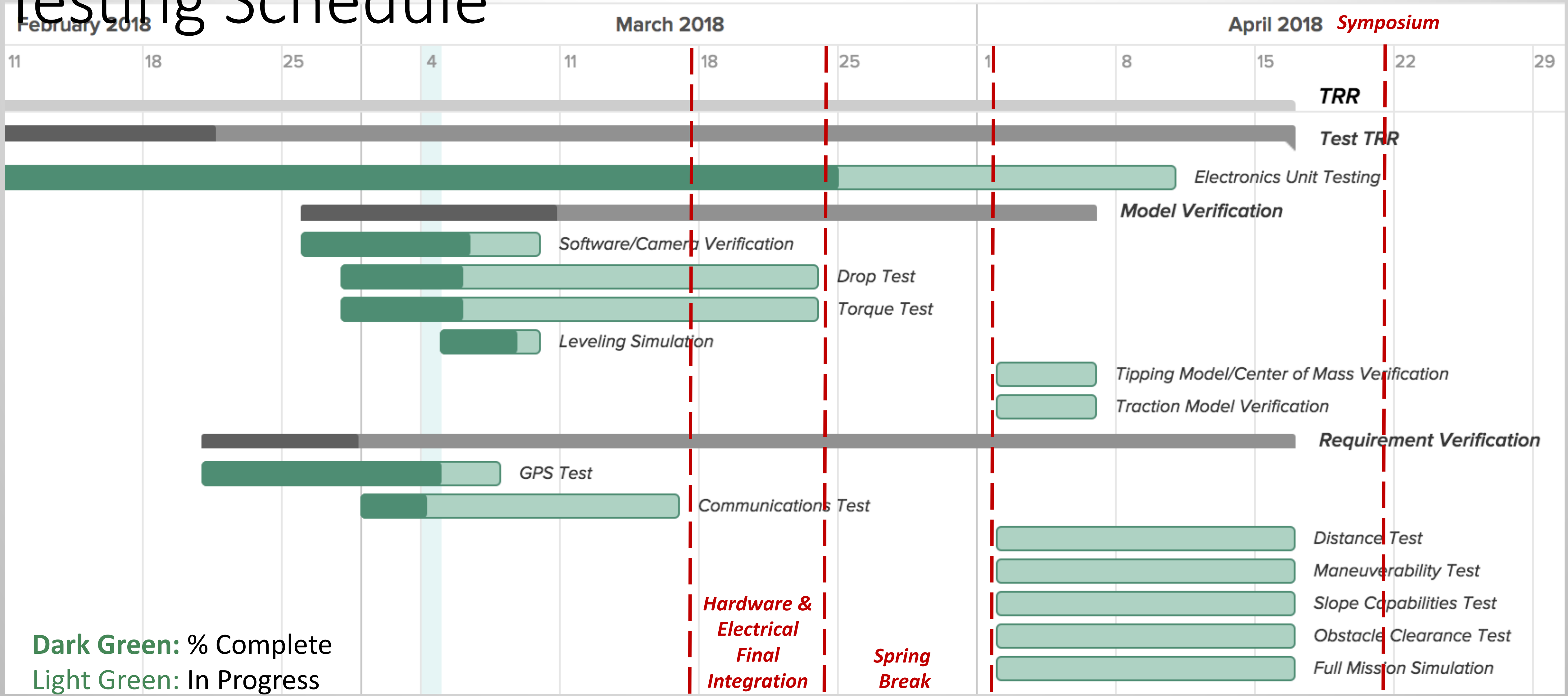
Schedule Breakdown

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

Manufacturing Schedule

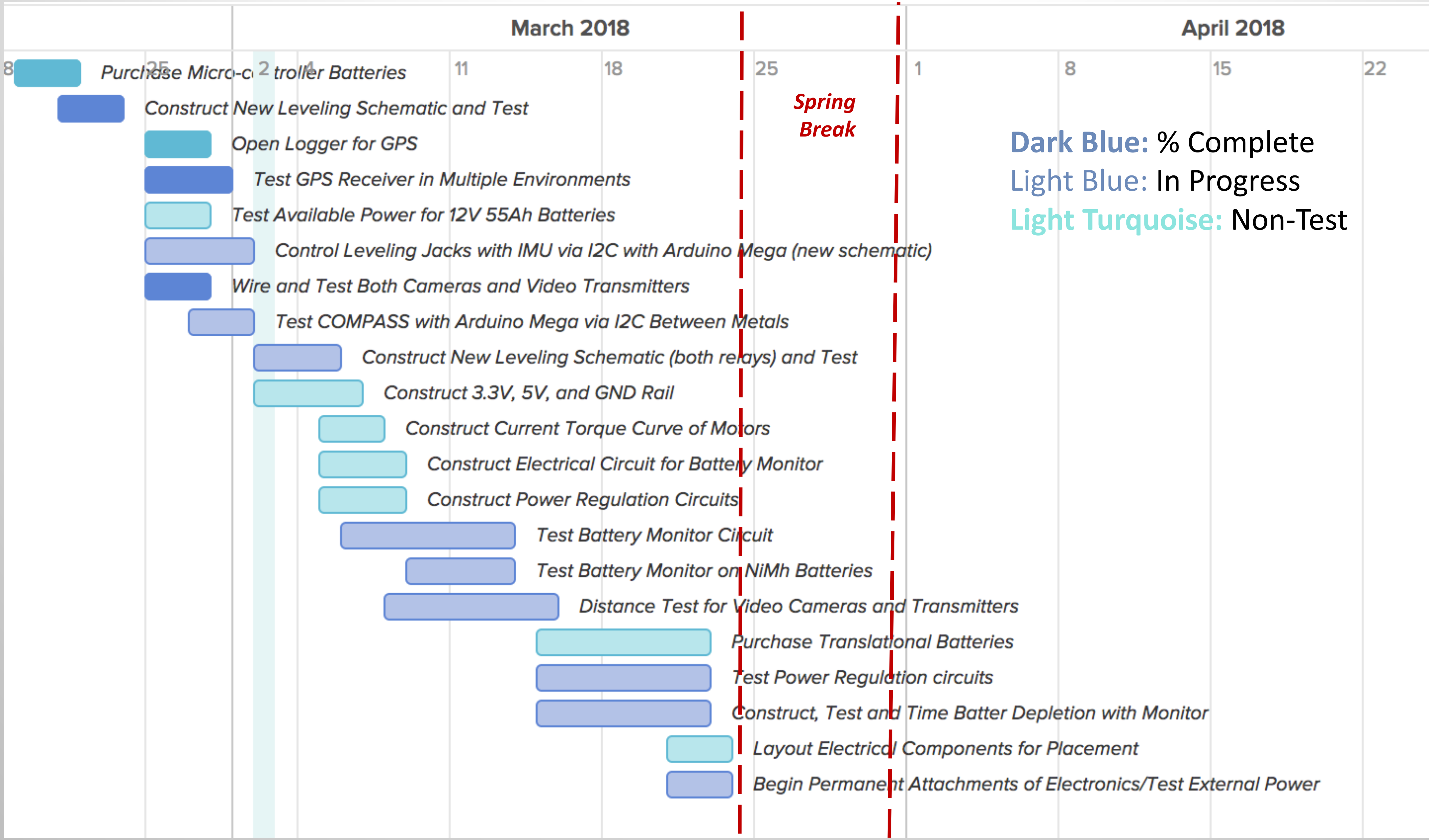


Testing Schedule



Dark Green: % Complete
Light Green: In Progress

Electrical/Software Schedule



Dark Blue: % Complete
Light Blue: In Progress
Light Turquoise: Non-Test

Financial Status Update

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

Financial Status: Subsystems Budget

What Changed?

- Communications
  - Found parts from previous years
- Leveling System
  - Change in design – reduced cost
- Translational
  - Addition of pins, connectors, shaft key, chain tensioners
  - Received metal plates for free
- Shipping
  - Developed more accurate estimates

MSR Budget

Summary	
Subsystem	**Cost**
Administrative	$150.00
Communications	$193.59
Electronics	$525.36
Leveling	$439.08
Shipping	$370.43
Testing	$100.00
Translational	$3,058.23
Budget	**$5,000.00**
Total Cost	**$4,836.69**
Margin	**$163.31**

TRR Budget

Summary	
Subsystem	**Cost**
Administrative	$150.00
Communications	$151.76
Electronics	$523.70
Leveling	$273.83
Shipping	$396.81
Testing	$100.00
Translational	$3,081.54
Budget	**$5,000.00**
Total Cost	**$4,677.64**
Margin	**$322.36**

Amount Spent: $3,375.88

Financial Status: Major Component Procurement

Arrived (3/2/2018)

- 2 Bison Gear Motors
- 2 American Control Motor Drivers
- Rover Raw Materials
- 2 Leveling Jacks
- Arduino Mega Microcontroller
- Wheels, Tires, Bearings
- 2 Cameras
- Aluminum Plates

En Route

- 2 Xbee Pros

Planned

- Leveling Raw Materials
- Chains, connectors, tensioners
- Electronics connections

EEF (3/15/2018)

- 2 12V 100 Ah Batteries
- Backup components
- Indoor testing components
- Additional allocation to printing posters/reports

Major components to be purchased by March 9

EEF components to be purchased by March 22

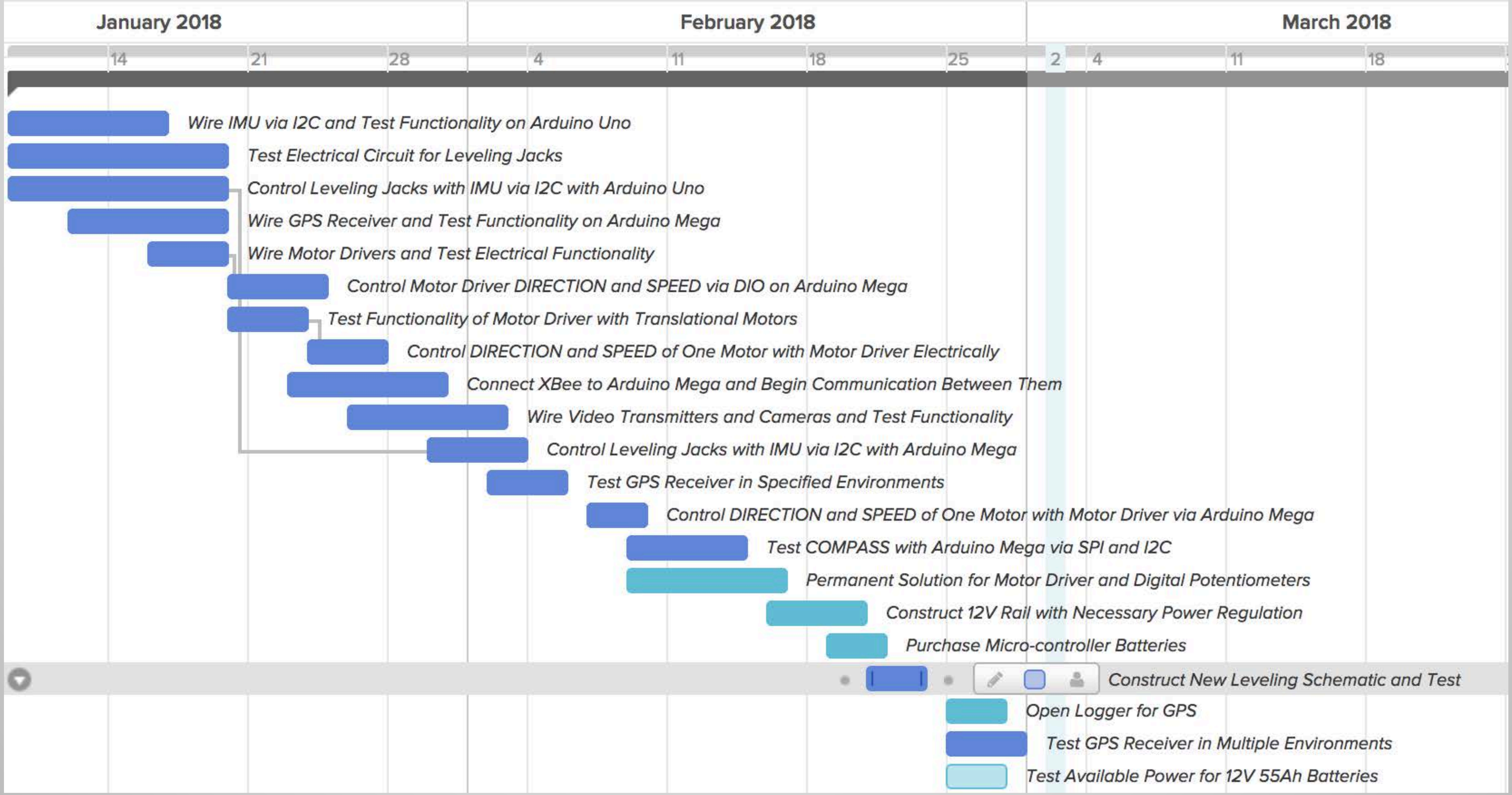
Conclusion

- Changes from MSR
  - Leveling System Modifications
- Schedule
  - Unit Testing for Electrical/Software 85% Complete
  - Manufacturing and Integration of subsystem parts will be completed by March 23rd
  - Integrated Testing will begin on April

Questions?

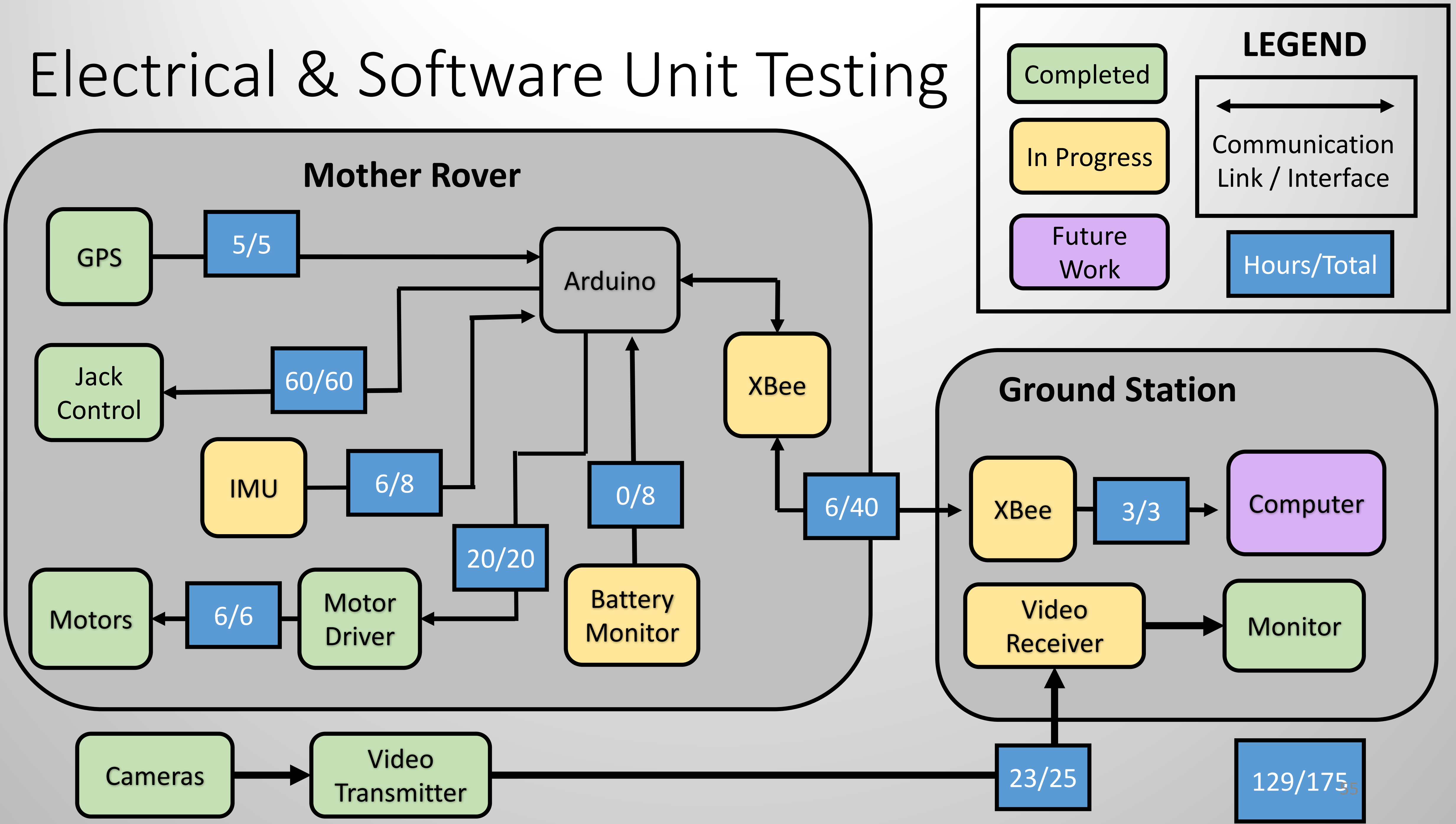
Backup Slides

Schedule Backup

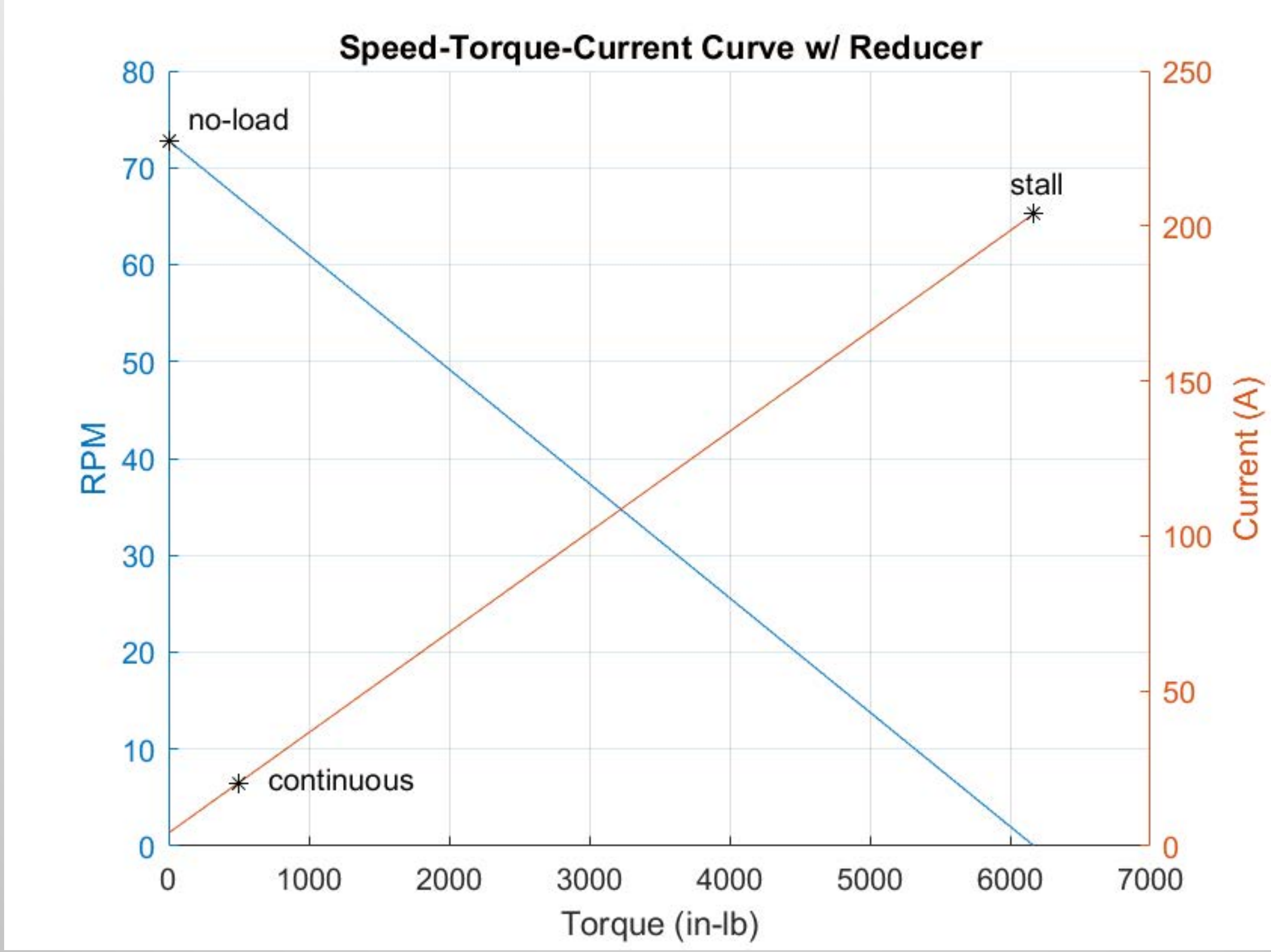

January 2018
February 2018
March 2018
14
21
28
4
11
18
25
2
4
11
18
Wire IMU via I2C and Test Functionality on Arduino Uno
Test Electrical Circuit for Leveling Jacks
Control Leveling Jacks with IMU via I2C with Arduino Uno
Wire GPS Receiver and Test Functionality on Arduino Mega
Wire Motor Drivers and Test Electrical Functionality
Control Motor Driver DIRECTION and SPEED via DIO on Arduino Mega
Test Functionality of Motor Driver with Translational Motors
Control DIRECTION and SPEED of One Motor with Motor Driver Electrically
Connect XBee to Arduino Mega and Begin Communication Between Them
Wire Video Transmitters and Cameras and Test Functionality
Control Leveling Jacks with IMU via I2C with Arduino Mega
Test GPS Receiver in Specified Environments
Control DIRECTION and SPEED of One Motor with Motor Driver via Arduino Mega
Test COMPASS with Arduino Mega via SPI and I2C
Permanent Solution for Motor Driver and Digital Potentiometers
Construct 12V Rail with Necessary Power Regulation
Purchase Micro-controller Batteries
Construct New Leveling Schematic and Test
Open Logger for GPS
Test GPS Receiver in Multiple Environments
Test Available Power for 12V 55Ah Batteries

Electrical & Software Backup

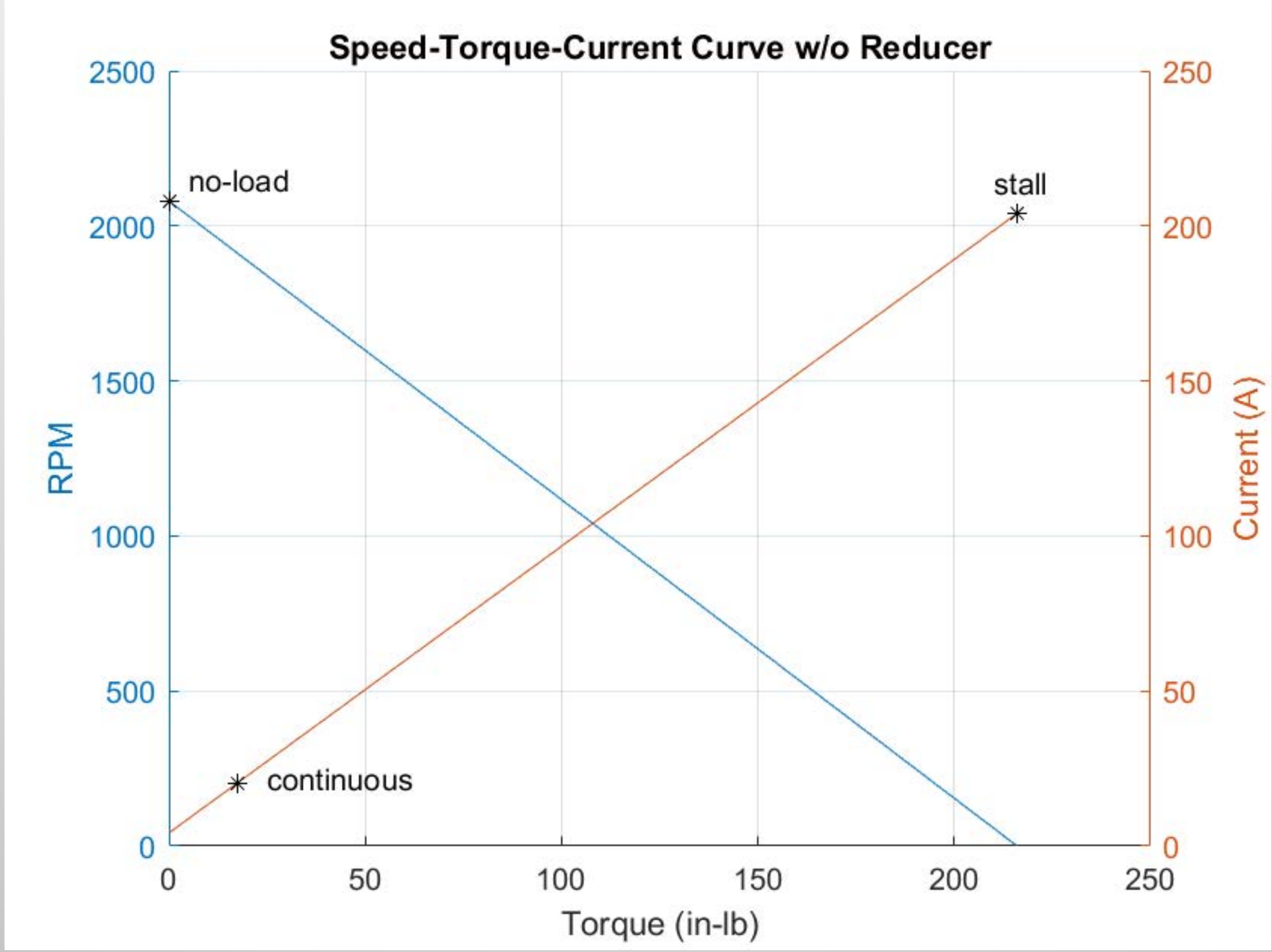
Electrical & Software Unit Testing



Speed Torque Curve With Reducer



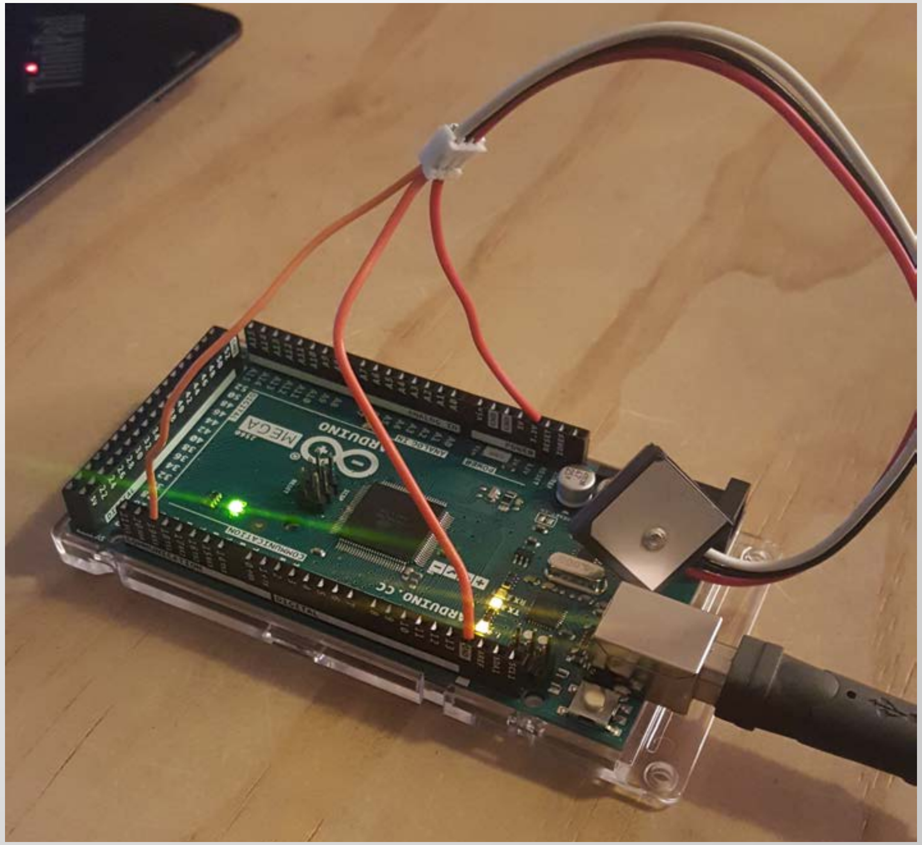
Speed Torque Curve Without Reducer



GPS Test

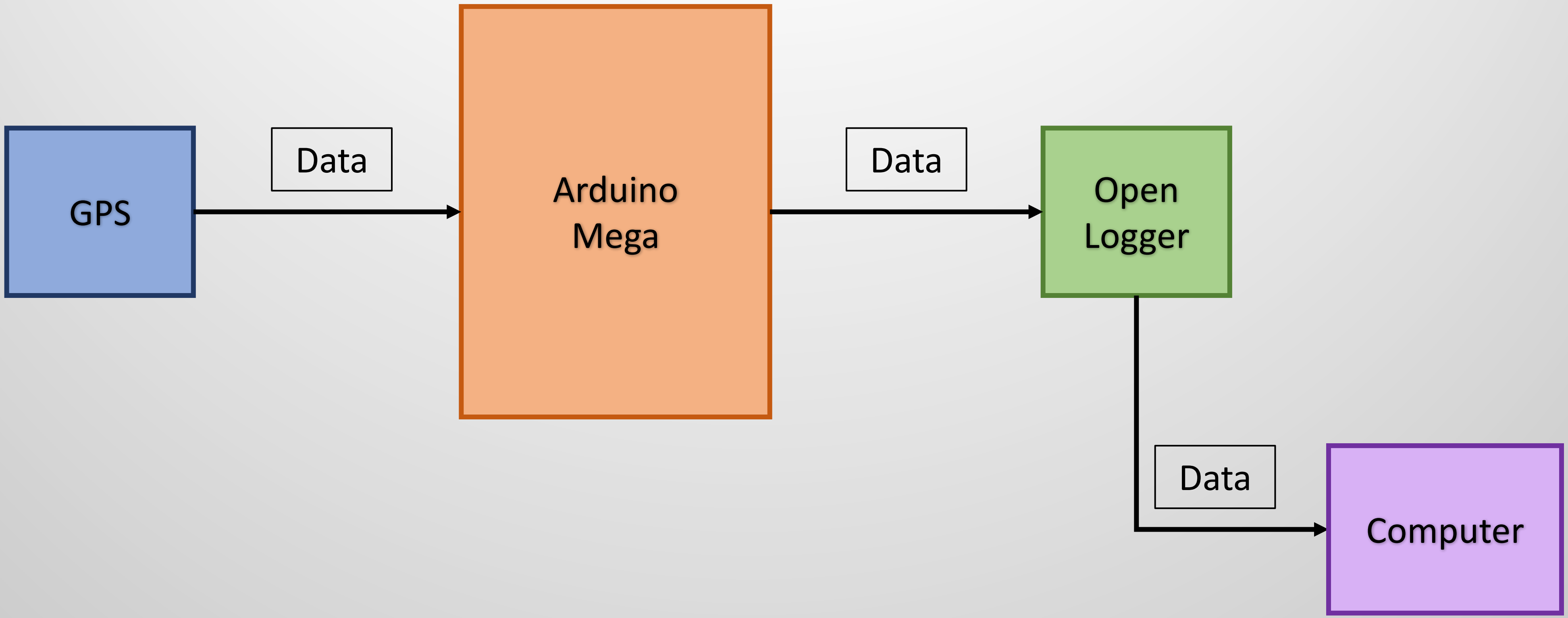
Software and Electronics Testing

- **Overview**
  - Verify the positional accuracy of the GPS including when it is surrounded by metals
- **Test Equipment**
  - GP20U7
  - Open Logger – DEV-13712
  - Arduino Mega
  - 2 GB microSD Card
  - microSD Card Adapter
- **Risk Reduction**



GPS Test

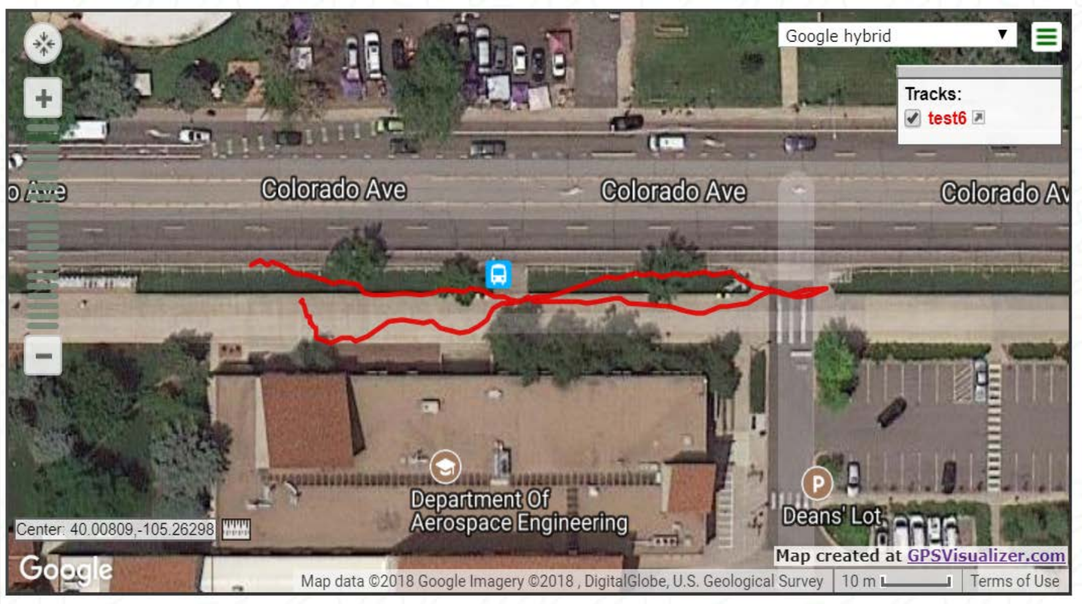
Software and Electronics Testing



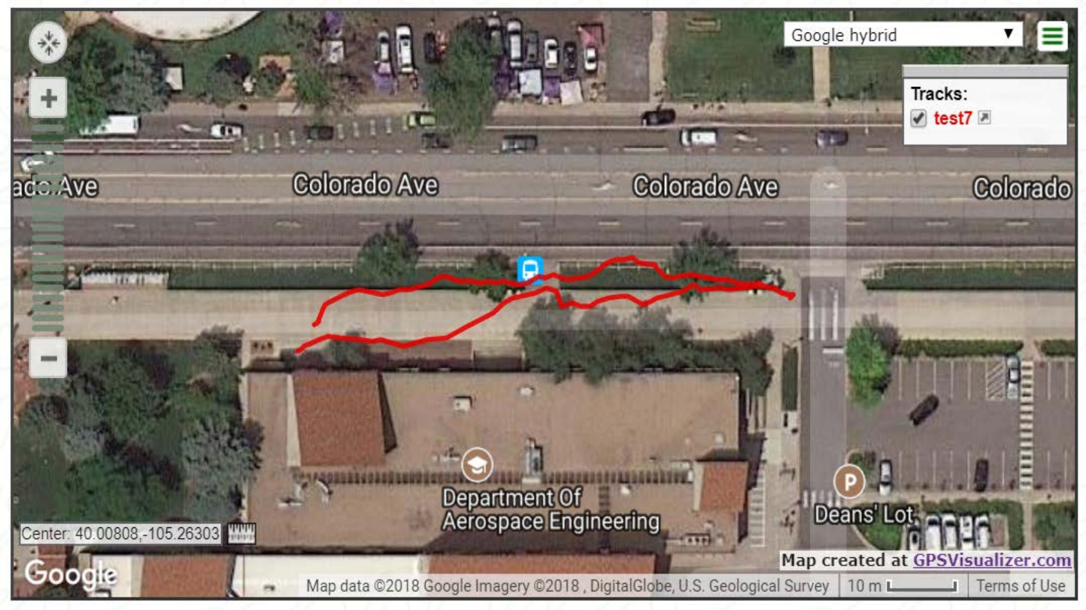
GPS Functionality & Metals Test 2/26/2018

Purpose	This test serves to provide evidence for whether or not metals affect the GPS readings from the GP20U7
Results	**SUCCESS** – metal does not produce significant changes in GPS readings

Test: No Metal



Test: Metal



GPS Testing

Integrated Testing

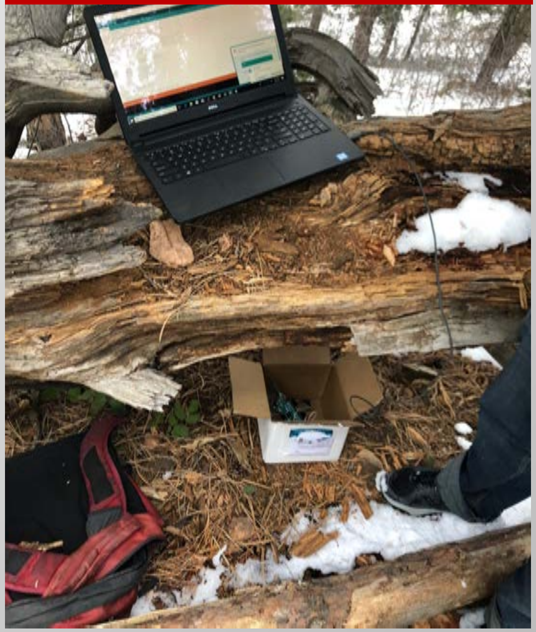
- Conducted on February 28th 2018
- Collected 4 sets of 5-10 minute data sets
  - Known GPS location (40°00'00.3"N 105°15'41.0"W)
  - Open Space
  - Approximately Mission Defined (Trees 10 ft apart)
  - Greater Interference than Mission Defined. Denser forest and under a log.
- Find Accuracy with known GPS then find how forest environment effected GPS readings.
- Attempt to Verify DR 3.1 (GPS accuracy of 5 m. in mission environment)

Known Location

Open Space

Mission Analog

Greater Interference



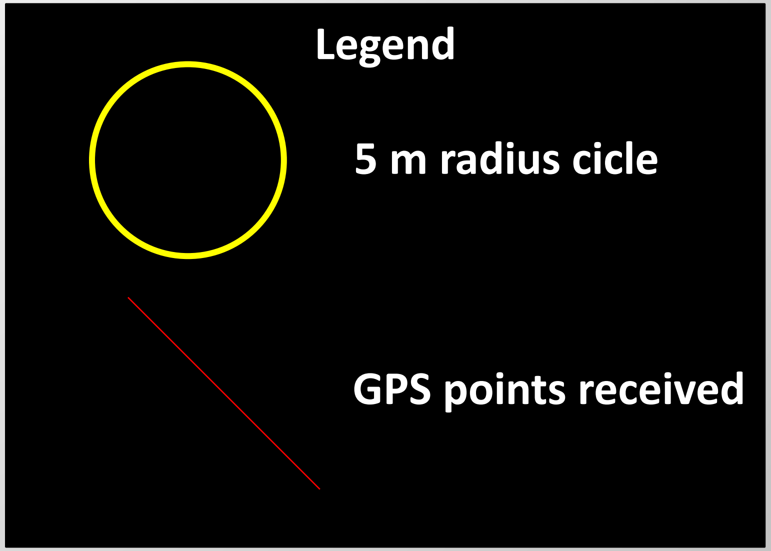
GPS Testing

Integrated Testing

- Initial Data Analysis – Use a GPS plotter and construct a 5 m circle to find points variation with respect to the requirement
- High percentage of confidence in mission GPS being within 5 m of actual.
  - Will perform more analysis to quantify this confidence

Known Location

Mission Simulated



Open Space

High Density Environment

Camera Testing

Software and Electronics Testing
Requirements Verified

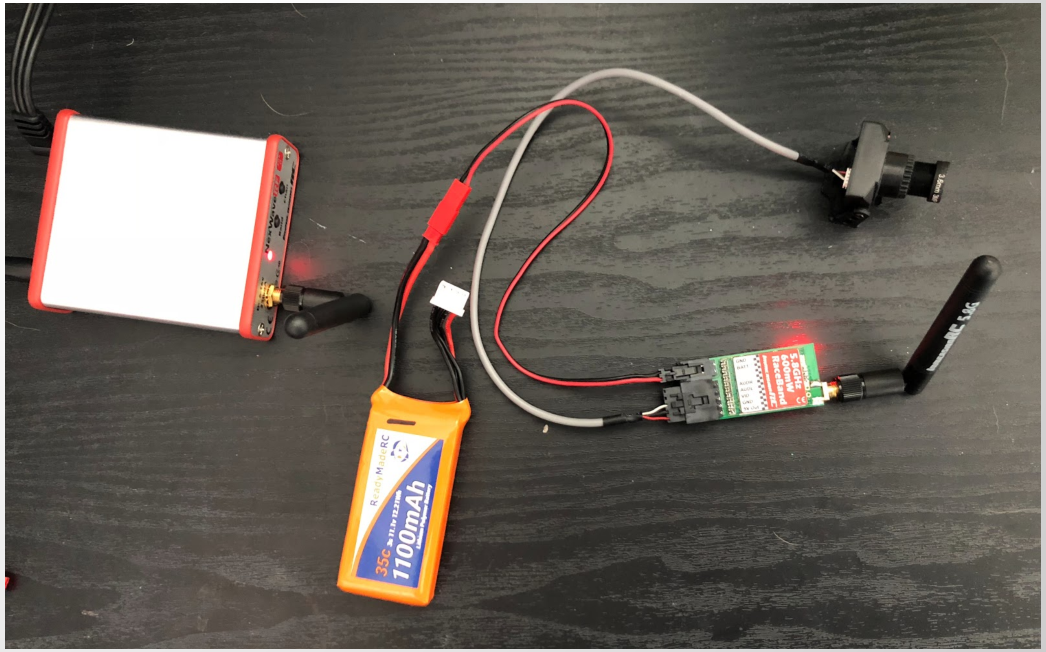
Functional Requirement	Description
FR3.0	The MR shall ***transmit data to the GS at a rate of 30 HZ***.
DR3.2	The MR Shall Transmit ***Live Video Feed*** at 1080p at 30 fps. Validation and Verification:

Camera Testing

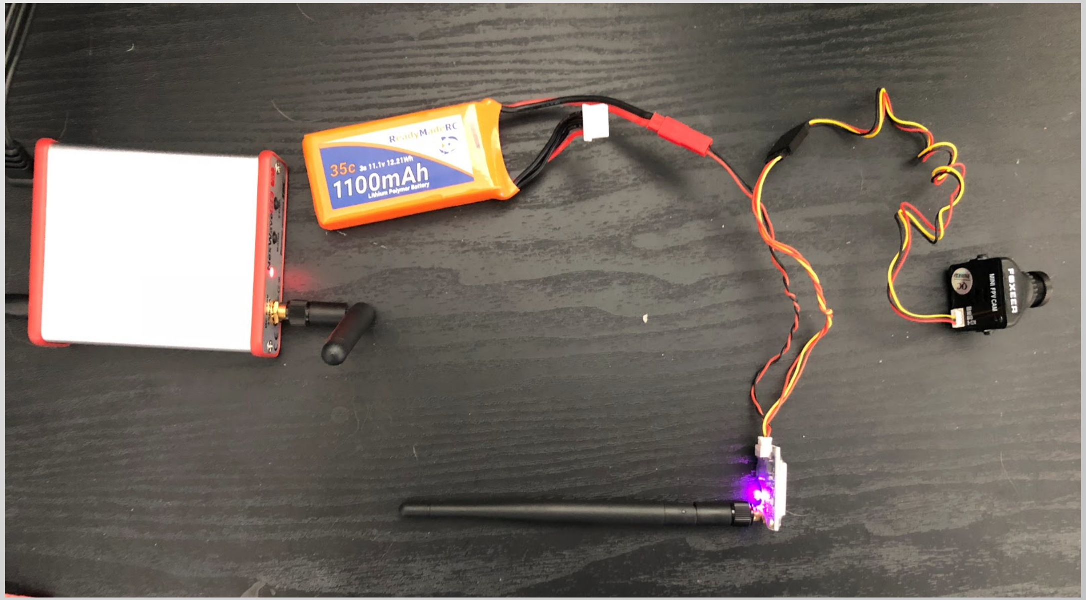
Software & Electronics Testing

- **Overview**
  - Two cameras used for MR navigation
  - Live video transmitted from MR to GS
- **Test Equipment**
  - 900 TVL WDR **FatShark Camera**
  - Foxeer HS1177 V2 2.8mm **Mini FPV Camera**
  - Two **5.8 GHz Transmitters**
  - 3 **5.8 GHz Antennas**
  - NexWave RF **Receiver**
  - **Monitor** with AV Connection
- **Risk Reduction**

FatShark Camera

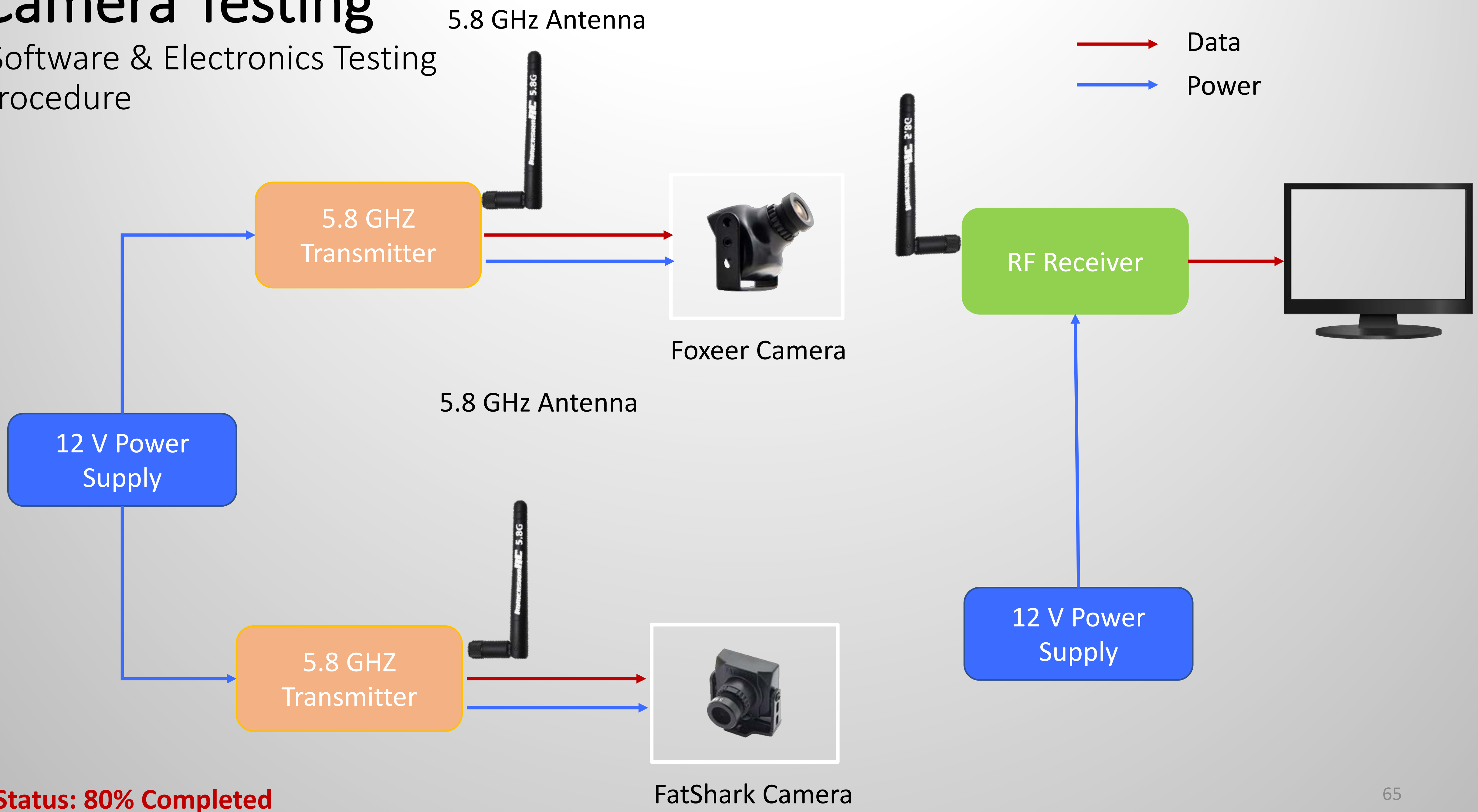


Foxeer Camera



Camera Testing

Software & Electronics Testing Procedure



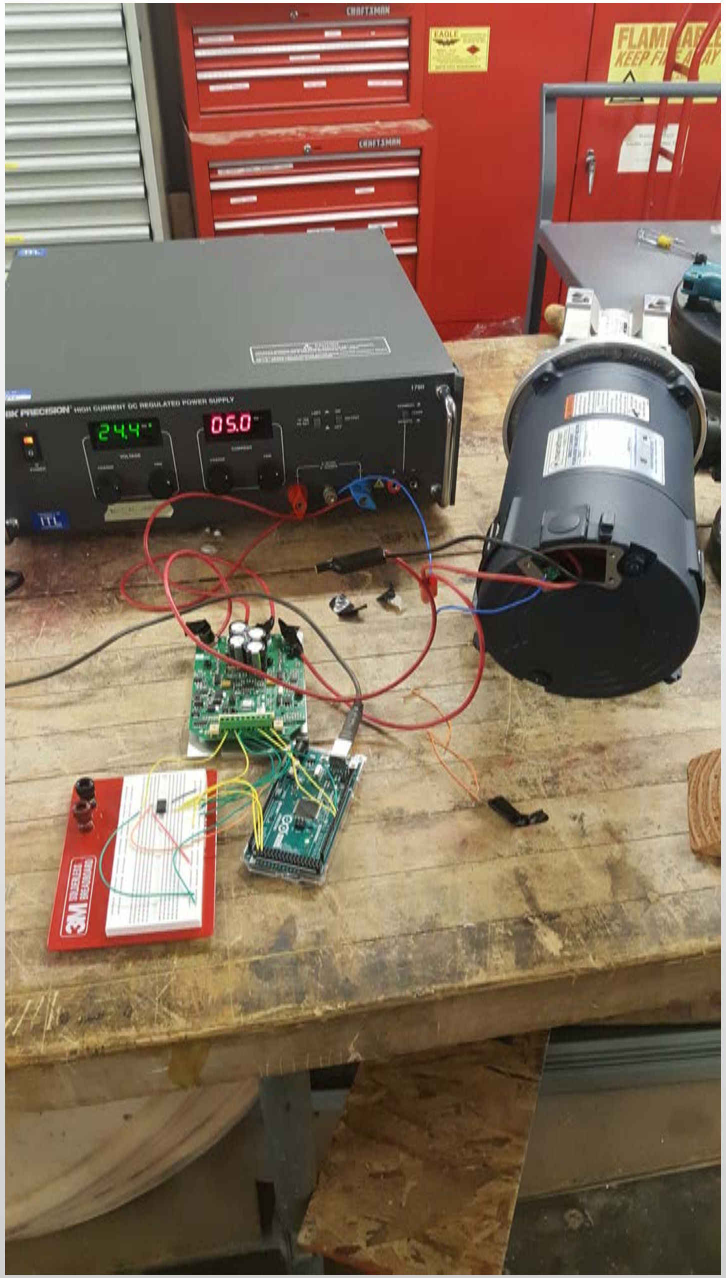
Status: 80% Completed

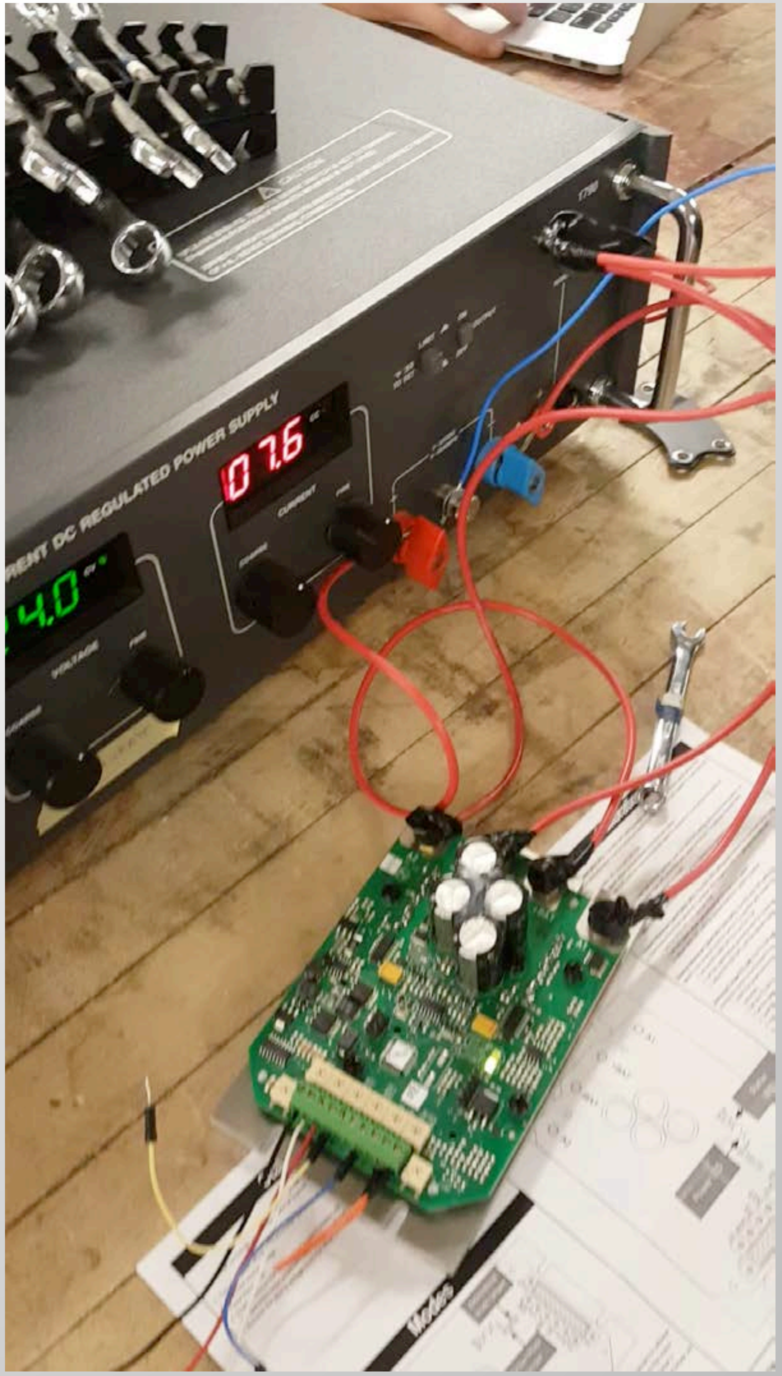
Motor Driver Testing Breakdown

Date	Test
01/22/2018	Motor Driver Electrical Functionality Test
01/22/2018	Motor Driver Command Test
01/23/2018	Motor Driver – Motor Integration Test
02/05/2018	Digital Pot Functionality Test
02/06/2018	Motor Driver, Motor, and Digital Potentiometer Test
02/09/2018	Motor Driver, Motor Commands Test
02/19/2018	Two Permanently Circuited Digital Potentiometers with Motors and Motor Drivers Test

Motor Driver Functionality Test 1/22/2018

Purpose	Test the electrical functionality of the motor drivers at 12V with a small motor.
Results	**SUCCESS** – can begin programming the Arduino Mega to control the motor driver.





Battery Depletion

Software and Electronics Testing Requirements Verified

Rough Terrain

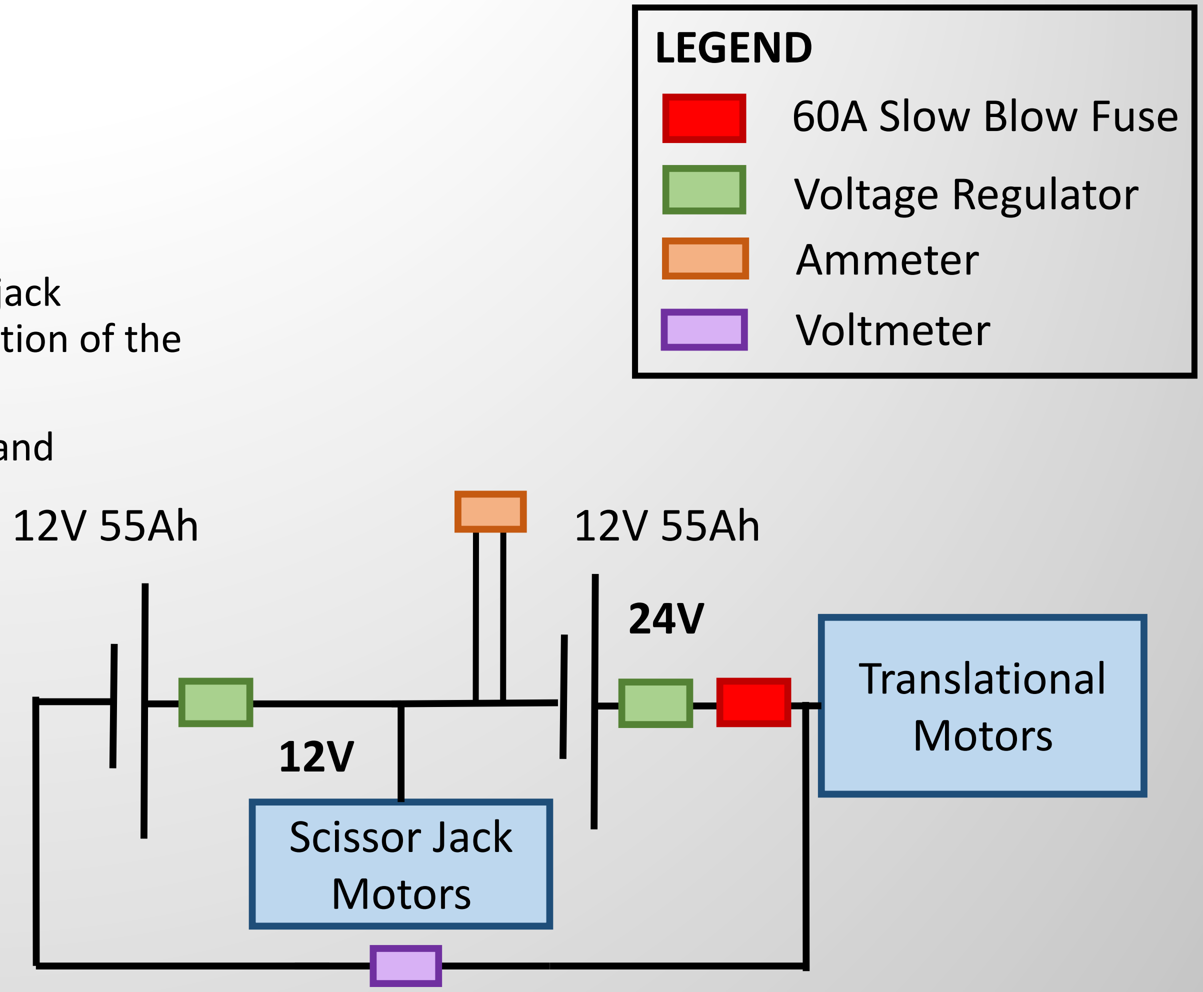
- Materials: lawn grass, small gravel, and fine dirt
- Varying slopes from 0 to 20^0
- Traversable obstacles up to 5 in tall
- Non-traversble obstacles at least 10 feet apart.

Functional Requirement	Description
FR4.0	The MR shall traverse over rough terrain up to 250 meters away from the GS to a specified location of interest.
DR4.1	The MR shall travel at a speed within the range of 0 to 0.5 m/s in forward and reverse.
DR4.2.1	***The batteries shall provide enough power to the motors*** such that the MR is able to traverse the defined rough terrain
DR4.5	The MR shall traverse up and down a 20^0 slope.
DR4.5.1	The MR ***motors shall provide enough torque*** to traverse up and down the defined slope.

Battery Depletion

Software & Electronics Testing

- **Overview**
  - To provide evidence that the translational motors and scissor jack motor(s) will be delivered enough power throughout the duration of the mission
  - Verify current draw from motors by applying loads to motors and measuring current draw and remaining battery voltage
- **Test Equipment**
  - Marathon Electric DC Brushed **Motor**
  - **Scissor Jack Motor(s)**
  - **12V 55/100Ah Batteries**
  - **Battery Monitor**
  - **Voltmeter**
  - **Ammeter**
- **Results Expected**
  - The 12V 55Ah batteries borrowed will not provide sufficient power for the expected duration of the mission
  - If EEF funding is received, the 12V 100Ah batteries will be purchased and will undergo the same test
- **Risk Reduction**
  - Implementing a battery monitor to calculate battery voltage



Model Verification Backup

COG

o Overview

- o Locate the center of gravity of the rover in all 3- axis by taking weight experienced on 4 scales once all that the same level and again with two scales elevated.
- o Re-execute the tipping analysis to find the maximum slope the rover can overcome without tipping

o Test Equipment

- o 4 Scales
- o Fully Constructed Rover with Child Drone

o Results Expected

- o Center of Gravity of Rover
- o Maximum slope before tipping

o Risk Reduction

- o Verify security of rover at all stages

$$W_F = W_{FR} + W_{FL}$$

$$W_B = W_{BR} + W_{BL}$$

$$W_R = W_{FR} + W_{BR}$$

$$W_L = W_{FL} + W_{BL}$$

$$W_T = W_F + W_B$$

$$x_{cg} = \frac{W_F}{W_T} * d_{wheelbase}$$

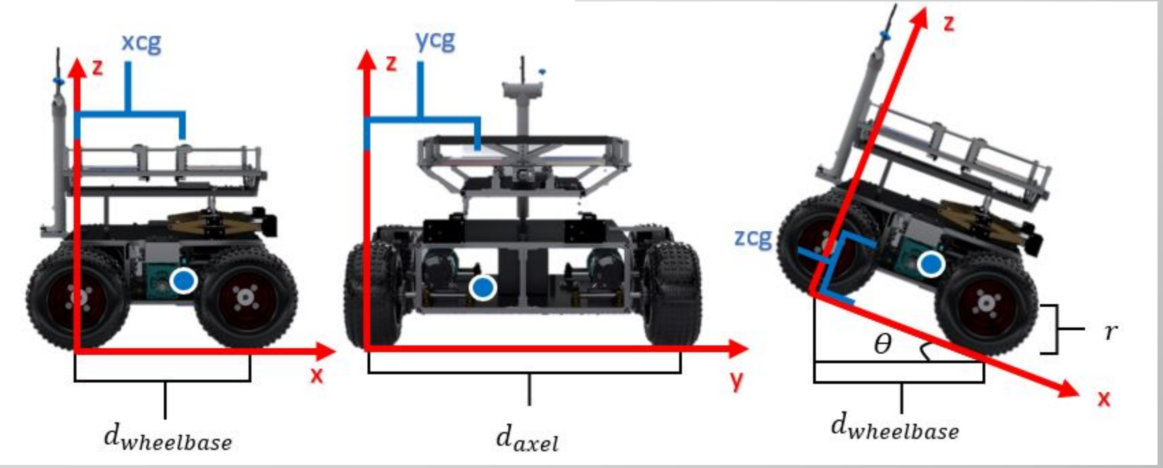
$$y_{cg} = \frac{W_R}{W_T} * d_{axel}$$

$$W_{F2} = W_{FR2} + W_{FL2}$$

$$W_{B2} = W_{BR2} + W_{BL2}$$

$$W_{T2} = W_{F2} + W_{B2}$$

$$z_{cg} = \left[x_{cg} d_{wheelbase} \frac{R_{f2}}{W_3} \right] cot(\theta) + r$$



Friction

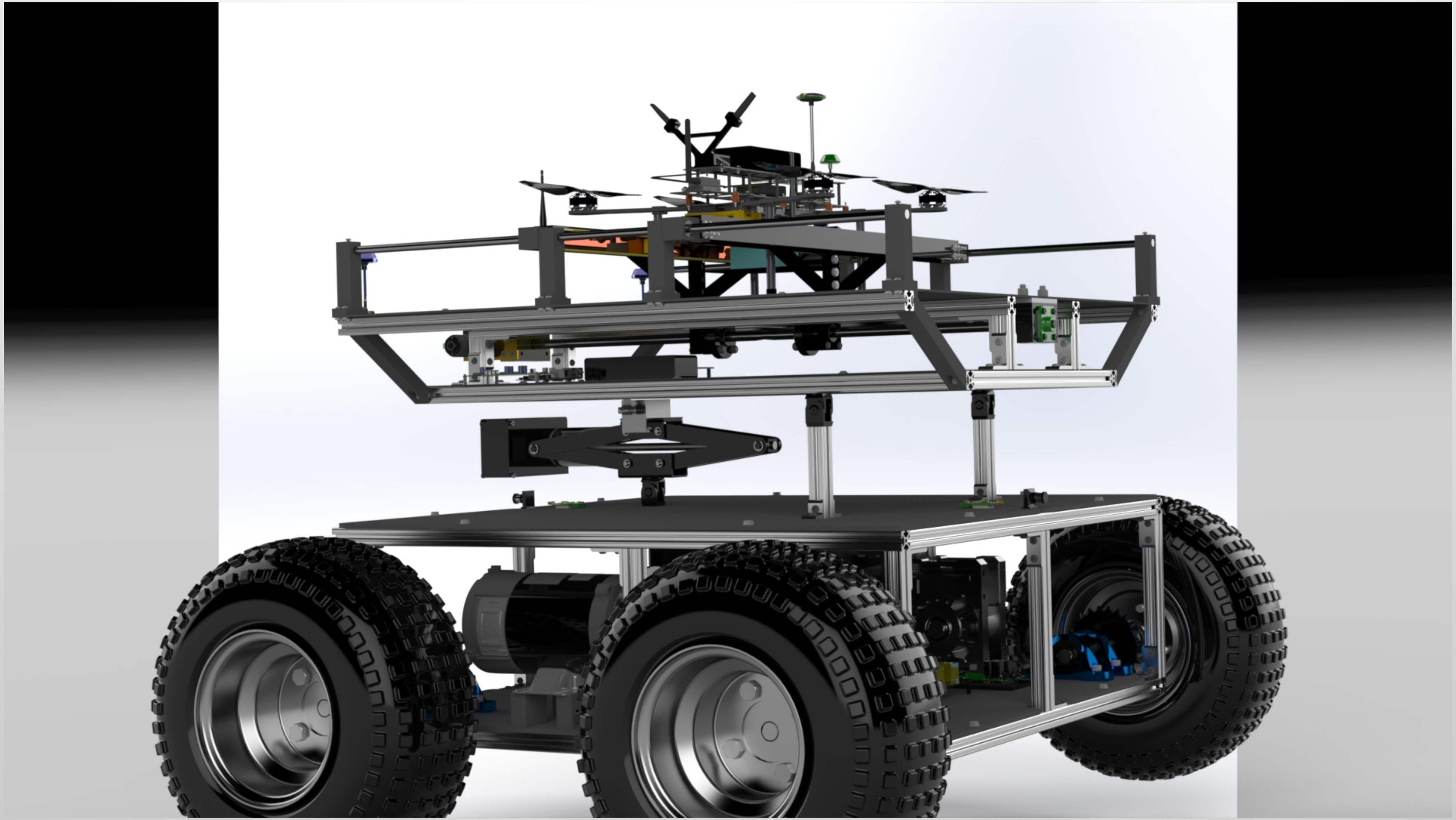
- **Overview**
  - Find coefficient of friction and compare to model.
  - Push rover until it moves while recording force and use force and weight to find coefficient of friction
- **Test Equipment**
  - Two scales
  - Rover
  - Teammates
- **Results Expected**
  - Coefficient of Friction to verify torque model
- **Risk Reduction**
  - Only using strengthened areas of rover for pushing

Leveling Simulation
Model Validation

- **Overview**
  - Verifies the dynamics of the leveling system with two small scale models
- **Test Equipment**
  - T-slotted framing to function as scissor jacks
  - Plywood
  - Miniature U-joints
  - Ball Joints
  - Springs
  - Hinges
- **Results Expected**
  - The simulation is expected to demonstrate the dynamics of the leveling system prior to complete construction, allowing for the determination of which finalized system to use.
- **Risk Reduction**
  - No risks to project

1-D System Model

Spring-supported system model



Software

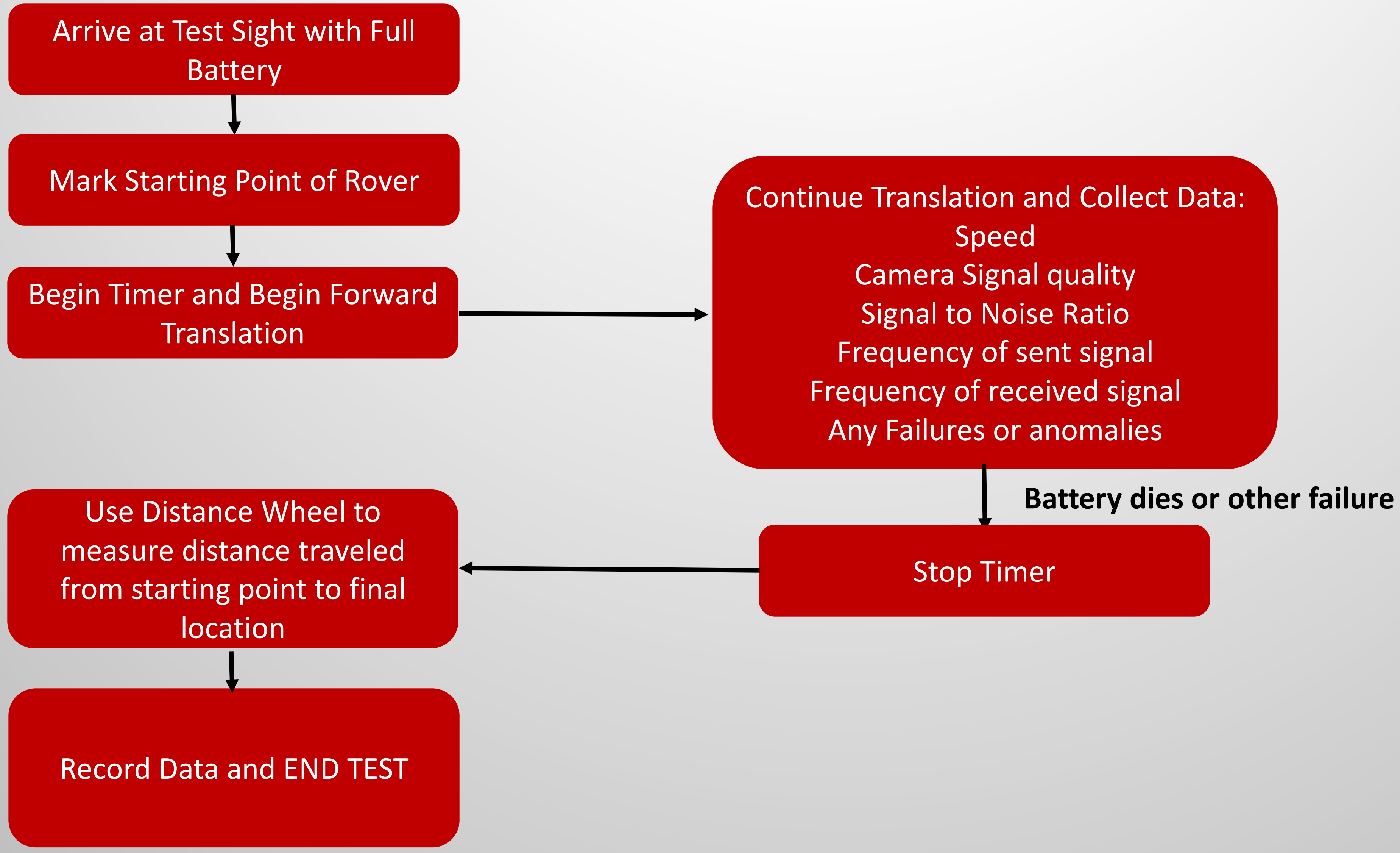
- **Overview**
  - Send the entire control scheme to the rover and verify each command is executed properly
    - Forward
    - Reverse
    - Turning
    - Leveling
    - Camera control
- **Test Equipment**
  - Rover
  - Ground Station
- **Results Expected**
  - Execution of all commands
- **Risk Reduction**
  - Conduct inside with GS near rover to not have to move rover and maximize testing window.

Integrated Testing Backup

Distance/Battery Capability Test

- **Overview**
  - Measure distance the rover can traverse on the specified terrain with a full battery.
  - Requirement 500m total capability
- **Test Equipment**
  - Distance measurement tool
  - Full Rover
  - Full Communication Suite
- **Results Expected**
  - Distance capable on full battery
  - Speed
- **Risk Reduction**
  - Make sure battery can be charged or replaced to return

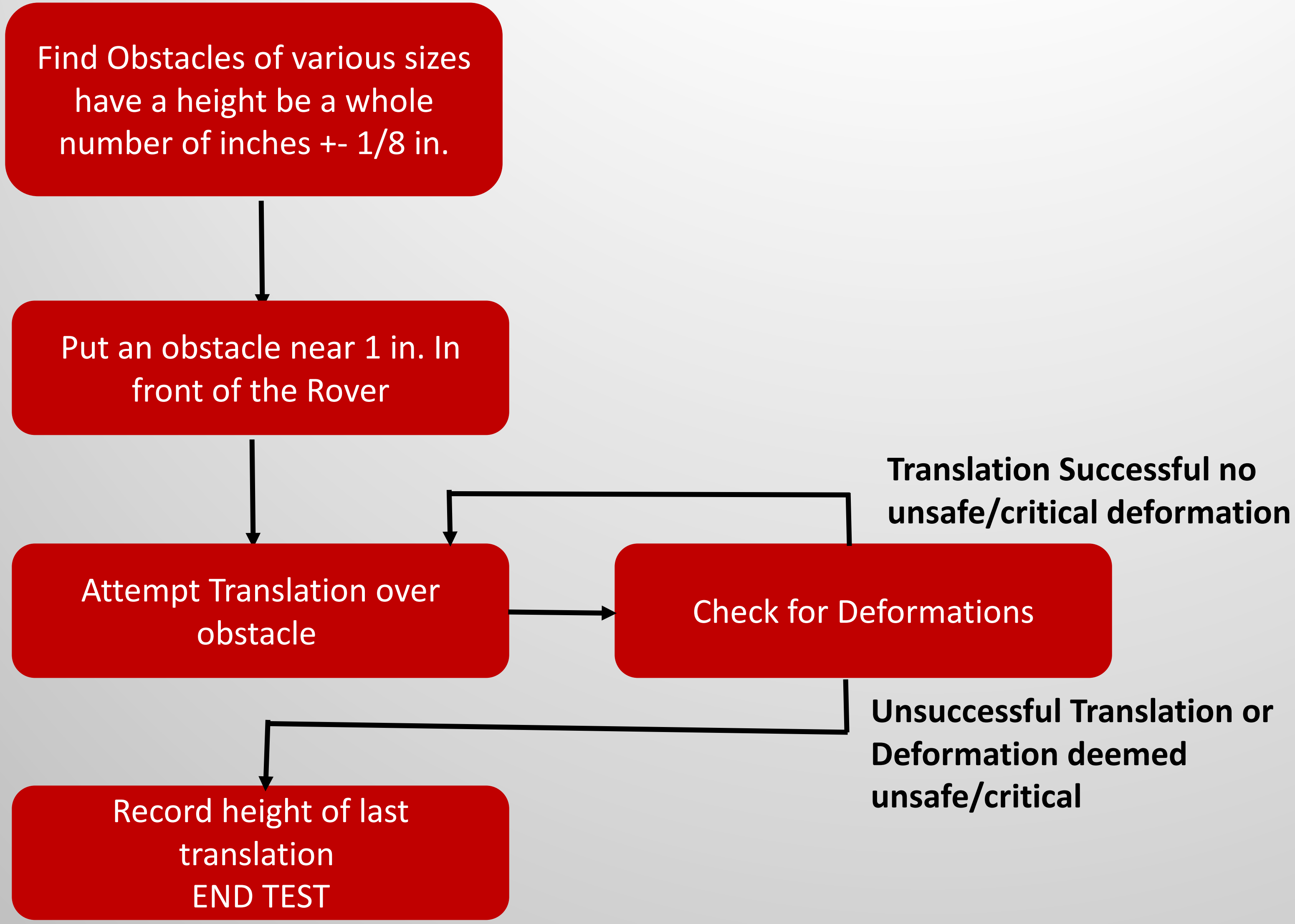
Distance Battery Capability Test



Obstacle Clearance

- **Overview**
  - Verify that the rover can overcome 5 in. Obstacles
  - Find the maximum height obstacle the rover can achieve.
- **Test Equipment**
  - Various height objects
  - Full Rover
  - Full Communication Suite
- **Results Expected**
  - Maximum obstacle height achievable
- **Risk Reduction**
  - Construction of a drop test with solid works
  - Check for deformations on rover after each obstacle

Obstacle Clearance



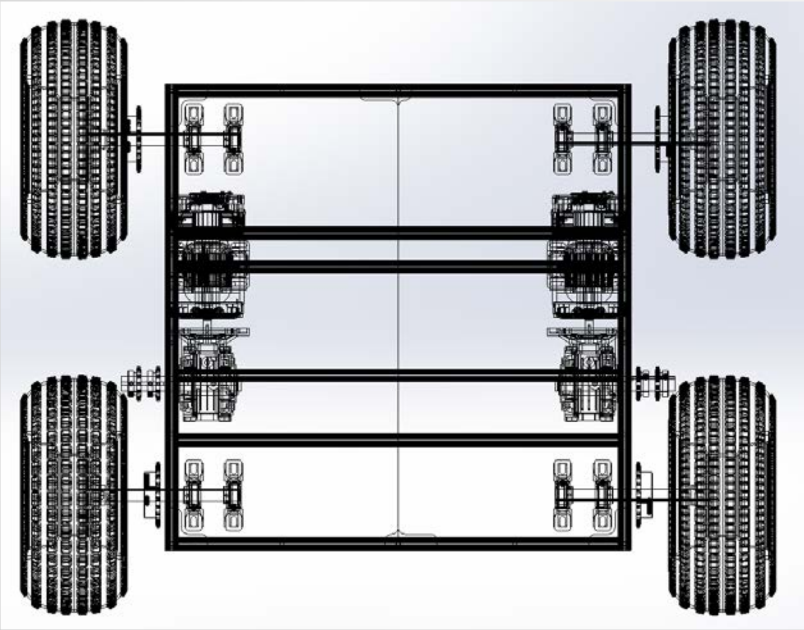
Full Mission Simulation (Time Permitting)

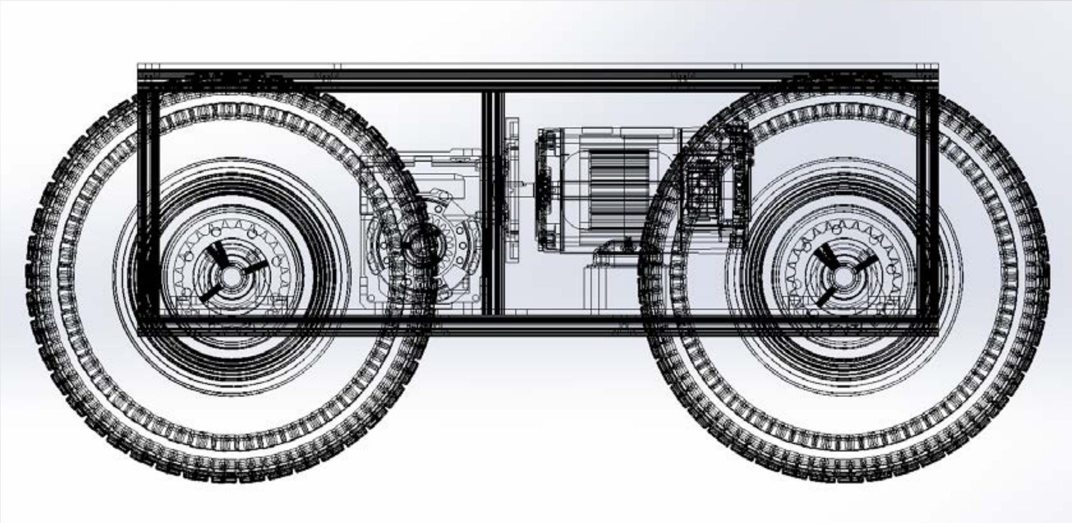
- Requirements Satisfying: DR 4.2
- General Goal: Execute an entire mission as defined by the requirements for completion.
- Data Required: Pass failure of mission
- Tasks Required before Test Execution: Full construction and integration of rover and software
- Location Used: Switzerland Trail

Poor Weather Backup Tests

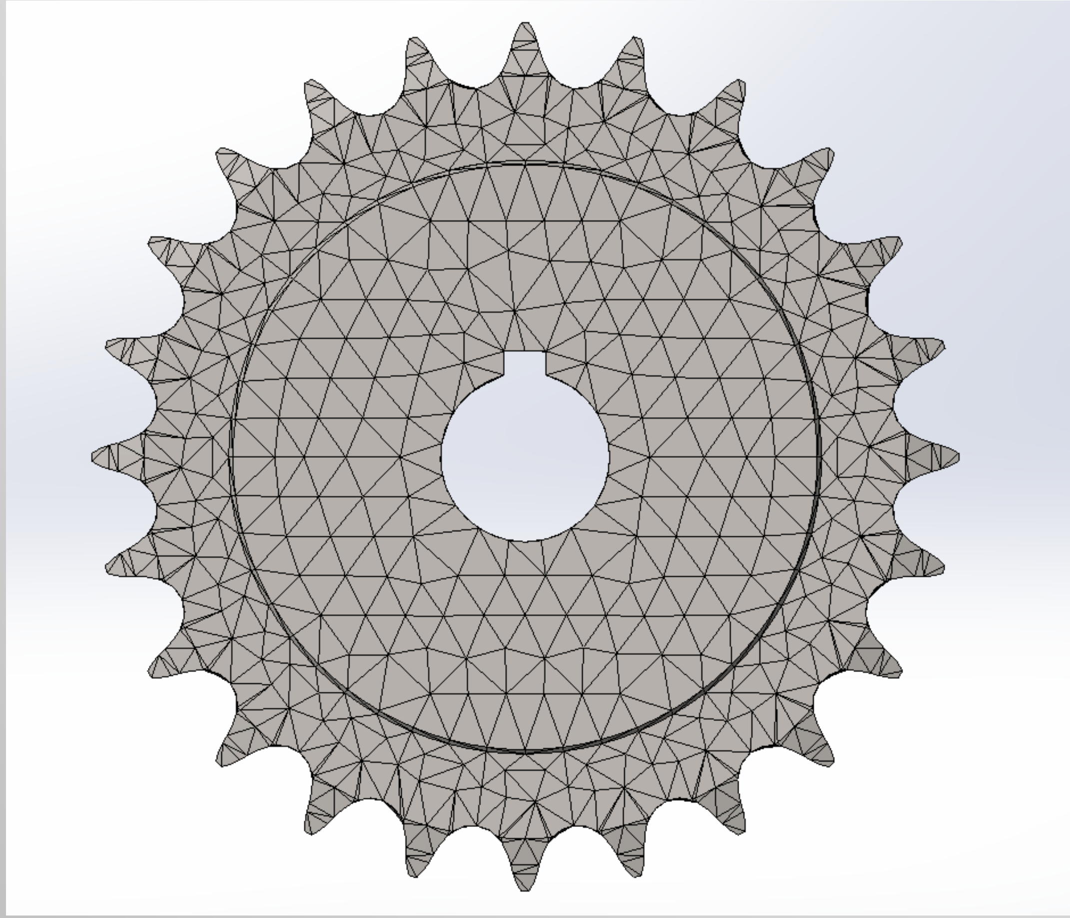
- Obstacle Test – Conduct test same but indoors
  - Non ideal due to lack of defined terrain. Indoor ground more likely to lead to drop danger
- Maneuverability – Conduct test but indoors with dirt under rover budget permitting
  - Difficulty with providing defined terrain in large enough area for test
- Communications – Outdoors but utilize warmth protection or rain protection as needed. (Tarp, insulation, umbrella etc.)
- Distance/Battery - Use hallway in Engineering Center or using grassy area near Engineering Center if Boulder not weather constrained
  - Non ideal due to lack of defined terrain
- Slope Capability and Leveling – Construct 20 degree slope and cover in dirt.
  - Requires extra budget and requires a large construction to accommodate the size of the rover

Model Backup Images- Mesh





Gear Mesh



Rim Mesh