ARGOS

Autonomous Rover for Ground-based Optical Surveillance

Spring Final Review

April 26, 2021 5:10pm

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Jet Propulsion Laboratory
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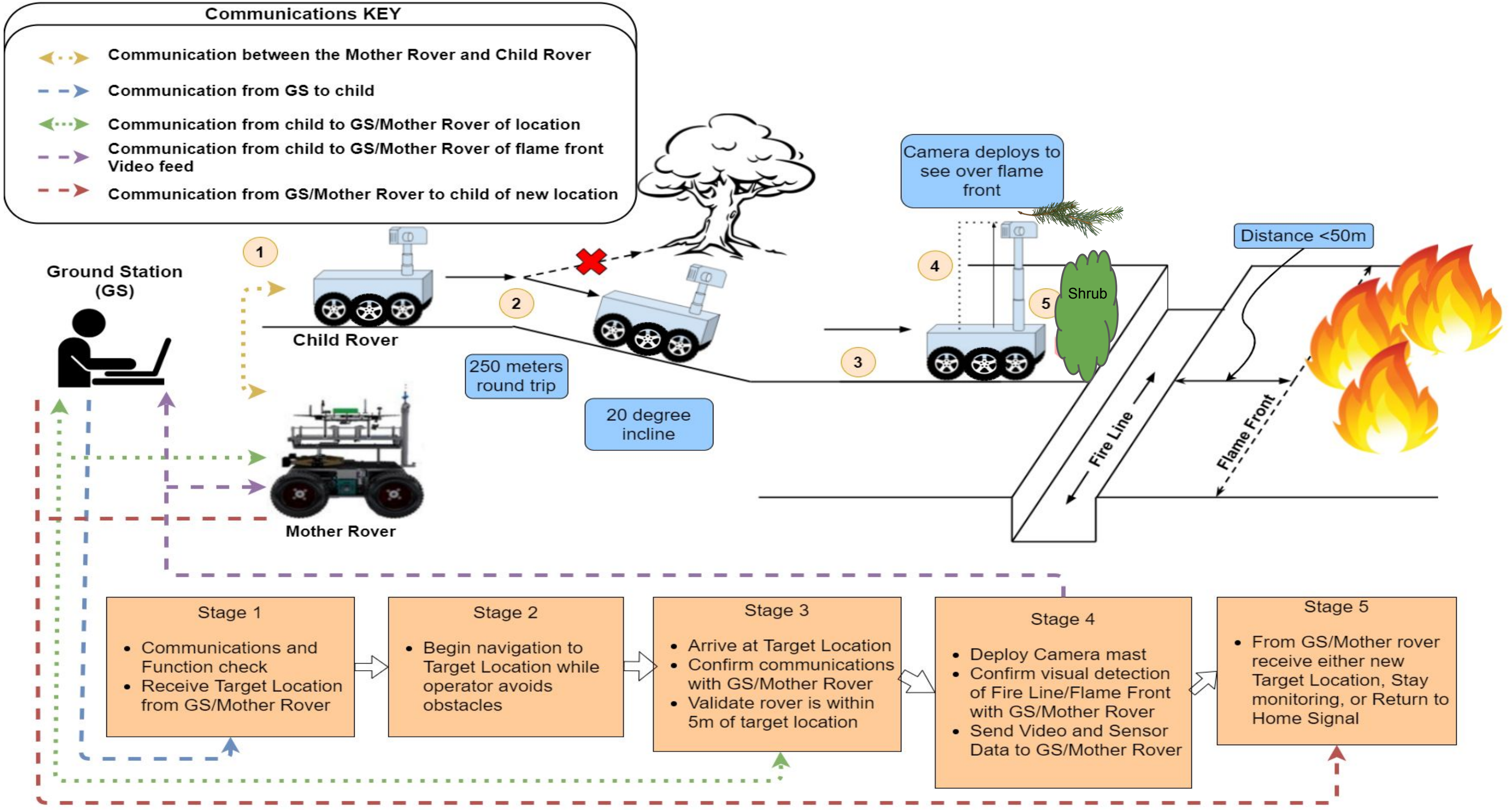
Project Purpose & Objectives

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)
1
Child Rover
2
250 meters round trip
20 degree incline
3
4
5
Shrub
Camera deploys to see over flame front
Distance <50m
Fire Line
Flame Front
Mother Rover
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

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.

Levels of Success

Level met =

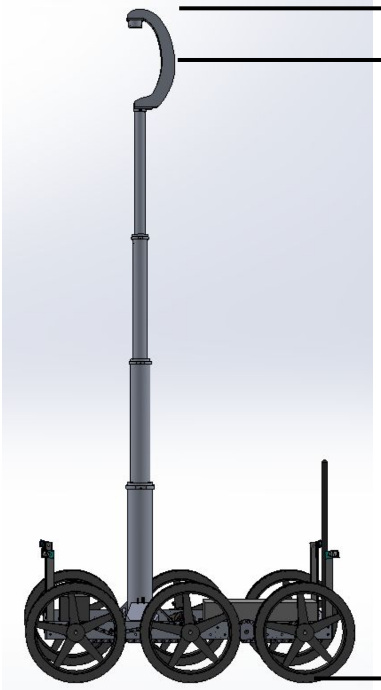
	Rover Movements and Control	Surveillance	Communications
Level 1	Rover can travel on flat ground for 100 m via manual control. Rover can travel in the forward direction and can turn 360 degrees with a turn radius less than two rover body lengths (2.3 m).	Ambient temperature data is recorded from a temperature 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 (1.15 m).	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 +/-5 m 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).

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

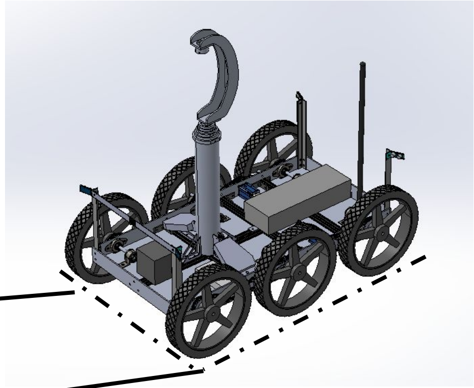
Design Description

Full Design



Total Extended Height: 2.38m

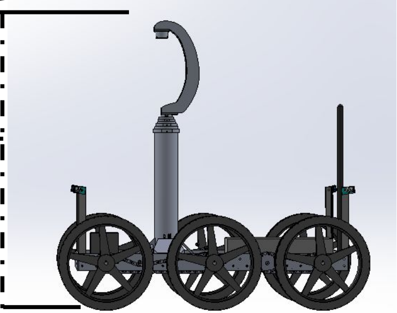
Camera Height: 2.15m



Total Width: 0.65m

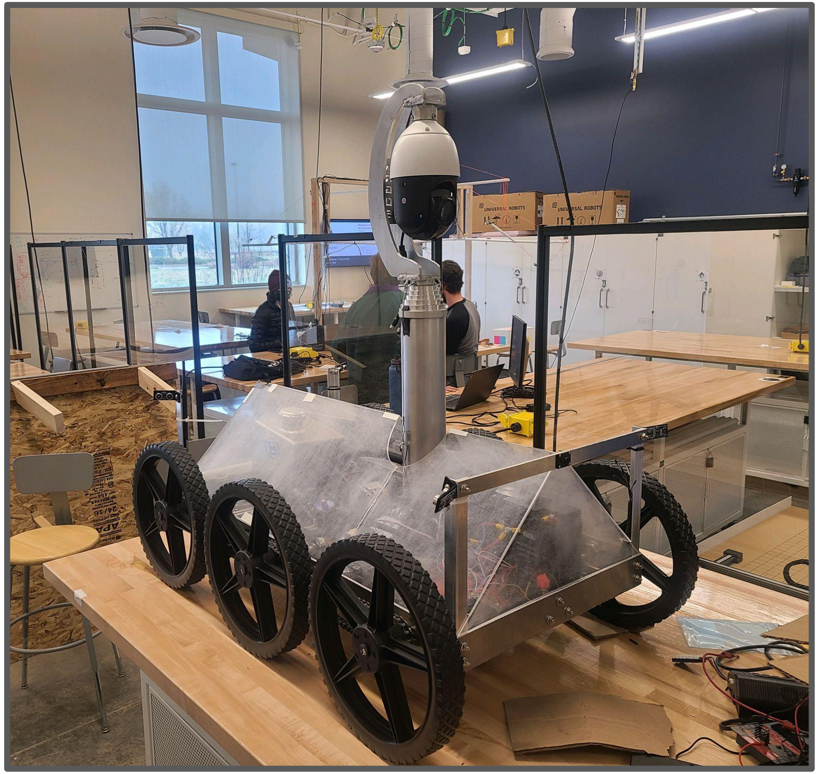
Total Length: 1.15m

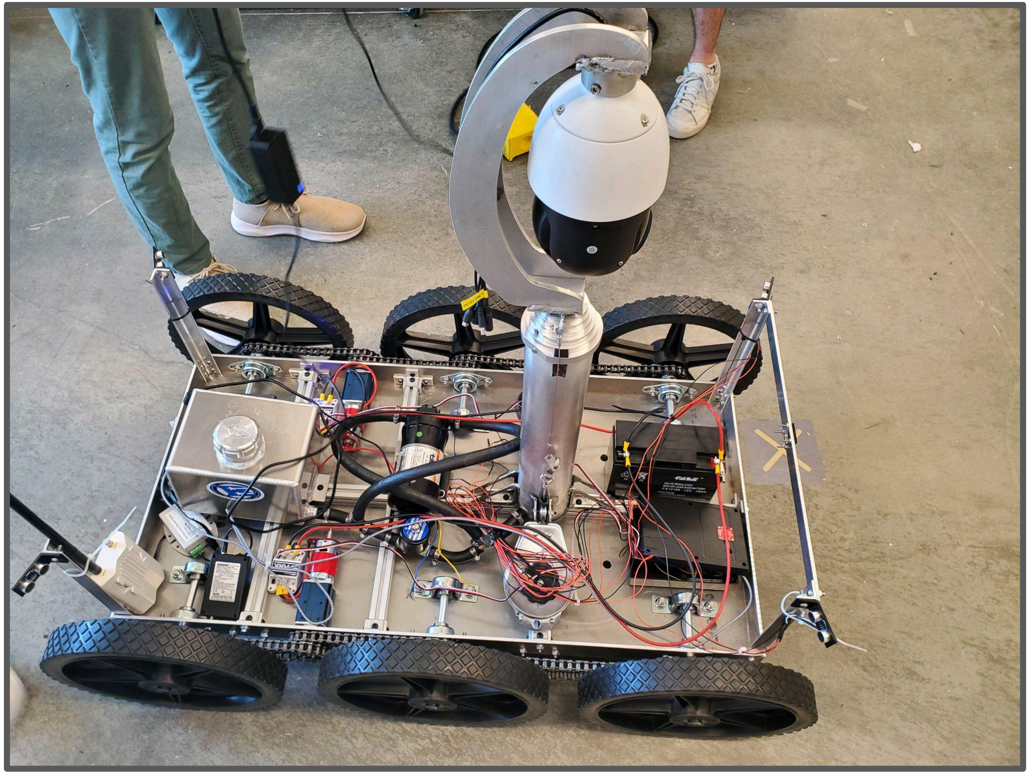
Total Unextended Height: 1.1m



Total Mass: 54.25 kg

Full Design



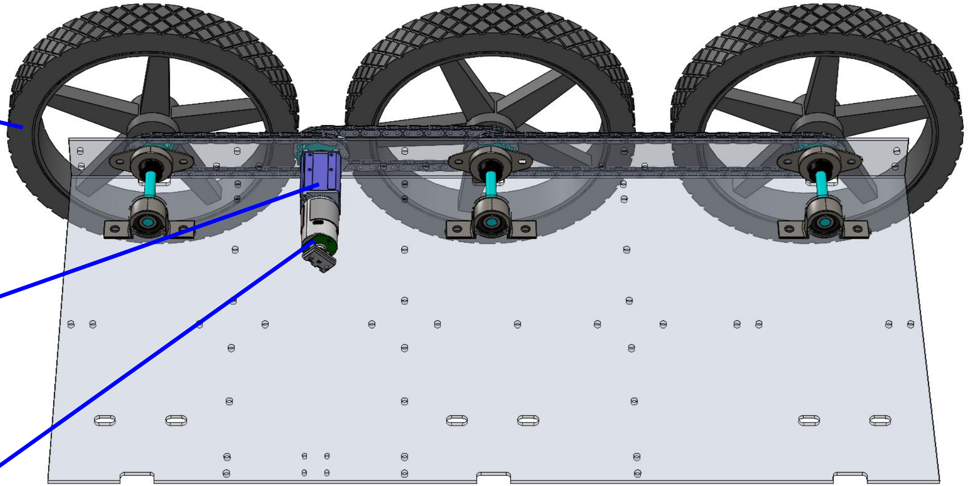


Drivetrain Design

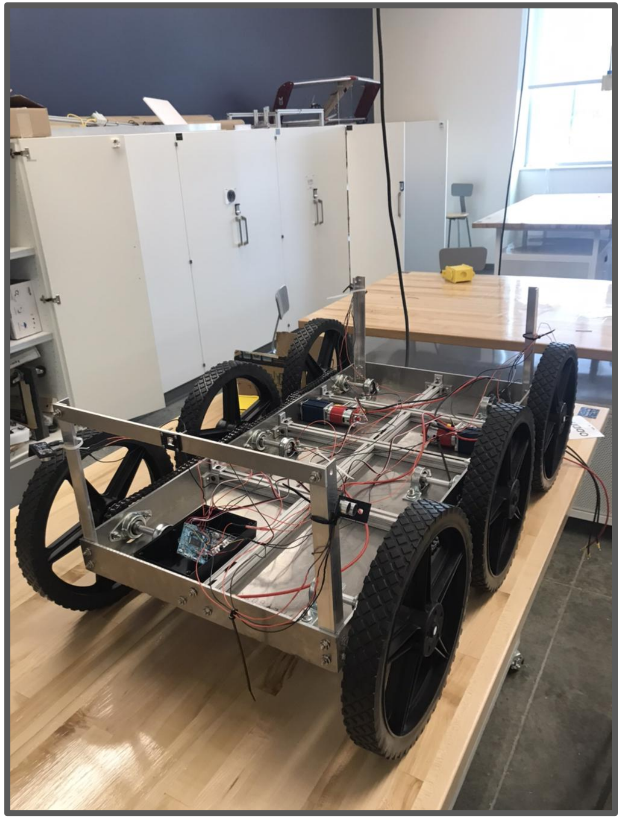
Swisher Wheels
- 34.925 cm Diameter

57 Sport Gearbox
- 64:1 Gear Ratio
- Replaced with 100:1

AndyMark 775 Redline Motor

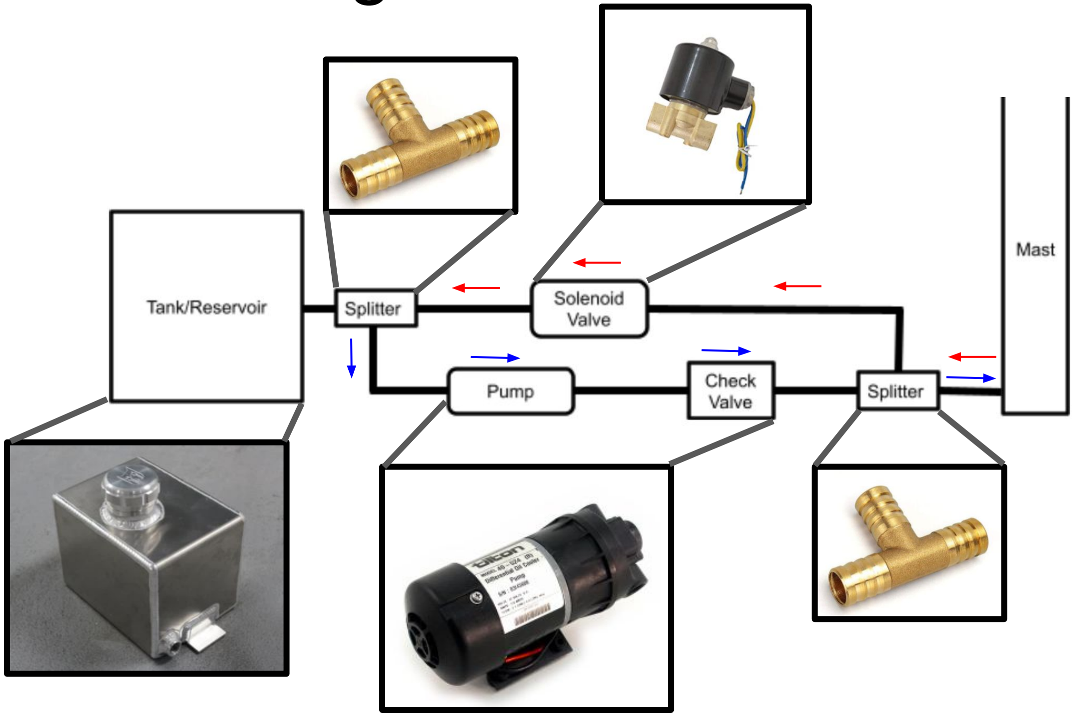


Drivetrain/Chassis

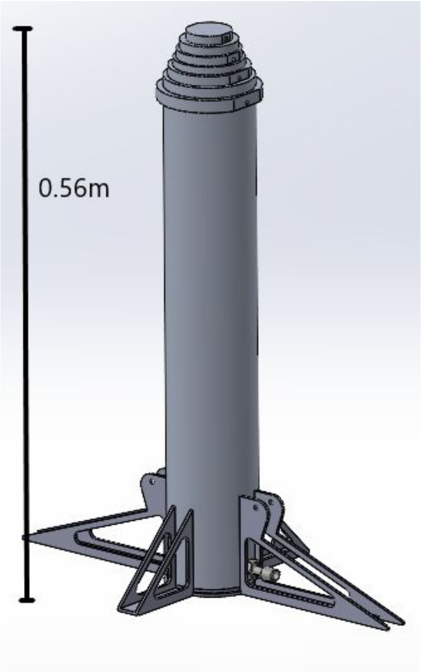


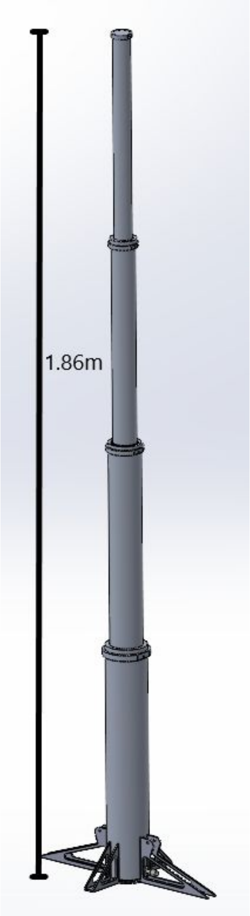
Mast Design

Normally Closed 12V Solenoid Valve



Tilton 12V 40-524/5 Oil Pump w/ Internal Check Valve

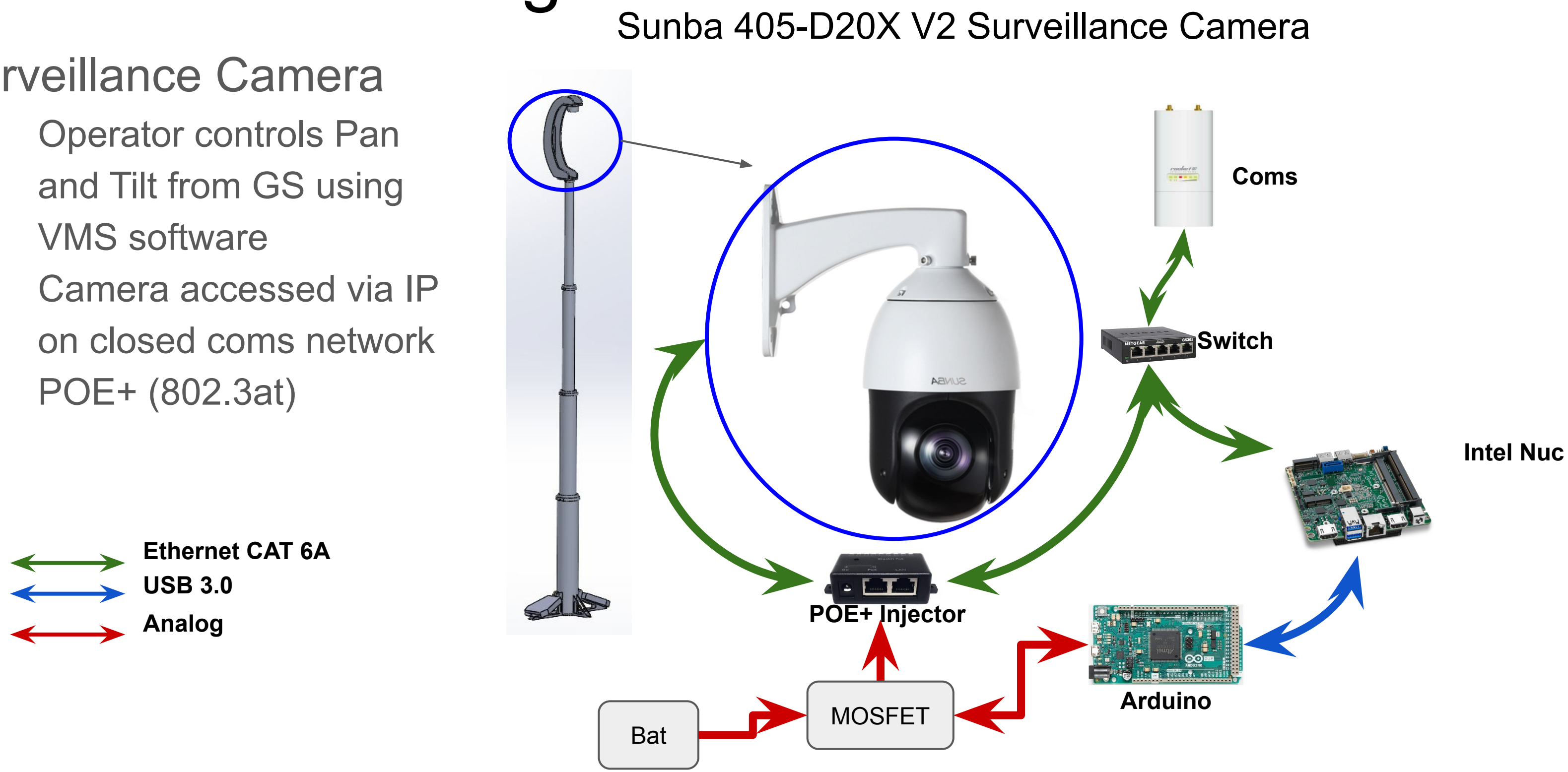




Surveillance Design

Surveillance Camera

- Operator controls Pan and Tilt from GS using VMS software
- Camera accessed via IP on closed coms network
- POE+ (802.3at)

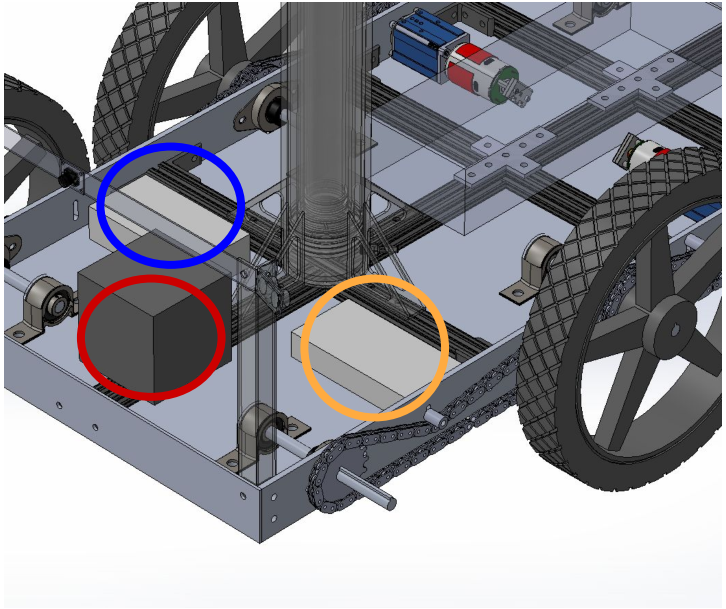


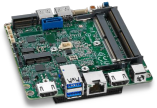
Mast/Surveillance Camera

0.56m

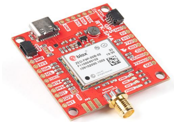
1.85m

Electronics / Communication Design



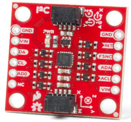


Intel Nuc



Sparkfun ZED-F9P

Arduino



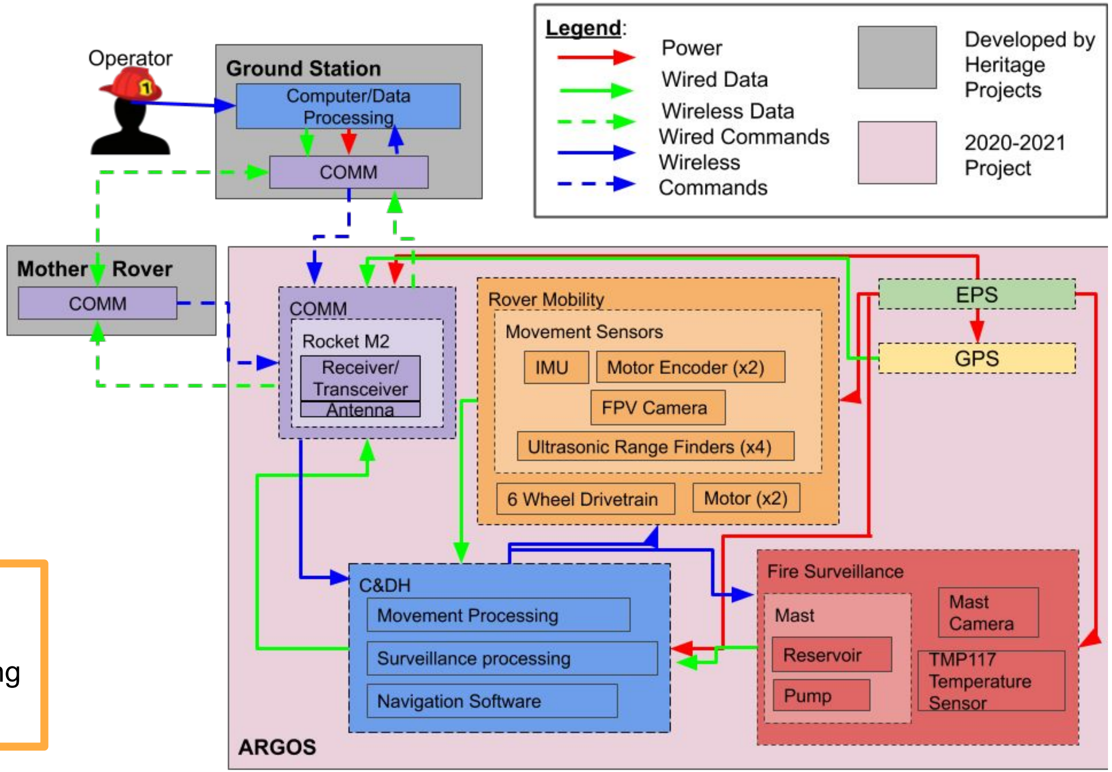
Sparkfun BNO080

12V Battery

Secondary 11.1V Battery

Rocket M2

Functional Block Diagram



Note:
Acknowledgements are also sent following every command.

Test Overview

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	• Mobility Test	• 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	• Full Mast Test	
• Live video	• Sensor output - Kalman Filter • UI of sensor data	
	• Total throughput test	

Mobility Test

- **Test Facility:** Aerospace Building project room and outside around building
- **Test Purpose:**
    - Satisfy FR.1
    - Verify rover can perform basic maneuvering functions needed to complete mission
    - Validate incline model
- **Test Procedure:**
    - Command rover forwards and backwards
    - Command rover forward at full speed briefly
    - Command rover up 20 degree incline
    - Command rover to turn 360 degrees
- **Necessary Equipment:**
    - Assembled rover
    - 20 degree ramp

Mast Test

- **Test Facility:** Aerospace Building project room
- **Test Purpose:**
  - Satisfy FR.3
  - Verify mast can fully extend and retract with no leaks or malfunctions
  - Validate spring system's ability to compress mast
- **Test Procedure:**
  - Fill reservoir with hydraulic fluid
  - Turn pump on to raise mast
  - Observe extension, stop at full extension
  - Open solenoid to lower mast
  - Observe compression
  - Repeat with springs and added weight
- **Necessary Equipment:**
  - Fully assembled mast system, spring system, mounted camera
  - Hydraulic fluid

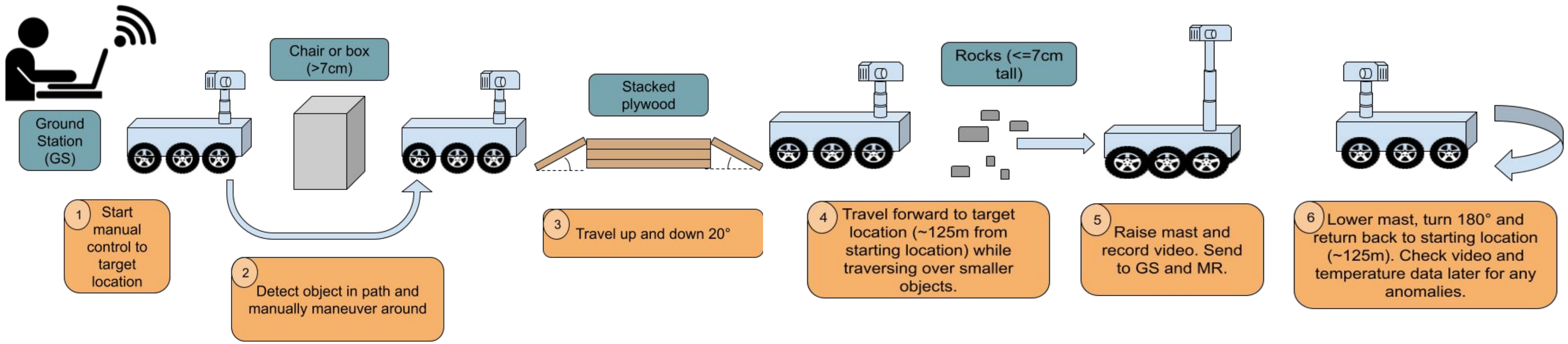
Total Throughput Test

- **Test Facility:** Outside aerospace building
- **Test Purpose:**
  - Satisfy FR.1 and FR.4
  - Verify communications system has bandwidth to process all sensor data being transmitted
- **Test Procedure:**
  - Activate all sensors on ARGOS
  - Monitor maximum data rates being transmitted through communications system
- **Necessary Equipment:**
  - Communications system (2 Rocket M2 radios)
  - All sensors running concurrently
  - GS laptop

Taken via Mast Camera at ~200m range

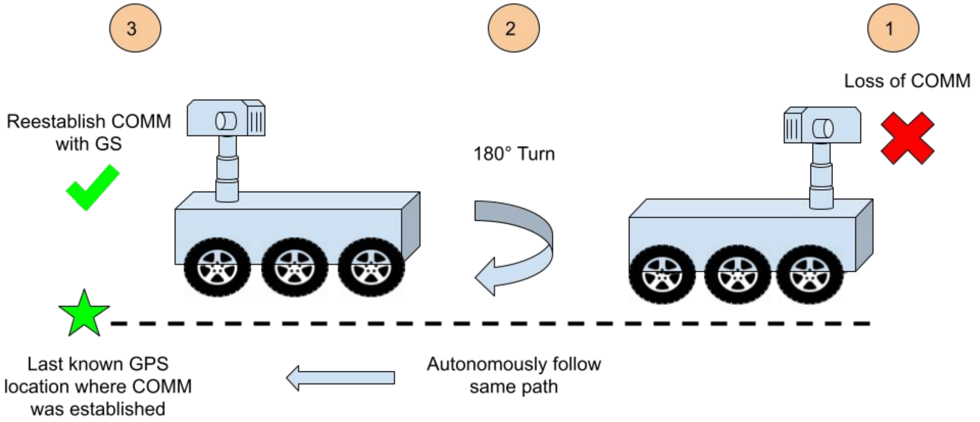
Full Mission Simulation Plan

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



Loss of COMM Test Plan

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



Test Results

Mobility Test

- **Test Results:**
  - Rover successfully moves forwards and backwards
  - Rover successfully turns 360 degrees
  - Rover reached top of ramp before the motors stalled from being over torqued
- **Implications of Results:**
  - Replace gear boxes with a higher gear ratio
    - 64:1 to 100:1
  - Retest with new replaced parts 4/20 - 4/23
- **Comparison to Model:**
  - Model significantly underestimated mass of rover
  - Model estimated an expected torque on a 20 degree incline of 16 Nm
  - Actual torque estimated at 30 Nm - much closer to motor limit of 33 Nm

Mast Test

- **Test Results:**
  - **Test 1:** Second seal malfunctioned causing fluid to leak
  - **Test 2:** After replacing two seals, no leaks occurred, mast extended and retracted successfully
- **Implications of Results:**
  - First test made the team rethink application process
  - Second test showed mast was ready to be integrated with rover
- **Comparison to Model:**
  - Pressure study was confirmed
    - Predicted ~40psi to raise
    - Pump max. pressure = 60psi gives FOS = 1.5
  - Model neglected friction → resulted in need for spring return system
    - Seal application problems result in higher friction

Test 2: Raise

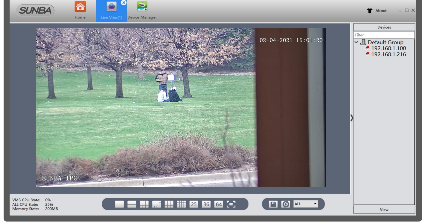
Raise Time: 00:39

Test 2: Lower

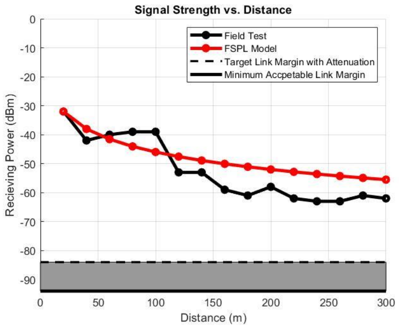
Lower Time: 01:37

Max. Level of Success Achieved

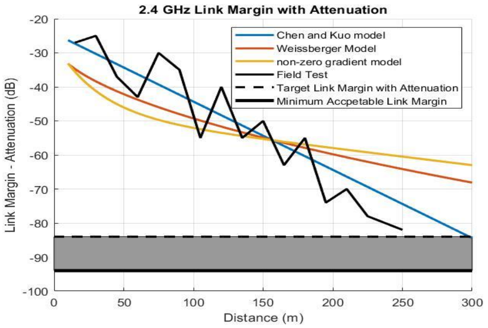
Total Throughput Test



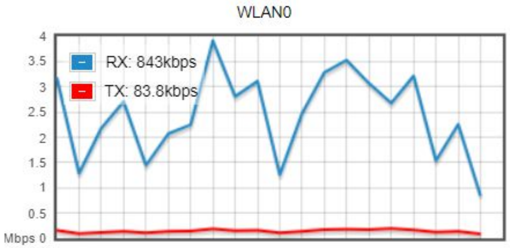
Open Field



Attenuation



Throughput



Test	Result	Implication	Comparison to Model
Open Field Test	23 dBm left of 57 dBm link budget @ 300m Bandwidth of 41 Mbps @ 300m	Design meets FR1 at Level of Success 1	Predicted 28 dBm left of 57 dbm link budget @ 300m
Attenuation Test	2 dBm left of 57 dBm link budget @ 250m **Bandwidth** of **27 Mbps @ 250m**	Design meets FR1 at Level of Success 4	Predicted 10 dBm left of 57 dBm link budget @ 250m
Full Throughput Test	**Maximum** data rate of **4Mbps**. **Margin** of **23 Mbps**	Design fulfills FR1 at Level of Success 4	Predicted Maximum 5.7 Mbps

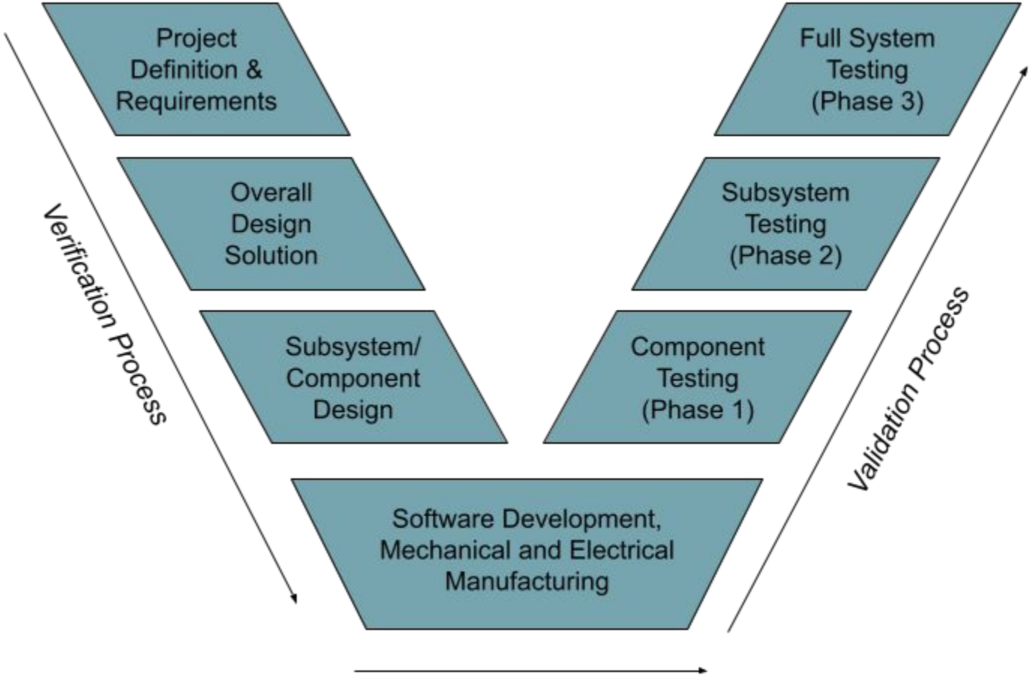
Max. Level of Success Achieved

Functional Requirement Satisfaction Summary

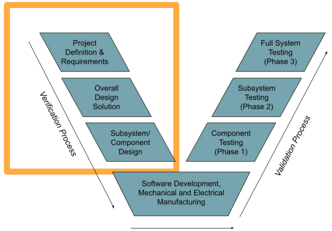
ID	Requirement Description	Satisfied?
FR.1	The child rover shall move from a starting location to a commanded location of interest and return back to the starting location.	Yes - Mobility Test
FR.2	The child rover shall take pictures, videos and ambient temperature data to be sent to the ground station.	Yes - Throughput Test
FR.3	The child rover shall use a mast to take photos and video from a vantage point above the rover's body.	Yes - Mast Test
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.	Yes - Throughput Test

Systems Engineering

Systems Engineering Overview

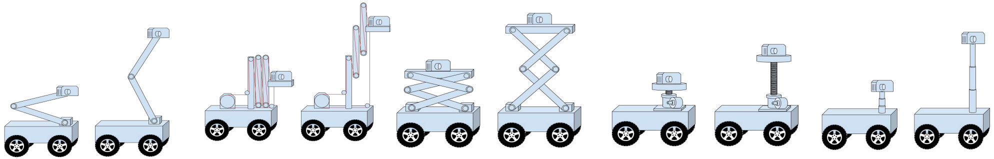


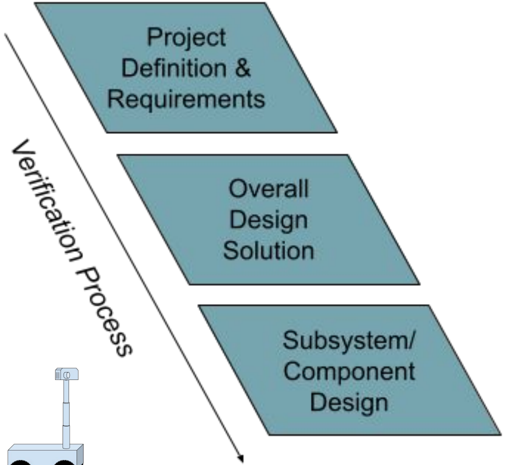
Verification Process



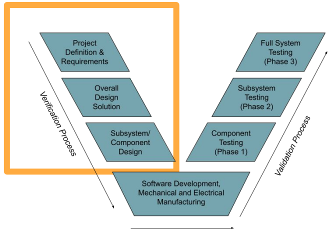
- Requirement development
  - List of customer requirements -> grouped into 4 functional
    - 1. Mobility/Navigation
    - 2. Surveillance/Sensor Data
    - 3. Extendable/Retractable Mast
    - 4. Communications with GS/MR
- Trade Studies
  - Mast
  - Drivetrain
  - Sensors
  - Camera

Design Options Considered

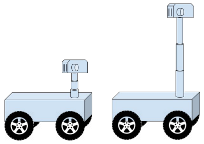




Verification Process (cont.)



- Trade Studies (cont.)



Hydraulic Telescoping

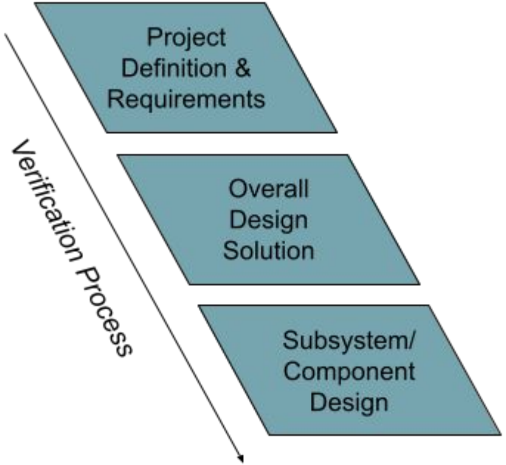
Trade Study Criteria

Support Weight and Stability	Extended to Compacted Height Ratio	Manufacturing Complexity
High	High	High

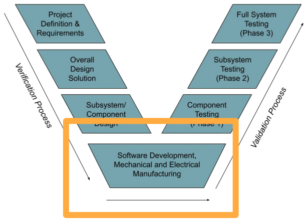
- Challenges/Risks

Risk	Type	Description
1	S	Software development will be time consuming and complex
2	T	Design of hydraulic mast is complex and requires seals connecting each section to have tight manufacturing tolerances
3	T	Attenuation of signal causing loss of communication with GS
4	T	Motor failure due to overheating from stalling

Note: Risks From CDR



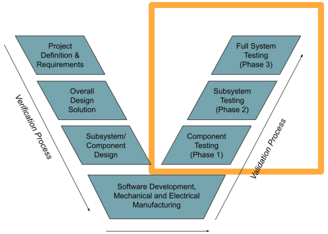
Implementation/Manufacturing

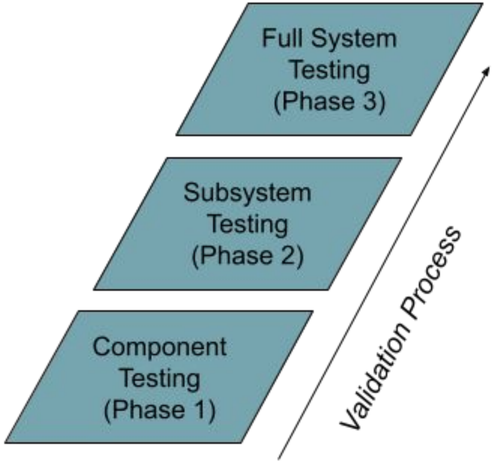


- Challenges
  - Sensor code (encoder cables not shipping)
  - Parts ordered took longer than expected to arrive
  - Mast compression (tolerances were too tight)
- Risks
  - Mast seal malfunction (Risk 2 from CDR)
- Lessons Learned
  - Be careful during assembly process - especially on high risk components
    - Account for shipping time in cost of components
  - Develope backups while waiting for components to ship.

Validation Process

- Challenges
  - Drivetrain over torque
  - Mass Growth 30kg ---> 54.25kg
- Risks
  - Motor failing (Risk 4 from CDR)
    - Underestimating mass
- Lessons Learned
  - Verify manufacturer specs
  - Add more FOS on mass estimations during modeling/design phase





Project Management

Project Management Overview

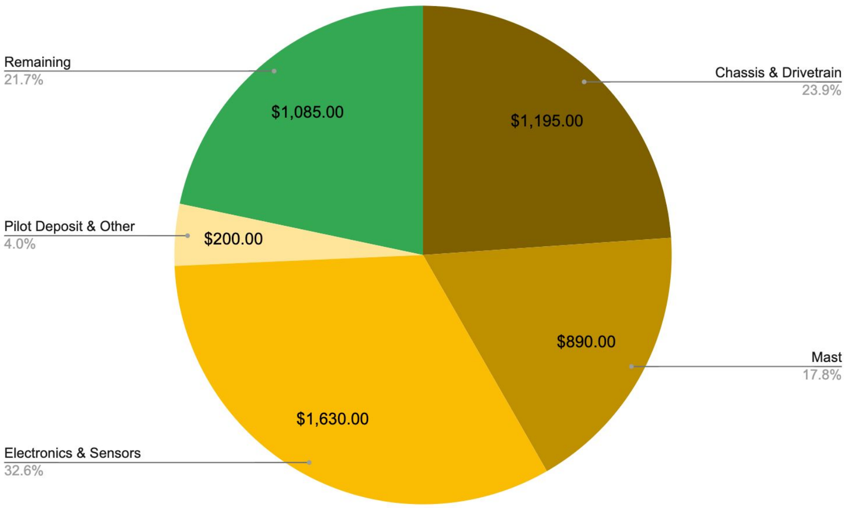
- General Approach:
  - create tasks for each subsystem, set deadlines around course deadlines (MSR, TRR, etc), provide various margins according to task difficulty/predictability
  - bi-weekly team meetings

Successes	Difficulties	Lessons Learned
• Finished manufacturing on schedule • Finished integration of entire system before schedule	• Estimating time for deliveries • Knowing all of the parts we might need in advance	• Provide more margin for earlier tasks • Get feedback early and often on deliverables

Budget Comparison

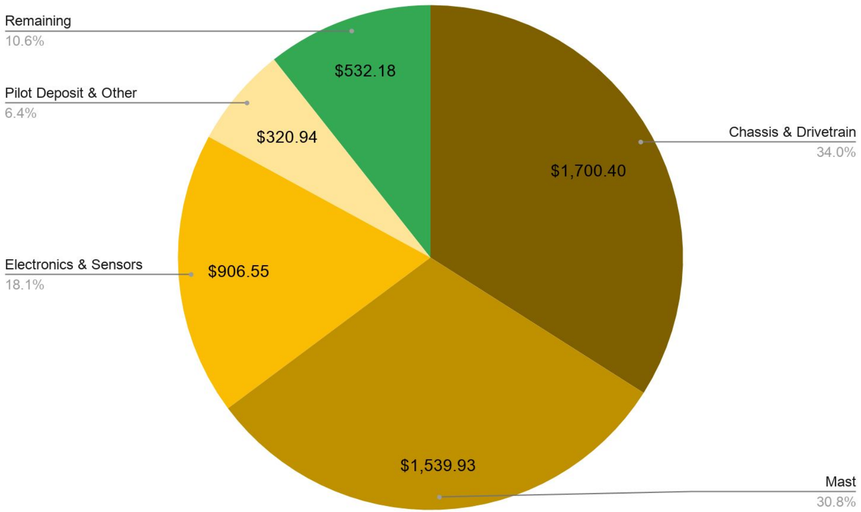
Planned Budget

- Estimated Total Cost = **$3,715**
- Margin = **$1,285**



Actual Budget

- Total Cost = **$4,467.82**
- Margin = **$532.18**
- Difference to Planned = **$752.82**



Estimated Industry Cost

- Total Hours Worked = 2,760.25 hr
  - 11 people
  - First 9 weeks were estimated at average of 7 hr/person
- Assuming salary of $65,000 for 2080 hours of work ($31.25/hr), total labor costs = **$86,257.81**
- Resulting "Industry" Cost = **$263,241.26**

Expense Type	Cost ($)
Labor (after 10/25/20)	64601.5625
Estimated Labor (before 10/25/20)	21656.25
Overhead	172515.625
Materials	4467.82
Total	263241.2575

Acknowledgements

- Dr. G
- Barbara Streiffert and others at JPL
- Matt Rhode, Nate Coyle and everyone at the machine shop
- Trudy Schwartz and Jarrod in the electronics shop
- Lara and Colin
- Professor Jackson
- PAB
- WASP Team

Thank you!

Questions?

References

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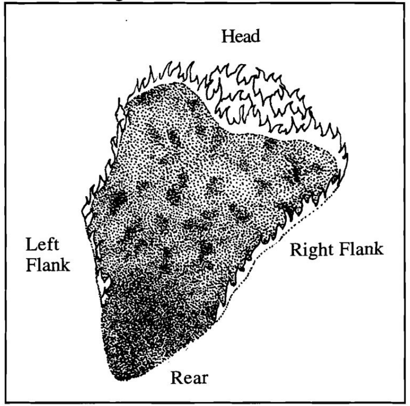
Backup Slides

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)

Figure 6—Parts Of A Fire



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.

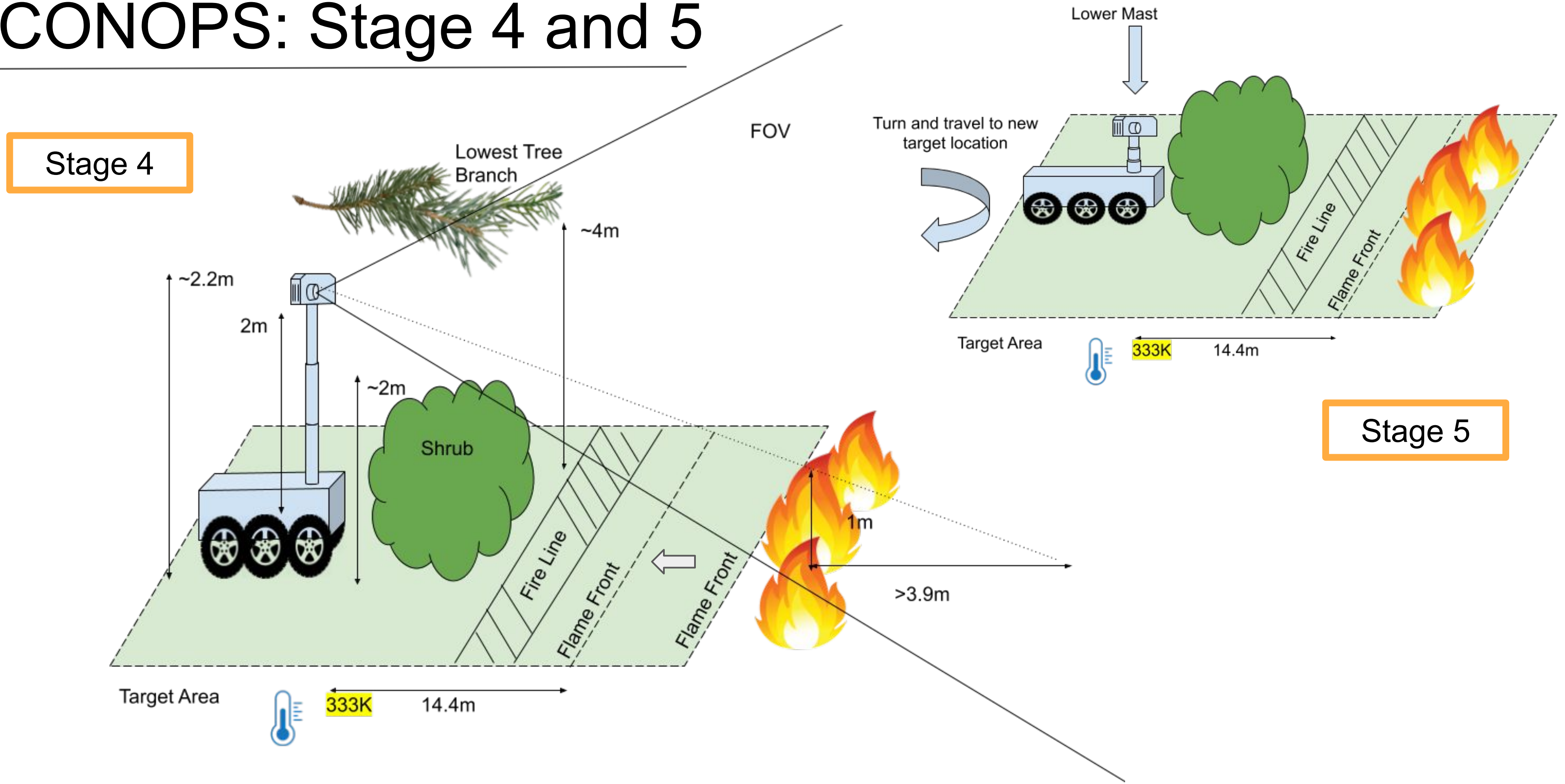
Design Requirement ID	Description
SURV.3.1	The child rover shall have a mast capable of extending to a height of 2m and retracting back down to its original height.
SURV.3.2	The child rover shall have a mast capable of supporting 10kg of weight on the top.

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

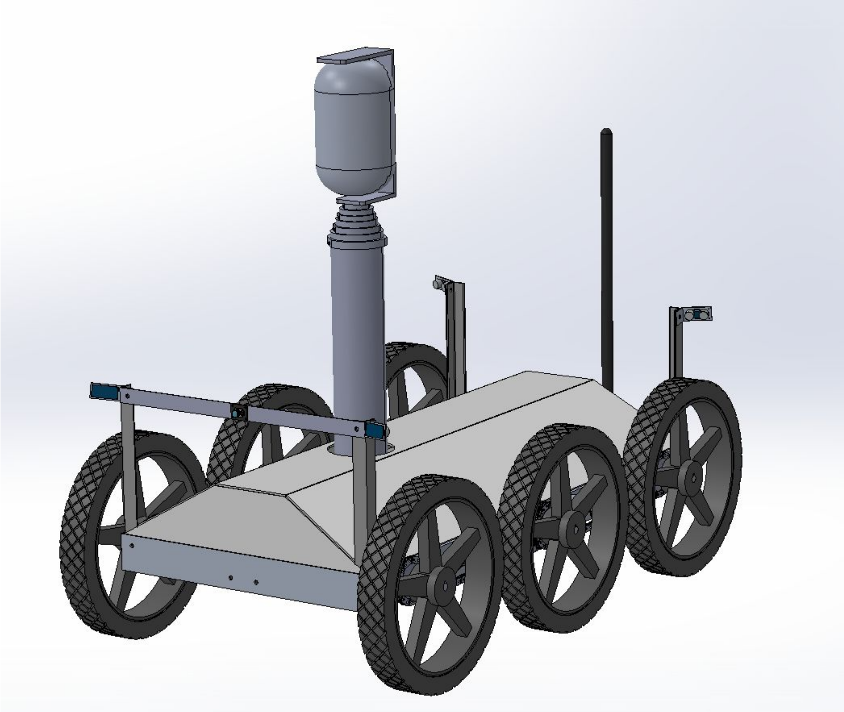


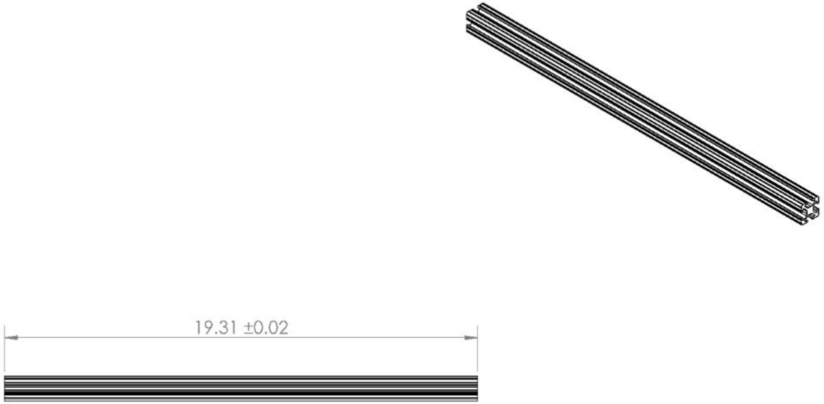
Levels of Success

	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

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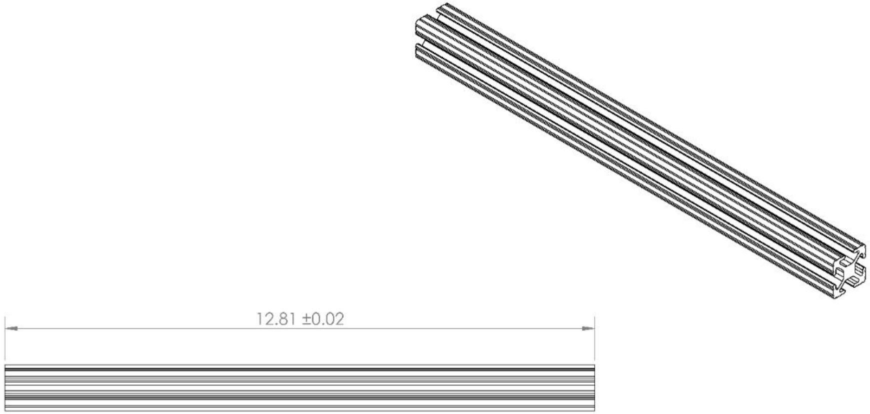
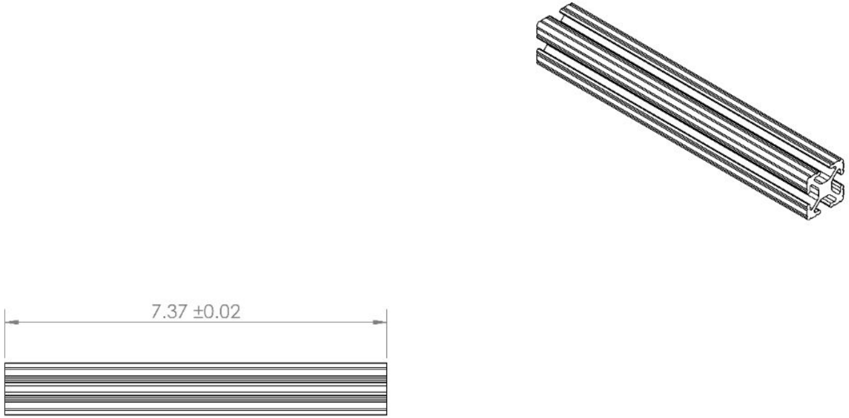
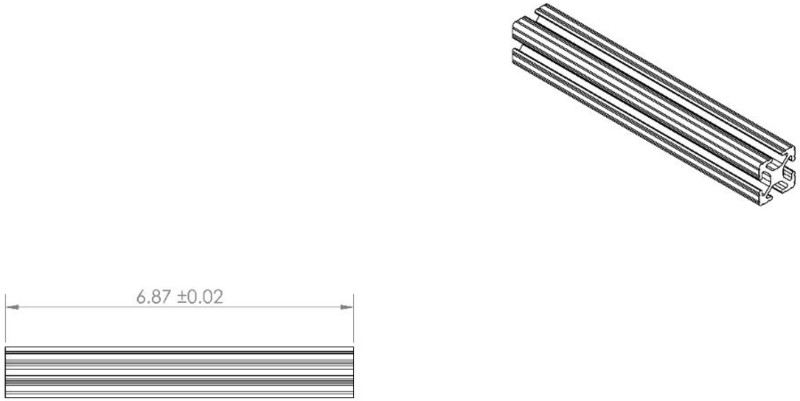
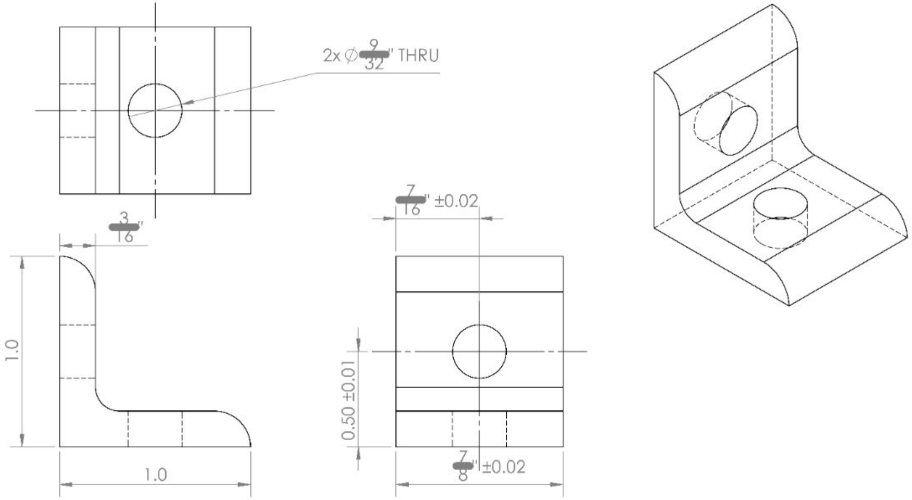
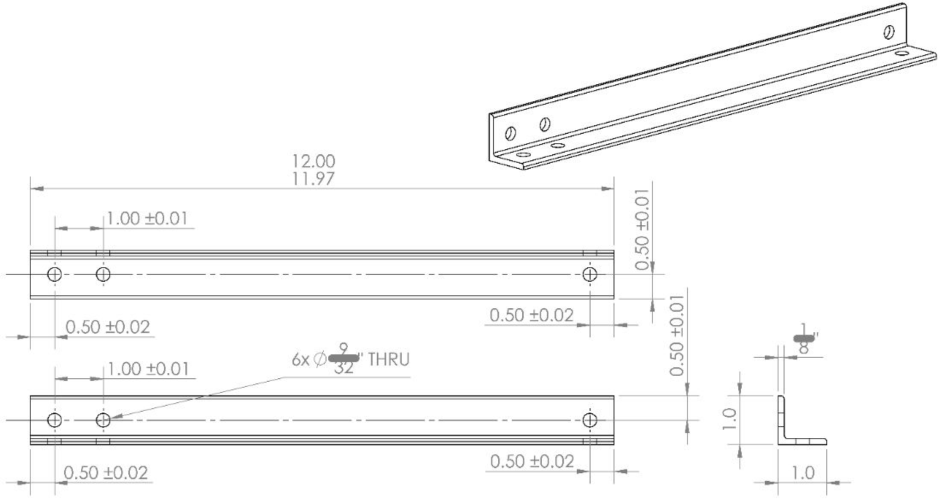

12.81 ±0.02


7.37 ±0.02


6.87 ±0.02



2x ∅ 9/32" THRU
3/16"
7/16" ±0.02
1.0
0.50 ±0.01
1.0
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
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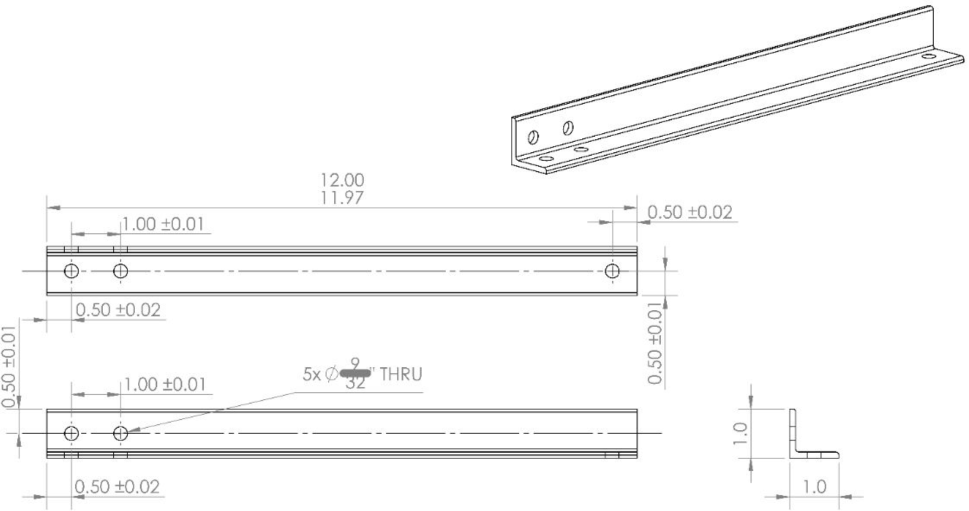
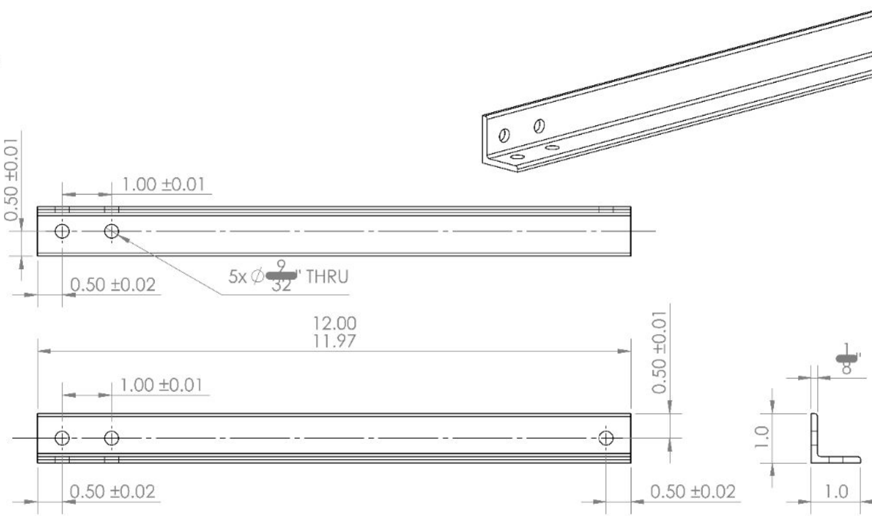
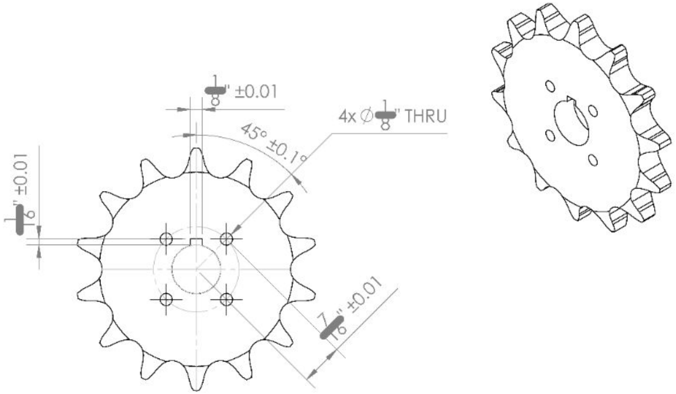
1.00 ±0.01
1/8"
1.0
0.50 ±0.02
0.50 ±0.02
1.0



12.00
11.97
0.50 ±0.02
1.00 ±0.01
0.50 ±0.02
0.50 ±0.01
0.50 ±0.01
5x ∅ 9/32" THRU
1.00 ±0.01
1.0
0.50 ±0.02
1.0



0.50 ±0.01
1.00 ±0.01
0.50 ±0.02
5x ∅ 9/32" THRU
12.00
11.97
0.50 ±0.01
1/8"
1.00 ±0.01
1.0
0.50 ±0.02
0.50 ±0.02
1.0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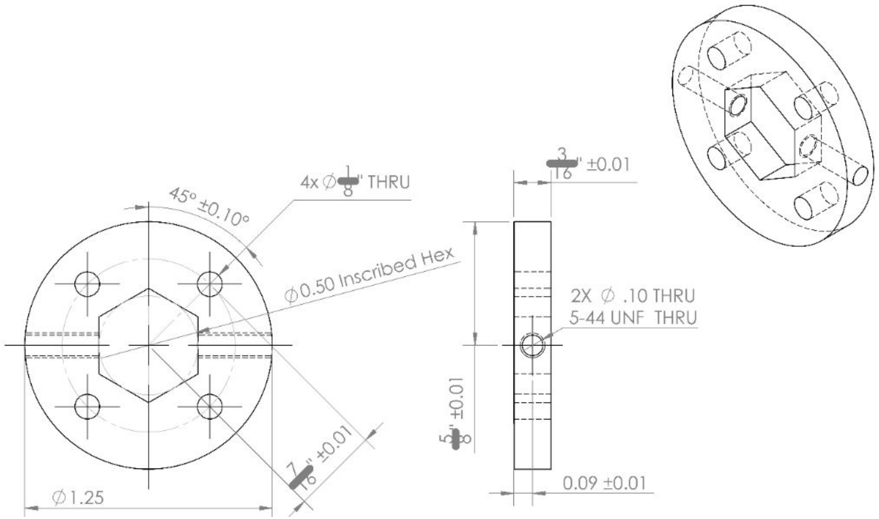
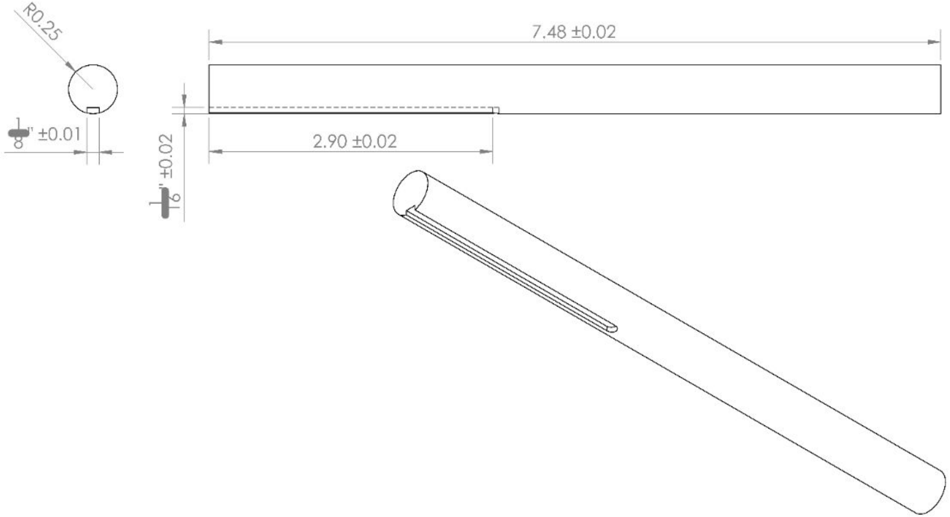
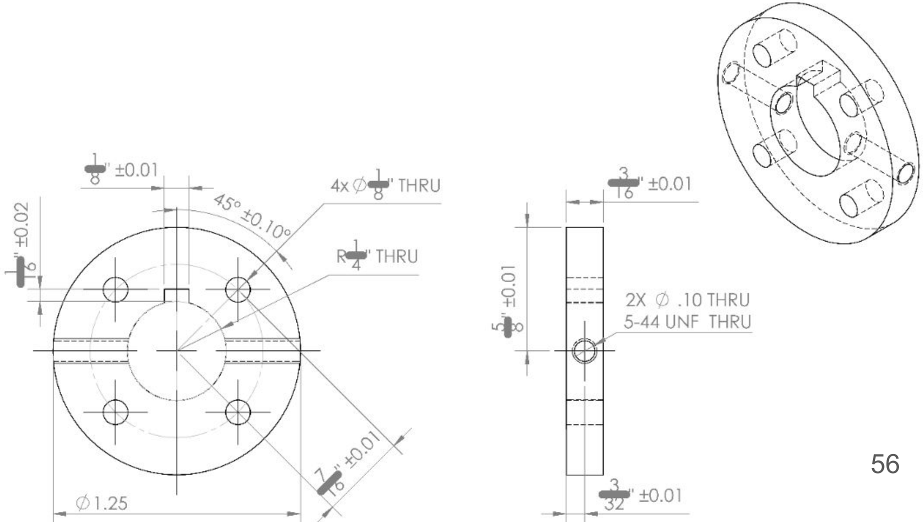
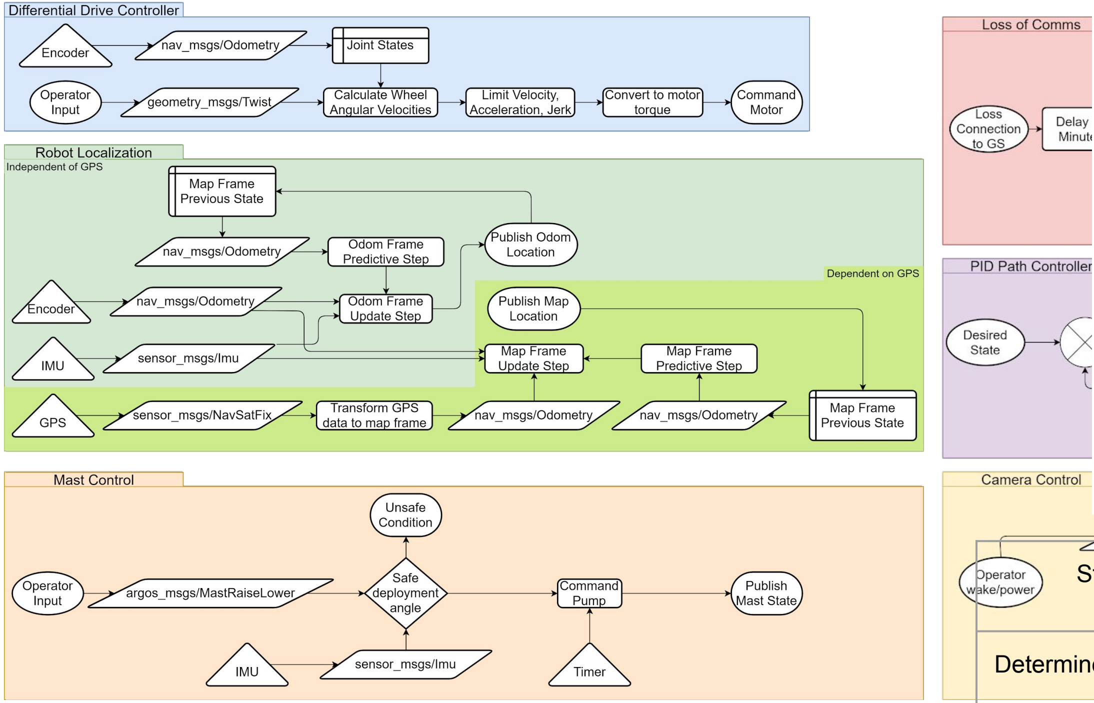
4x ∅1/8" THRU
45° ±0.1°
1/16" ±0.01
7/16" ±0.01

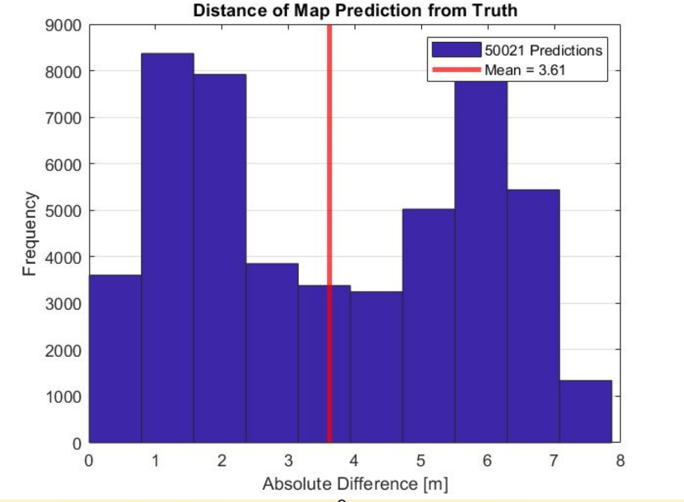

45° ±0.10°
4x ∅1/8" THRU
∅0.50 Inscribed Hex
7/16" ±0.01
∅1.25
3/16" ±0.01
2X ∅ .10 THRU
5-44 UNF THRU
5/8" ±0.01
0.09 ±0.01


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


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

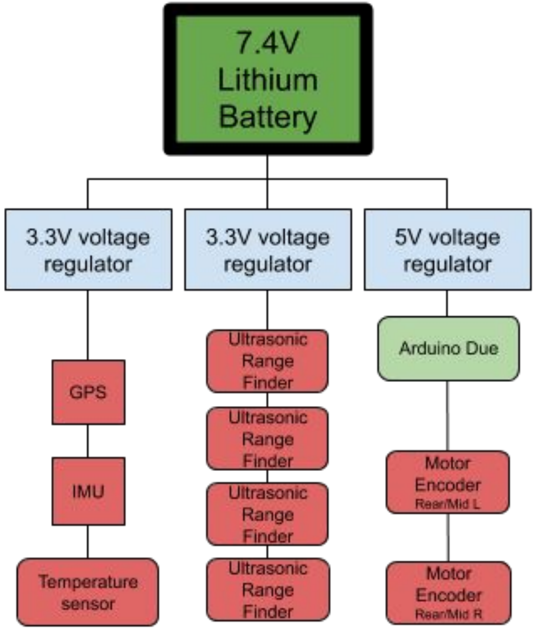
Software Diagram

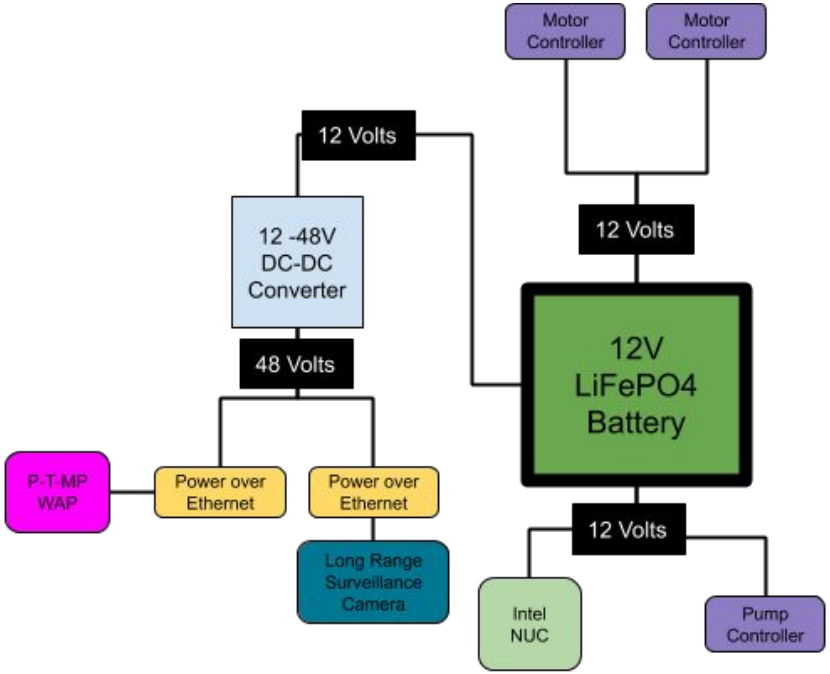




Study	Feasibility Outcome	Maximum Allowable Difference
Determine Position	± 3.61 m	± 5 m

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