ARGOS
Autonomous Rover for Ground-based Optical Surveillance

Manufacturing Status Review
February 4, 2021

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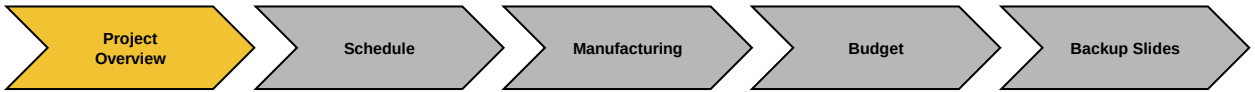
University of Colorado Boulder

Jet Propulsion Laboratory
California Institute of Technology

Project Overview

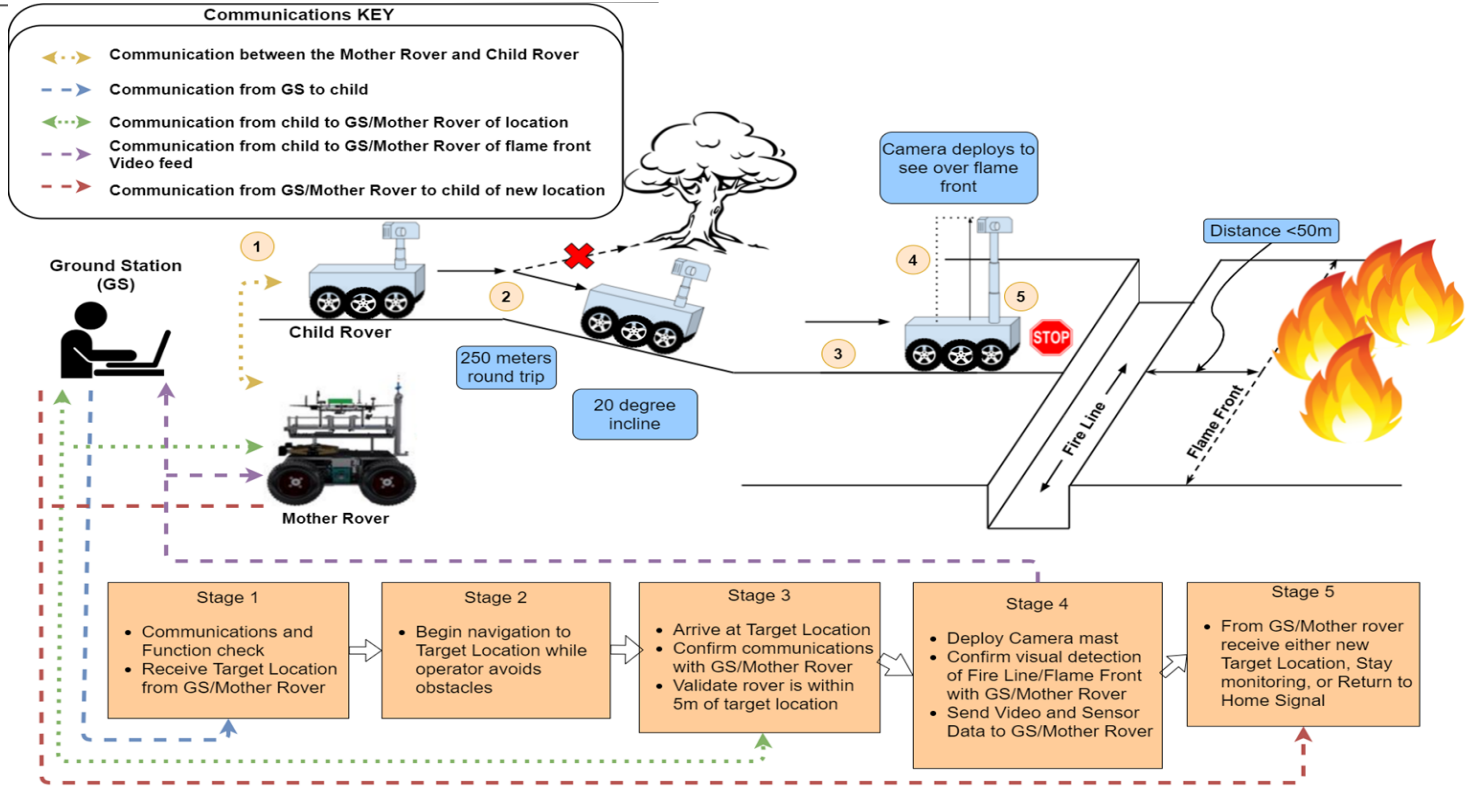


Mission Statement / Objectives

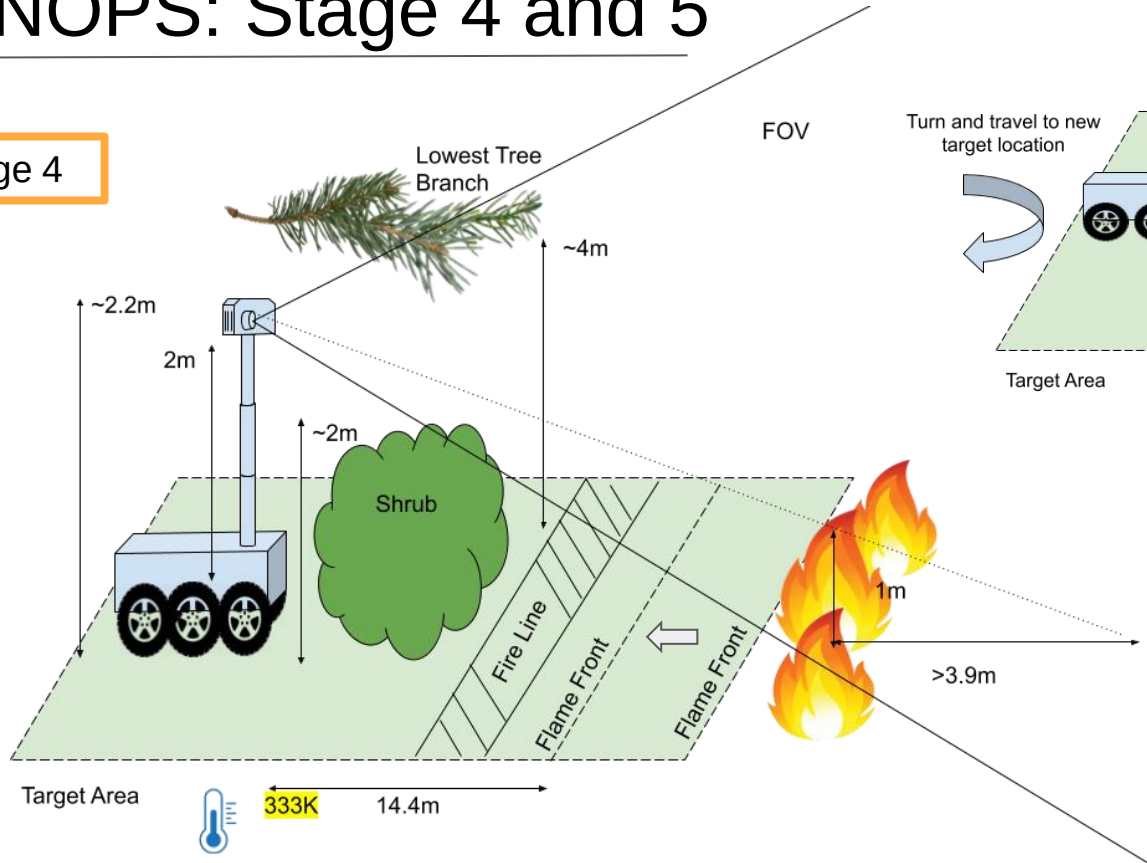
The ARGOS team shall design, build, and test a child rover that will :

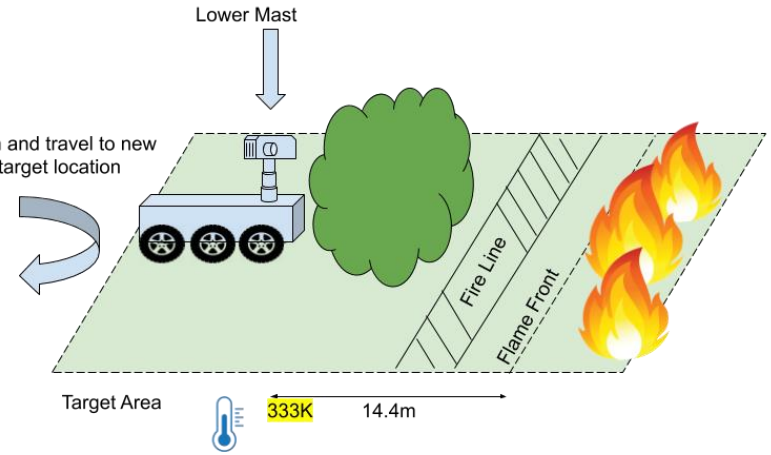
1. **Navigate** to a fireline via commands from a ground station (GS) and mother rover (MR)
2. **Collect ambient temperature data** throughout the duration of the mission
3. **Record photos/video** of a flame front from the top of an **extendable/retractable mast**
4. **Communicate** temperature data,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

CONOPS


Communications KEY
Communication between the Mother Rover and Child Rover
Communication from GS to child
Communication from child to GS/Mother Rover of location
Communication from child to GS/Mother Rover of flame front Video feed
Communication from GS/Mother Rover to child of new location
Ground Station (GS)
Child Rover
Mother Rover
250 meters round trip
20 degree incline
Camera deploys to see over flame front
Distance <50m
STOP
Fire Line
Flame Front
1
2
3
4
5
Stage 1
Communications and Function check
Receive Target Location from GS/Mother Rover
Stage 2
Begin navigation to Target Location while operator avoids obstacles
Stage 3
Arrive at Target Location
Confirm communications with GS/Mother Rover
Validate rover is within 5m of target location
Stage 4
Deploy Camera mast
Confirm visual detection of Fire Line/Flame Front with GS/Mother Rover
Send Video and Sensor Data to GS/Mother Rover
Stage 5
From GS/Mother rover receive either new Target Location, Stay monitoring, or Return to Home Signal

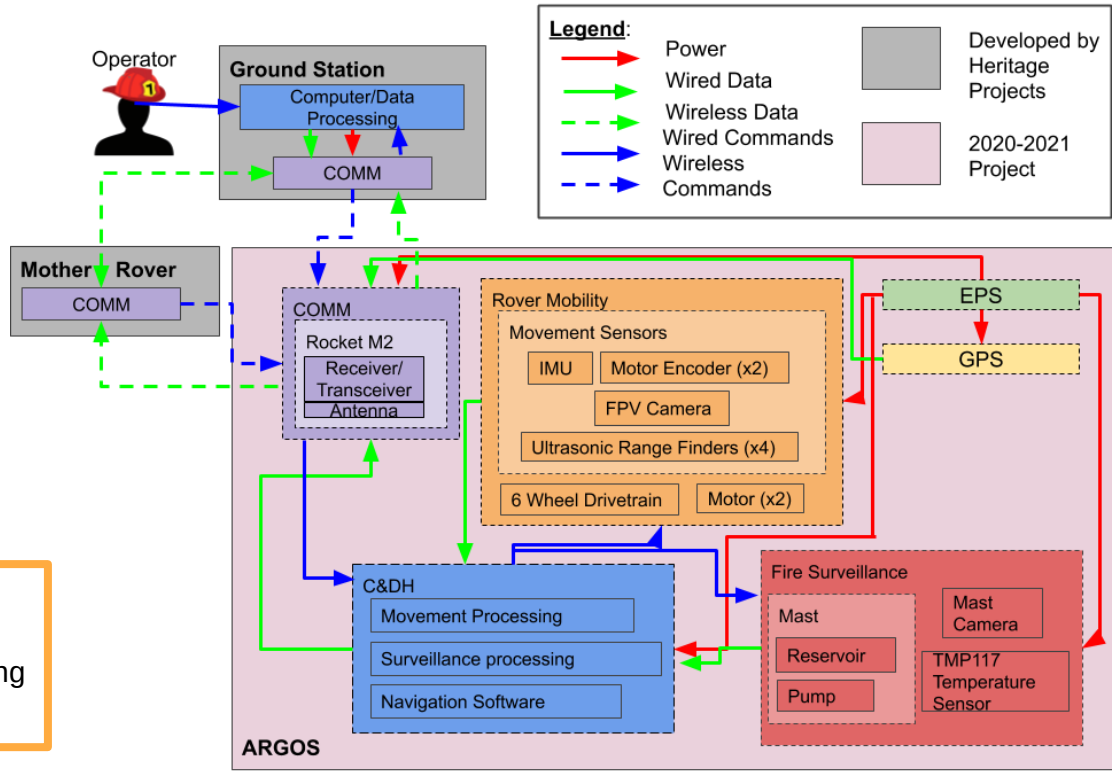
CONOPS: Stage 4 and 5





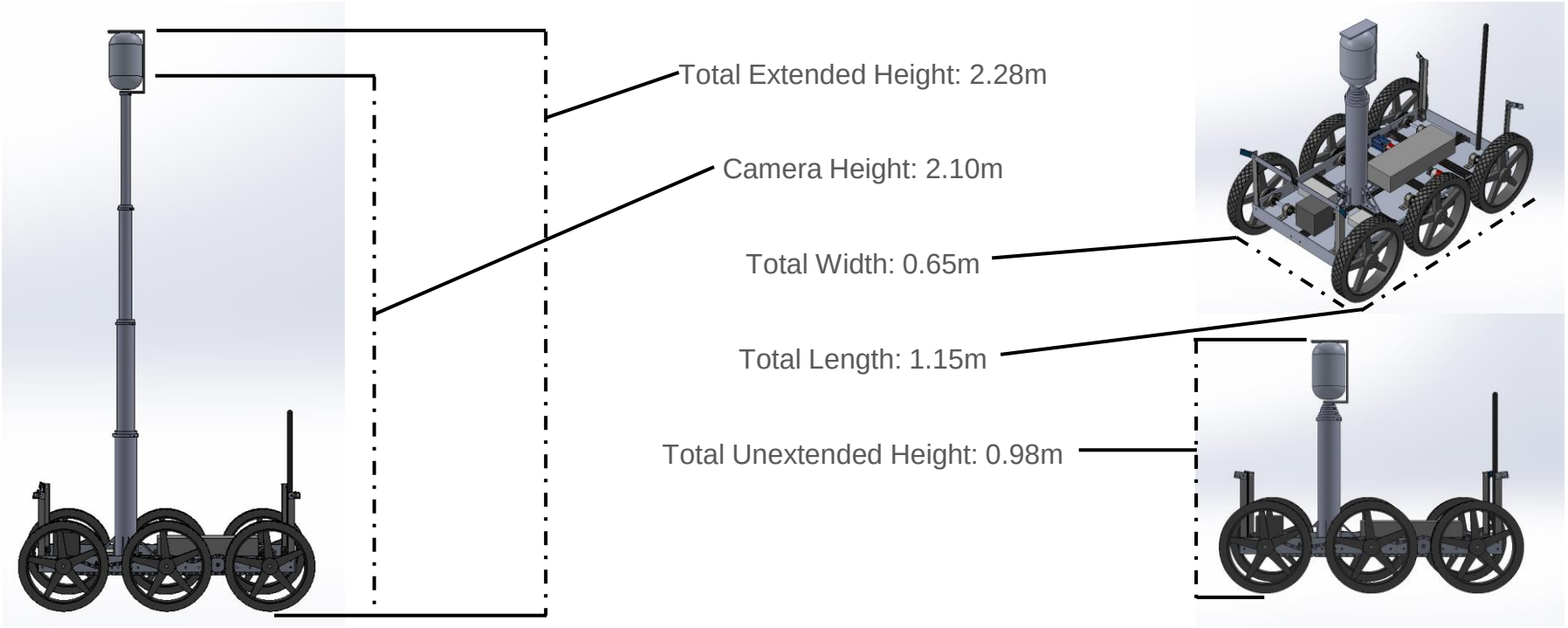
Stage 5

Functional Block Diagram



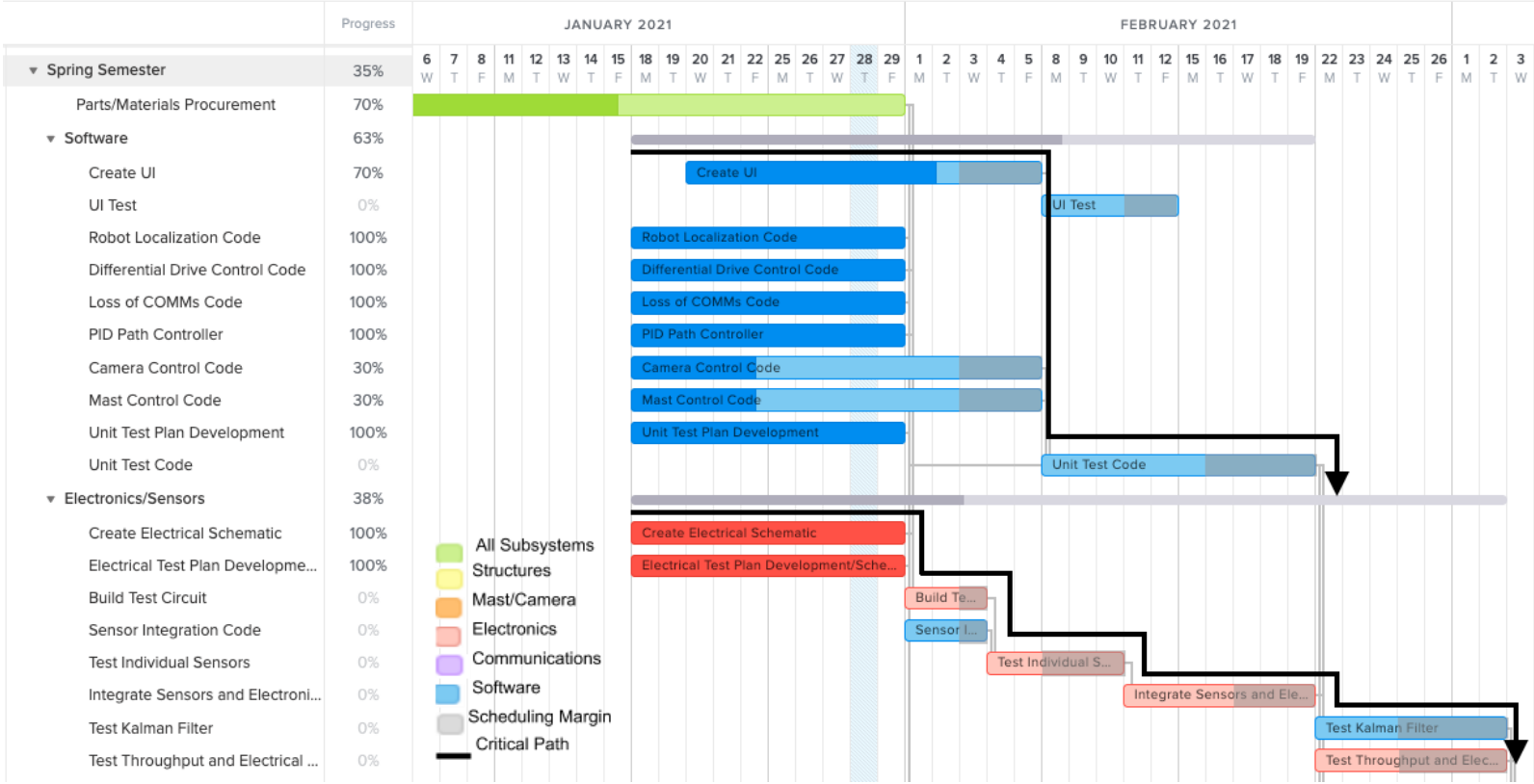
Note:
Acknowledgements are also sent following every command.

Full Design Recap

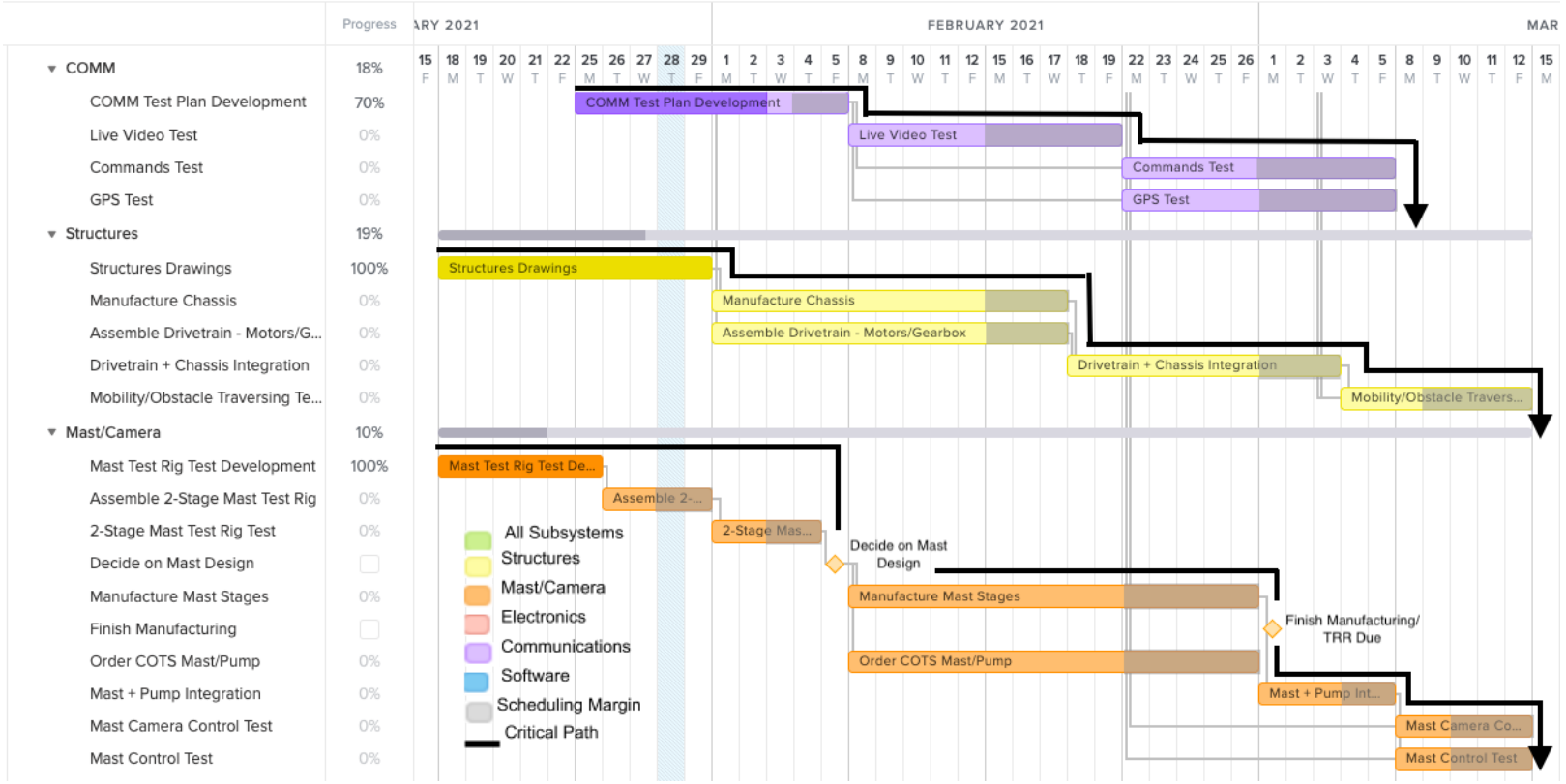


Schedule

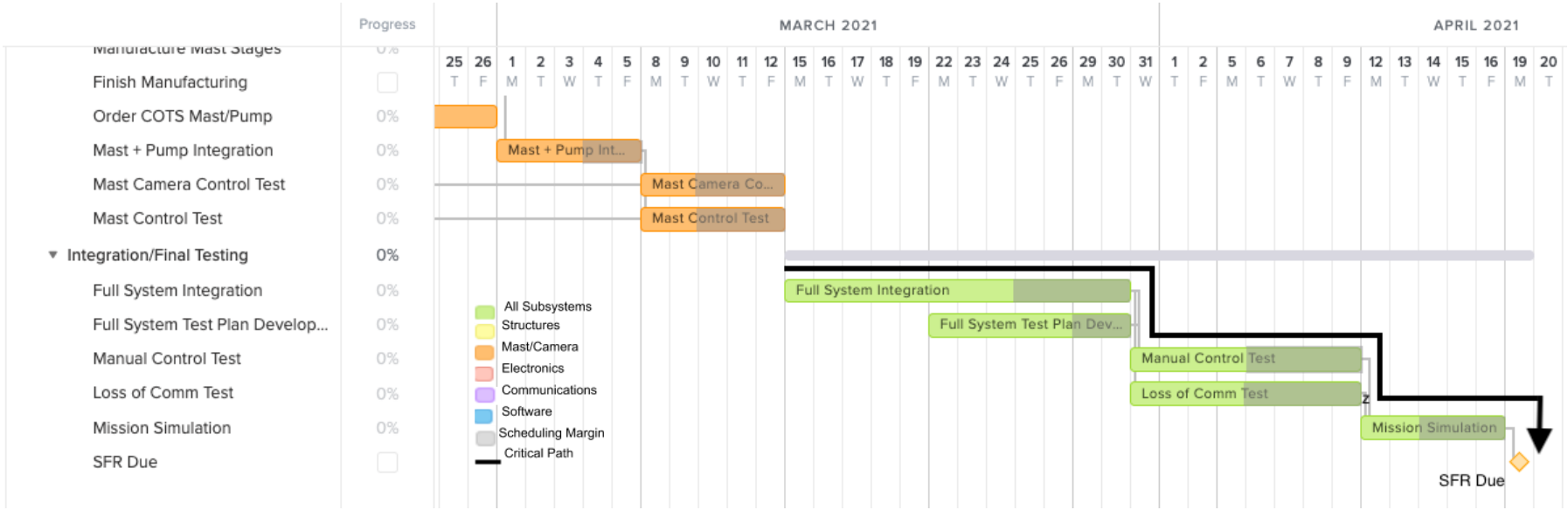
Work Plan - Software and Electronics/Sensors



Work Plan - COMM, Structures, and Mast/Camera

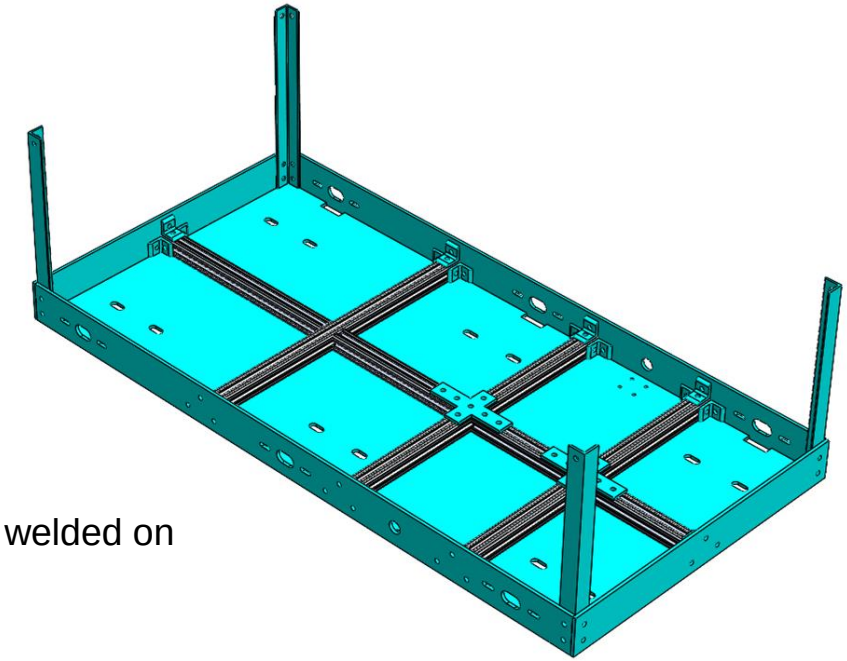


Work Plan - Final Integration/Testing



Manufacturing

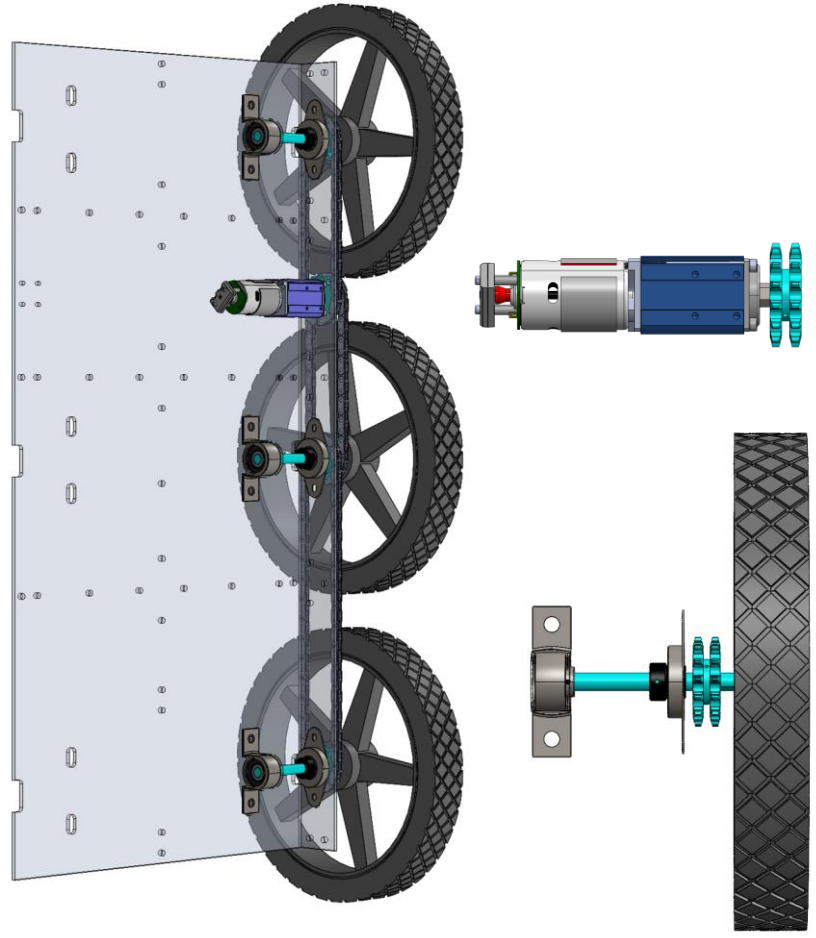
Mechanical: Chassis



- COTS parts ordered
  - T-Slotted Framing (needs to be cut to length)
  - End-Feed Single Nuts with Button Head
  - Button Head Hex Drive Screws
  - Locknuts
- Manufactured parts highlighted in **blue**
  - Aluminum Base:
    - Needs to be CNC cut and sides need to be welded on
    - Estimated completion date: 2/12/21
  - L-Brackets
    - Needs to be cut and holes need to be drilled
    - Estimated completion date: 2/12/21
  - Aluminum Supports
    - Needs to be cut and holes need to be drilled
    - Estimated completion date: 2/12/21

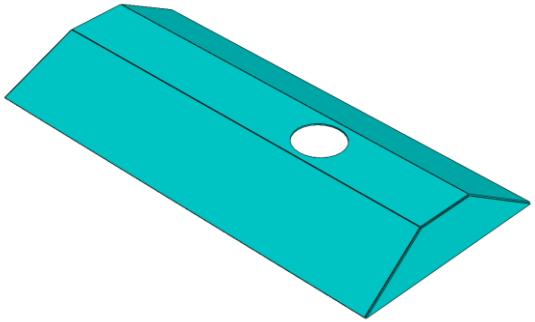
Mechanical: Drivetrain

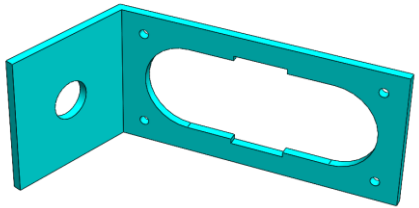
- COTS parts have been ordered
  - Motor and Gearbox
  - Bearings
  - Wheels
  - Chains and connecting link
- Manufactured parts highlighted in **blue**
  - Shafts:
    - Need to be cut to size and keyed
    - Estimated completion date: 2/12/21
  - Sprocket spacers
    - Need to be manufactured
    - Estimated completion date: 2/12/21
  - Sprockets
    - Need to be machined
    - Estimated completion date: 2/12/21

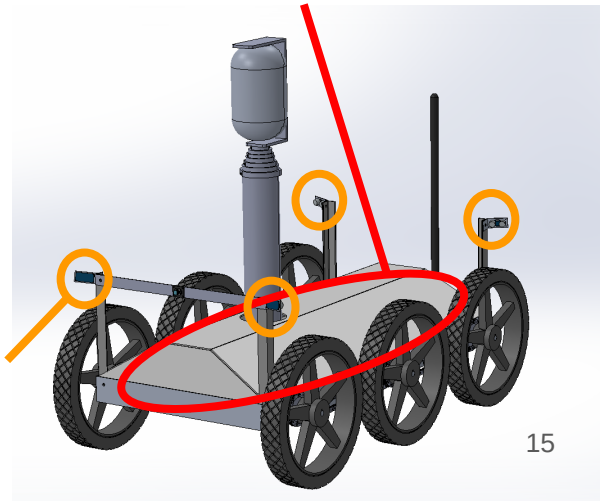


Mechanical: Chassis Acrylic Housing & Sensor Mounts

- Manufactured parts highlighted in **blue**
  - Acrylic housing
    - Needs to be purchased and laser cut
    - Estimated completion date: 2/12/21
  - Sensor Mounts
    - Need to be 3D Printed
    - Estimated completion date: 2/12/21







Mechanical: Mast Test Rig

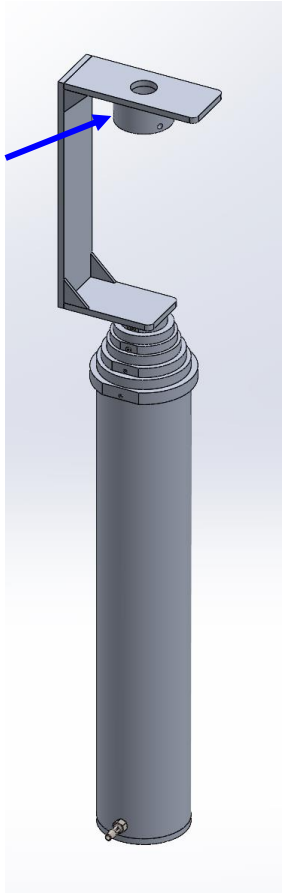
- Test Rig Assembly Finished
  - Testing reservoir complete
  - Test rig machined components assembled
  - Testing planned for Thursday 2/4
- Test Procedure
  - Pressurize reservoir with high pressure air
  - Extend and retract mast multiple times
  - Check for binding and/or degradation
  - Seal has higher coefficient of friction than expected which may pose a problem for compression
    - Test weight force required to compress
  - If test rig passes all tests without issue, hydraulic mast is chosen for the final design

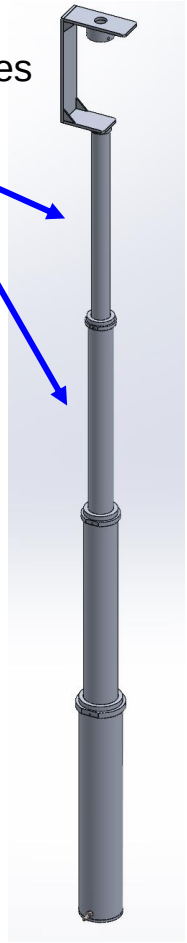
Reservoir

Test Rig

Mechanical: Full Hydraulic Mast

- COTS parts ordered:
  - Shared parts with test rig
    - Top two stages w/ internals
    - Hydraulic Oil
  - No other COTS parts ordered
    - Waiting on test rig results
- Manufacturing
  - Stages 1, 2 and 3
    - Outer diameter machined down; holes tapped
  - Stage 1 and 2 donuts
    - Machined out of aluminum round stock
    - Holes tapped
  - Stage 1 cap needs to be welded to stage 1
  - Camera mount needs to be cut and welded
  - Base mount needs to be cut and welded to stage 1



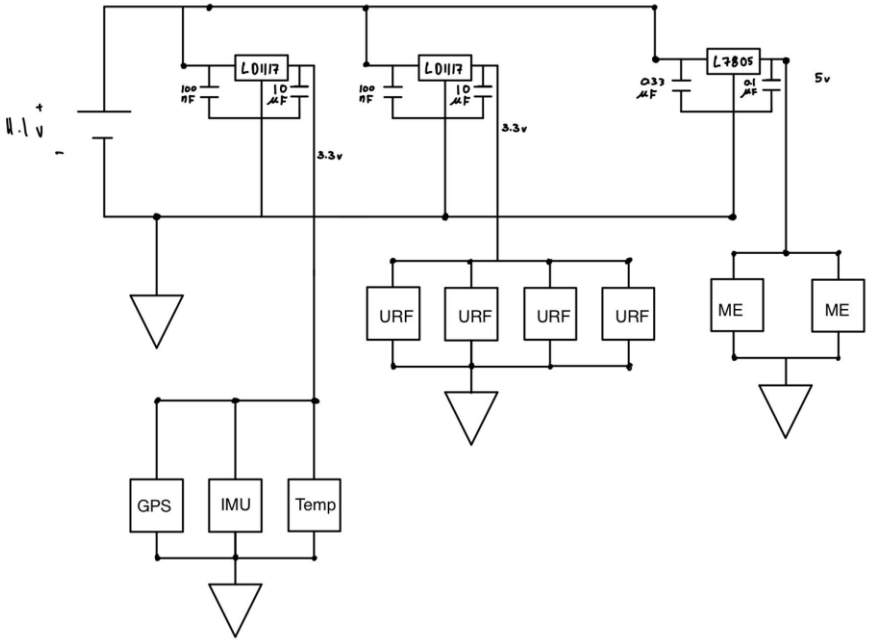


Mechanical: Off-Ramp COTS Mast

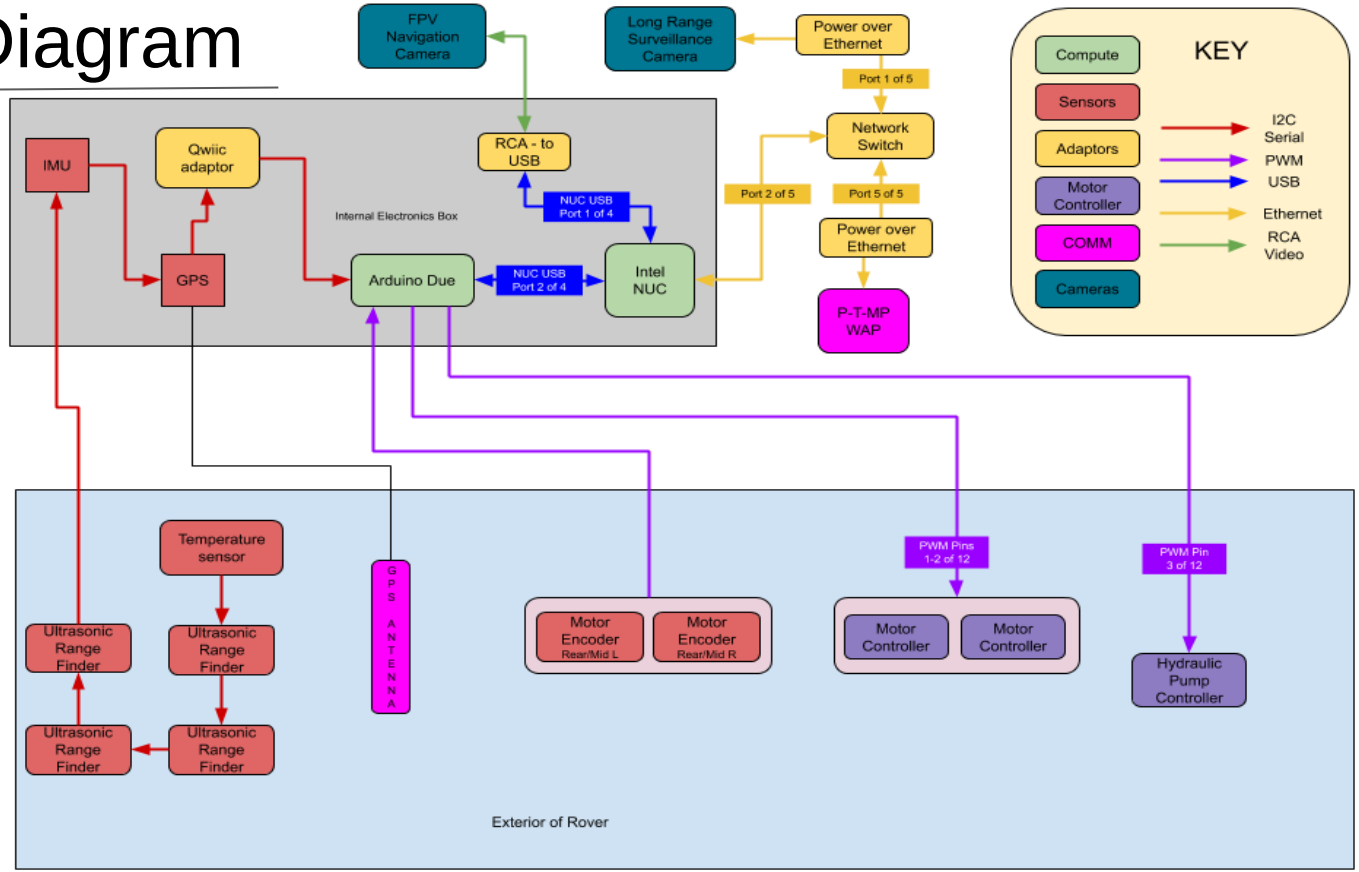
- COTS parts ordered
  - None
  - Waiting on test rig results
- Manufacturing
  - Camera mount needs to be cut and welded
    - Attachment to COTS mast → weld
  - Base mount needs to be cut, drilled and put on rover body
  - Mounts for air compressor need to be machined
- Assembly/Integration
  - All valves and air lines need to be connected
  - Mast needs to be mounted to body of rover
  - Compressor controller needs to be programmed communicate with air compressor

Electrical

- COTS parts ordered
  - 12 V battery
  - Sensors voltage regulators
  - All sensors - Tested by 2/10
- Parts left to order
  - LS7412 Data Filter
  - Additional Wiring
  - NUC Power Cable
  - 19 V voltage regulator
- Procedures Created
  - Retool of 12 V system needed
- All Assembly Needed - by 2/19
  - Soldering of power circuits
  - Soldering of data transmission lines



Electronics Diagram



More detailed pin-out diagrams and procedures have been made already.

Software

Task	Status	Number of Team Members Currently Contributing	Estimated Ready to Integrate Date
ROS: Localization	Ready to Integrate with Hardware	-	-
ROS: Differential Drive	Ready to Integrate with Hardware	-	-
ROS: PID Path Control	Ready to Integrate with Hardware	-	-
UI: Surveillance Tab	Validate in Simulation	2	2/5
UI: Movement Tab	Validate in Simulation	2	2/5
UI: Camera Control	In Progress	1	2/5
UI: Integrate with ROS	In Progress	1	2/5
Sensors: Arduino Code	In Progress	2	2/5
ROS: Loss of Comms	In Progress	1	2/5
ROS: Integrate with Rocket M2	To Do	0	2/5 Waiting on Comms Test
ROS: Mast Control	To Do	0	2/10 Dependent on Mast Test Rig Outcome

Ready for Testing/Integration with Hardware. Begins 2/8.

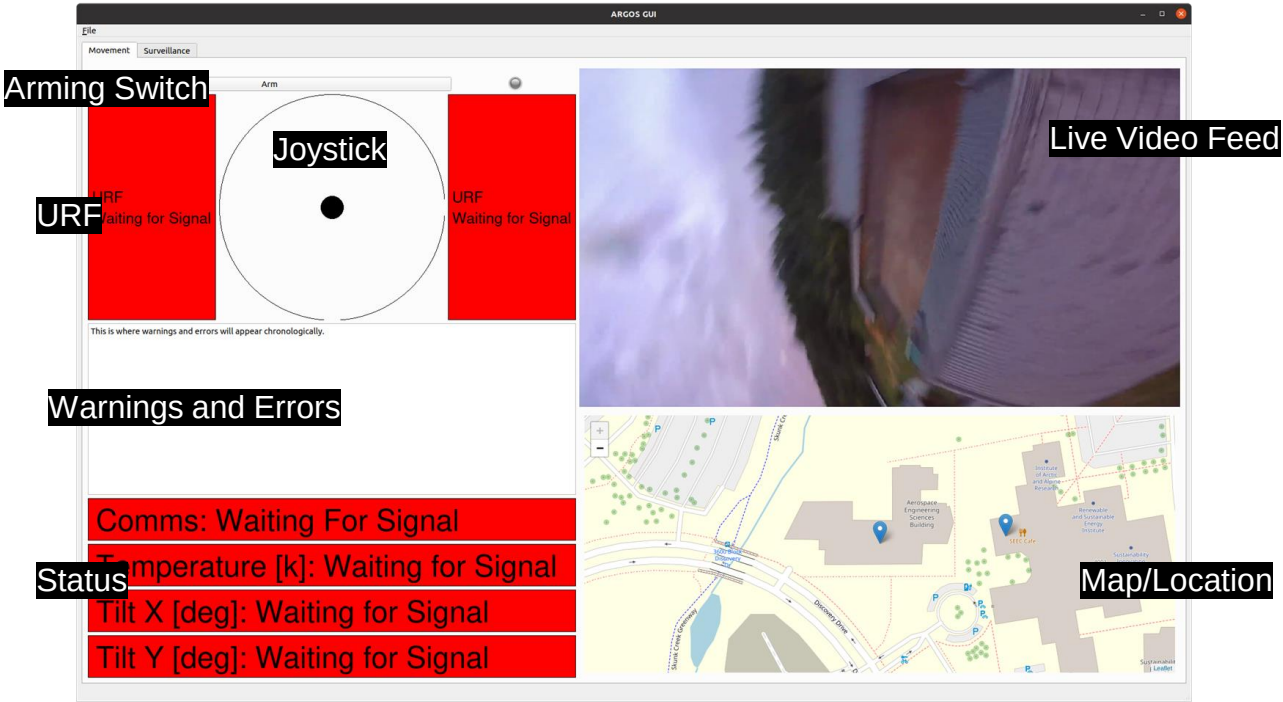
Ready for Validation in simulation. Note: only used for software compatible with Gazebo.

In Progress. Being Developed by one or more team member.

To do. Not started yet due to dependence on other in progress software or future test.

Software: UI

- Completed
  - Movement and Surveillance Tabs
  - Camera Controlled via webpage contained in UI
- Development
  - Integration with ROS using python_qt_binding package
  - Estimated Completed Date: 2/5



Software: UI

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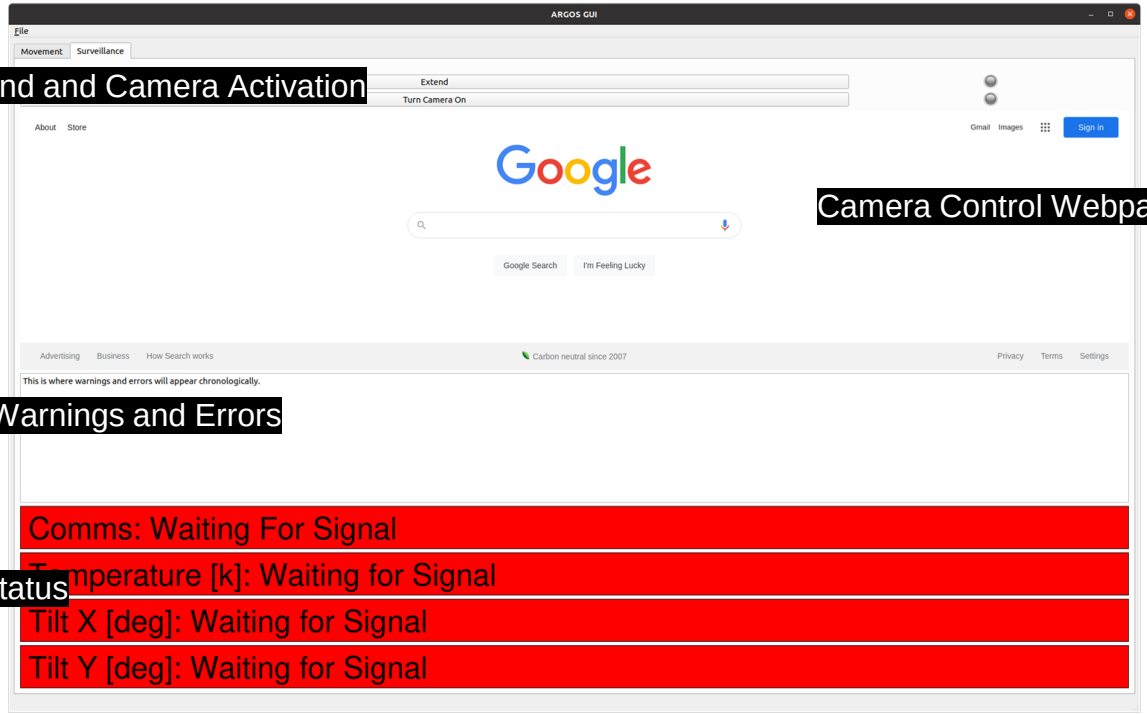
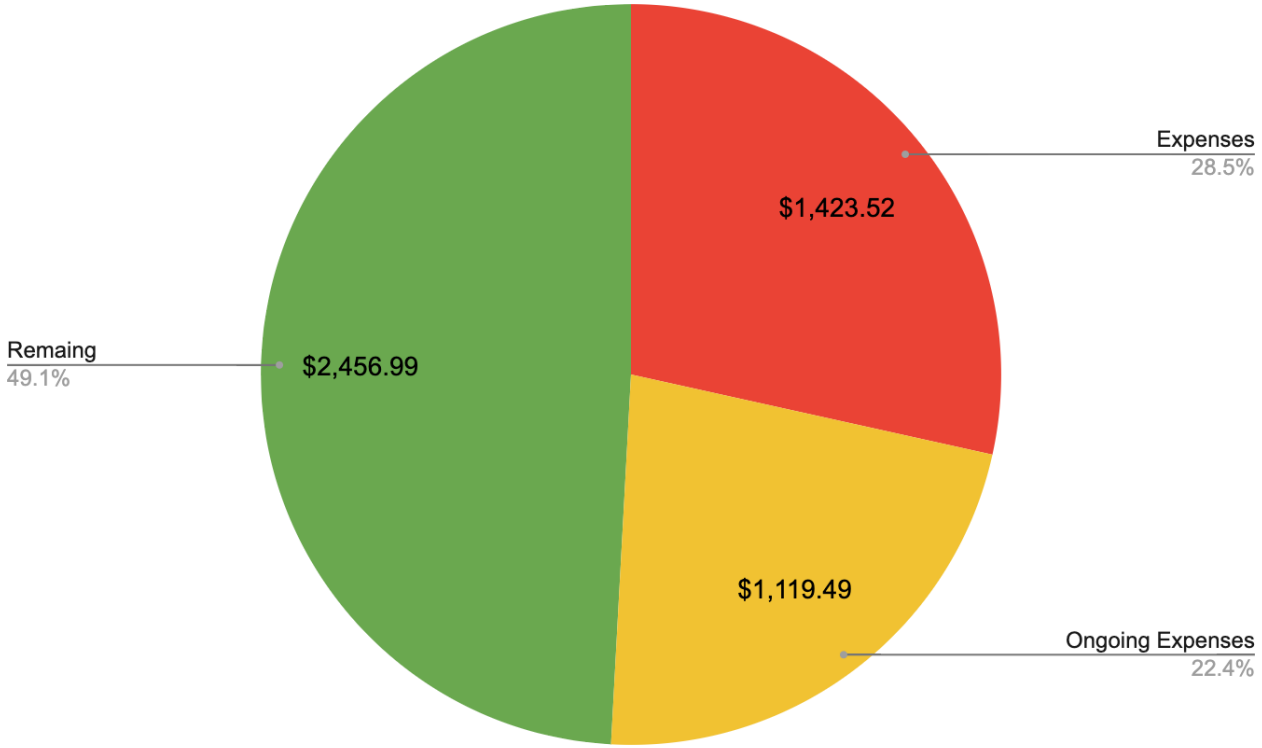


Budget



Ongoing expenses does not include shipping costs

Budget

- Major Procurements
  - Sensors: Camera, GPS
  - Electronics: Nuc, IMU, thermometer
  - Drivetrain: Motors, gear boxes, wheels
  - Chassis: Aluminum sheet and frame
  - Communications: Rocket M2 radio
- Remaining purchases
  - Rest of mast
  - Pump and reservoir
- Ongoing Order
  - $1,119.49 not including shipping
  - Made on 1/20/21

Expenses: $2,543.01

Estimated Final Cost: $3,354.72

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

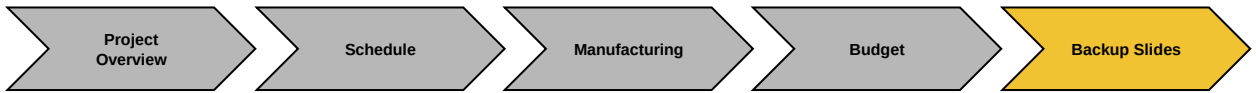
POE TP-DCDC-1224 Adapter	PoETexas	2	5.49		10.98	Communication
TRENDnet Reverse SMA Female to N-Type Male Weatherproof Connector Cable (6.5ft, 2M), TEW-L202	Trendnet	1	19		19	Communication
Antenna 2.4GHz 12dBi Omni-Directional WiFi w/ RP-TNC	Data Alliance	1	8.99		8.99	Communication
1ft Cat6 550 MHz UTP 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

- Most manufacturing completion date: **2/12**
  - Mast completion date (and everything else): **3/1**
- Electrical assembly completion date: **2/19**
- Software completion date: **2/10**
- Most all parts have arrived or have been ordered
  - Parts that have not arrived - no cause for concern

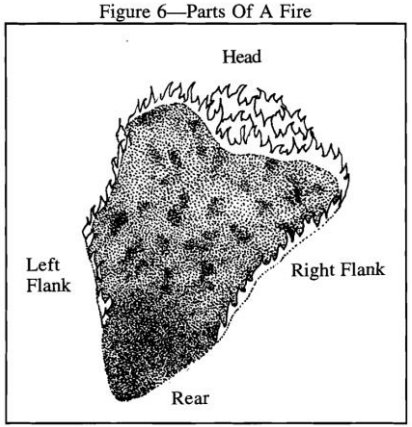
Questions?

Backup Slides



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)



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.

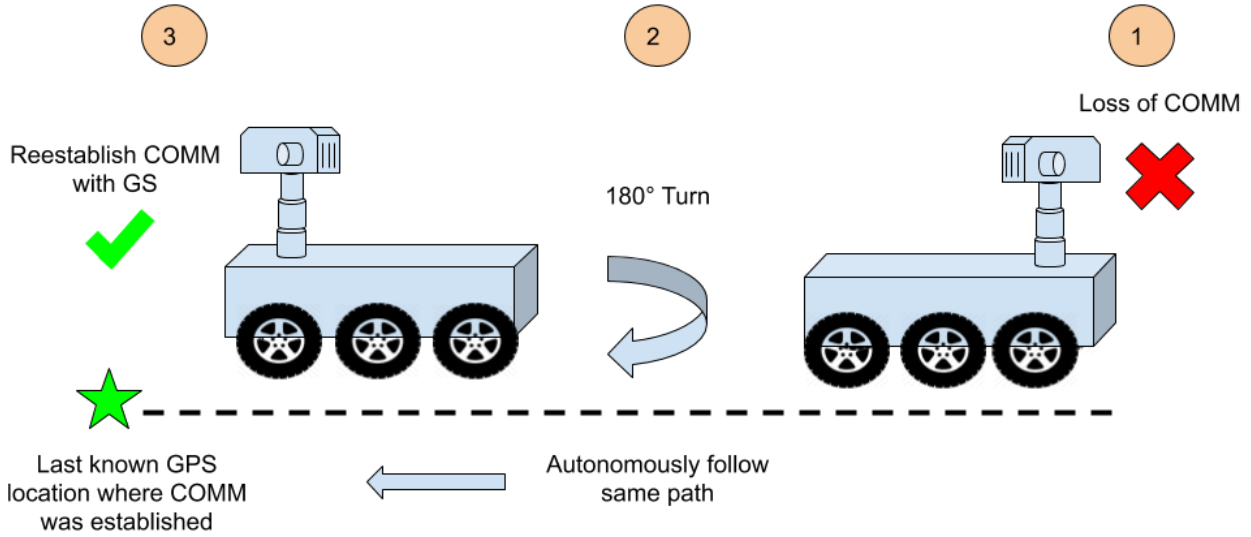
Design Requirement ID	Description
SURV.3.1	The child rover shall have a mast capable of extending to a height of 2m and retracting back down to its original height.
SURV.3.2	The child rover shall have a mast capable of supporting 10kg of weight on the top.

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.

Loss of Communications CONOPS

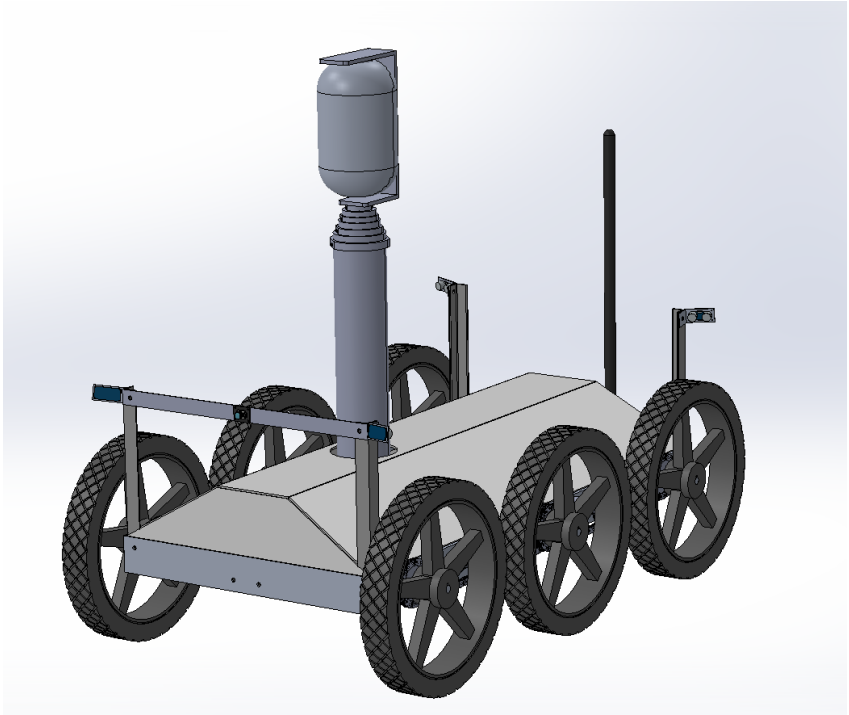


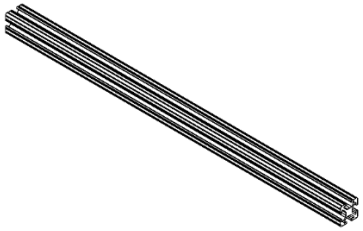
Levels of Success

	Rover Movements	Surveillance	Communications
Level 1	Rover can travel on flat ground for 100m. Rover can travel in the forward direction and can turn 360 degrees with a turn radius less than two rover body lengths.	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 or in the same room via radio remote control.
Level 2	Rover can travel on various terrain, including leaves, scattered 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.	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 100m with no obstacles (0 trees/m2).
Level 3	Rover can turn 360 degrees on the spot. Rover can follow GPS waypoints and detect large obstacles, such as trees and dense bushes, in its path and avoid hitting them. 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 with obstacles (0.25 trees/m^2).
Level 4	Rover can detect small obstacles, such as rocks and small bushes, and navigate a path around them. Rover can navigate to a GPS waypoint within +/-5m of the coordinates.	N/A	Rover can communicate with the ground station and the mother rover up to 250m.

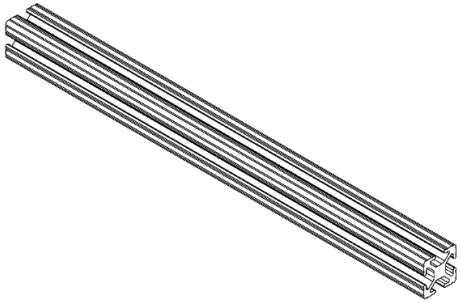
Final Design With Top Panels

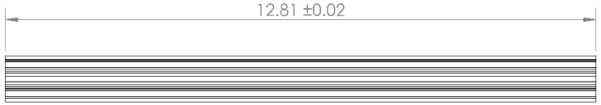
- Panels made of acrylic
- Connected using angled aluminum brackets

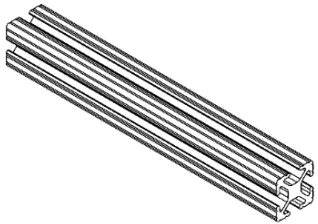


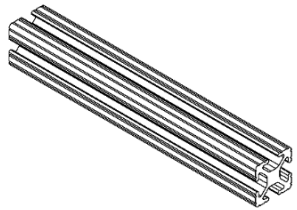


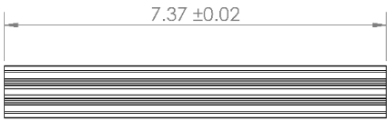

19.31 ±0.02

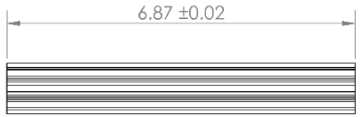


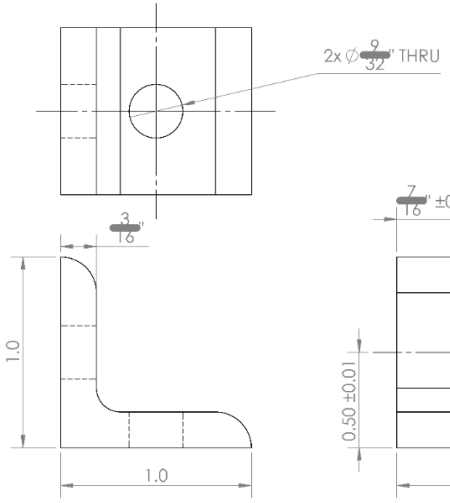

12.81 ±0.02

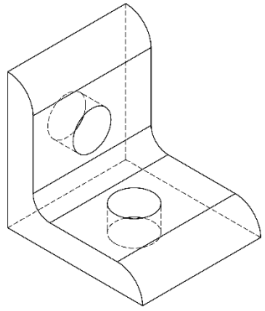


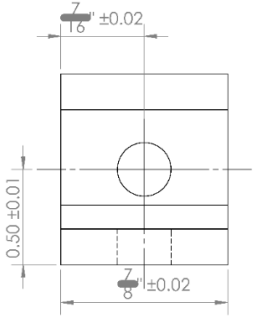


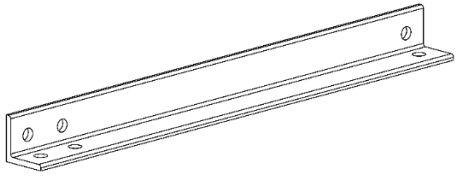

7.37 ±0.02

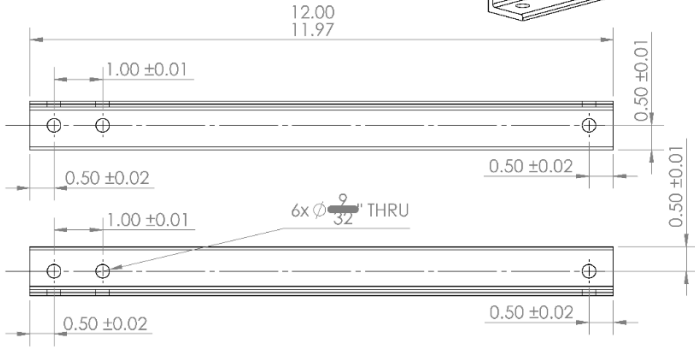

6.87 ±0.02

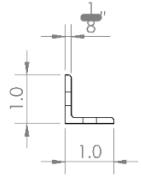

2x ∅9/32" THRU
3/16"
1.0
1.0

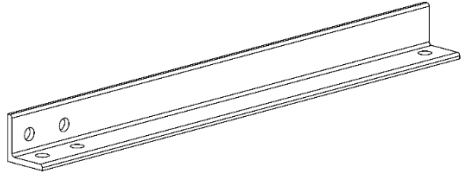


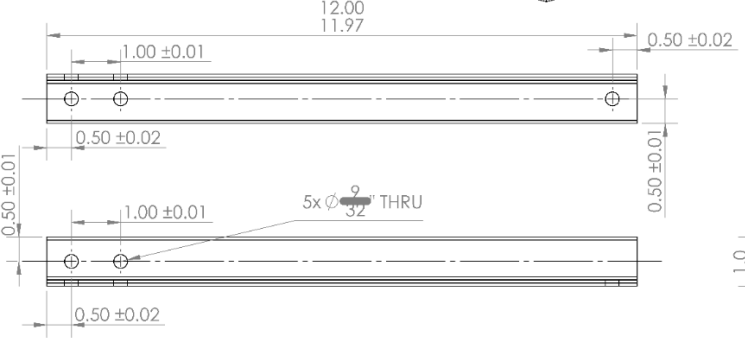

7/16" ±0.02
0.50 ±0.01
7/8" ±0.02

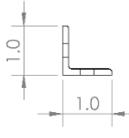


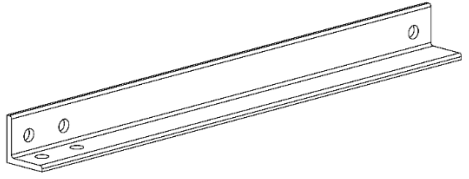

12.00
11.97
1.00 ±0.01
0.50 ±0.01
0.50 ±0.02
0.50 ±0.02
6x ∅9/32" THRU
1.00 ±0.01
0.50 ±0.01
0.50 ±0.02
0.50 ±0.02

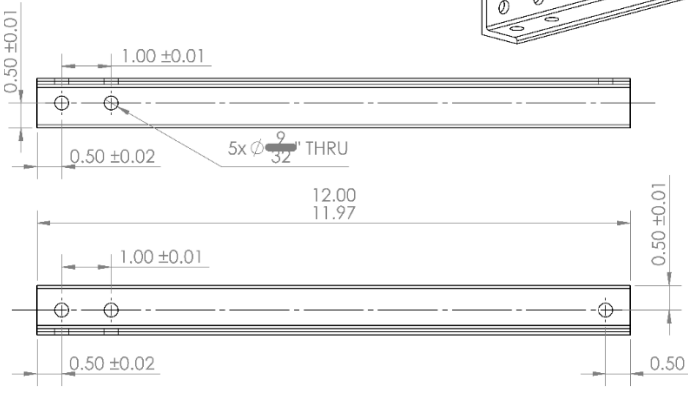

1/8"
1.0
1.0

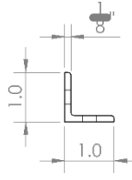


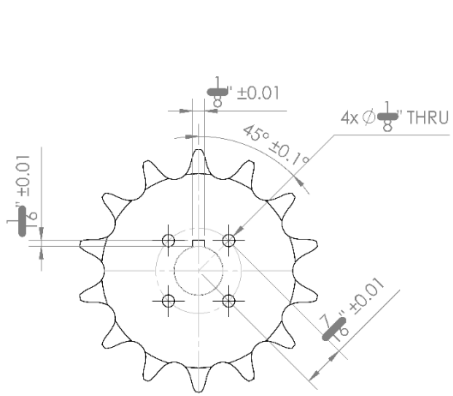

12.00
11.97
1.00 ±0.01
0.50 ±0.02
0.50 ±0.02
0.50 ±0.01
0.50 ±0.01
1.00 ±0.01
5x ∅9/32" THRU
0.50 ±0.02

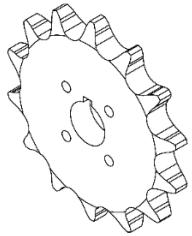

1.0
1.0

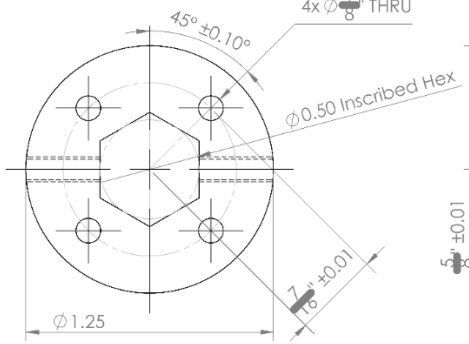


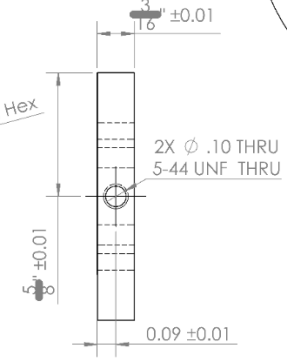

0.50 ±0.01
1.00 ±0.01
0.50 ±0.02
5x ∅9/32" THRU
12.00
11.97
1.00 ±0.01
0.50 ±0.01
0.50 ±0.02
0.50 ±0.02

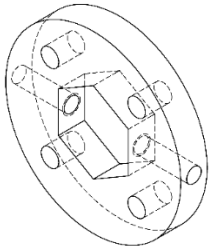

1/8"
1.0
1.0

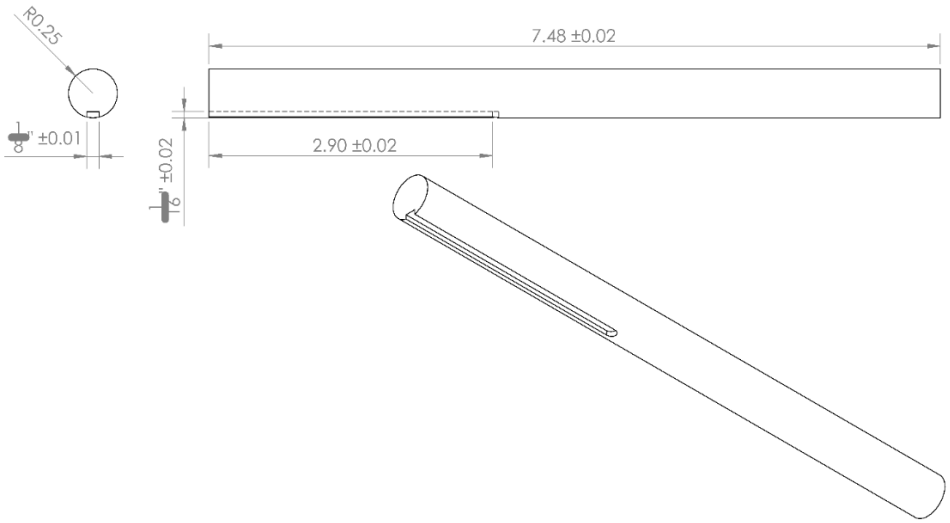

1/8" ±0.01
4x ∅1/8" THRU
45° ±0.1°
1/16" ±0.01
7/16" ±0.01

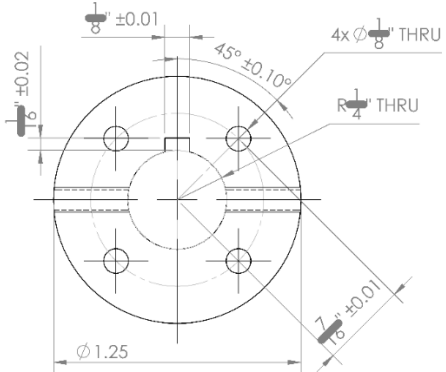


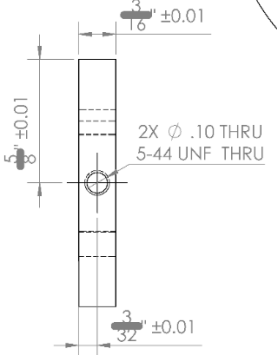

45° ±0.10°
4x ∅1/8" THRU
∅0.50 Inscribed Hex
7/16" ±0.01
∅1.25

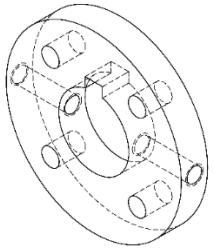

3/16" ±0.01
2X ∅ .10 THRU
5-44 UNF THRU
5/8" ±0.01
0.09 ±0.01




R0.25
1/8" ±0.01
7.48 ±0.02
1/16" ±0.02
2.90 ±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
2X ∅ .10 THRU
5-44 UNF THRU
5/8" ±0.01
3/32" ±0.01



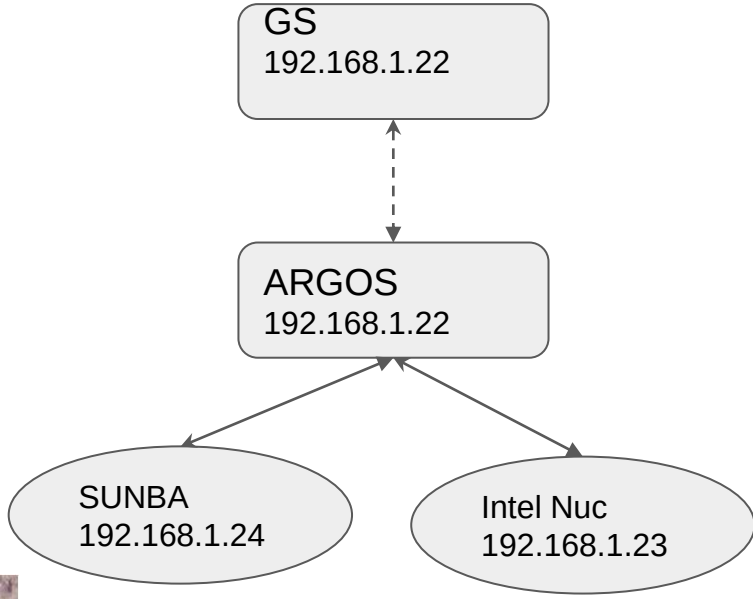
Communications

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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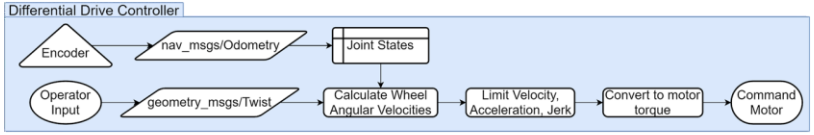
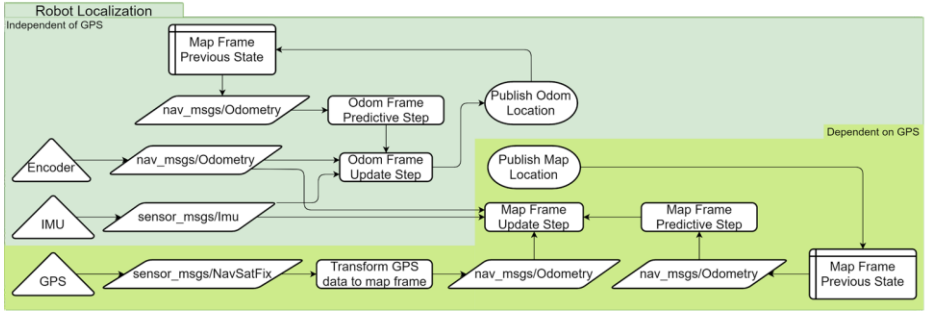
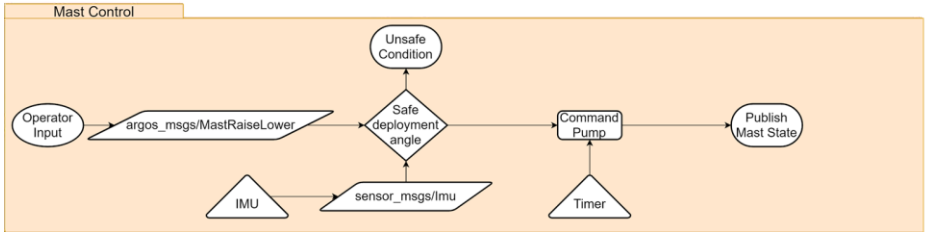
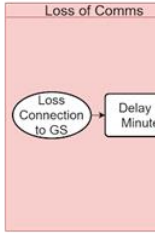
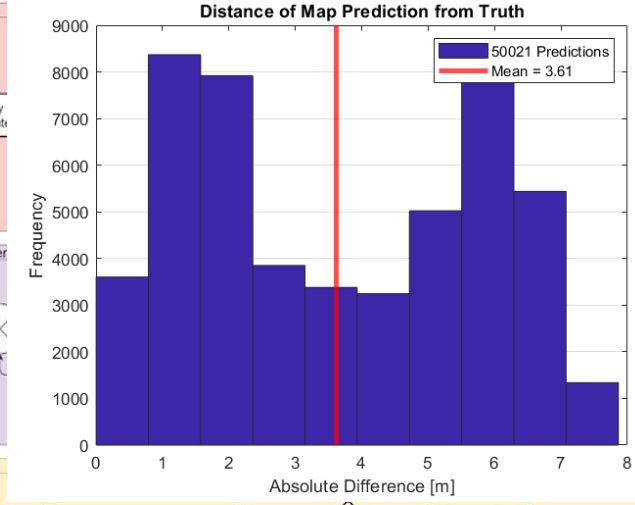
Software Diagram

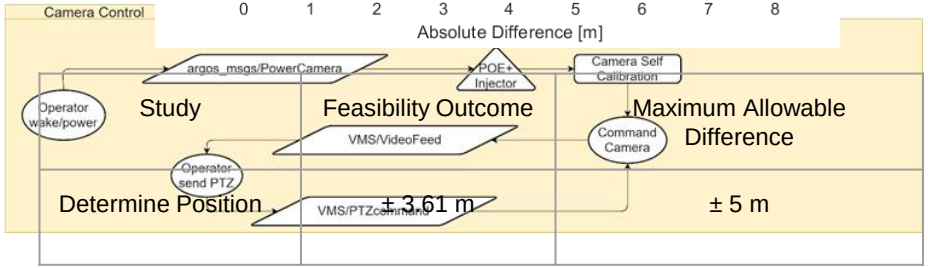












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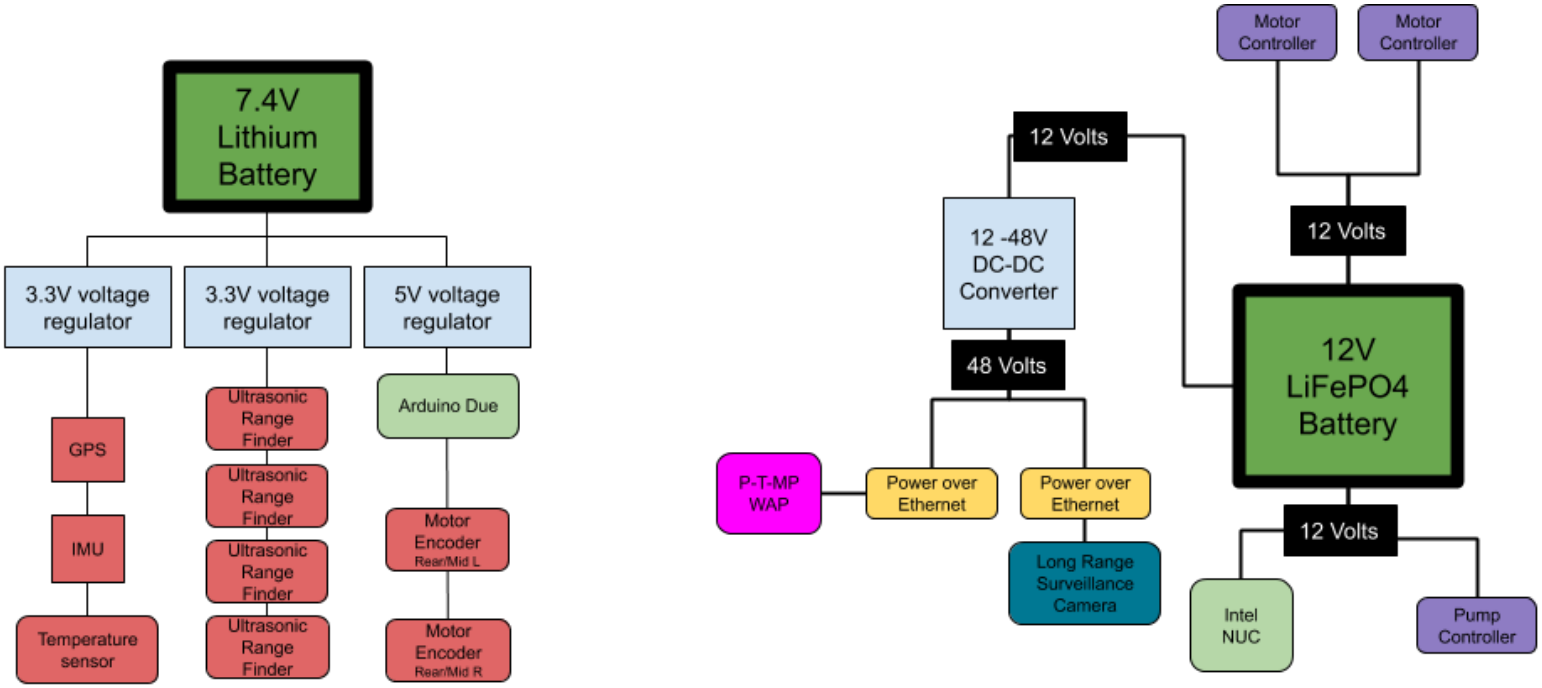
Power Diagram



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

Full Gantt Chart