ARGOS

Autonomous Rover for Ground-based Optical Surveillance

Test Readiness Review

March 4, 2021

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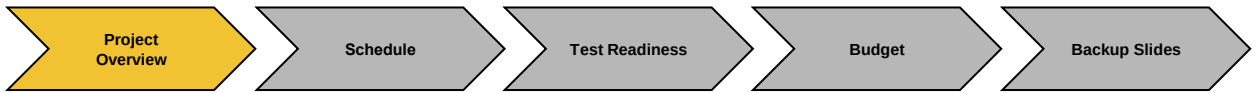
Project Overview

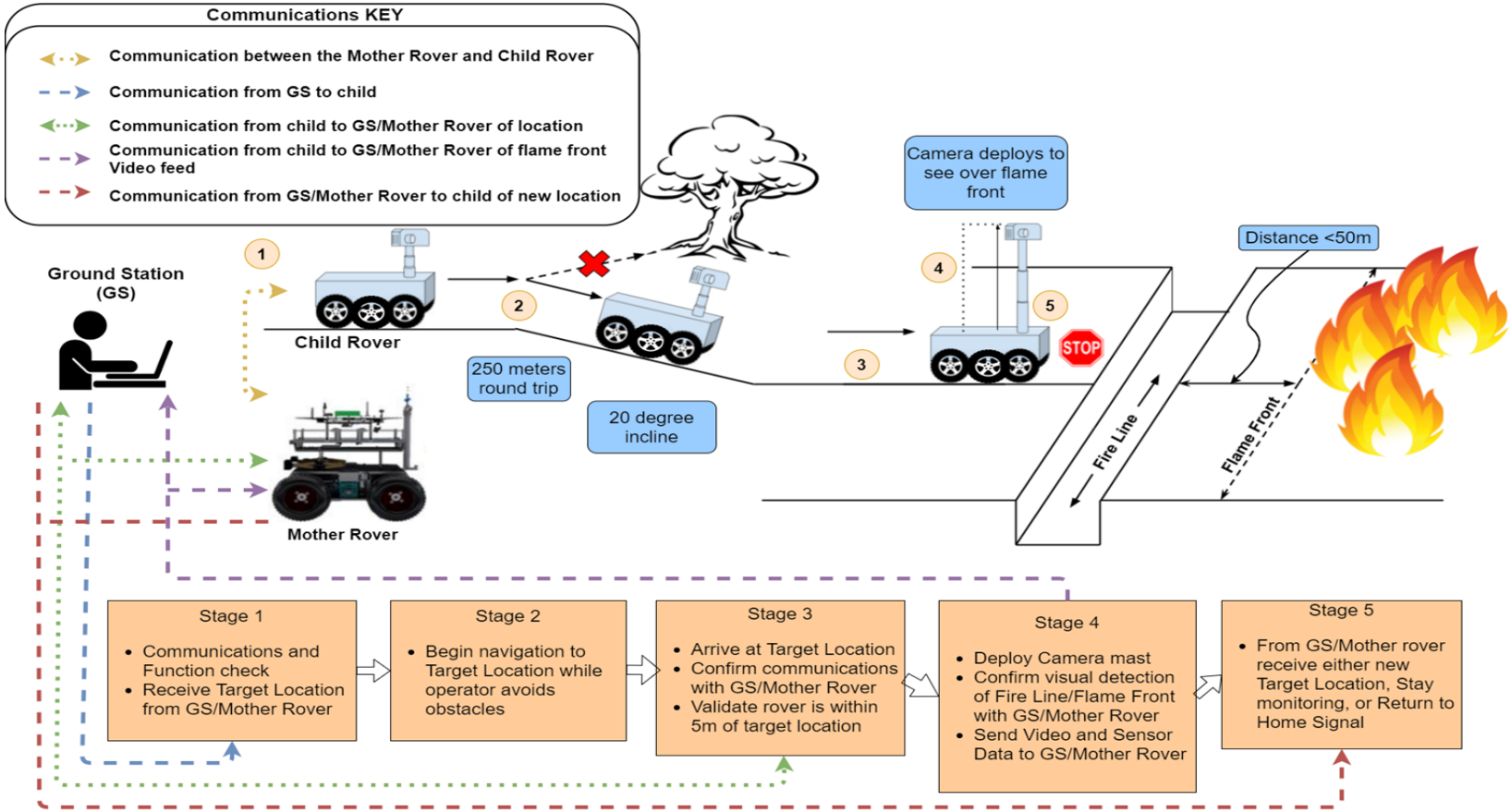


Mission Statement / Objectives

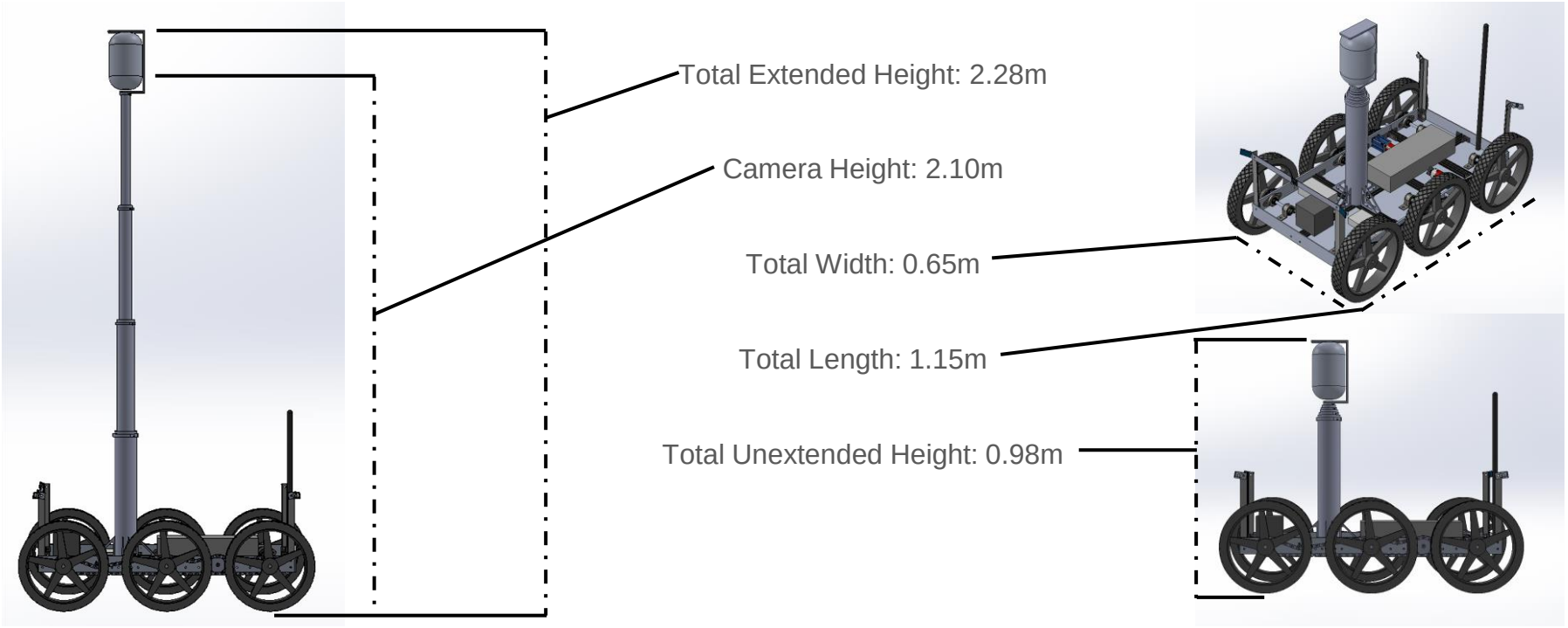
The ARGOS team shall design, build, and test a child rover that will :

1. **Navigate** to a fireline via commands from a ground station (GS) and mother rover (MR)
2. **Collect ambient temperature data** throughout the duration of the mission
3. **Record photos/video** of a flame front from the top of an **extendable/retractable mast**
4. **Communicate** temperature data, photos, and video to the GS/MR

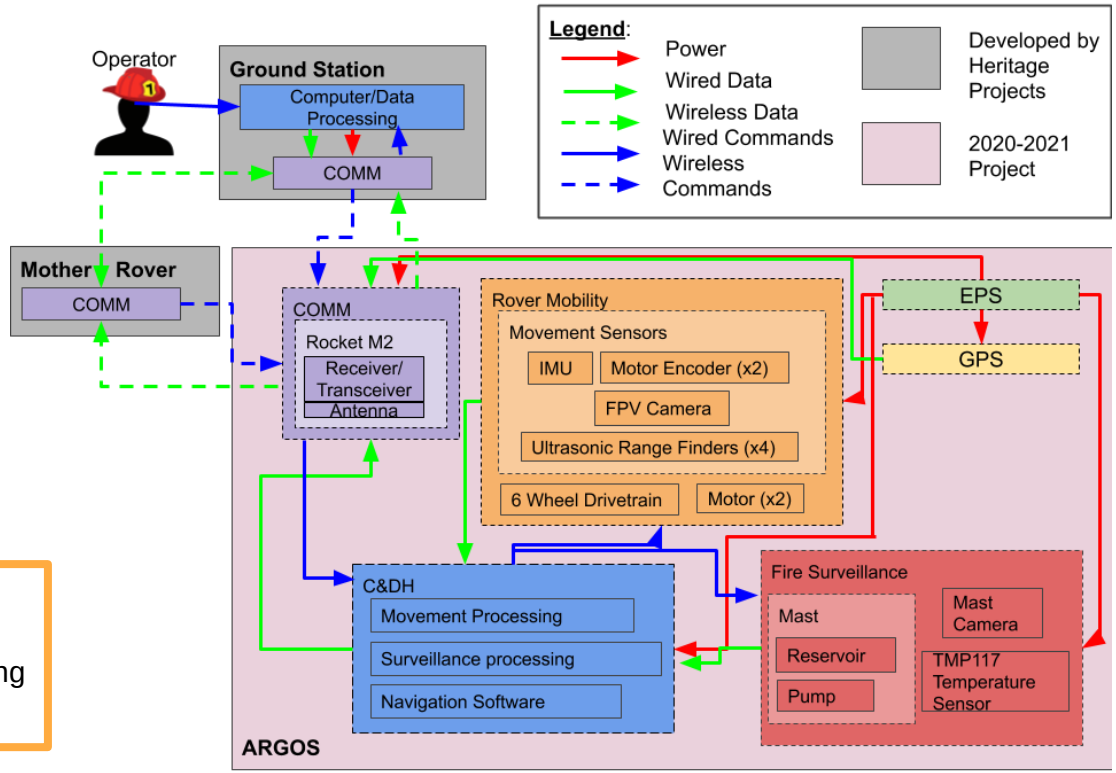
CONOPS



Full Design Recap



Functional Block Diagram



Note:
Acknowledgements are also sent following every command.

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Critical Project Elements (CPEs)

CPE	Description/Level of Success	Reasoning
Maneuverability	• Traversing obstacles/inclines of 20° without tipping (level 2)	• Failure results in tipping, damaged rover • FR.1
Control	• Manual control (level 1) • Mast control (level 3) • Autonomous control in event of comm loss (level 4)	• Failure results in possible crash, loss of rover • FR.1 • FR.3
Sensors	• Temperature (level 1) • Video via mast (level 2) • Movement sensors (level 3)	• Failure results in no useful data • FR. 2
Communications /Integration with Heritage Projects	• Transferring commands and data 250m away in an overstocked forest (level 4) • MR, GS and ARGOS comm systems	• Failure results in not receiving any useful data, loss of rover • FR.1 and FR.4

Updates since MSR

Mechanical:

- 2-stage mast test successful
- Beginning assembly of drivetrain
- Only chassis housing and last 2 mast stages left to manufacture

Electrical:

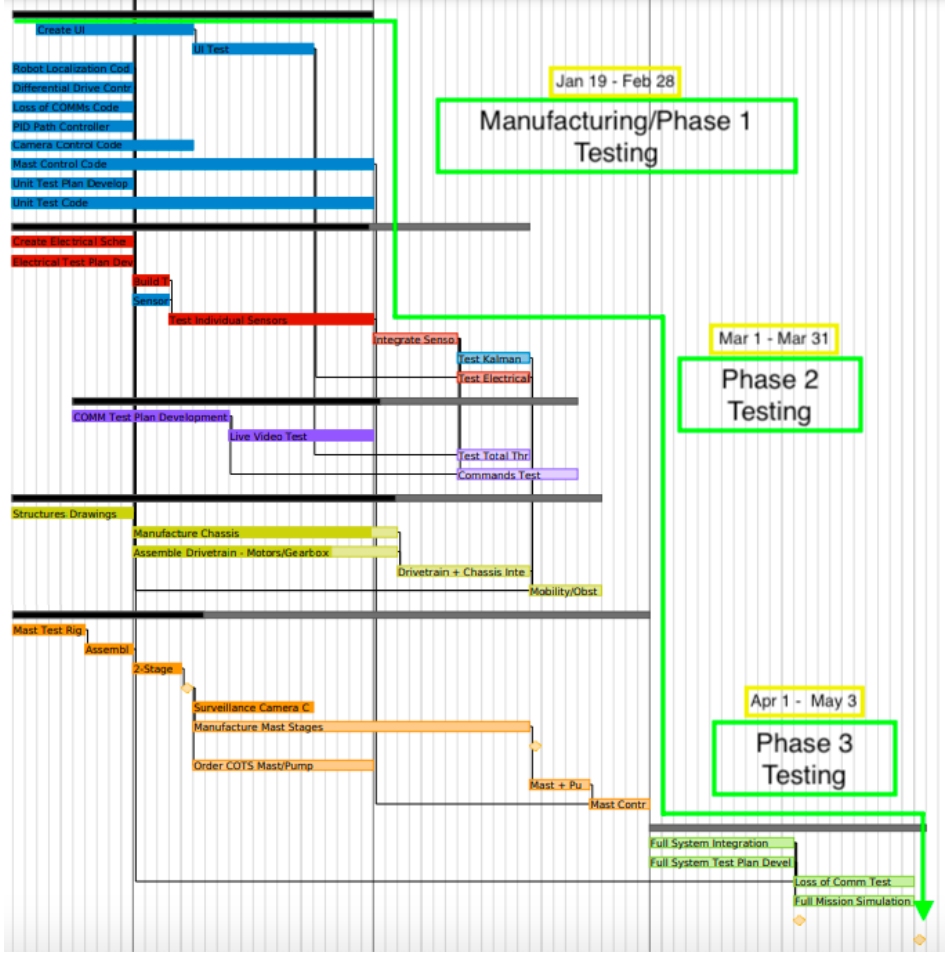
- All sensors arrived except IMU
- Individual sensor tests complete
- Video feed tested successfully

Software:

- Camera control and loss of comms code complete
- Unit tests complete

Schedule

Work Plan - Full Overview



- Software
- Electronics/Sensors
- Communications
- Structures
- Mast/Camera
- Integrated System
- Scheduling Margin
- Critical Path

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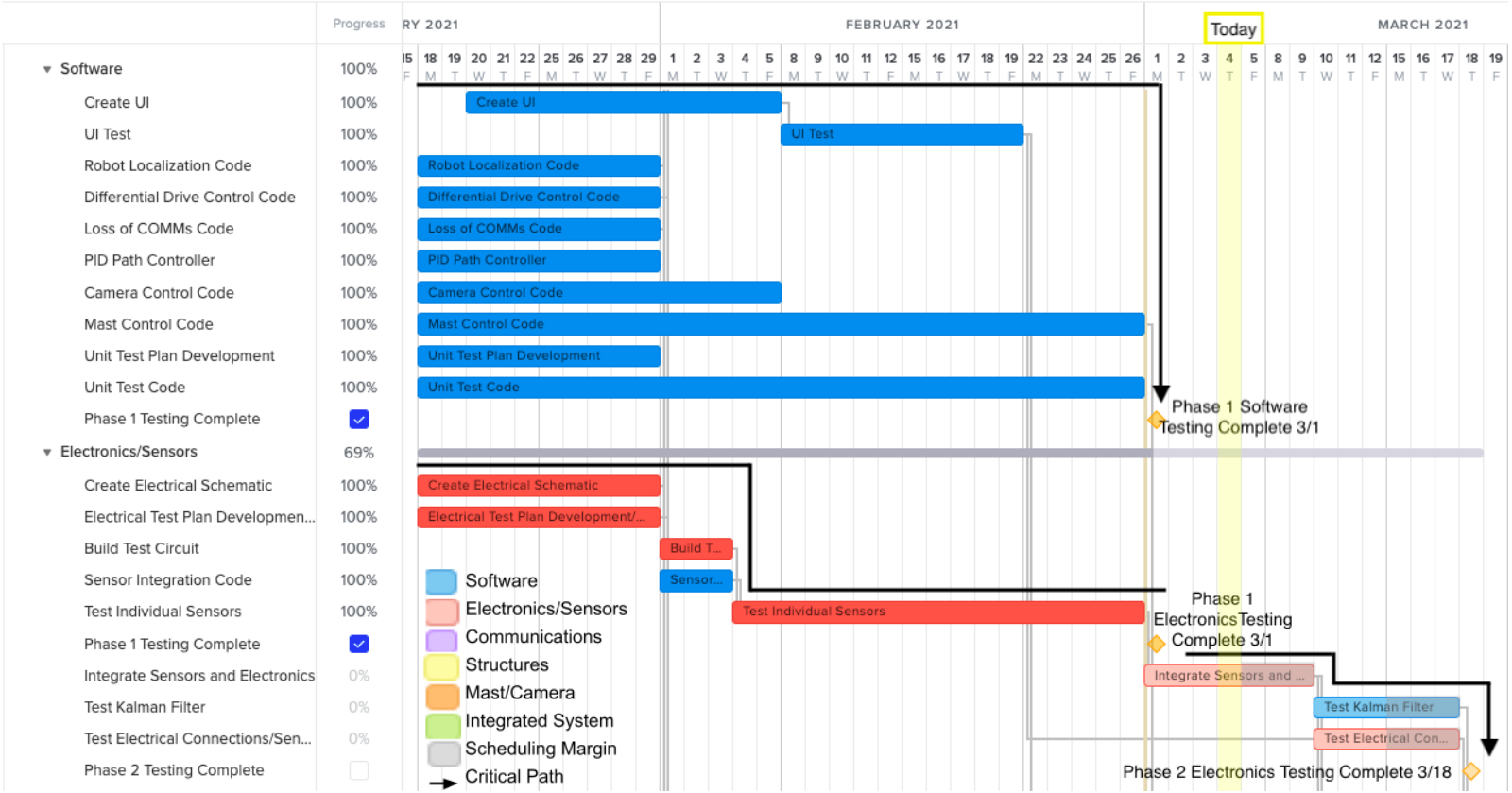
Work Plan - Software and Electronics/Sensors



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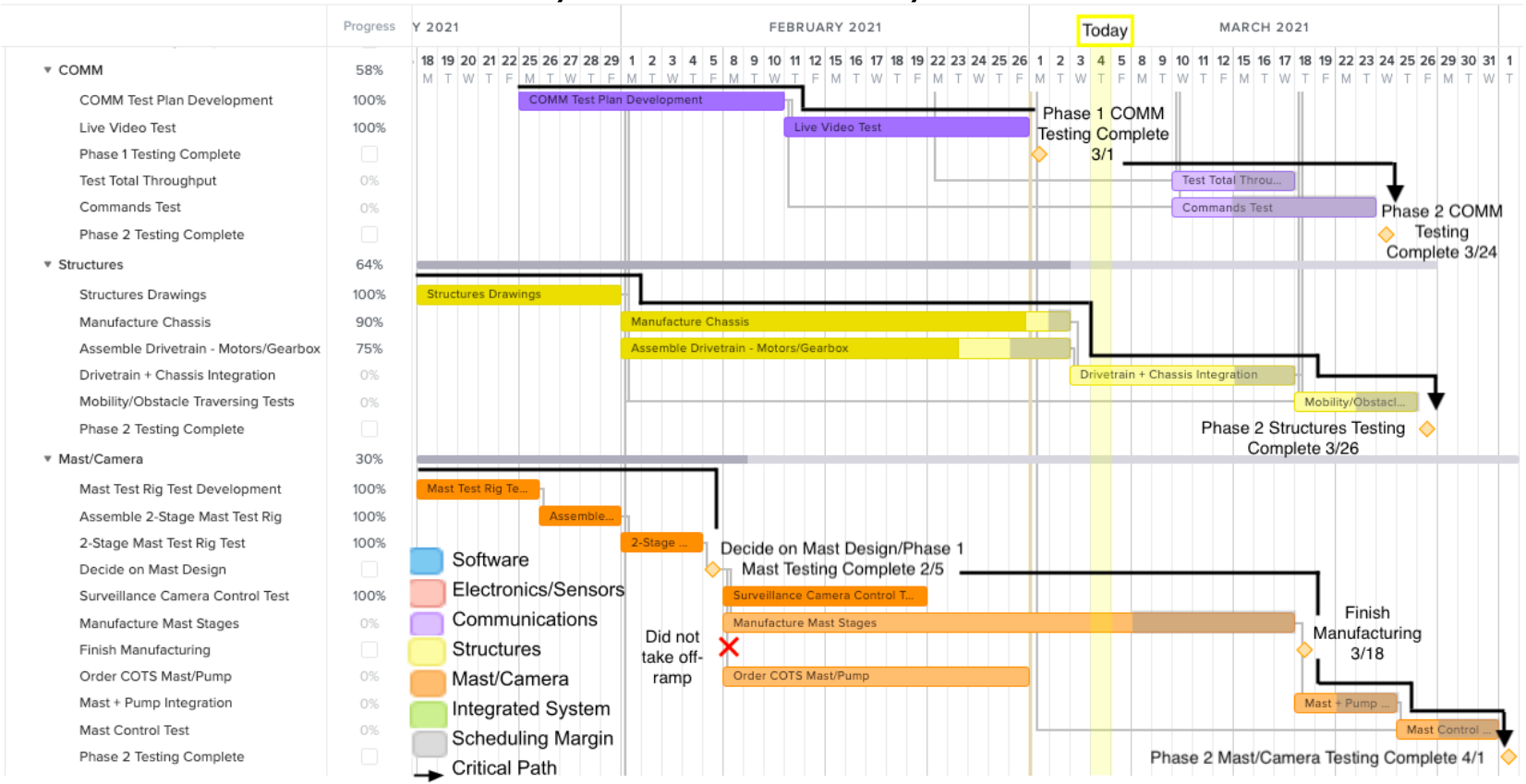
Work Plan - COMM, Structures, and Mast/Camera



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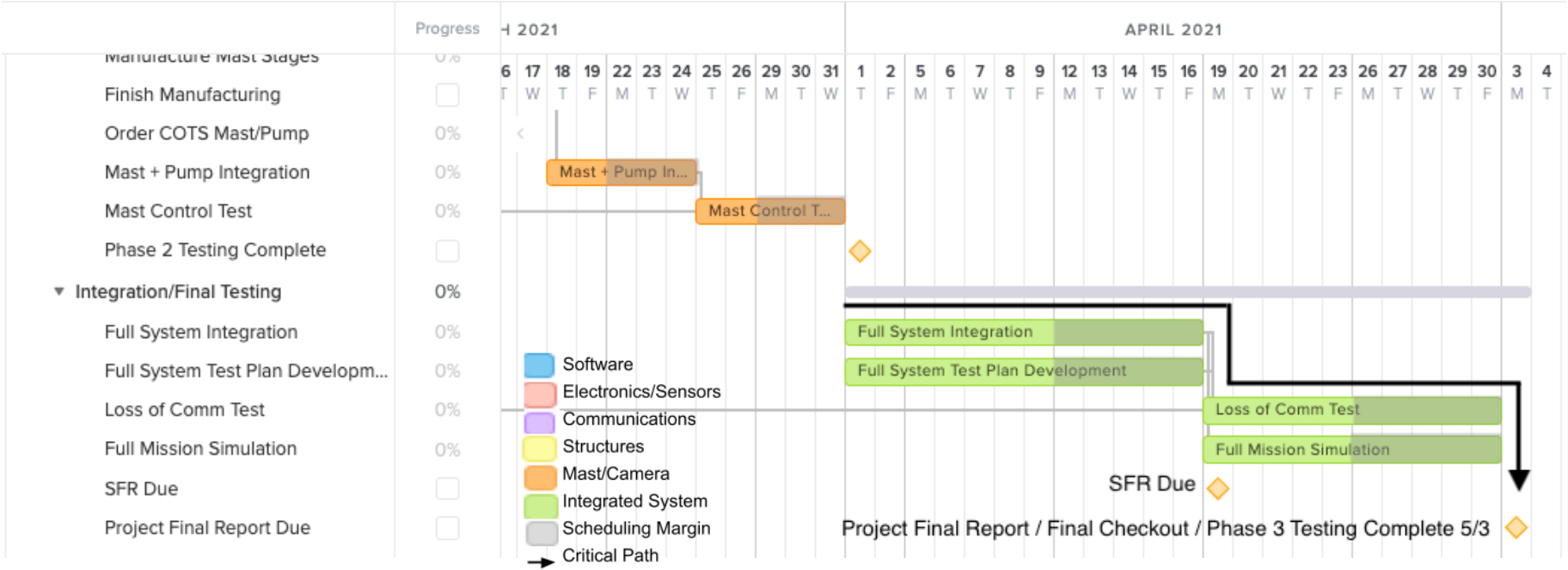
Work Plan - Final Integration/Testing



Test Readiness

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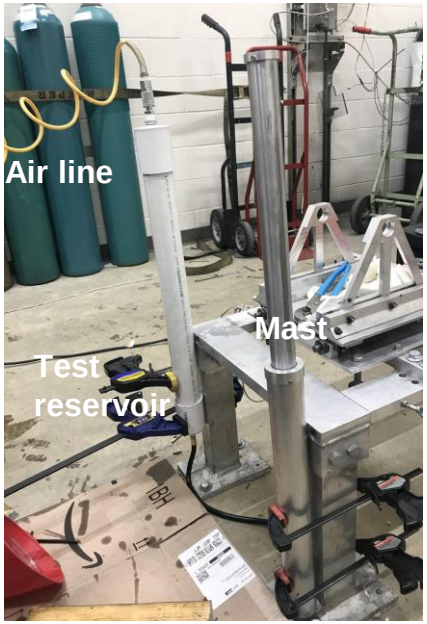
Overall Testing Status

= completed
= in progress
= future work

Phase 1	Phase 2	Phase 3
Component Testing	**Subsystem Testing**	**Full System Testing**
• 2-stage mast test rig	• Drivetrain + motor + Differential Drive Controller	• Full mission simulation
• Individual sensor accuracy and throughput	• Surveillance Camera + Camera Controller	• Loss of COMM test
• UI of ground station with sample data • Unit tests	• 4-Stage Mast + Pump and Controller	
• Live video	• Sensor output - Kalman Filter • UI of sensor data	
	• Sample commands • Full throughput test	

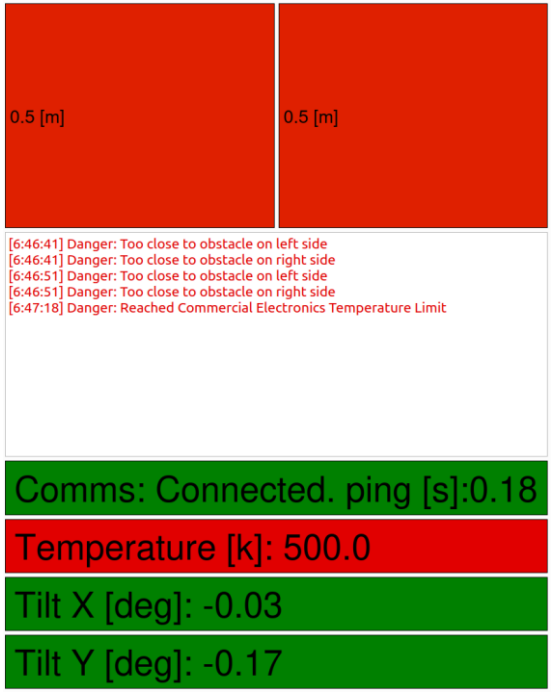
Phase 1 : 2-Stage Mast Test Rig

- **Purpose:** Finalize mast design
- **Rationale:** FR.3, SURV.3.1, SURV.3.2
- **Test Facility:** Aerospace Building
- **Test Procedure:**
  - Fill mast and reservoir with hydraulic fluid
  - Connect air line and pressurize
  - Observe extension, record pressure and mass
  - Depressurize and check for damages or leaks
  - Repeated until 13 trials were completed
- **Completion Date:** 2/4/21
- **Results:** Moving forward with manufactured hydraulic mast with addition of spring system to assist with mast compression



Phase 1: Software Unit Tests

- **Purpose:** Validate Code in Typical and Atypical Operation
- **Rationale:** FR.2, FR.4
- **Test Facility:** ROS/Gazebo Simulation
- **Necessary Equipment:** Linux Computer with 3 threads
- **Test procedure:**
  - Glass Box
    - Handling of normal, abnormal, and invalid data
    - Catch any edge cases
  - Black Box
    - GUI tests on inexperienced users
- **Completion Date:** 2/26/21
- **Results:**
  - Code functions in normal, abnormal, invalid conditions
  - Use of ROS prevents nodes from receiving an unexpected data type
  - Complete list of unit tests results in backup slides



GUI Output with Abnormal Data

Phase 1 : Communications Tests

- **Purpose:**
  - Ensure ARGOS is capable of transmitting and receiving data at rates of 5.1 Mbps out to 250m away.
- **Rationale:**
  - FR. 4 The child rover shall receive commands from both the ground station and the mother rover and transmit captured data to the ground station and the mother rover.
- **Test Facility:**
  - Open field and Forest
- **Necessary equipment:**
  - Two Rocket M2 radios, Tupavco panel antenna, omni-directional antenna, and GS laptop.
- **Test Procedure:**
  - Measure signal strength, data rates, and latency by walking one radio out by 20m. increments out to 250m.
- **Completion Date:** 02/25/2021

Ground station at 300 meters away

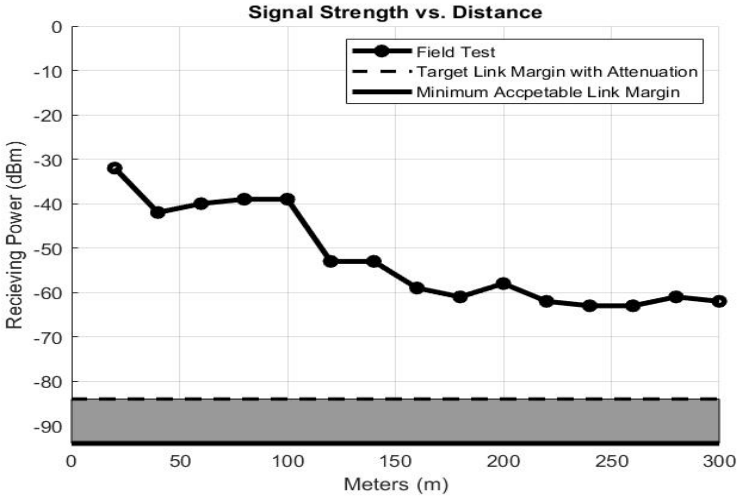
Tree Separation

Ground station

Phase 1 : Communications Results

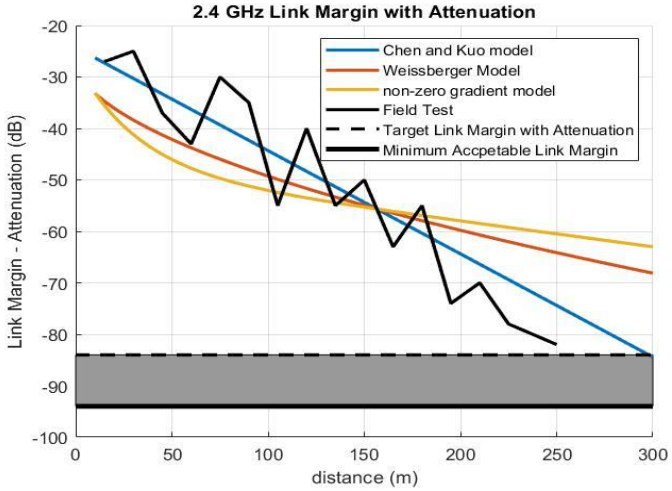
Goal: Achieve live video/ data rates necessary to handle rest of sensors and still fall within 10 dBm of receiver's sensitivity of -94 dBm

Open field test: Pass
23 dBm left of 57 dBm link budget @ 300m
Bandwidth of 41 Mbps @ 300m



Goal: Validate attenuation models by overlaying physical data we acquired from the forest.

Attenuation Test: Pass
2 dBm left of 57 dBm link Margin @ 250m
Bandwidth of 27 Mbps @ 250m



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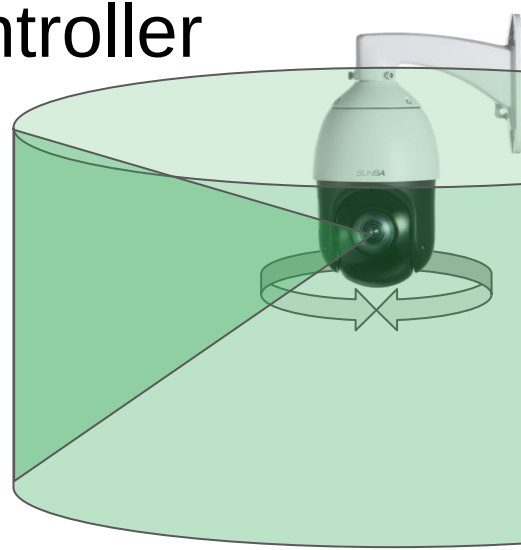
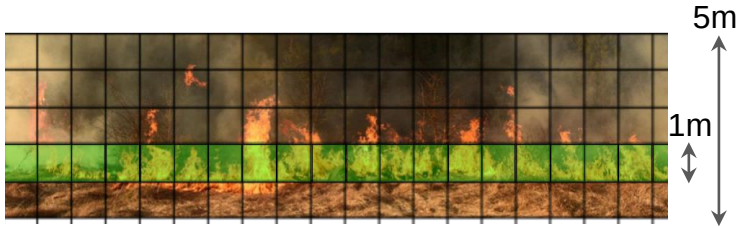
Phase 2 : Motor Controller and Drivetrain Integration

- **Purpose:** Assemble and integrate drivetrain system and motor controllers/ software.
- **Rationale:** FR.1
- **Test Facility:** Aerospace Building
- **Necessary Equipment:** Drivetrain components, motor controllers, arduino, laptop with software.
- **Test procedure:**
  - Assemble drivetrain subsystem
  - Send basic movement commands
  - Record results and make necessary adjustments.
- **Testing Dates:** 2/15/21 - 3/18/21
- **Progress:**
  - Sprockets have been successfully fit to gearbox and shafts
  - Full forward reverse and proportional control has been successfully achieved

Phase 2 : Surveillance Camera and Controller

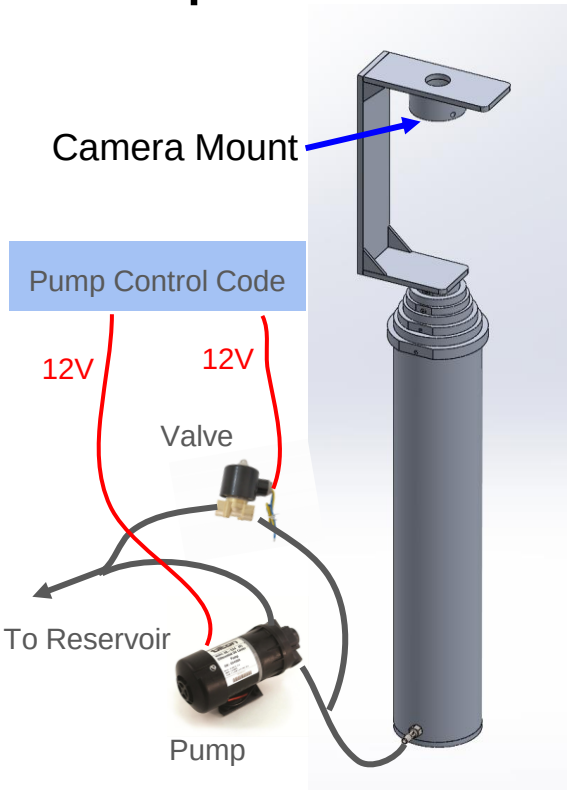
- **Purpose:** Validate surveillance camera remote operation programming with physical camera test
- **Rationale:** FR.3
- **Test Facility:** Aerospace Building/Open Field
- **Necessary Equipment:** Surveillance camera and ground station Laptop with VMS software
- **Test procedure:**
  - Connect camera to ground station
  - Pan/Tilt/Zoom test
  - Validate at **132m** a 1m tall object occupies 20% vertical image
- **Testing Dates:** 3/01/21

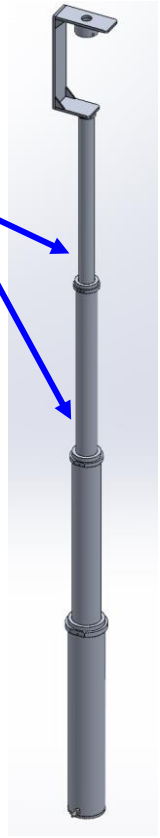




Phase 2 : 4-Stage Mast and Pump

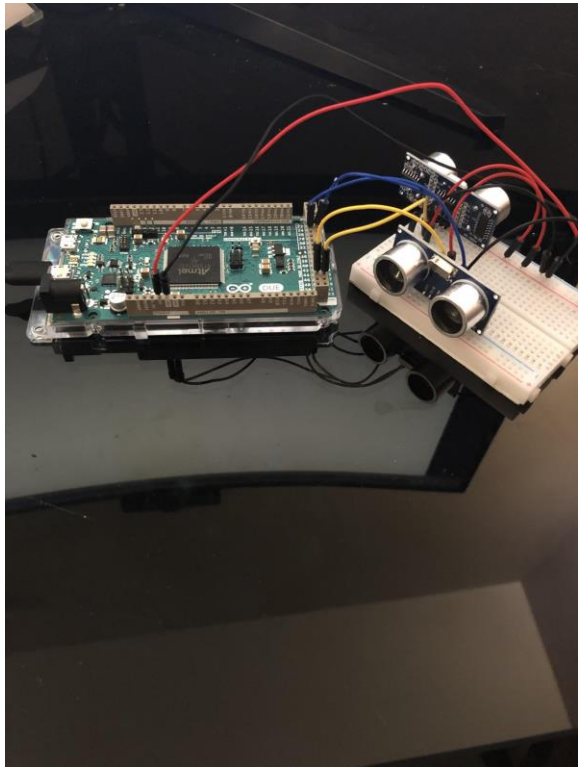
- **Purpose:** Test of finalized mast
- **Rationale:** FR.3, SURV.3.1, SURV.3.2
- **Test Facility:** Aerospace Building
- **Necessary Equipment:** Mast assembly and hydraulic network, pump controller
- **Test procedure:**
  - Test pump/valve control
  - Fill hydraulic network with oil
  - Pressurize mast, observe extension, depressurize, record results
  - Repeat with camera mass and cables
- **Testing Date:** 3/18/21 - 3/31/21





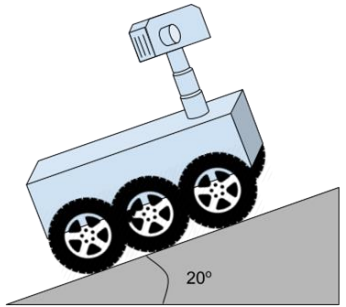
Phase 2 : Sensor Output Test

- **Purpose:** Validate precision and throughput of sensor/arduino system
- **Rationale:** FR. 2
- **Test Facility:** At home and aerospace building/pilot lab
- **Necessary Equipment:** Sensors, arduino, computer and code
- **Test procedure:**
  - Individual: confirm accurate readings by comparing to known or target values
  - Combined: confirm data is received from each within specified time limits
- **Testing Date:** 2/10/21 - 3/18/21



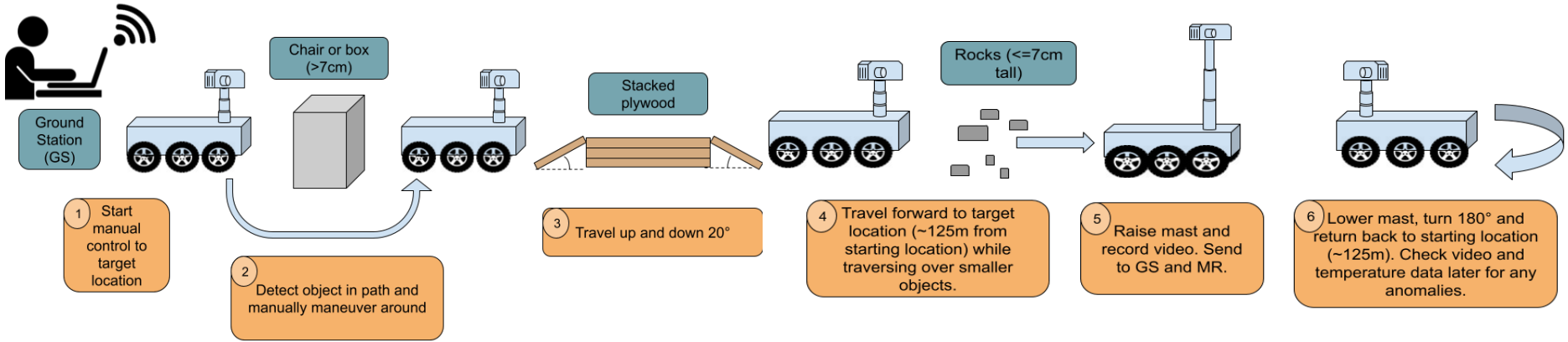
Phase 2 : Sensor Output Test - Kalman Filter

- **Purpose:** Validate accuracy of Kalman Filters
- **Rationale:** FR. 1
- **Test Facility:** Outside Aerospace building
- **Necessary Equipment:** ARGOS with sensors, motors, computer, and software. Measuring tape and protractor.
- **Test procedure:**
  - Move rover known distance, verify filter reports location to within +/- 5m
  - Tilt ARGOS 20º in both axes, verify filter reports angle to within +/- 1º
- **Testing Date:** 3/10-3/18



Phase 3 : Full Mission Simulation

- **Purpose:** to test how ARGOS performs during a simulated mission
- **Rationale:** to prove satisfaction all requirements
- **Test Facility:** outside/open field (Business Field)
- **Estimated Completion Date:** 4/30/21

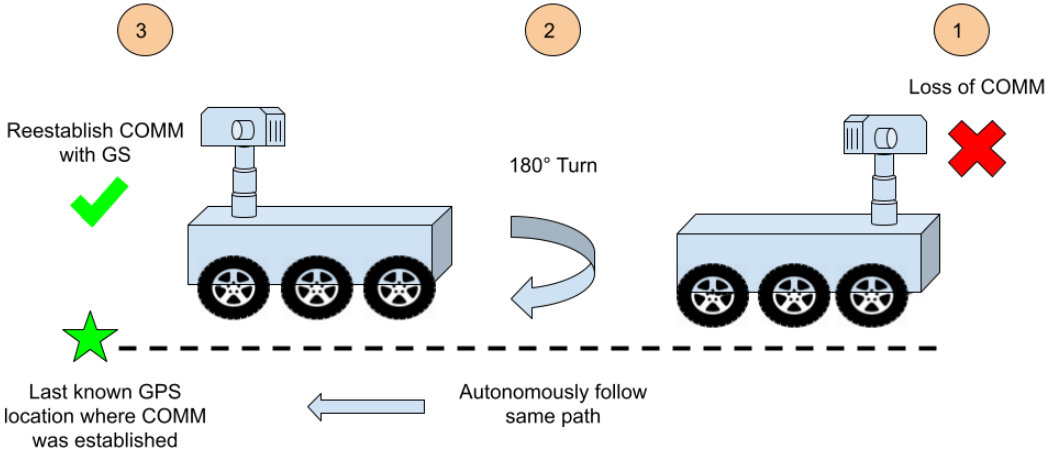


Phase 3 : Loss of COMM Test

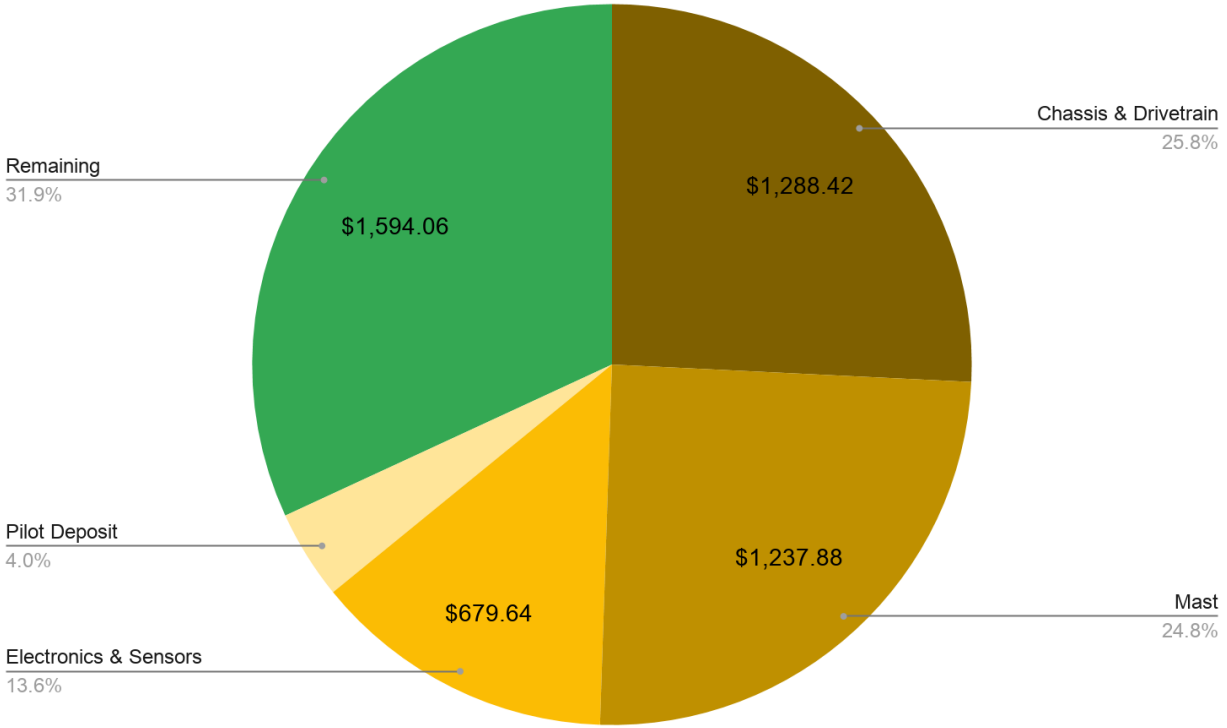
- **Purpose:** to validate whether ARGOS returns to the last known GPS coordinate upon loss of communications
- **Rationale:** COM.4.1
- **Test Facility:** outside
- **Estimated Completion Date:** 4/30/21

Two different ways to cut off signal:

1. Software
2. Physical block (under engineering center)



Budget


Chassis & Drivetrain
25.8%
$1,288.42
Remaining
31.9%
$1,594.06
Pilot Deposit
4.0%
$679.64
$1,237.88
Mast
24.8%
Electronics & Sensors
13.6%

Budget

- Major Procurements
  - All major components have been purchased
- Remaining purchases
  - Miscellaneous items
    - wiring, replacements, etc
- Ongoing Order
  - Mast tubing needs to be repurchased
    - Totaling $99.50
  - Aluminum Plate for Chassis
  - Wheels being delivered

Expenses: $3,405.94

Remaining: $1,594.06

Estimated Final Cost: $3,700

Bill Of Materials

Component	Distributer	Quantity	Unit Price	Shipping	Total Price	Subsystem
GPS-RTK-SMA Breakout - ZED-F9P	Sparkfun	1	219.95	0	219.95	Sensors
RedLine Encoder Kit	AndyMark	2	47	0	94	Sensors
Zio Ultrasonic Distance Sensor - HC-SR04 (Qwiic)	Sparkfun	4	13.95	0	55.8	Sensors
SLAMTEC A2M8	SAMTEC	1	319		319	Sensors
Runcam Nano 2 FPV Camera	Flight Test	1	19.99		19.99	Sensors
Infrared Thermometer - MLX90614	Sparkfun	1	29.95	0	29.95	Sensors
SparkFun VR IMU Breakout - BNO080 (Qwiic)	Sparkfun	1	34.95	0	34.95	Sensors
Arduino Due	amazon	1	39.9	0	39.9	electronics
Intel NUc	Intel	1	247	10	257	electronics
Kingston A400 120G Internal SSD M.2	amazon	1	19.99	0	19.99	electronics
GPS/GNSS Magnetic Mount Antenna	Sparkfun	1	12.95	0	12.95	electronics
SPARK Brushed DC Motor Controller	AndyMark	2	50	10	110	electronics
NETGEAR 5-Port Gigabit Ethernet Unmanaged Switch (GS305)	amazon	1	15	0	15	electronics
REDGO Video Audio VHS VCR USB Video Capture Card to DVD Converter Capture Card Adapter	amazon	1	10.99	0	10.99	electronics
SMAKN Waterproof DC/DC Converter 12V (10-30V) Step UP to 48V/4A 192W Power Supply Module	Amazon	1	29.99		29.99	electronics
12V 16Ah Deep Cycle LiFePO4 Battery	Amazon	1	49.99		49.99	electronics

Qwiic JST Connector - SMD 4-pin (Horizontal)	spark fun	4	0.5	0	2	electronics
2-Bolt Flange Bearing	Grainger	6	19.35	12.83	128.93	Drivetrain
Metal Gear	McMaster	0	60.4		0	Drivetrain
Standard Sprocket	Misuni	10	8.19	13.4	95.3	Drivetrain
Radial Ball Bearing	Grainger	12	3.91	0	46.92	
Pillow Block Bearing	Grainger	6	21	0	126	Drivetrain
Talon SRX Speed Controller	AndyMark	2	99	0	198	Drivetrain
Ventilation Spacer	AndyMark	2	5	0	10	Drivetrain
1/2" Shaft	McMaster	6	8.71		52.26	Drivetrain
Chain	McMaster	10	5.49		54.9	Drivetrain
775 Redline Motor	AndyMark	2	19	8.5	46.5	Drivetrain
Swisher 13.75 in Rear Wheel	Lowe's	6	24.1	0	144.6	Drivetrain
57 Sport Gearbox	AndyMark	2	96	0	192	Drivetrain
6061 Aluminum Sheet 20x36.5	MidWest Steel & Aluminum	1	52.33	10.48	62.81	Drivetrain - Chassis
Plexiglass Black Acrylic Plate 24inx36inx1/8in	Home Depot	2	39.99	0	79.98	Drivetrain - Chassis

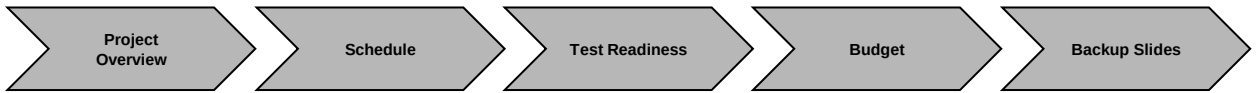
Plexiglass Black Acrylic Plate 24inx36inx1/8in	Home Depot	2	39.99	0	79.98	Drivetrain - Chassis
1-3/4" Bore Wear Ring	McMaster	2	4.73		9.46	Mast
1/4 Machine Screws	McMaster	2	2.83		5.66	Mast
3/8 Machine Screws	McMaster	2	2.74		5.48	Mast
2" OD 1.25" ID Aluminum Tube	McMaster	1	95.58		95.58	Mast
2.25" OD 1.75" ID Aluminum Tube	McMaster	1	78.26		78.26	Mast
1-3/4" Bore Dynamic Seal	McMaster	1	5.93		5.93	Mast
O-ring 1.25" bore x100 for whatever reason	McMaster	1	6.95		6.95	Mast
Quick Disconnect Fitting	McMaster	1	11.3		11.3	Mast
SUNBA 601-D25X	Amazon	1	269.99		269.99	Camera
Rocket M2	Amazon	2	80		160	Communication

POE TP-DCDC-1224 Adapter	PoETexas	2	5.49		10.98	Communication
TRENDnet Reverse SMA Female to N-Type Male Weatherproof Connector Cable (6.5ft, 2M), TEW-L202	Trendnet	1	19		19	Communication
Antenna 2.4GHz 12dBi Omni-Directional WiFi w/ RP-TNC	Data Alliance	1	8.99		8.99	Communication
1ft Cat6 550 MHz UTP Snagless Ethernet Network Patch Cable, Blue	Cable Leader	2	0.77		1.54	Communication
1 Foot Male to Male 2.1mm x 5.5mm Plug DC Power Adapter Cable 18GA	Valley Enterprises	1	3.99		3.99	Communication
Tupavco tp511 Panel Antenna 2.4 GHz 20 dBi directional antenna	Tupavco	1	54.98		54.98	Communication
TP-Link 5 Port Fast Ethernet 10/100Mbps PoE Switch	Amazon	1	34.99		34.99	Communication
USB 2.0 Audio/Video Converter	Amazon	1	11.99		11.99	Communication
Total					3354.72	

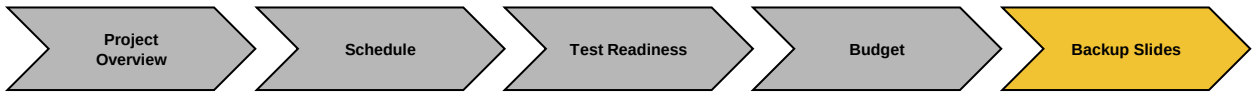
Summary

- Phase 1 Testing = complete
- Phase 2 Testing = in progress
- Some minor manufacturing delays, but do not affect schedule

Questions?


Project Overview
Schedule
Test Readiness
Budget
Backup Slides

Backup Slides



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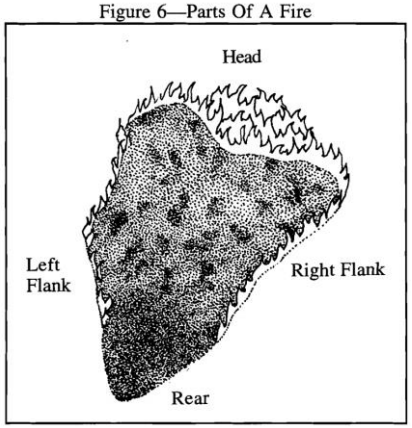
Definitions

- **Fireline :** a trench cleared of any flammable material, dug at the edge of a forest or brush fire to halt the spread
- **Flame Front :** the leading edge of the forest fire perimeter
- **Survey :** to record video/take photos
- **Fire Surveillance :** a subsystem of ARGOS consisting of the sensors and components needed to survey the fire line
- **Tipping Condition :** condition when rover tips too far to the side or in the front or back and falls over
- **Obstacles :** rocks, tree stumps, fallen branches, or other debris found on the forest floor which can have heights up to 7cm
- **Tree density :** measure of how many trees will be in an area (# trees/acres)
- **Terrain :** specification of the forest floor which ARGOS must traverse (detailed definition in backup slides)



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Functional Requirements

Requirement ID	Requirement Description
FR.1	The child rover shall move from a starting location to a commanded location of interest and return back to the starting location.
FR.2	The child rover shall take pictures, videos and ambient temperature data to be sent to the ground station.
FR.3	The child rover shall use a mast to take photos and video from a vantage point above the rover's body.
FR.4	The child rover shall receive commands from both the ground station and the mother rover and transmit captured data back to the ground station and the mother rover.

Design Requirements

FR. 1 The child rover shall move from a starting location to a commanded location of interest and return back to the starting location.

Design Requirement ID	Description
MOV.1.1	The child rover shall be able to perform a 360 degree turn.
MOV.1.2	The child rover shall be able to travel in forward and reverse motion.
MOV.1.3	The child rover shall be able to travel up and down slopes of 20 degree inclination.
MOV.1.4	The child rover shall be able to travel over obstacles with heights as tall as 7cm.
MOV.1.5	The child rover shall be able to travel 250m round trip in any direction from its starting location.
CDH.1.1	The child rover shall be able to detect when a tipping condition is met(when the rover falls over) and send an alert to the ground station/mother rover.

Design Requirements

FR. 2 The child rover shall take pictures, videos and ambient temperature data to be sent to the ground station.

Design Requirement ID	Description
SURV.2.1	The camera shall have >100 degrees field of view.
SURV.2.2	The camera shall provide operator with pictures and video of fire that occupy at least 20% of the vertical image.
CDH.2.3	The child rover shall be able to determine the ambient temperature within +/- 1 °K at the location of interest.

Design Requirements

FR. 3 The child rover shall use a mast to take photos and video from a vantage point above the rover's body.

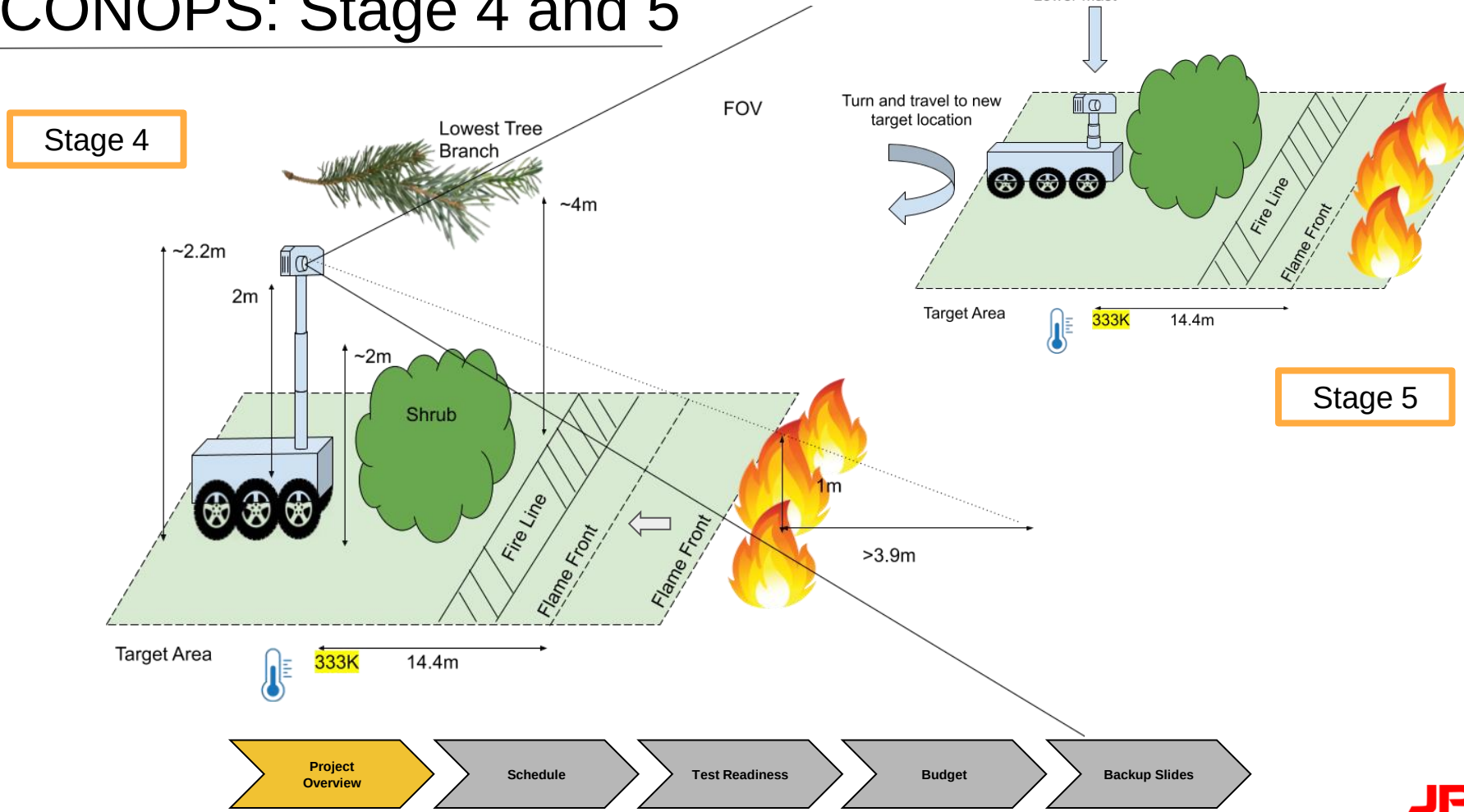
Design Requirement ID	Description
SURV.3.1	The child rover shall have a mast capable of extending to a height of 2m and retracting back down to its original height.
SURV.3.2	The child rover shall have a mast capable of supporting 10kg of weight on the top.

Design Requirements

FR. 4 The child rover shall receive commands from both the ground station and the mother rover and transmit captured data to the ground station and the mother rover.

Design Requirement ID	Description
COM.4.1	Upon loss of communication, the child rover shall return to its last known GPS location (storage of waypoints).
COM.4.2	The child rover shall send time stamped video, image, and temperature data to the ground station and mother rover at a data rate up 25Mbps.
COM.4.3	The ground station shall confirm if the child is within +/- 5m of the desired location.
COM.4.4	The child rover shall send its location every 1.5s to the ground station/mother rover.
COM.4.5	The mother rover/ground station shall be able to command the child rover to navigate to specified GPS coordinates in real time .
COM.4.6	The mother rover/ground station shall be able to command video feed on/off.
COM.4.7	The mother rover shall be able to receive commands from the ground station at a data rate up 25Mbps.
COM.4.8	The mother rover shall be able to send temperature data and video to the ground station and vice versa.

CONOPS: Stage 4 and 5

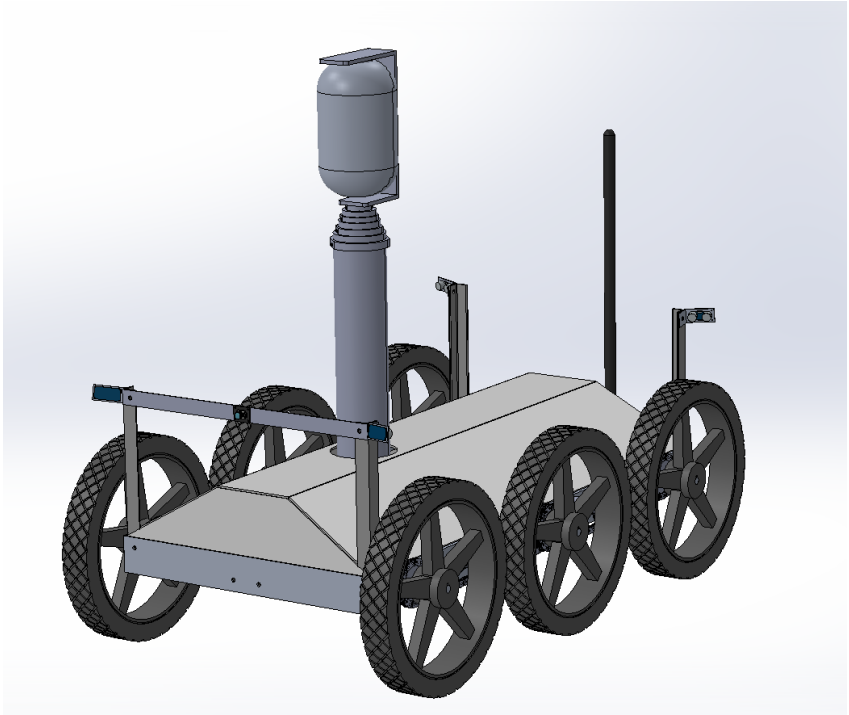


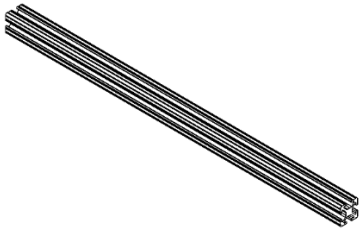
Levels of Success

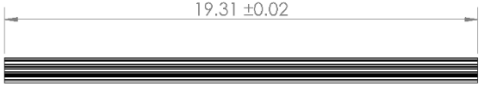
	Rover Movements and Control	Surveillance	Communications
Level 1	Rover can travel on flat ground for 100m via manual control. Rover can travel in the forward direction and can turn 360 degrees with a turn radius less than two rover body lengths (2.3m).	Ambient temperature data is recorded from a temperature sensor with an accuracy of +/- 1°C throughout the mission. Rover records timestamped photos of the flame front via a camera on a mast.	Rover can receive GPS commands from the ground station and the mother rover. Rover can transmit temperature data and video/images to the ground station and mother rover at 1 Hz 0m from ground station in an open area (tree density of 0 trees/acre) or in the same room.
Level 2	Rover can travel on various terrains, including leaves, underbrush, dirt and mud while staying upright. Rover can travel on a 20 degree incline. Rover can turn 360 degrees with a turn radius less than one rover body length (1.15m).	Rover records timestamped video of the flame front via a camera on a mast.	Rover can communicate with the ground station and the mother rover up to 100 m in an understocked forest (tree density of 100 trees/acre).
Level 3	Rover can turn 360 degrees on the spot. Rover can autonomously return to the last known GPS coordinate if communications are lost. Rover can detect large obstacles, such as trees and dense bushes, in its path. Rover can detect a tipping condition by measuring its angular motion.	Rover's mast is extendable and retractable.	Rover can communicate with the ground station and the mother rover up to 250 m and in a fully stocked forest (tree density of 170 trees/acre).
Level 4	Rover can detect small obstacles, such as rocks and small bushes, and navigate a path around them. Rover navigate to a GPS waypoint within +/-5m of the desired coordinate.	N/A	Rover can communicate with the ground station and the mother rover in an overstocked forest (tree density of 200 trees/acre).

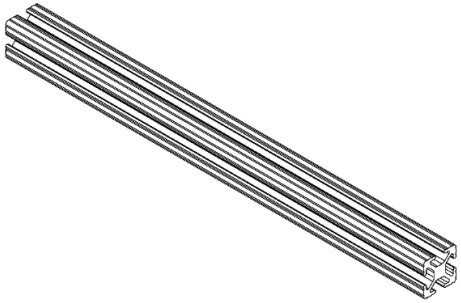
Final Design With Top Panels

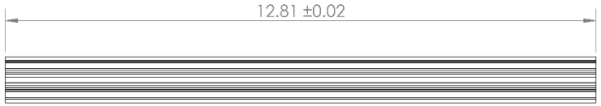
- Panels made of acrylic
- Connected using angled aluminum brackets






19.31 ±0.02

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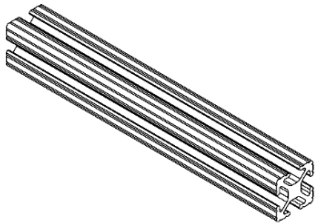
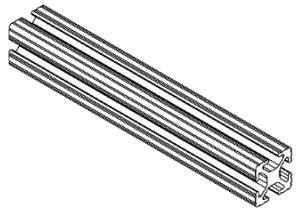
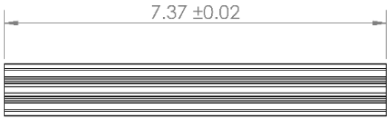
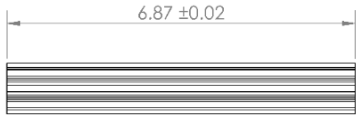





7.37 ±0.02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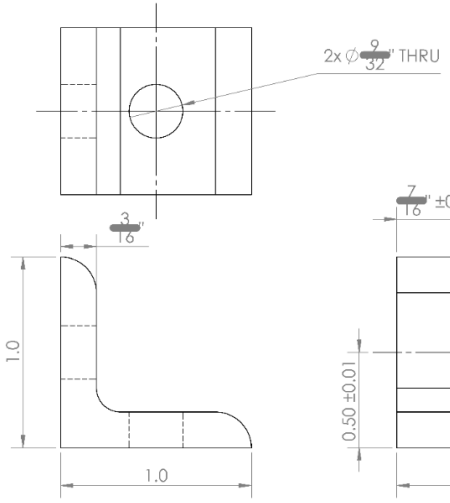
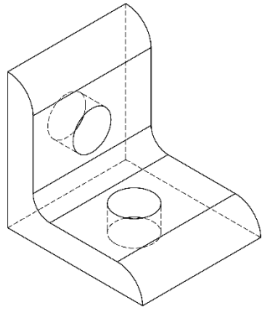
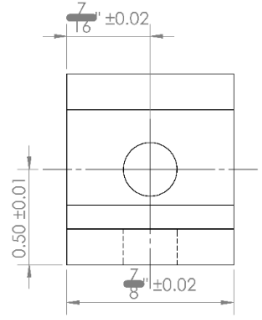
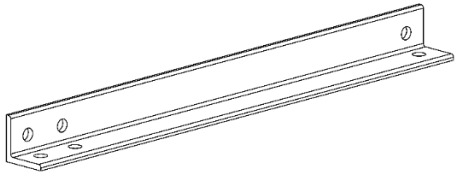
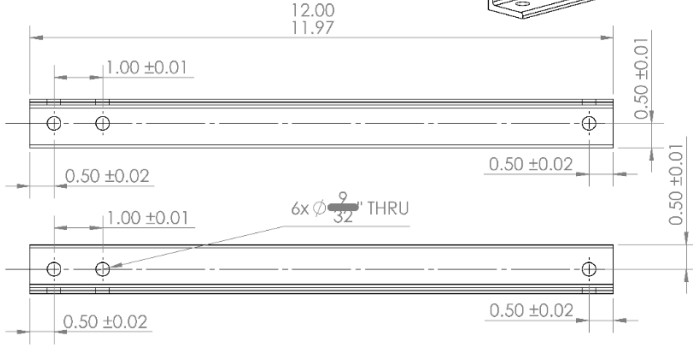
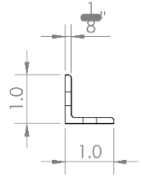

2x ∅9/32" THRU
3/16"
1.0
1.0

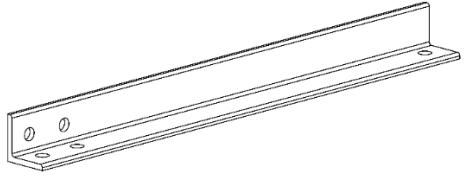


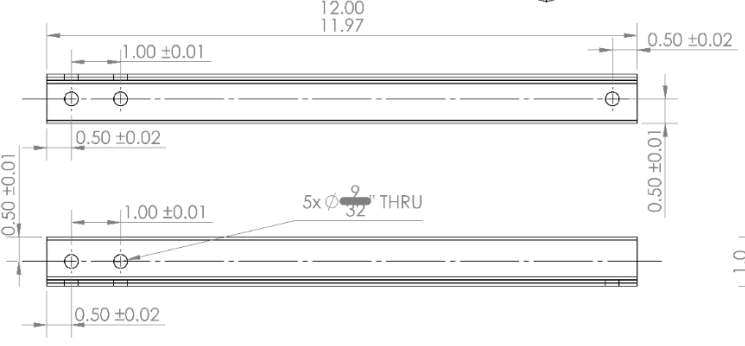

7/16" ±0.02
0.50 ±0.01
7/8" ±0.02

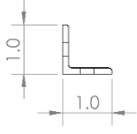


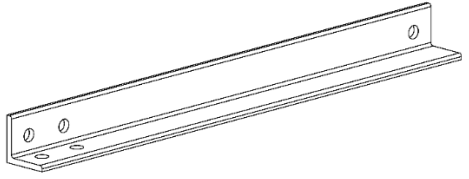

12.00
11.97
1.00 ±0.01
0.50 ±0.01
0.50 ±0.02
0.50 ±0.02
0.50 ±0.01
1.00 ±0.01
6x ∅9/32" THRU
0.50 ±0.02
0.50 ±0.02

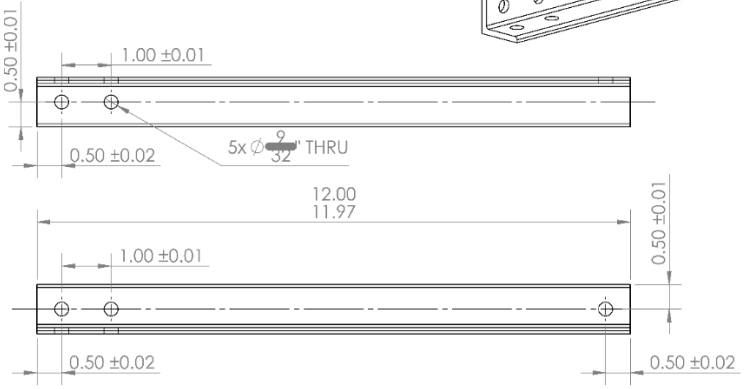

1/8"
1.0
1.0

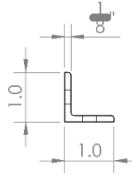


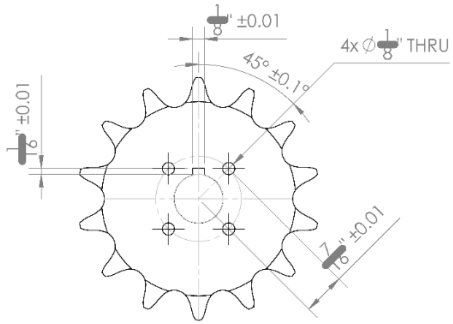

12.00
11.97
1.00 ±0.01
0.50 ±0.02
0.50 ±0.02
0.50 ±0.01
0.50 ±0.01
1.00 ±0.01
5x ∅9/32" THRU
0.50 ±0.02

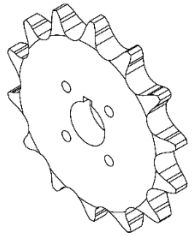

1.0
1.0

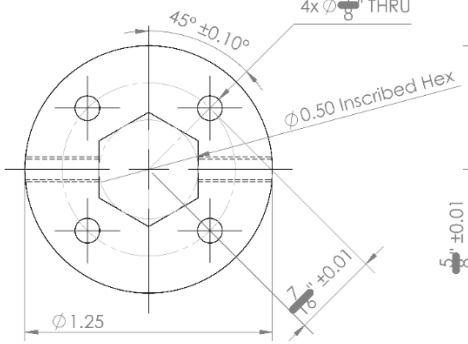


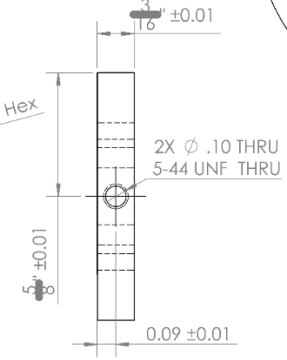

0.50 ±0.01
1.00 ±0.01
0.50 ±0.02
5x ∅9/32" THRU
12.00
11.97
1.00 ±0.01
0.50 ±0.01
0.50 ±0.02
0.50 ±0.02

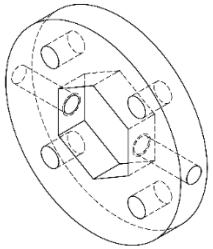

1/8"
1.0
1.0

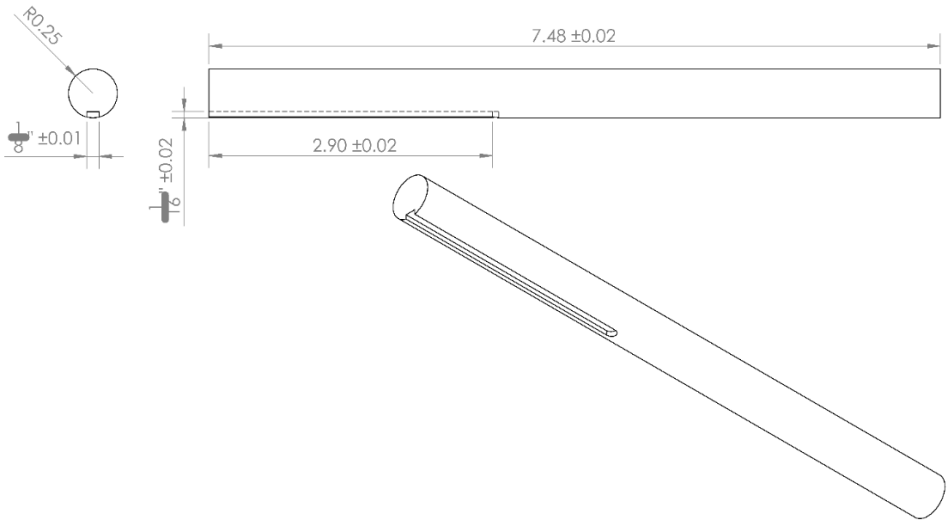

1/8" ±0.01
4x ∅1/8" THRU
45° ±0.1°
1/16" ±0.01
7/16" ±0.01

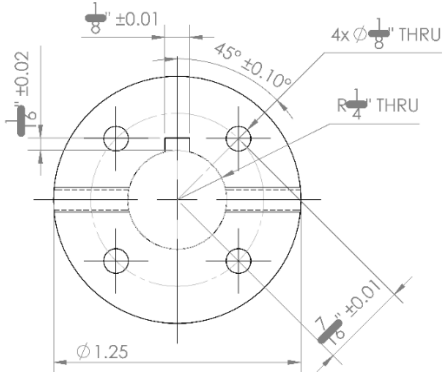


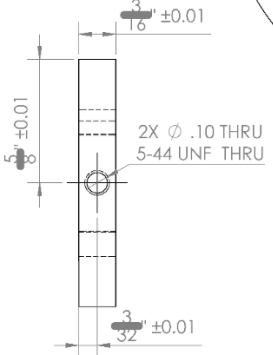

45° ±0.10°
4x ∅1/8" THRU
∅0.50 Inscribed Hex
7/16" ±0.01
∅1.25

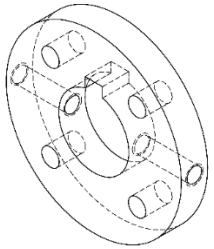

3/16" ±0.01
2X ∅ .10 THRU
5-44 UNF THRU
5/8" ±0.01
0.09 ±0.01




R0.25
1/8" ±0.01
7.48 ±0.02
2.90 ±0.02
1/16" ±0.02


1/8" ±0.01
45° ±0.10°
4x ∅1/8" THRU
1/16" ±0.02
R1/4" THRU
7/16" ±0.01
∅1.25


3/16" ±0.01
5/8" ±0.01
2X ∅ .10 THRU
5-44 UNF THRU
3/32" ±0.01



Phase 2 : Drivetrain Maneuverability Test

- **Purpose:** Determine if rover is capable of maneuvering over 7 cm obstacles and slopes of up to 20 degrees
- **Rationale:** FR.1
- **Test Facility:** Aerospace Building
- **Necessary Equipment:** Integrated drivetrain components, wooden blocks of heights up to 7 cm, ramp of incline up to 20 degrees
- **Test procedure:**
  - Drive rover over standard obstacles of increasing height up to 7 cm. Record performance and data from controllers.
  - Drive rover up slopes of increasing gradient up to 20 degrees. Record performance and data from controllers
- **Testing Dates:** 3/18/21 - 3/25/21

Mechanical Testing - Drivetrain Initial Fitting Test

- **Purpose:** Assess how completed drivetrain components fit together including gear box, sprockets, spacers, chains, and shafts
- **Rationale:** FR.1
- **Test Facility:** Aerospace Building
- **Necessary Equipment:** Completed machined drivetrain components, screws, and nuts
- **Test procedure: Completion Date:** 2/22/21
- **Results:** Spacers for sprockets were not large enough to fit chains and need to be remachined. Everything else was successful.

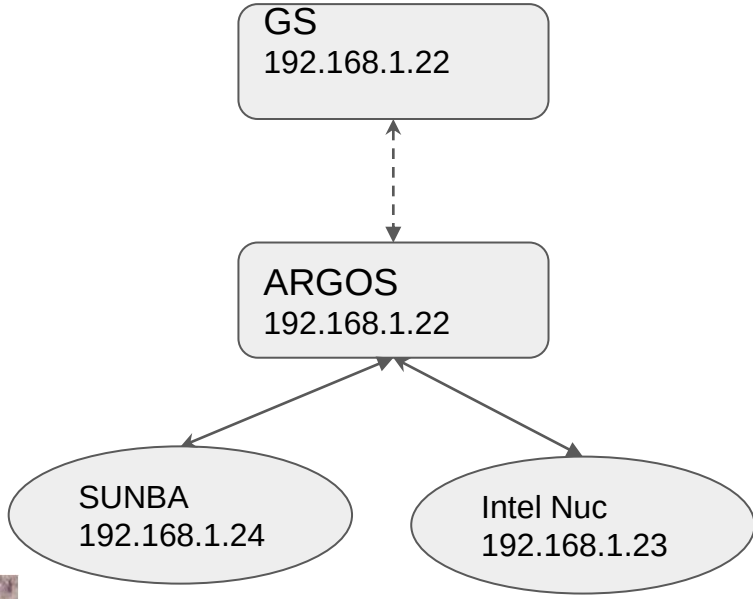
Communications

Update:

- Comm parts are being shipped

Tasks:

- Establish comm link between radios
- Analyze bandwidth, latency, and power received up to 250m.



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Software Unit Tests: Glass

GUI	Valid Data	Unexpected Data	Nan/None	No Active Rostopic
Comms	Yes	Yes: alerts in dialogue	Yes: displays none	Yes: different display message
Temp	Yes	Yes: alerts in dialogue	Yes	Yes: different display
Tilt	Yes	Yes: alerts in dialogue	Yes	Yes: different display
URF	Yes	Yes: alerts	Yes	Yes: disconnected displays
ARM	N/A	N/A	N/A	Yes
Waypoint	Yes	Yes	Yes: prevents waypoint addition	Yes
Location	Yes	Yes	Yes	Yes: alerts in dialogue
Mast	N/A	N/A	N/A	Yes
Camera	N/A	N/A	N/A	Yes

Comms Ping	Passed
No Data	Yes: emits disconnect
Data	Yes: emits connect
Nan Data	Yes: emits warn signal

Loss of Comms	Passed
No Odom Data	Yes: non functional as expected
Odom Data	Yes
No Comms ping	Yes: maneuvers
Comms Ping	Yes: stores odom
Reconnect	Yes: exit maneuver

Localization	Passed
No Data	Yes: doesn't publish as expected
Data	Yes
Partial Data	Yes: publishes

Diff Drive	Passed
No Data	Yes: doesn't move
Data	Yes
Unexpected Data	Yes: capped linear and angular speeds

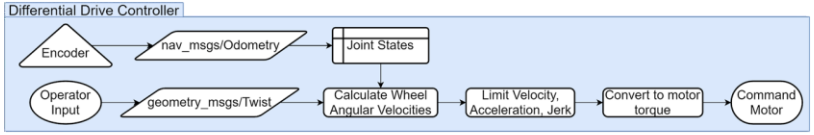
Gamepad Controller	Passed
No Data	Yes: doesn't publish
Data	Yes
Unexpected Data	Yes: only intakes joystick, caps value with linear transform and conditional
Disconnect	Yes: removes functionality

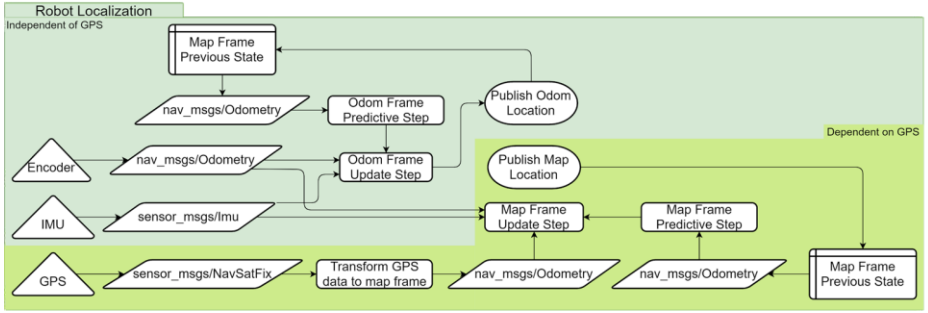
Software Unit Tests: Black Box

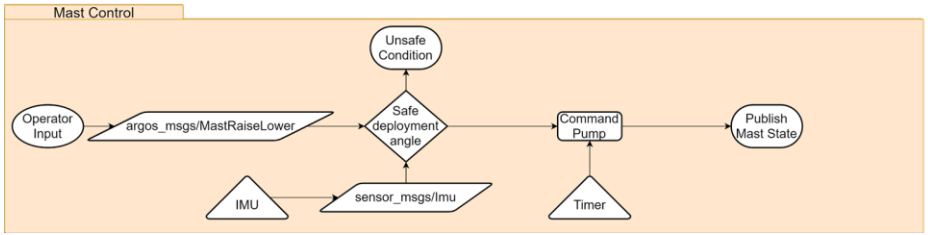
- 3 Users Tested on UI
  - Briefed on displays
  - Users were not a part of the senior projects team
  - Did not allow for malicious users

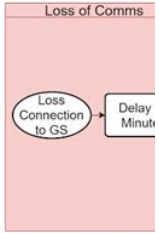
GUI	Valid Data	Unexpected Data	No Data
Comms	Yes	Yes: viewed alert	Yes: sees disconnect
Temp	Yes	Yes: viewed alert	Yes: sees disconnect
Tilt	Yes	Yes: viewed alert	Yes: sees disconnect
URF	Yes	Yes: viewed alert	Yes: sees disconnect
ARM	Yes: enabled	N/A	Yes: disabled
Waypoint	Yes	Allows for Malicious user	Yes: prevents waypoint addition
Location	Yes	N/A	Yes: viewed alert

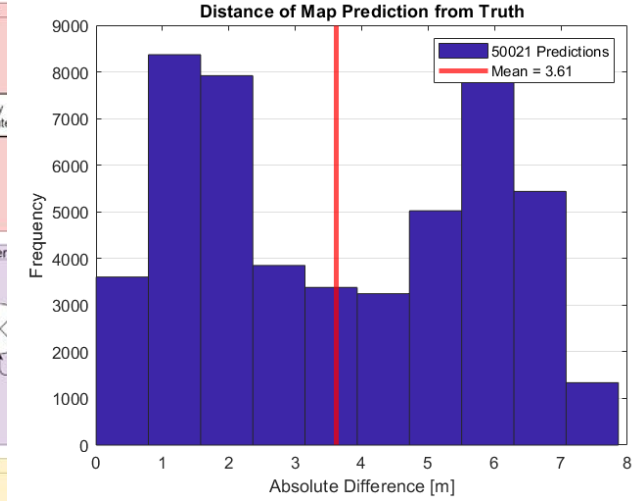
Software Diagram

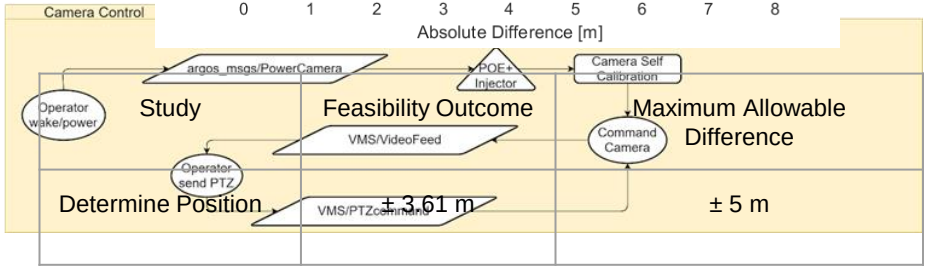












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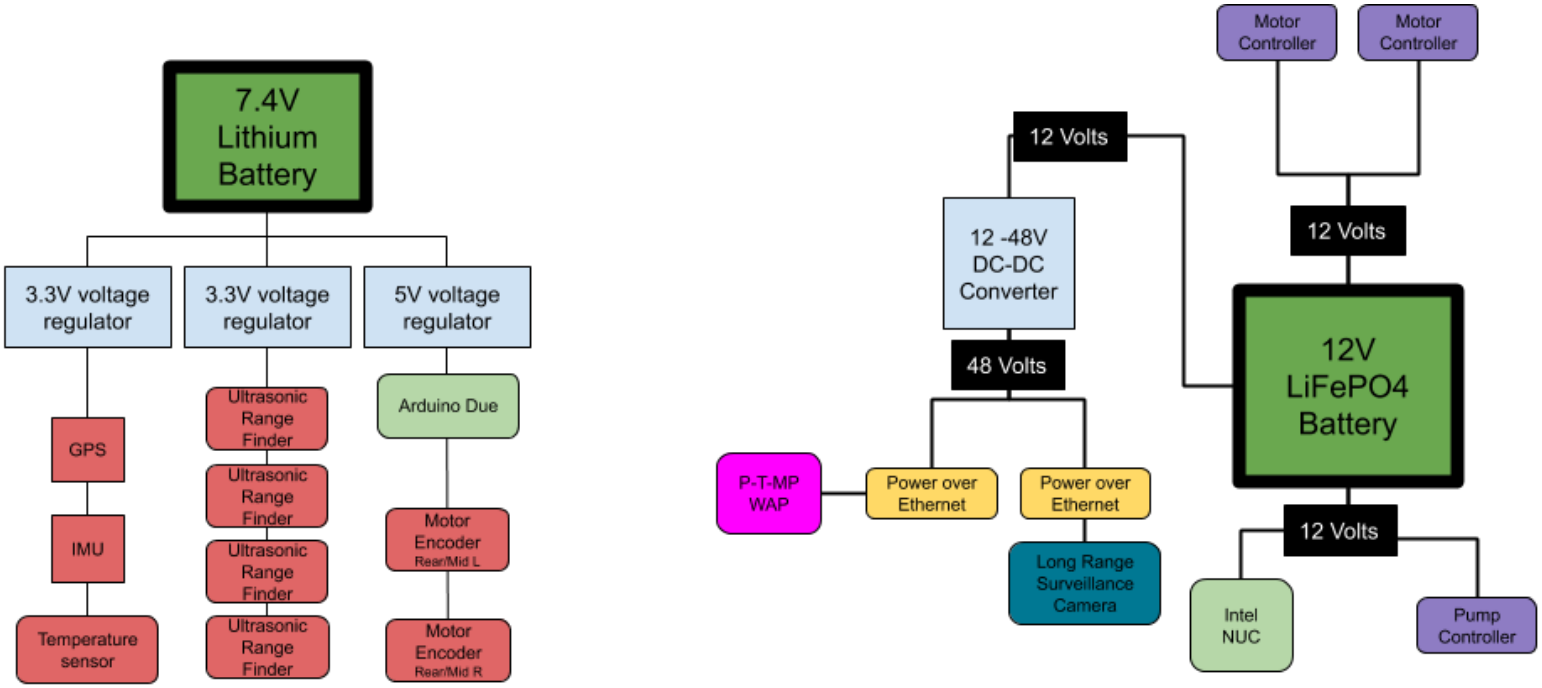
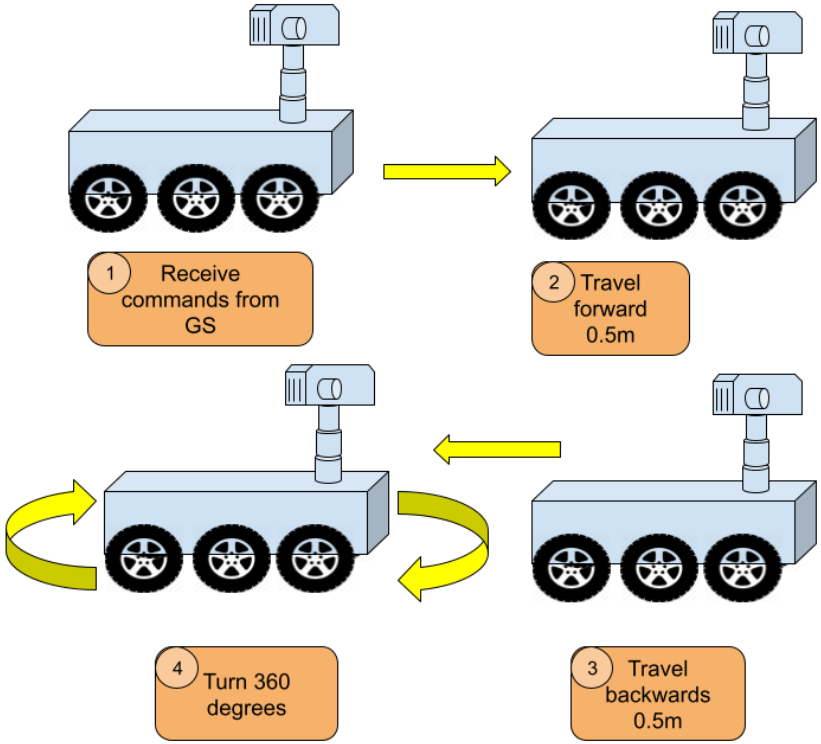
Power Diagram



Other Manual Control Tests



Subsystem Breakdown

Hydraulic Mast

Subsystem	Total
Sensors	$773.64
Electronics	$547.81
Drivetrain	$1,048.49
Chassis	$142.79
Camera	$269.99
Test Rig	$218.62
Hydraulic Mast	$400.00
Communications	$306.46
Total	**$3,707.80**
Remaining	**$1,292.20**

Off-Ramp Mast

Subsystem	Total
Sensors	$773.64
Electronics	$547.81
Drivetrain	$1,048.49
Chassis	$142.79
Camera	$269.99
Test Rig	$218.62
Off Ramp Mast	$900.00
Communications	$306.46
Total	**$4,207.80**
Remaining	**$792.20**

Forest Research : Trees

Source : https://www.fs.fed.us/psw/publications/documents/cfres_series/cfres_itr_afswp416.pdf

Tree Species	Average Height (ft)	Max Crown Length (ft)	Difference (ft)	Difference (m)
Ponderosa Pine	80	48.4	31.6	9.63168
Sugar Pine	175	19.6	155.4	47.36592
Western White Pine	175	48.95	126.05	38.42004
Lodgepole Pine	75	45.6	29.4	8.96112
Loblolly Pine	100	21.3	78.7	23.98776
White fir	50	49.4	0.6	0.18288
Grand fir	150	61.95	88.05	26.83764
Douglas fir	55	42.5	12.5	3.81
Engelmann Spruce	87.5	47.7	39.8	12.13104
Western Hemlock	125	39.45	85.55	26.07564
Incense Cedar	126.5	27.6	98.9	30.14472
Western Redcedar	200	31.9	168.1	51.23688
Western Larch	140	38.7	101.3	30.87624
			Average	23.82012

Forest Research : Shrubs/Bushes

Source: https://extension.colostate.edu/topic-areas/yard-garden/trees-and-shrubs-for-mountain-areas-7-423/

	Native Colorado Shrubs						
	Shrub Speciies	Max Height (when mature, ft)	Max Height (meters)	Max Width (ft)	Max Width (m)	Min Width (ft)	Min Width (f
	Red chokeberry	6	1.8288	4	1.2192	2	0.6096
	Black chokeberry	5	1.524	5	1.524	2	0.6096
	Japanese barberry	5	1.524	5	1.524	2	0.6096
	Siberian peashrub	10	3.048	6	1.8288	4	1.2192
	Peking or Hedge cotor	8	2.4384	6	1.8288	4	1.2192
	Burning bush	6	1.8288	6	1.8288	4	1.2192
	Forsythia	6	1.8288	8	2.4384	6	1.8288
	Creeping juniper	2	0.6096	6	1.8288	4	1.2192
	Savin juniper	4	1.2192	6	1.8288	4	1.2192
	'Cheyenne' Cheyenne	6	1.8288	6	1.8288	4	1.2192
	'Cheyenne' Cheyenne	6	1.8288	5	1.524	4	1.2192
	Common ninebark	6	1.8288	6	1.8288	4	1.2192
	Nanking cherry	8	2.4384	8	2.4384	6	1.8288
	Purpleleaf sand cherr	6	1.8288	6	1.8288	4	1.2192
	Staghorn sumac	12	3.6576	8	2.4384	6	1.8288
	Alpine currant	4	1.2192	4	1.2192	3	0.9144
	Elderberry	8	2.4384	8	2.4384	6	1.8288
	Ash-leaf spirea or Ura	6	1.8288	6	1.8288	4	1.2192
	Vanhoutte spirea	6	1.8288	6	1.8288	4	1.2192
	Coralberry, buckbrush	5	1.524	5	1.524	3	0.9144
	Common lilac	8	2.4384	6	1.8288	4	1.2192
	Preston or Canadian li	8	2.4384	6	1.8288	4	1.2192
	Wayfaringtree viburn	8	2.4384	8	2.4384	6	1.8288
	Nannyberry viburnum	10	3.048	8	2.4384	6	1.8288
	European cranberrybu	10	3.048	10	3.048	8	2.4384
	American cranberrybu	8	2.4384	6	1.8288	4	1.2192
		Average	2.074984615		1.922584615		1.31298462