Critical Design Review

Drone-Rover Integrated Fire Tracker

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Customer: Barbara Streiffert, Jet Propulsion Laboratory

Advisor: Dr. Jelliffe Jackson

Mission Statement

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

Project Overview

Project Overview | Design Solution | Critical Elements | DRs and Satisfaction | Validation and Verification | Project Risks | Project Planning | Conclusion

Project Overview: Fire Tracker System

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

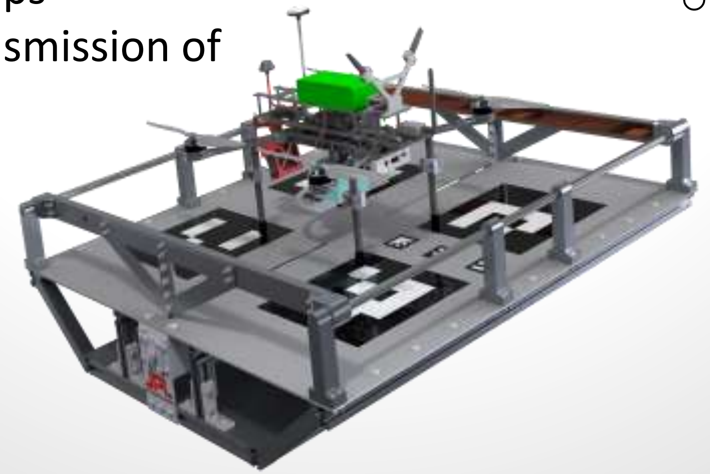
[1]The Rising Cost of Wildfire Operations: Effects on the Forest Service's Non-Fire Work." United States Department of Agriculture: Forest Service, 4 Aug. 2015.

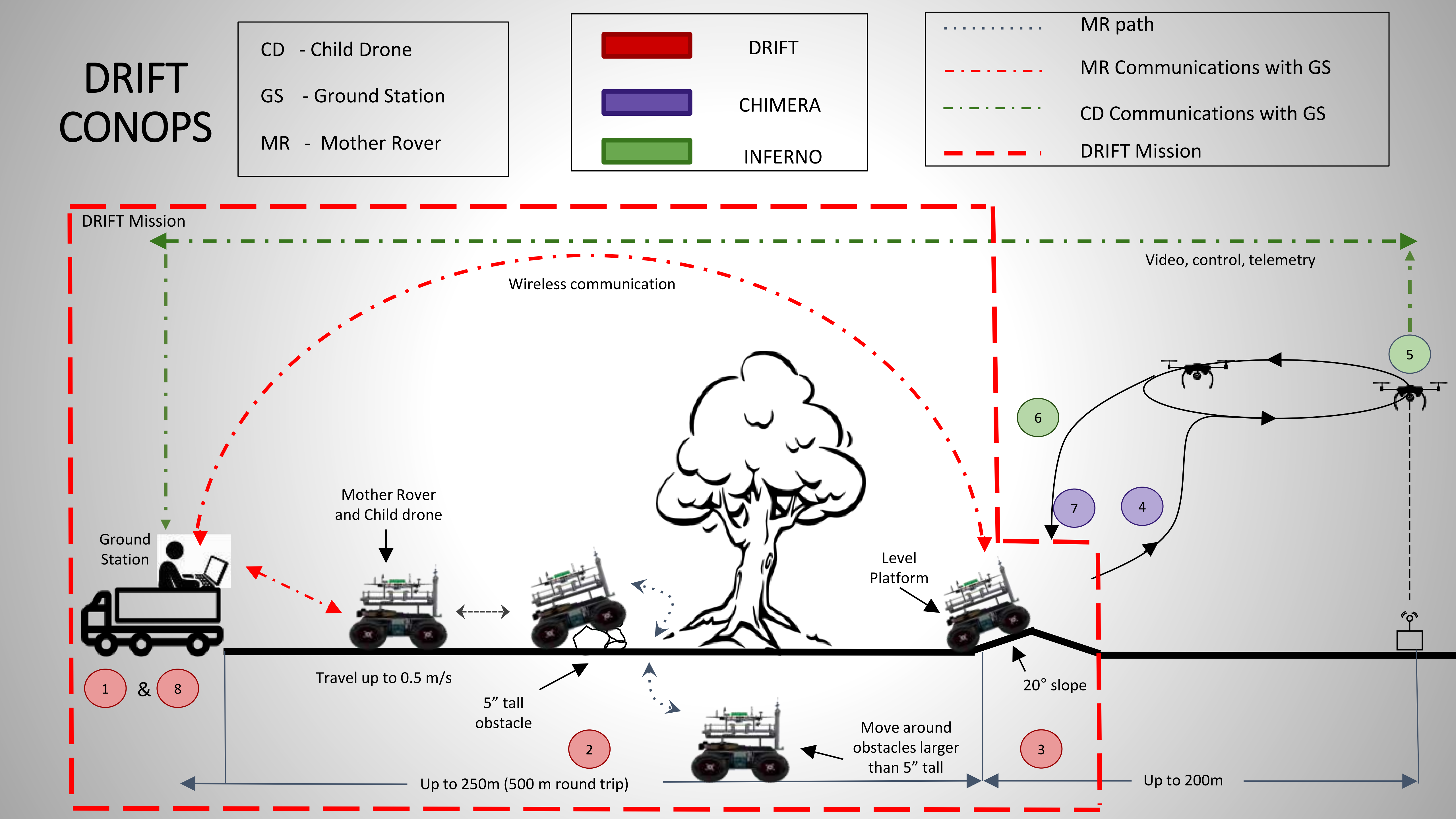
Project Heritage

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

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

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





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

Changes from PDR

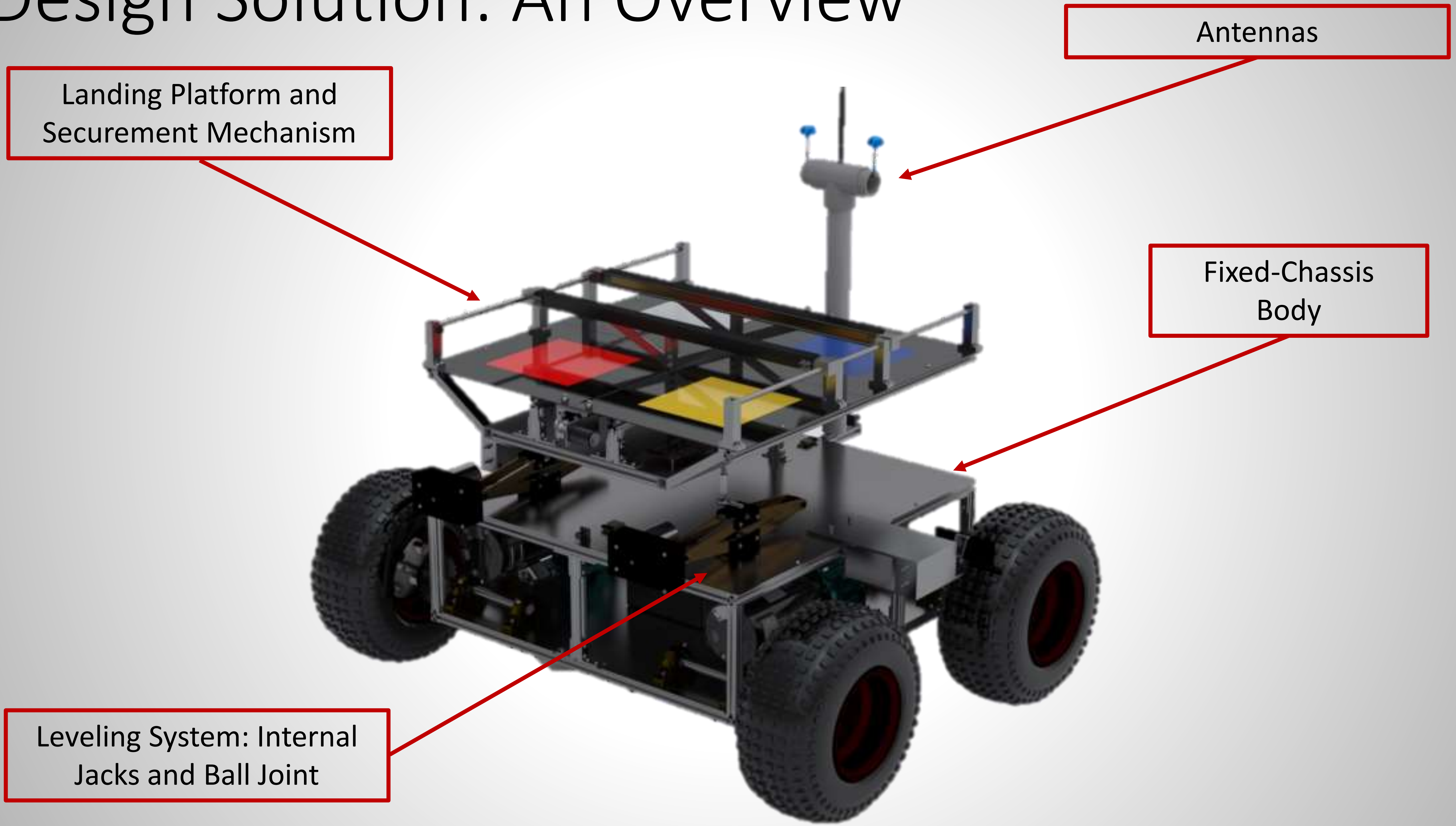
- Translational System
  - Modified from Rocker-Bogie to **Fixed-Chassis** design
    - Allows for **increased stability** – beneficial for leveling system
    - All 4 wheels powered – **increased traction**
    - Motors less expensive – **financially more efficient**
    - No legs and less motors - **decreased weight**
    - Decreased complexity – **more time** dedicated to leveling system
  - Range modified from 500 to 250 meters from GS
    - Batteries required for 500 meters out of budget
    - Modification approved by customer

Original Rocker-Bogie System

Fixed-Chassis System

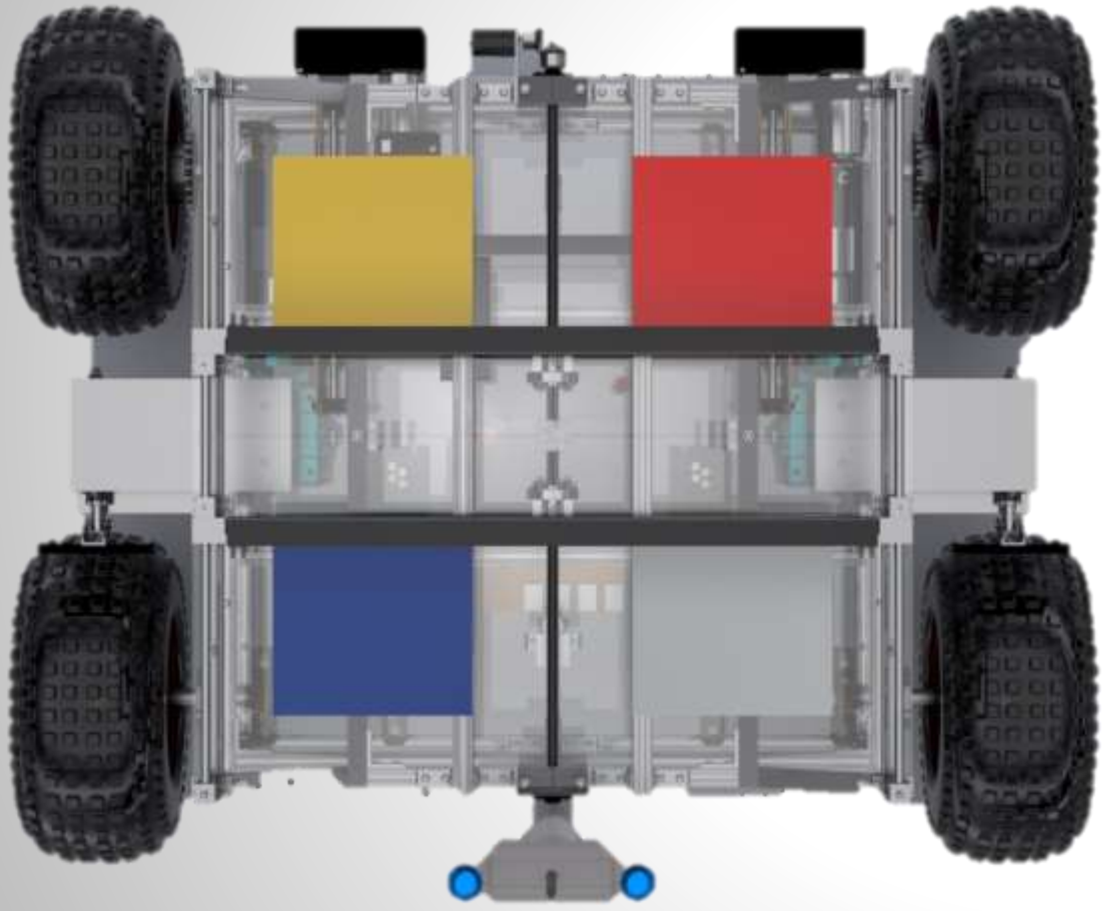
Design Solution

Design Solution: An Overview

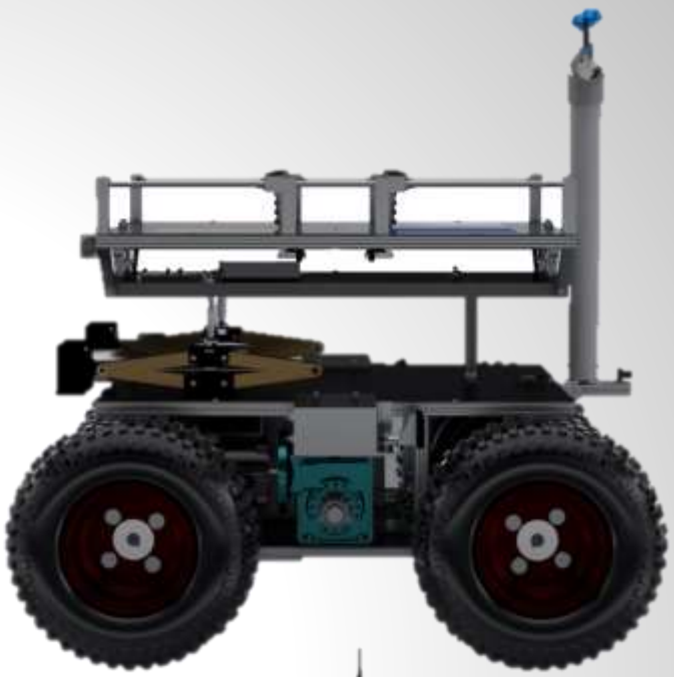


Design Solution: An Overview

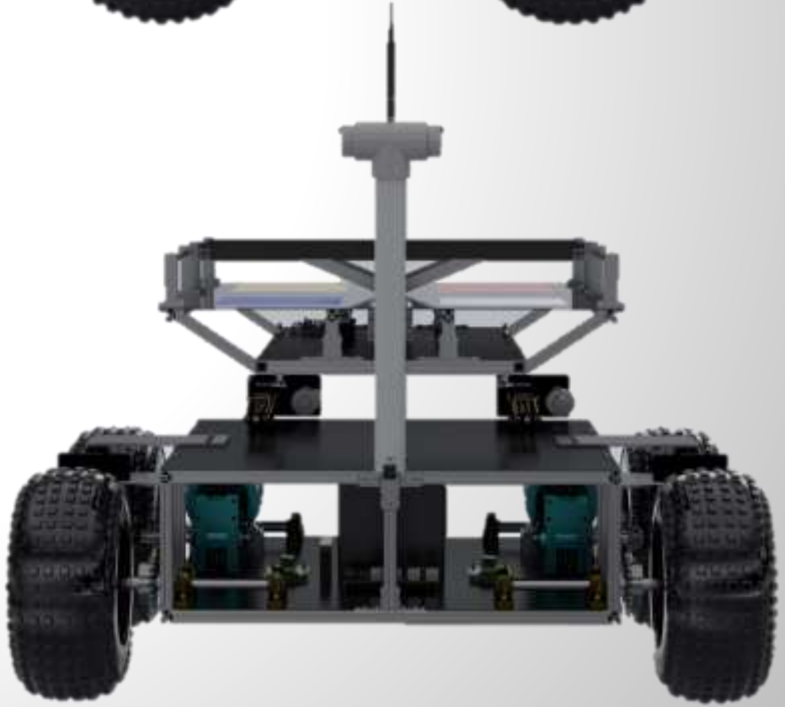
Top View



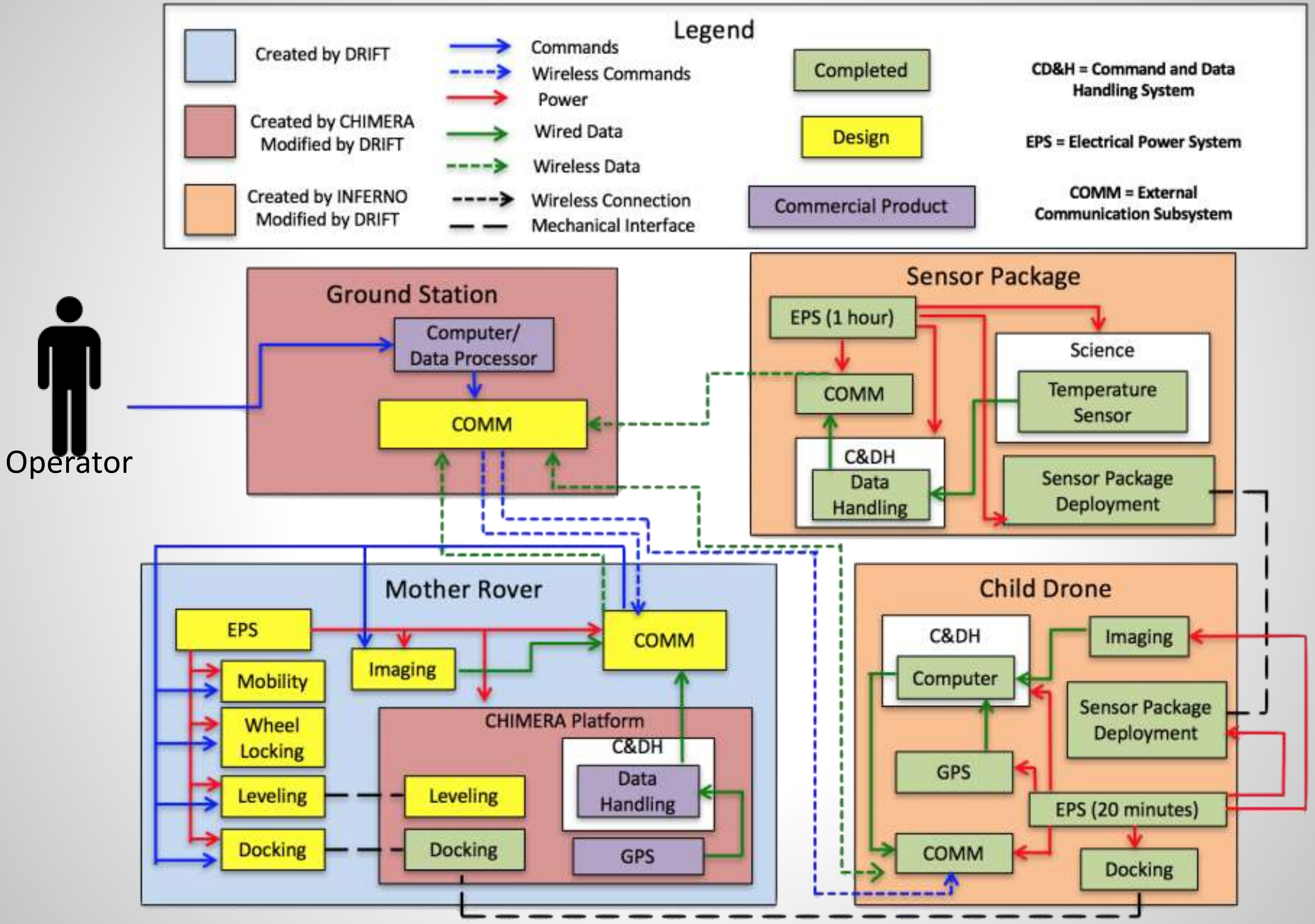
Side View



Front View



Functional Block Diagram



Critical Project Elements

Project Overview | Design Solution | **Critical Elements** | DRs and Satisfaction | Validation and Verification | Project Risks | Project Planning | Conclusion

Critical Project Elements

CPE 1

Translational System

CPE 2

Leveling System

CPE 3

Electronics & Communications

Translational System Importance

- Critical to the Mother Rover’s ability to **maneuver** to the desired GPS location.
- Gives Mother Rover ability to traverse terrain considered to be dangerous for firefighters.
  - Allows for firefighters to remain safe.
- Integrated with Landing Platform – carries Child Drone
- Houses all electrical and mechanical components

Critical Project Elements

CPE 1

Translational System

CPE 2

Leveling System

CPE 3

Electronics & Communications

Leveling System Importance

- Landing Platform must be level for Child Drone to autonomously land.
  - **CD Can land and takeoff at inclinations within 3.5° of level.**
  - Uses image recognition software for autonomous landing.
- Must level Landing Platform while on a 20^{o} slope.
- Must level Landing Platform while traversing a 5 inch obstacle.

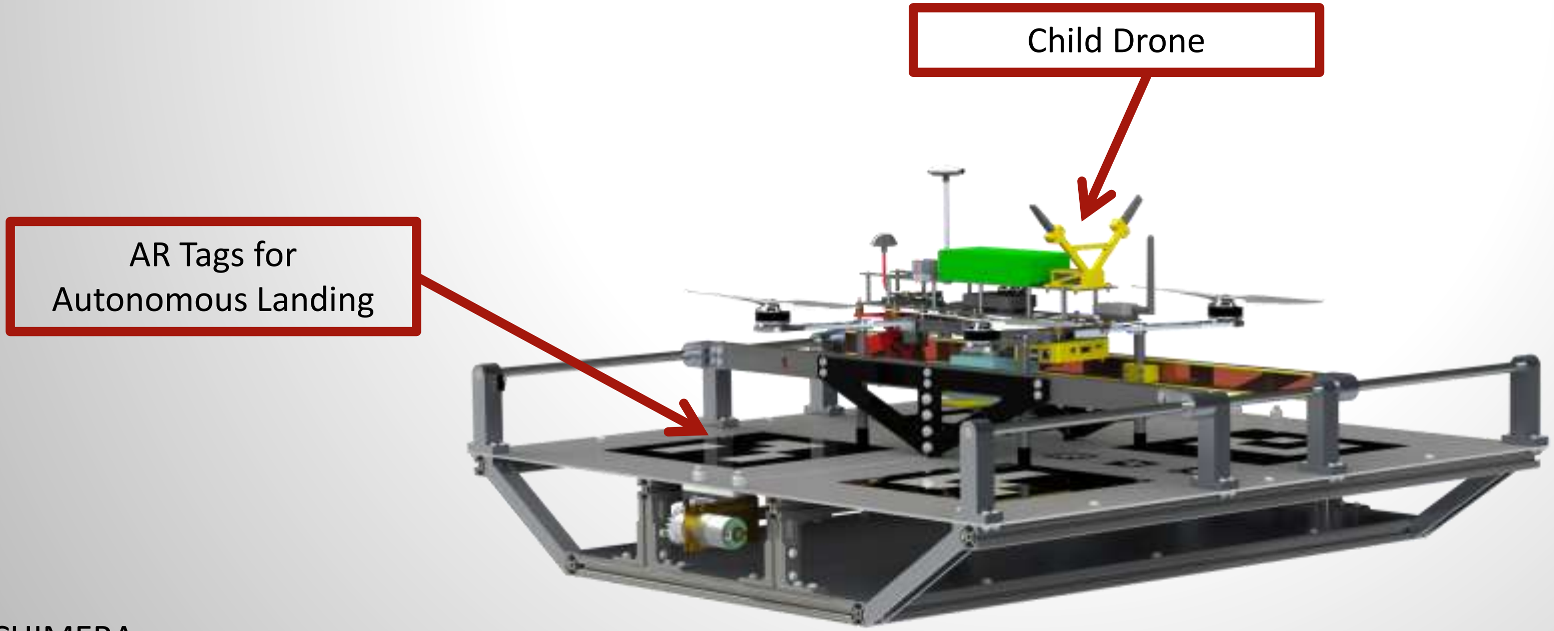


Image from CHIMERA

Critical Project Elements

CPE 1

Translational System

CPE 2

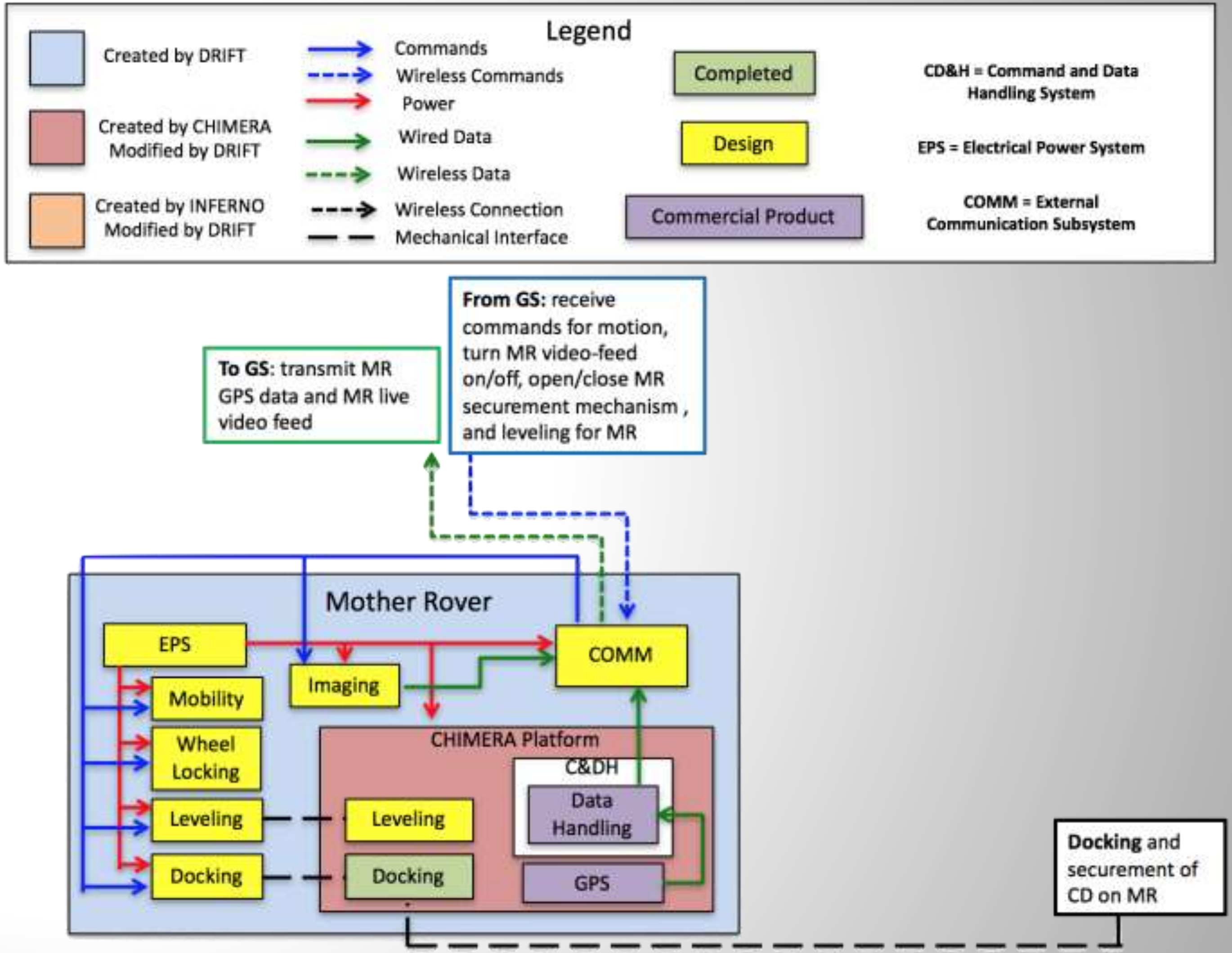
Leveling System

CPE 3

Electronics & Communications

Electronics and Communications Importance

- Mother Rover to Ground Station
  - Transmit MR GPS location and heading
  - Transmit MR live video feed
  - Both critical to **navigation**
- Ground Station to Mother Rover
  - Transmit commands for translational motion
  - Transmit commands to turn MR video feed on/off
  - Transmit commands to open/close MR securement mechanism
  - Transmit commands to level LP



Design Requirements and Satisfaction

Design Requirements and Satisfaction

Translational System

Translational System Requirements

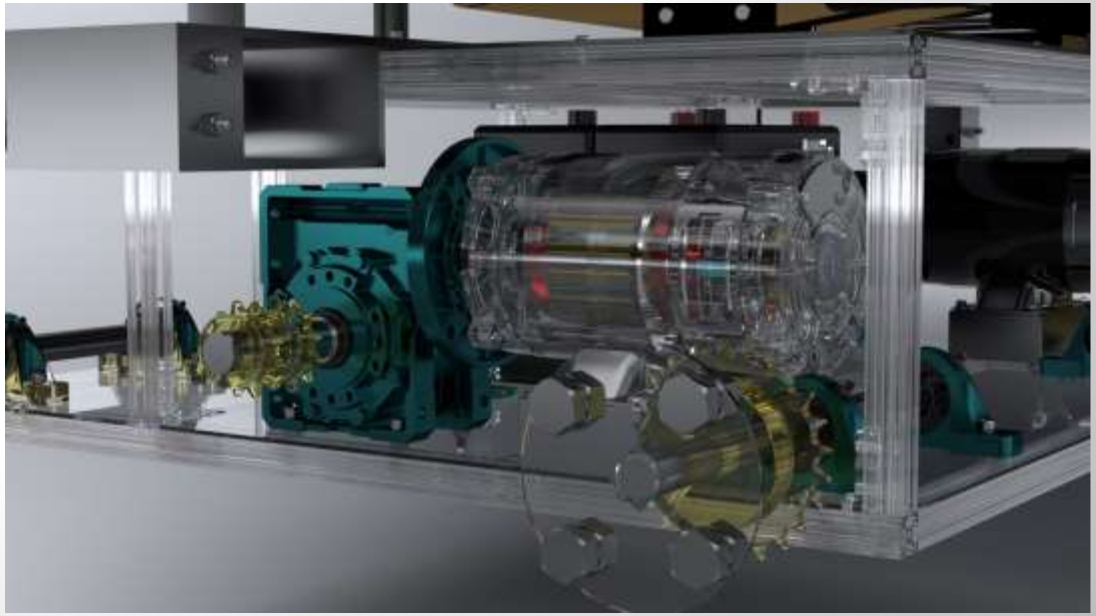
Functional Requirement	Description
FR4.0	The MR shall traverse 250 meters away from the GS to a specified GPS location over rough terrain defined by varying slopes and obstacles which require the MR to navigate over and around them. The MR shall return to the GS after the mission is complete.
Design Requirement	Definition
DR4.1	The MR shall travel at a speed within the range of 0 to 0.5m/s in forward and reverse.
DR4.3	The MR shall turn 90 degrees in a 10 ft. radius
DR4.4	The MR shall execute received commands including moving forwards, backwards, turning, speed variation, and coming to a complete stop.
DR4.5	The MR shall traverse up and down a slope of 20 degrees.
DR4.6	The MR shall traverse 5 in. tall obstacles.

Note: Modified FR4.0 distance from 500 to 250 meters due to budget constraints on battery size.

Design Solution for Translational System

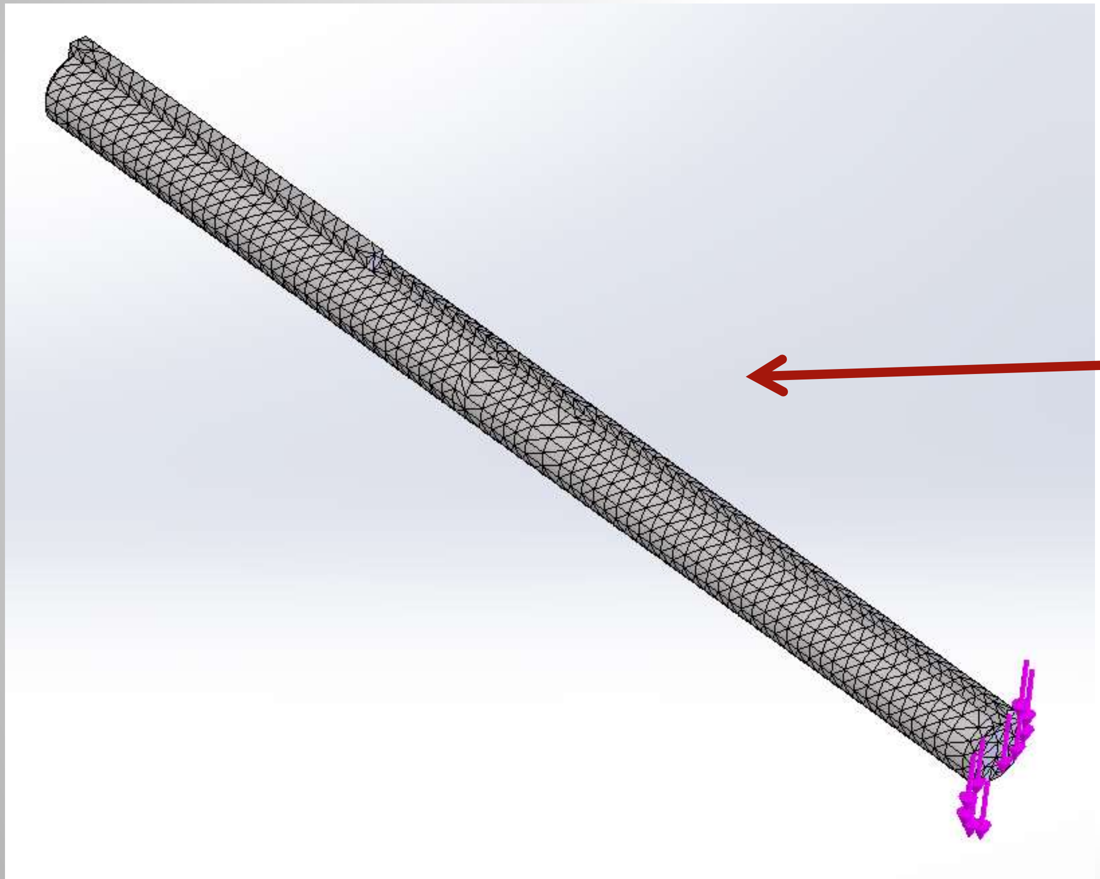
Entire MR Translational System

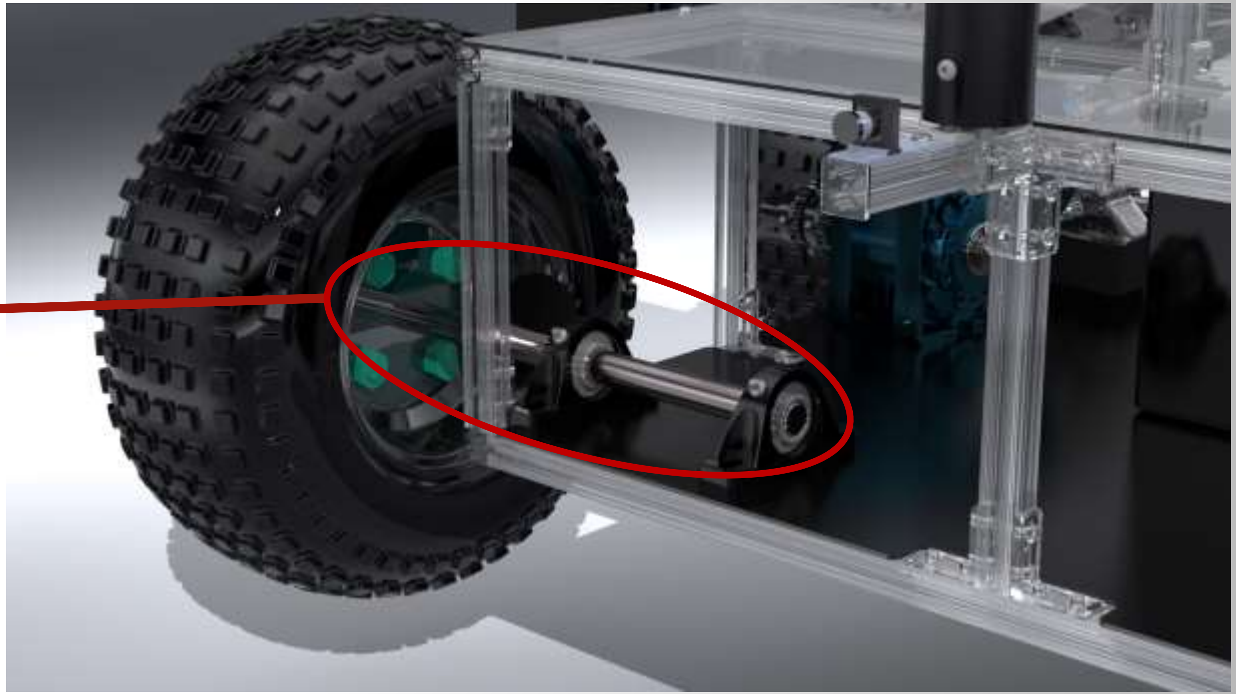
Wheels



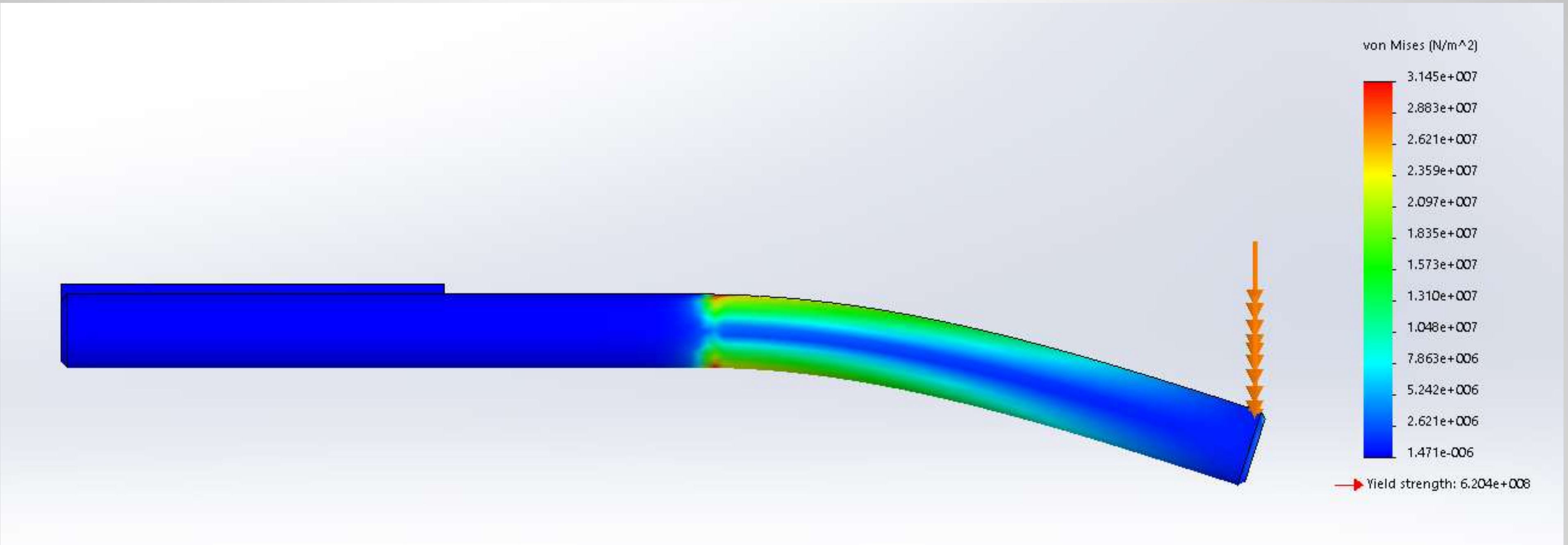
Motors

Finite Element Analysis – Wheel Shaft





Stress Contour



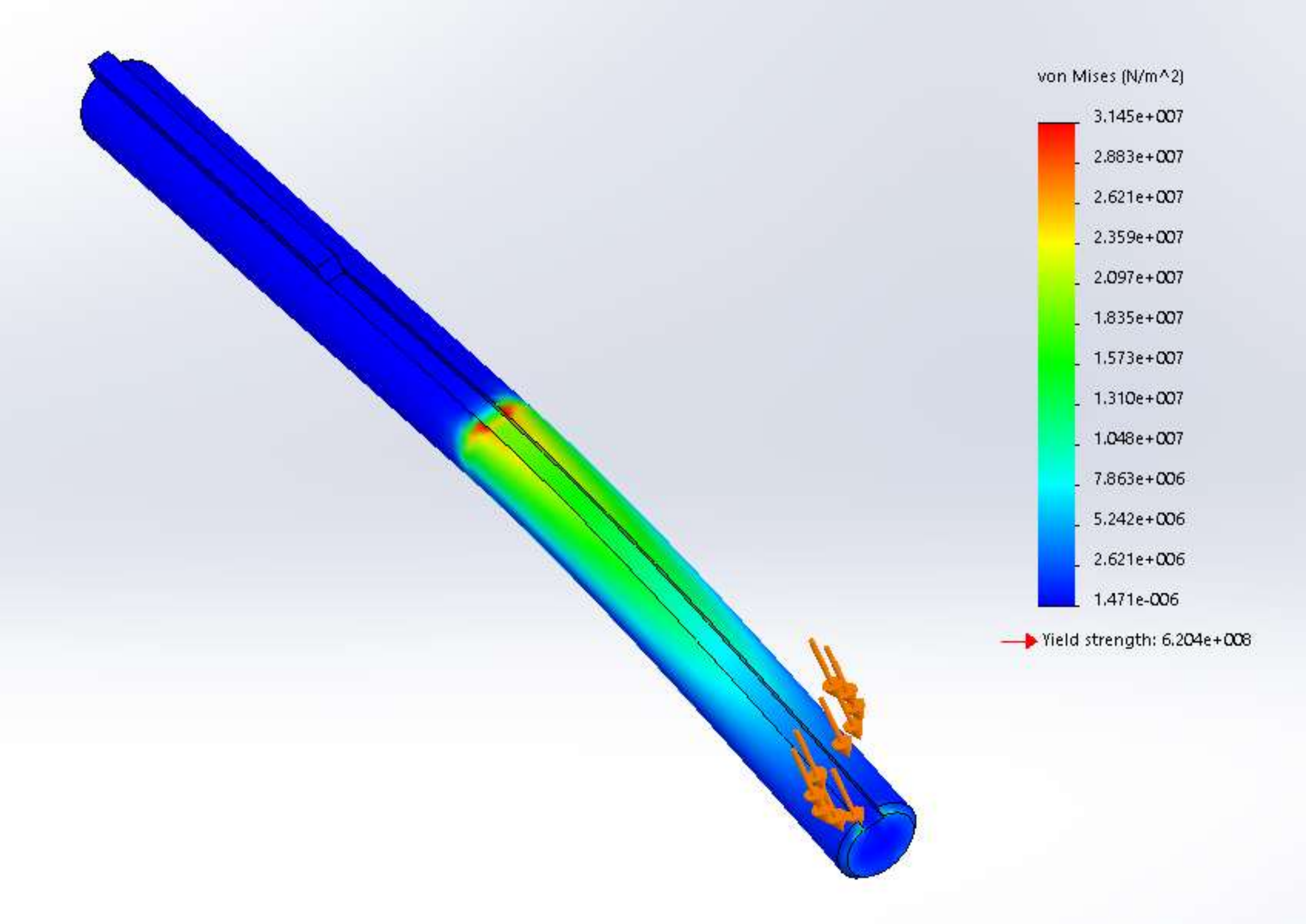
Parameters

- Surface contacts of the cylinder are fixed at the wheel and middle bearing
- Force load is applied at the end surface
- Force load is equivalent to one 1/4 of the weight of the rover (90 lb.)
    - 4 shafts
- Material: 1045 Carbon Steel

Assumptions

- Force load from the weight of the rover is all applied at the end surface of the shaft (worst case scenario)
- No deflections of the shaft in between the wheel and the middle bearing

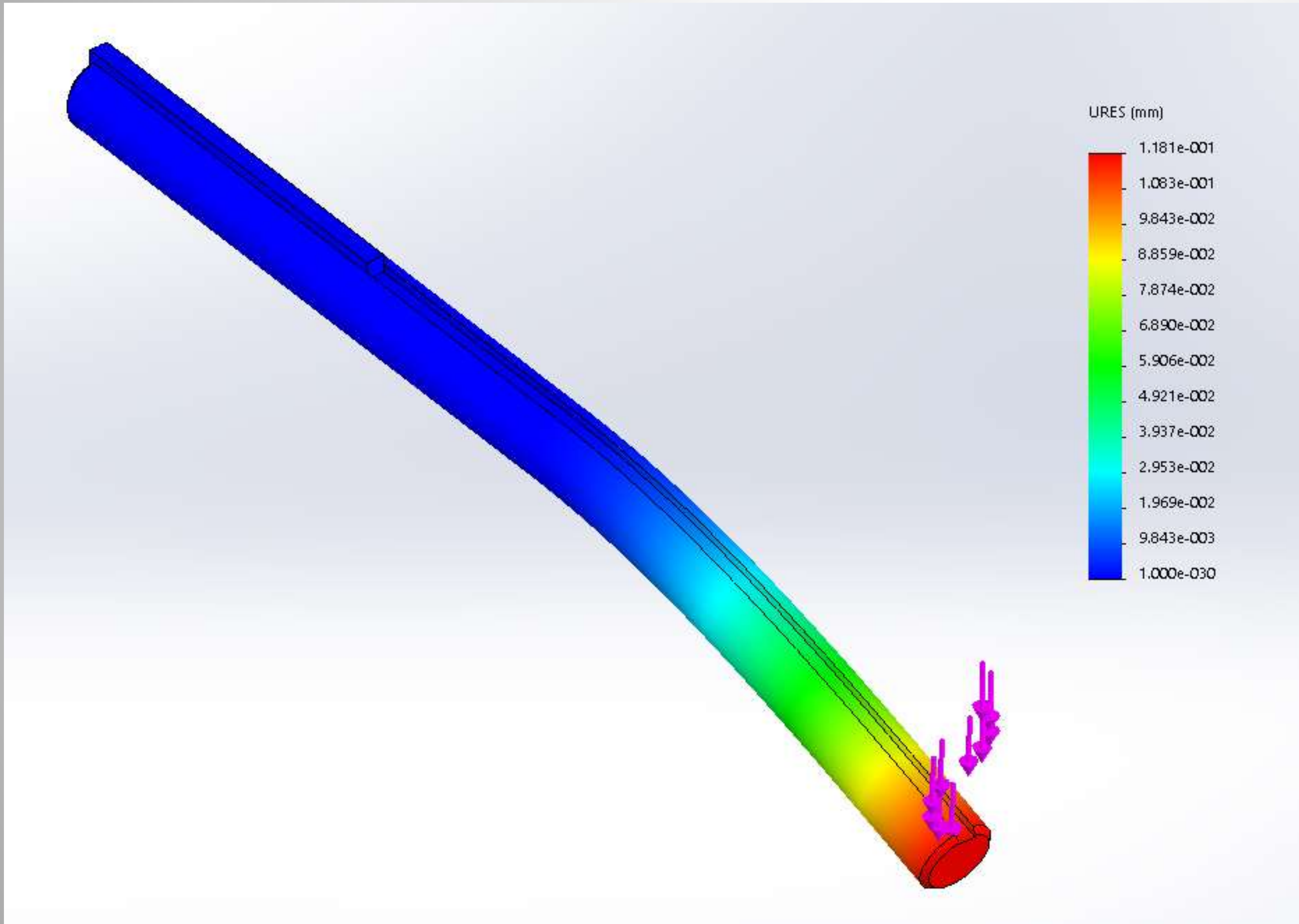
Stress Contour



Results

- Maximum stress at the edge of the middle bearing
- **Maximum stress:** $3.145E7 \frac{N}{m^2}$
- Maximum stress occurs due to sharp edge of the key insert

Deflection Contour



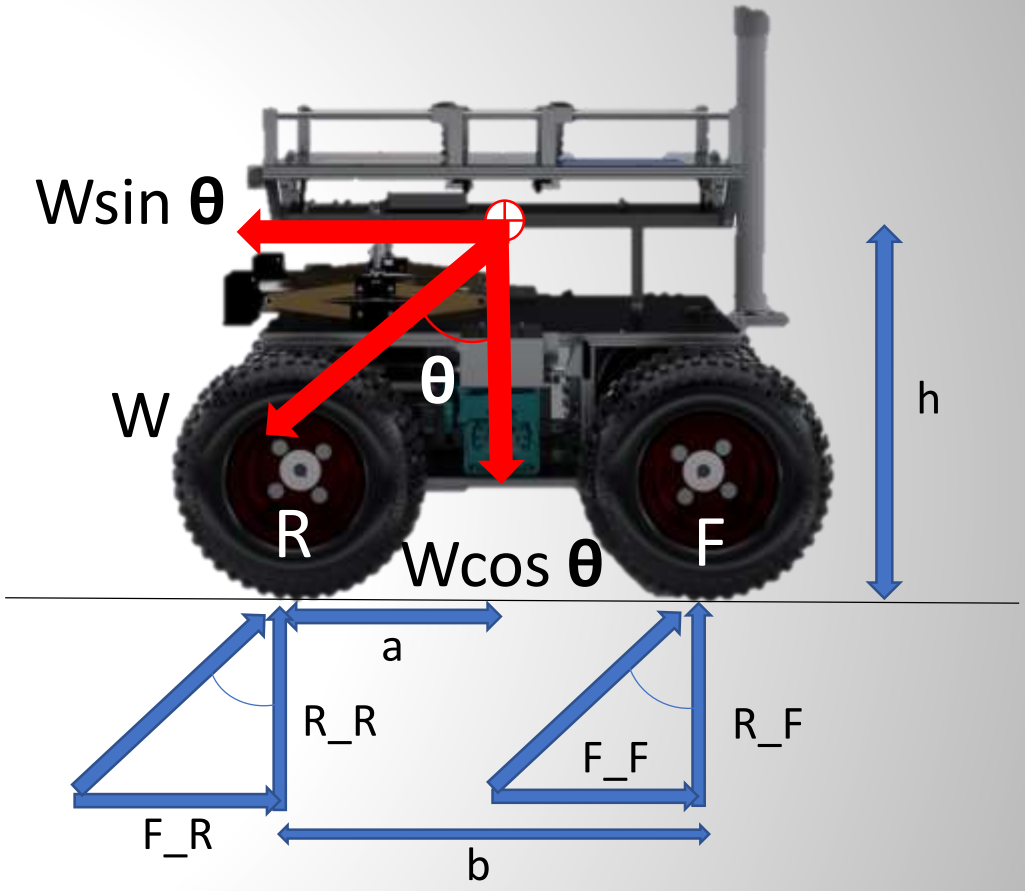
Results

- Maximum deflection at the end of the shaft at the bearing
- **Maximum deflection:** 0.1181 mm (0.0046'')
- Beam deflects a minimal amount in the absolute worst case scenario

Traction Analysis

- Traction and Torque models primarily defined from grade resistance (GR), rolling resistance (RR), and inertial resistance (FA)
  - These forces summed to get Total Tractive Effort (TTE)

Input Parameters	
Weight, W	250 lb.
Incline Angle θ	20 degree
Velocity, V	0.5 m/s
Rolling resistance factor, C_{rr}	0.037
Frictional loss factor, FR	1.1
Wheel radius, R_w	9 in.
Acceleration time, t_a	3 seconds
Coefficient of friction, μ	0.6



- $TTE[lb] = RR + GR + FA$
  - $RR = Reac_{wheel} \cdot C_{rr}$
  - $GR = Reac_{wheel} \cdot \sin(\theta)$
  - $FA = \frac{Reac_{wheel} \cdot V}{32.2\frac{ft}{s^2} \cdot t_a}$

- Wheel Torque Required: $T_w = TTE \cdot R_w \cdot RF$
- Max Tractive Torque: $MTT = Reac_{wheel} \cdot \mu \cdot R_w$
- Wheel Torque must be less than Max Tractive Torque, otherwise will slippage will occur.

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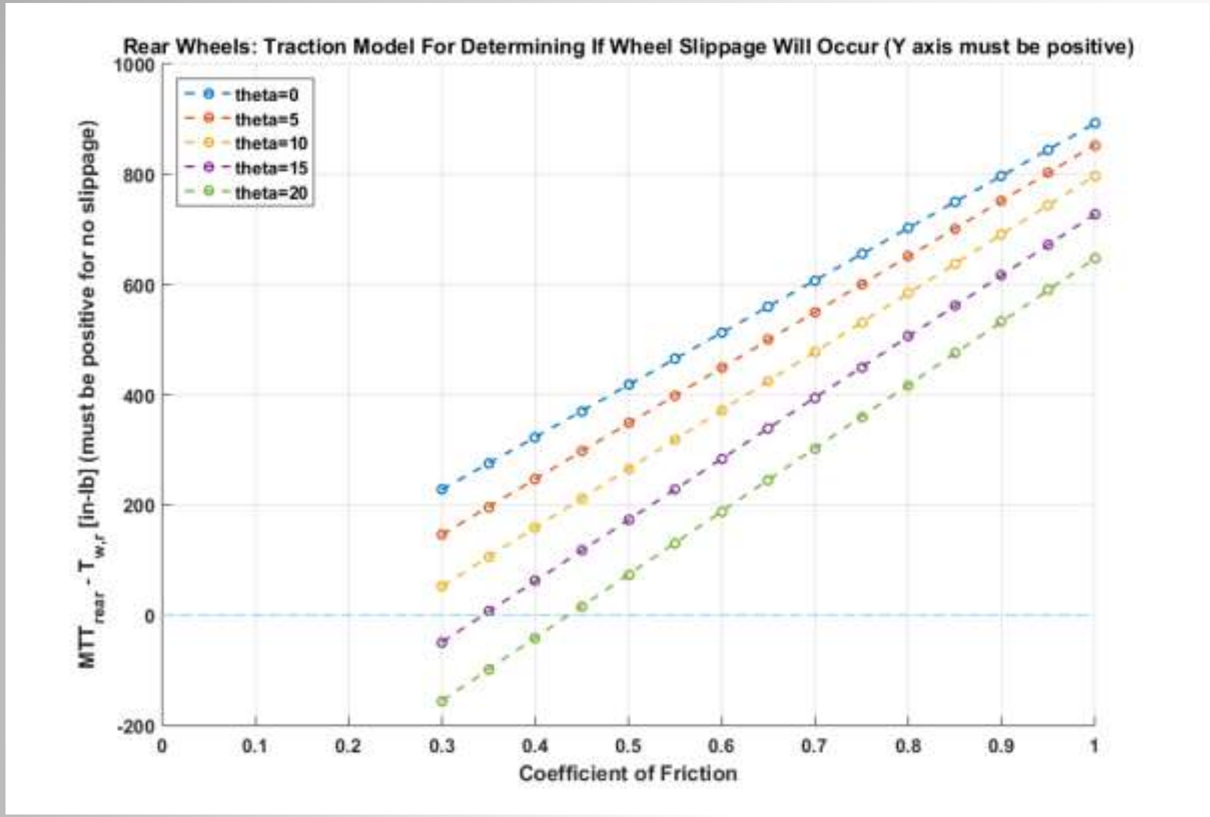
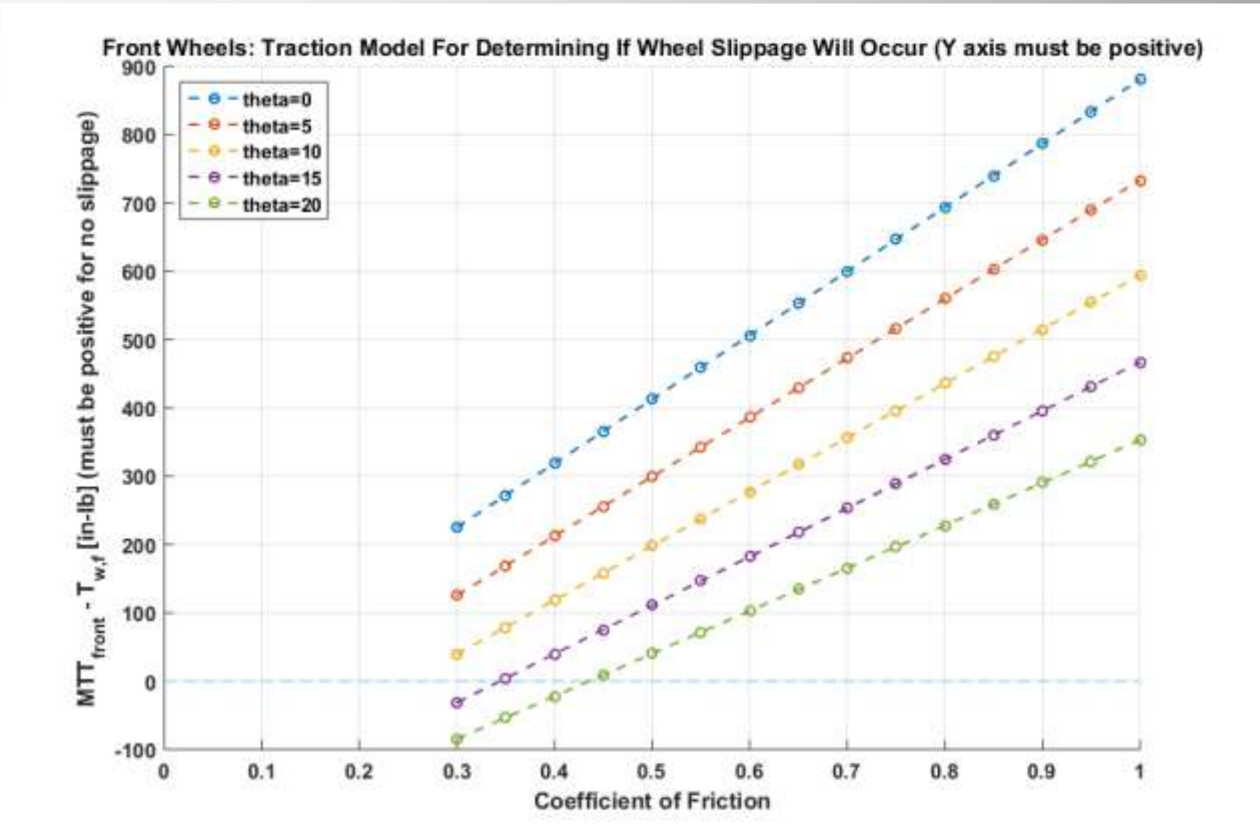
Driving Directly Uphill (Per Motor):





20 Degrees, Rear: $T_{wr} = 498.9\ inlb$

$MTT_r = 687.2\ inlb$

20 Degrees, Front: $T_{wf} = 272.4\ inlb$

$MTT_f = 375.2\ inlb$

Driving directly sideways along a 20 degree slope:

Left: $T_{w,left} = 135.4\ inlb$

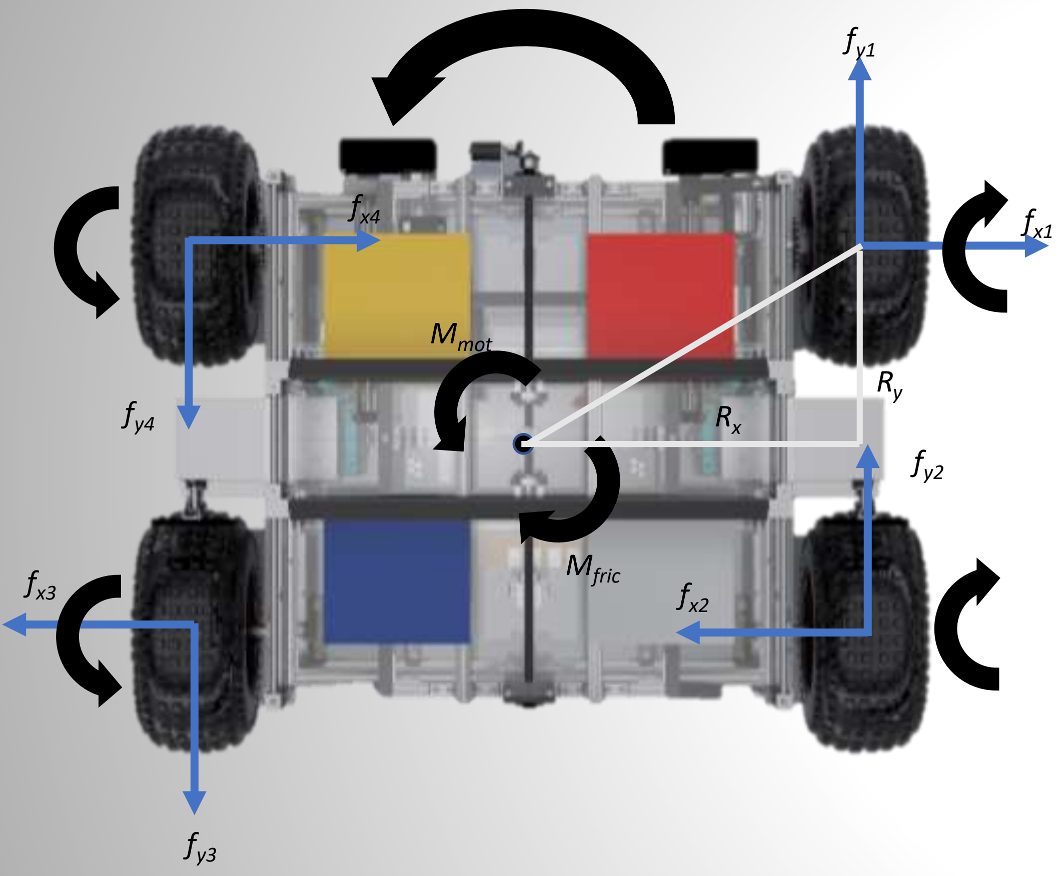
$MTT_{left} = 683.9\ inlb$

Right: $T_{w,right} = 74.9\ inlb$

$MTT_{right} = 378.5\ inlb$

All of the orientations in between these two cases will be characterized through testing

Skid Steering Axial Forces



Initial Equations:

- $M_{mot} = R_x(f_{y1} + f_{y2} + f_{y3} + f_{y4})$
- $M_{fric} = R_y(f_{x1} + f_{x2} + f_{x3} + f_{x4})$
- $\sum f_y = \frac{R_y}{R_x}(\sum f_x)$

- $\sum M_o = 0 \rightarrow M_{mot} = M_{fric}$
- $\sum f_y = ma \quad a = \frac{V_f - V_o}{\Delta t}$
- $V_f = V_{max} \quad V_o = 0$

Divide by 4 to get axial force at each Wheel

$$\boxed{f_x = \frac{R_x}{R_y}\frac{ma}{4}}$$

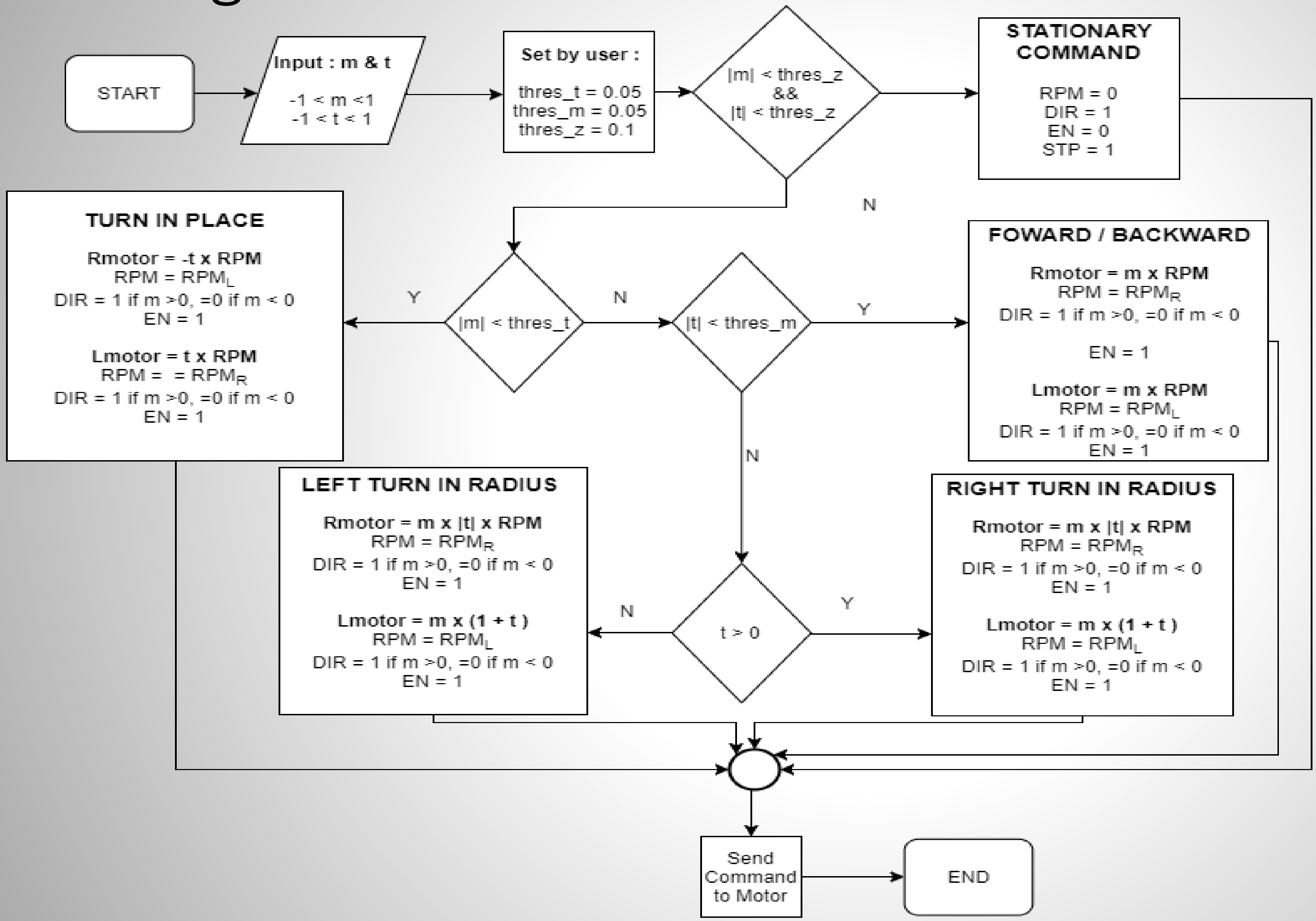
Parameters:

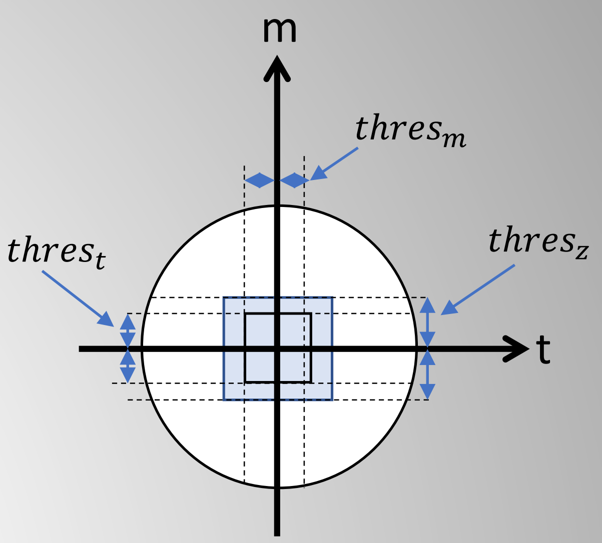
$R_x = 2.11 \text{ ft} \quad R_y = 1.23 \text{ ft} \quad m = 400\text{lbm} \quad V_f = 1.64\ \frac{ft}{s} \quad \Delta t = 2s$

Axial Force on Each Wheel

$$\boxed{f_x = 140.667\ \frac{lbm\ ft}{s^2} = 4.37\ lbf}$$

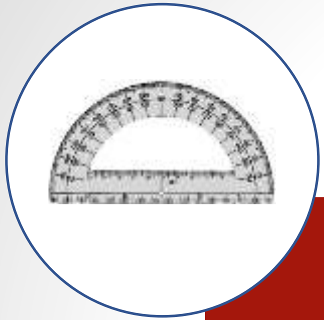
Steering Control Flowchart



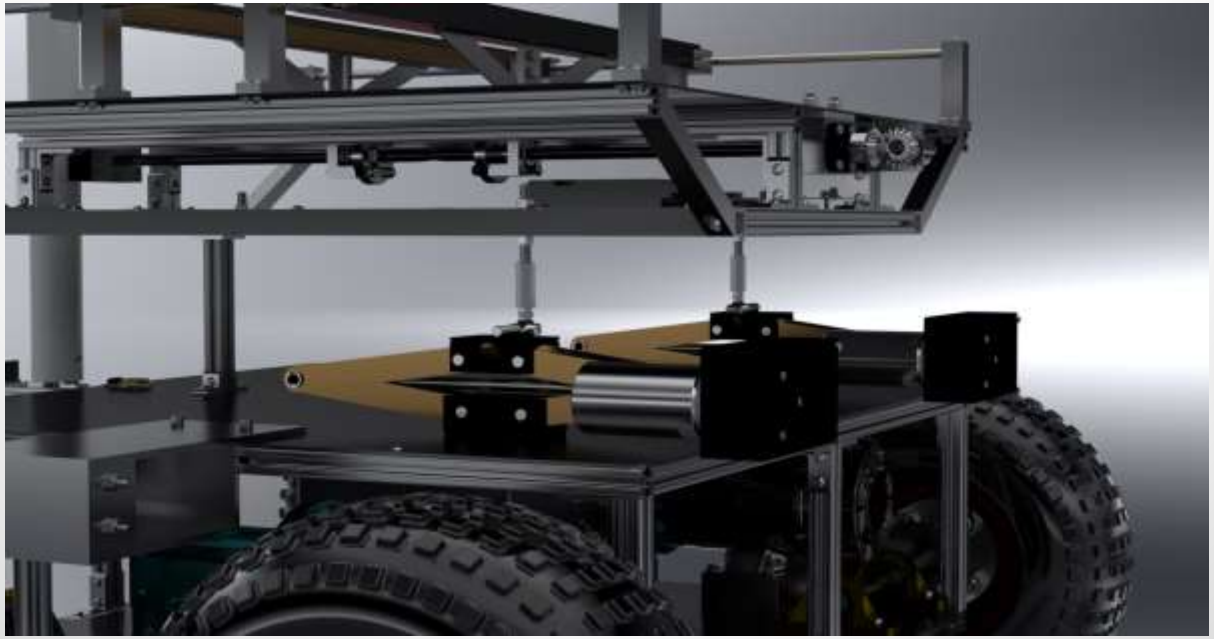


- Dead Zone (Stationary)

Design Requirements and Satisfaction



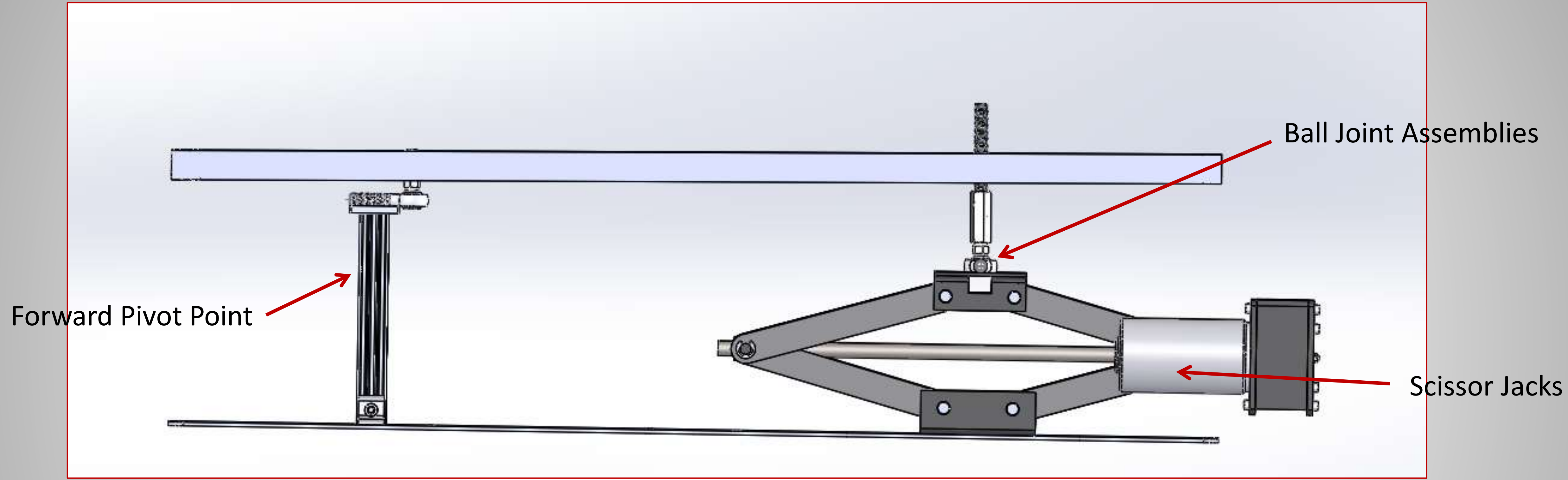
Leveling System



Leveling System Requirements

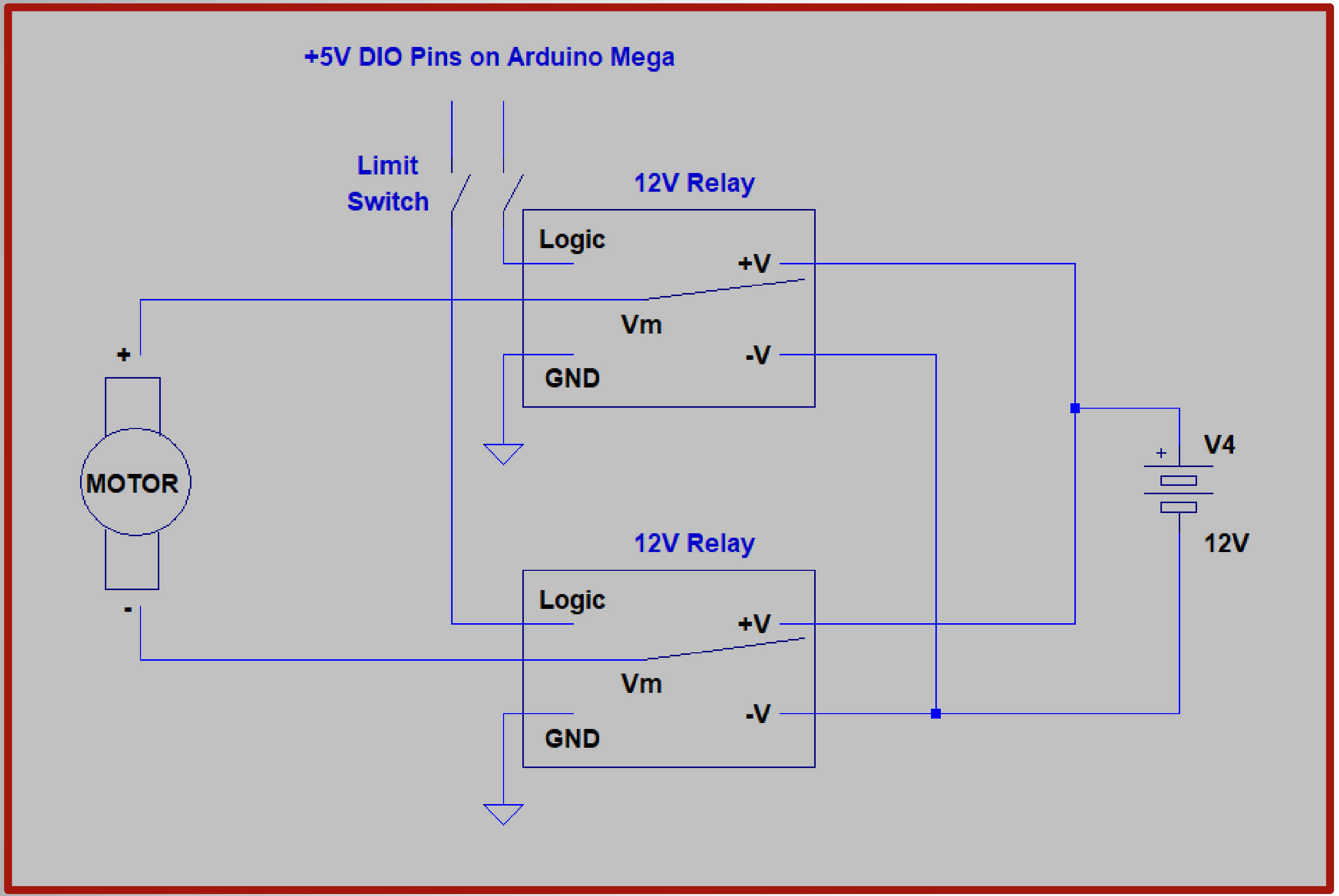
Functional Requirement	Description
FR5.0	The MR shall position itself for the CD to take-off and land safely such that it is able to be secured by the MR's securement mechanism
Design Requirement	Definition
DR5.1	The MR shall level itself within 3.5 degrees after coming to a complete stop.
DR5.2	The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

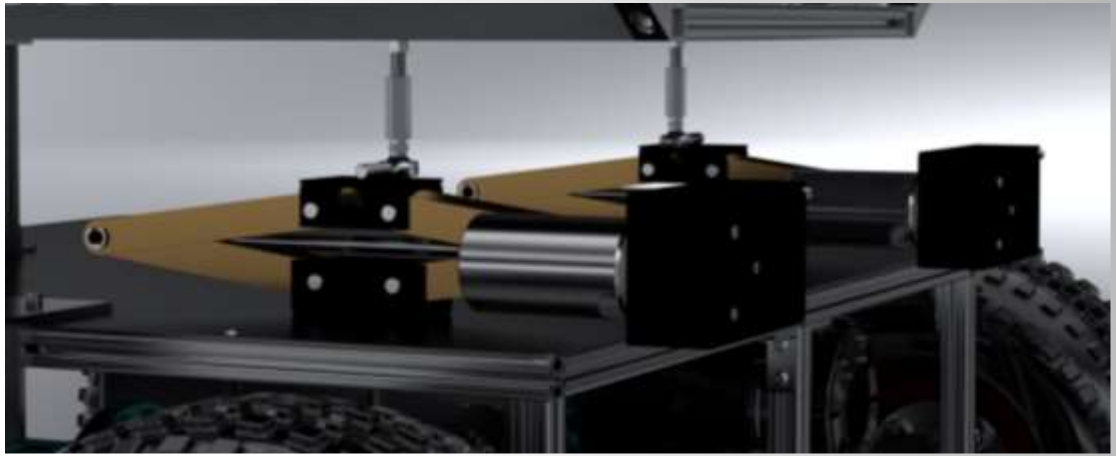
Design Solution for Leveling System



Component	Specifications	Manufacturer	Reason for Selection
EJ212 Electric Car Jack	Lift Height of 9.5" Max Lift Force of 2000 lb.	Black Bull Tools	Inexpensively provides motor and jack combination.
7/16"-20 Ball Joint Linkage	Rated for 1150 lb. Swivel Range of 44°	McMaster-Carr	Provides freedom of motion for attachment between LP and rover

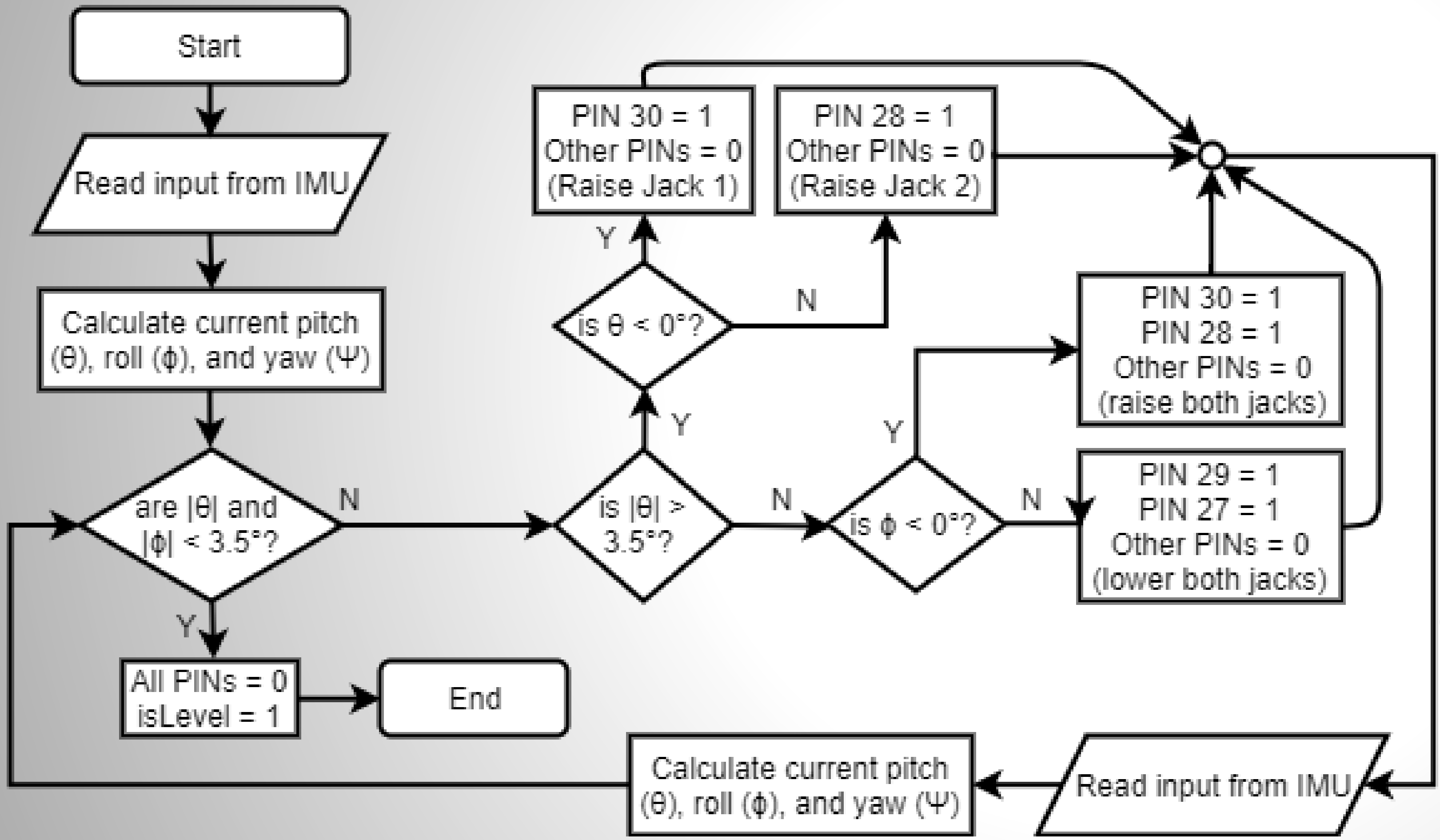
Controls for Leveling System

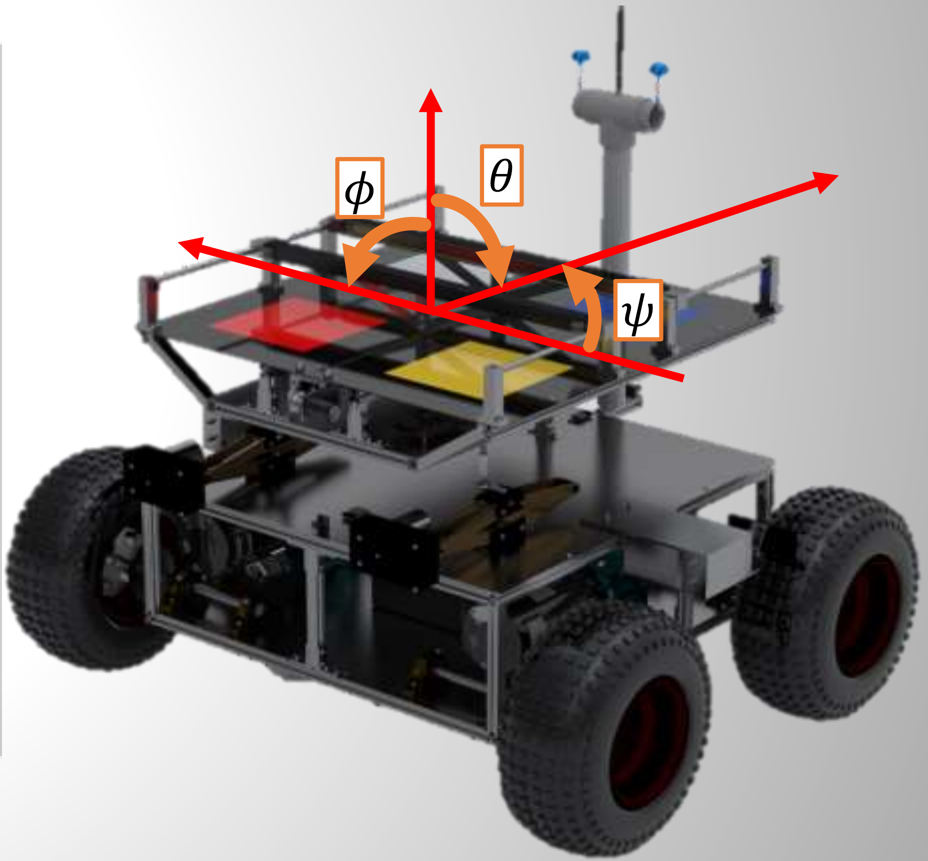




- When no command sent, jacks are stationary.
- When activating logic on one of the relays, a circuit is completed, allowing current to flow through the motor.
- Depending on which relay is triggered, current will flow in a different direction, creating upwards or downwards movement in jack, allowing for control.

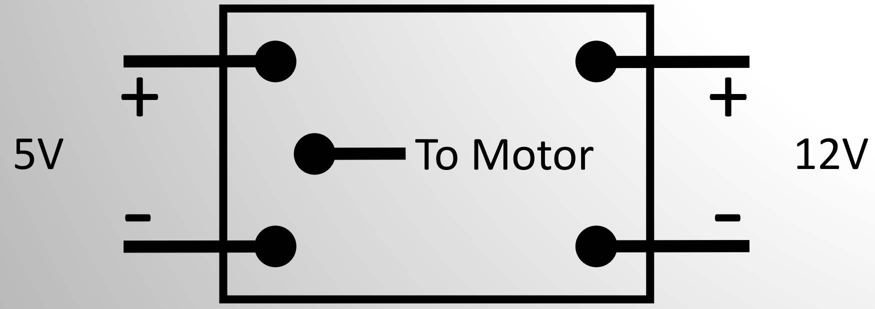
Controls for Leveling System

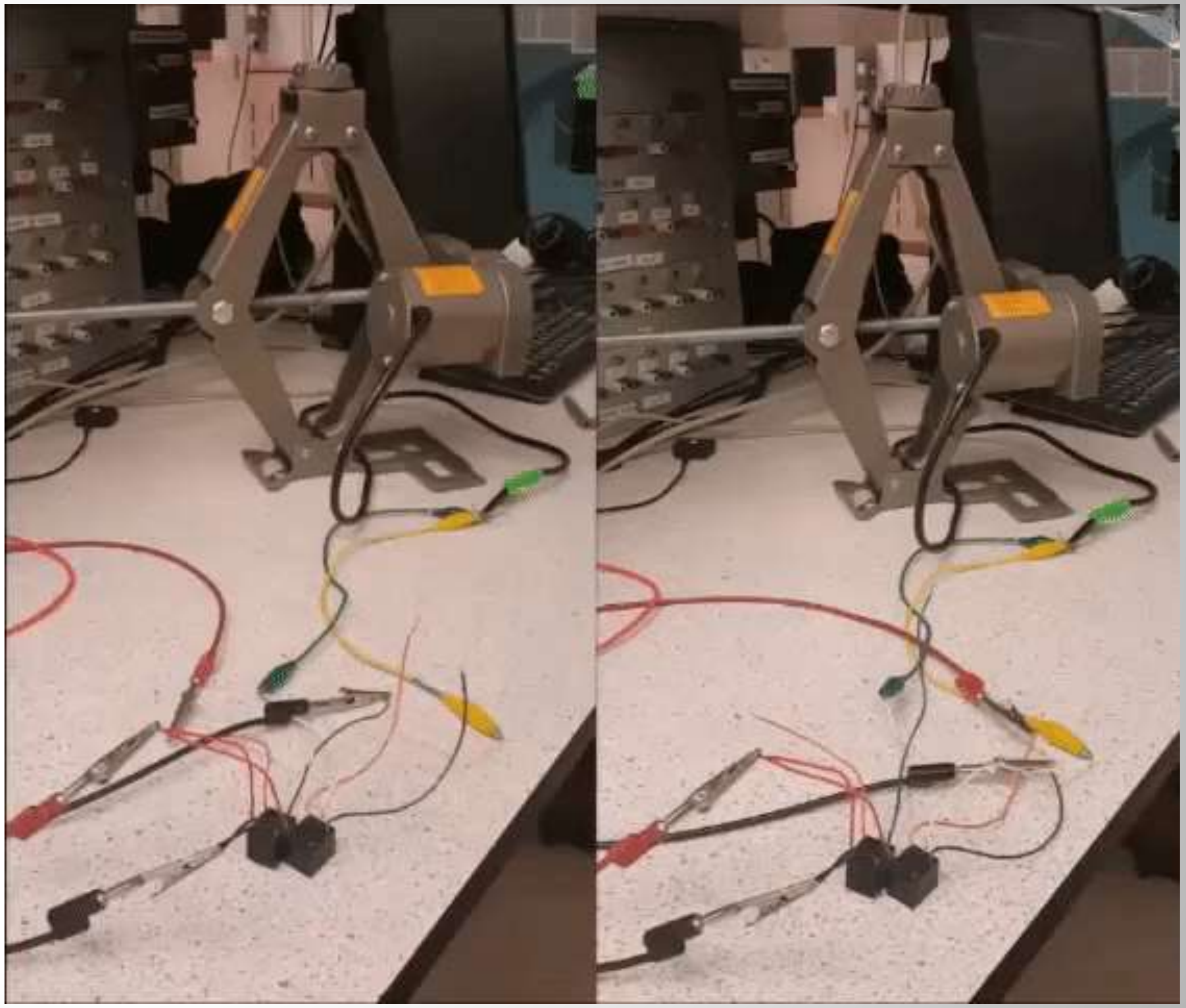




Leveling Simulation

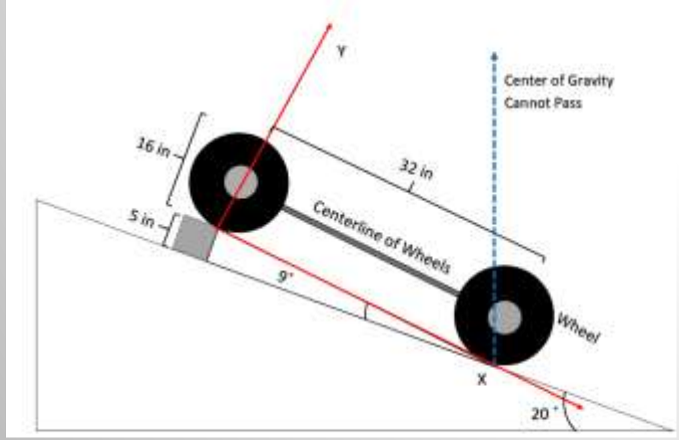
- Relays removed from button circuit, hooked up to:
  - 5 VDC power supply (upper connection to relays)
  - 12 VDC power supply (lower connection to relays)
- 5 VDC power supply to simulate voltage seen by Arduino to control the leveling jack
- Can see that when Arduino voltage is rerouted, the jack changes direction
- Gif is speed up 4x

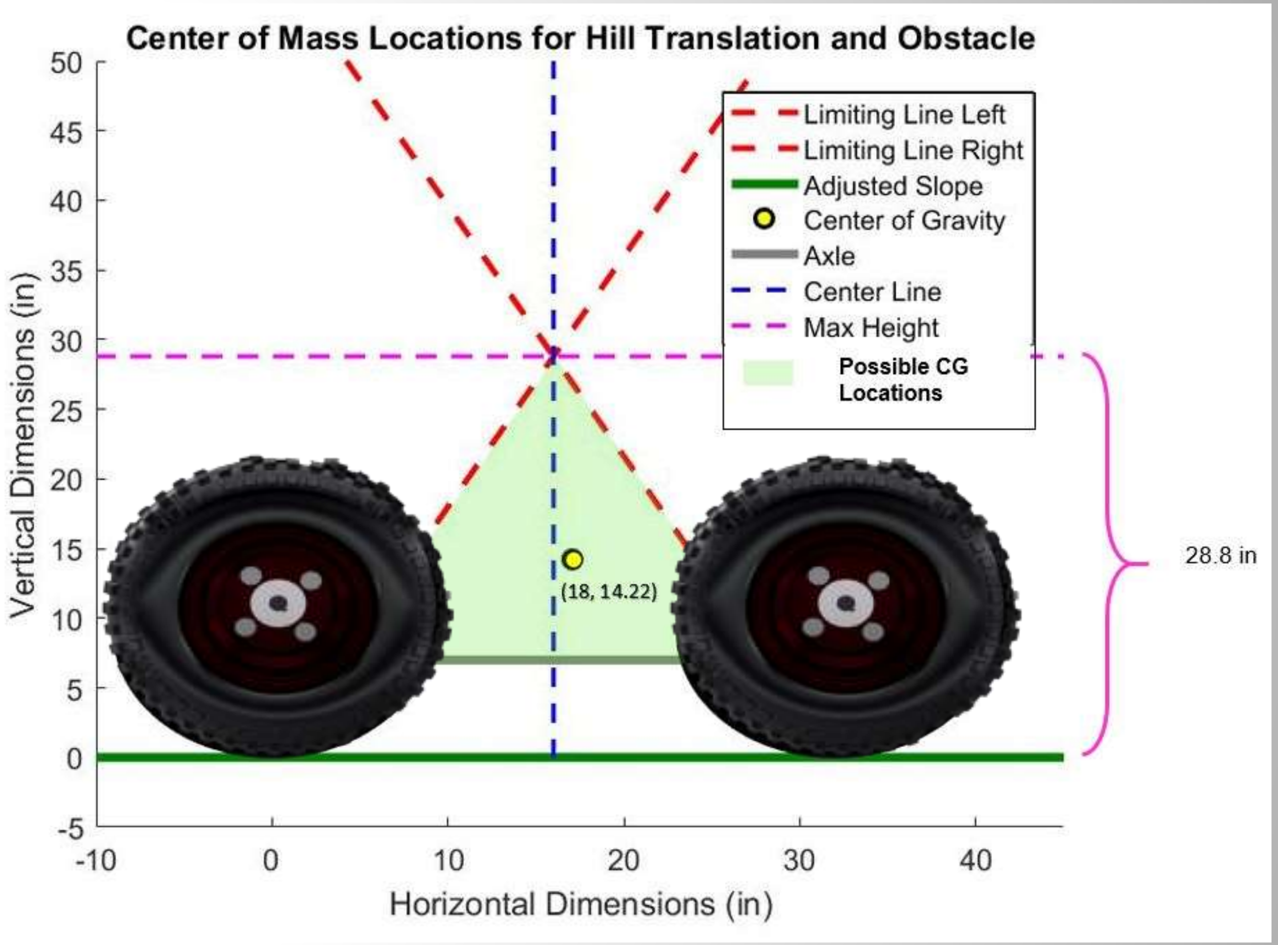




Tipping Analysis

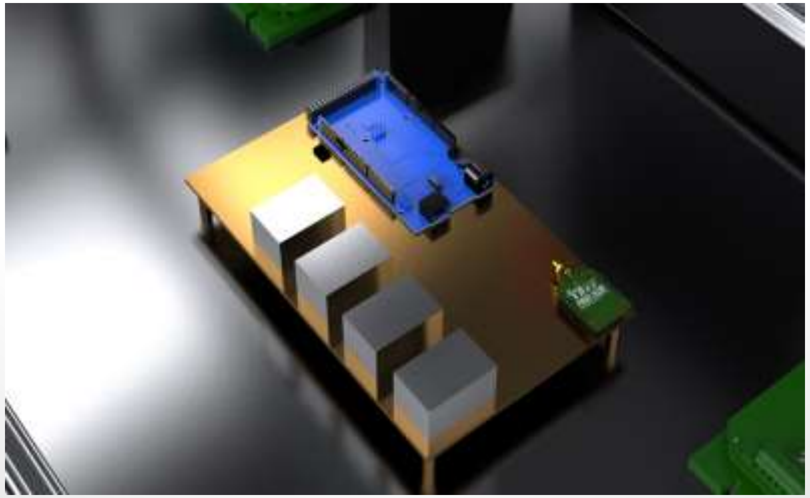
- Locations of valid center of gravity locations found for three cases:
  - Translate over 5 inch obstacle
  - Translate up 20 degree slope
  - Simultaneously translate up a 5 inch obstacle and a 20 degree slope. (Most tilted state)
- Trigonometry used to find the locations.
- **Center of gravity is:**
  - 18 inches from the end of the back left wheel
  - 17.06 inches forward from the back of the left wheel
  - 6.22 inches above the center of the wheels.





Design Requirements and Satisfaction

Electronics & Communications



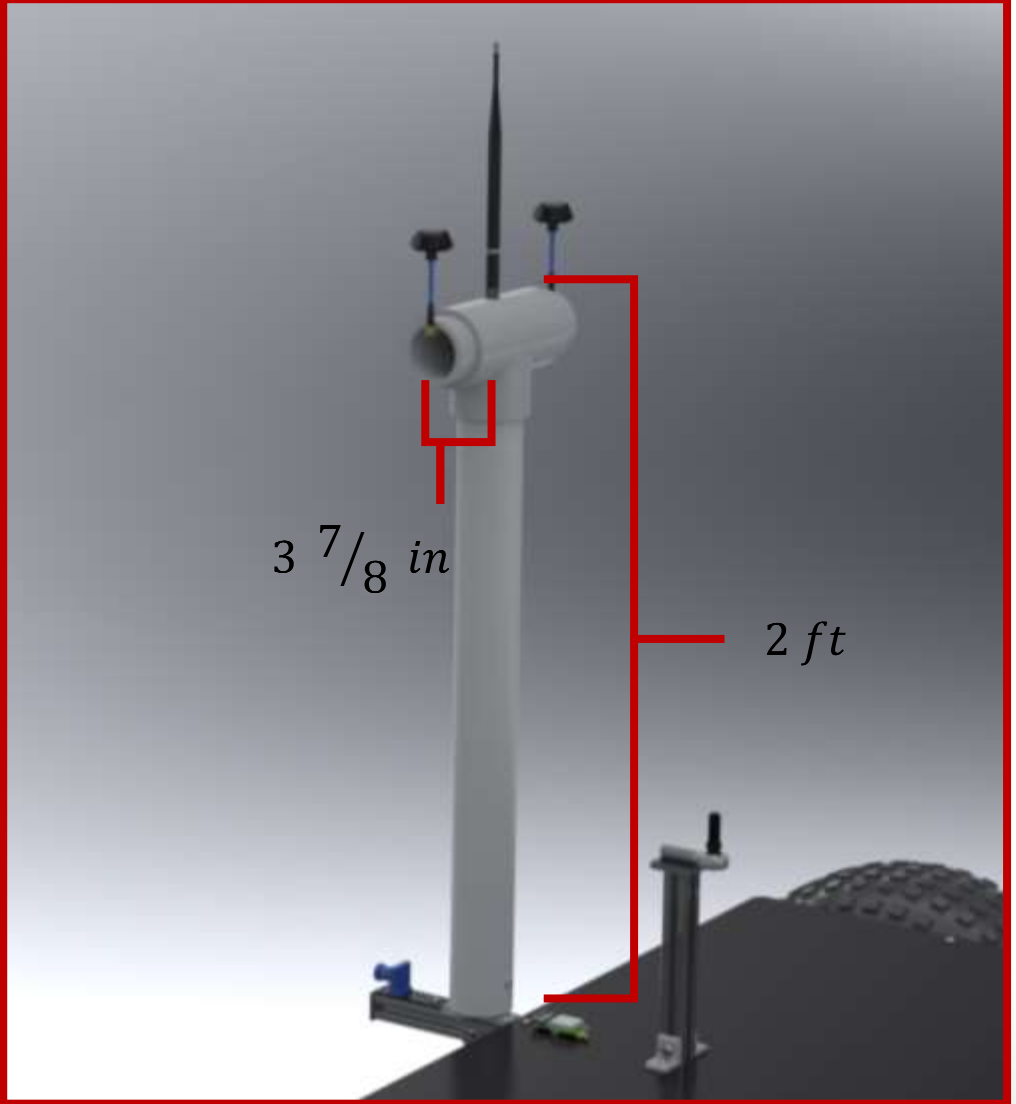
Communications Requirements

Functional Requirement	Description
FR2.0	The MR shall receive commands from the GS at 5 Hz.
Design Requirement	Definition
DR2.1	The MR shall record a log of received commands from the GS detailed in DR2.4.
DR2.2	The MR shall receive signals with a signal to noise ratio of at least 6 dB-Hz (industry standard).
DR2.3	The MR shall receive commands at a distance of 500 meters.
DR2.4	The commands to be received by the MR from the GS include: forward/backward translational motion, turning motion, to turn on/off the MR video feed, opening/closing the CD securement mechanism, and to level the LP.

Communication Requirements

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

Design Solution for Communications



Distance between antennas calculation:

$$\lambda = \frac{c}{f} = \frac{3 \text{ x } 10^8\ m/s}{5.8 \text{ x} 10^9\ Hz} = 0.0517 \text{ m} = 2 \text{ inch}$$

Parts chosen:

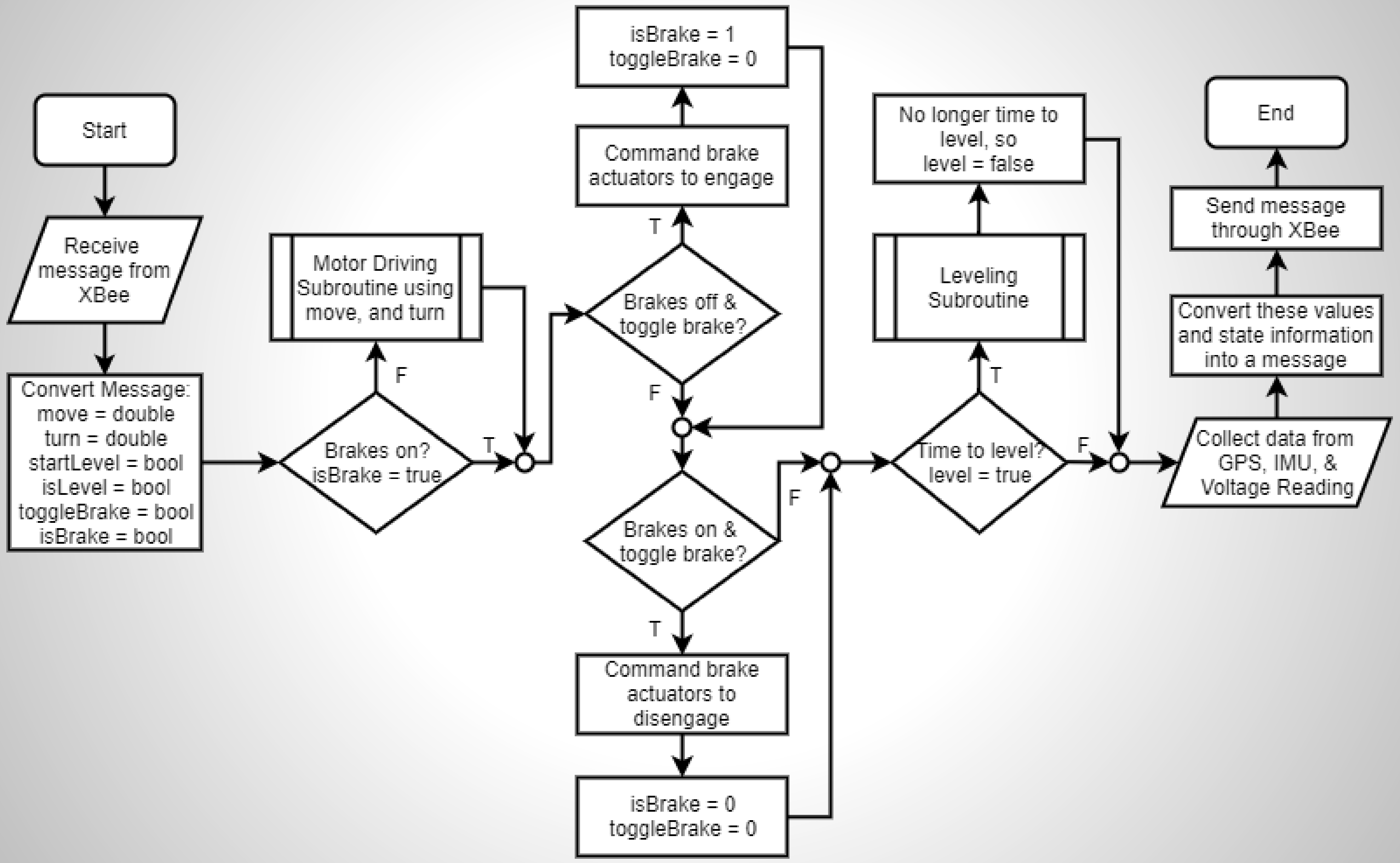
Immersion RC Video Transmitter

- Easy to use system
- Previous team already has multi-channel receiver for this piece

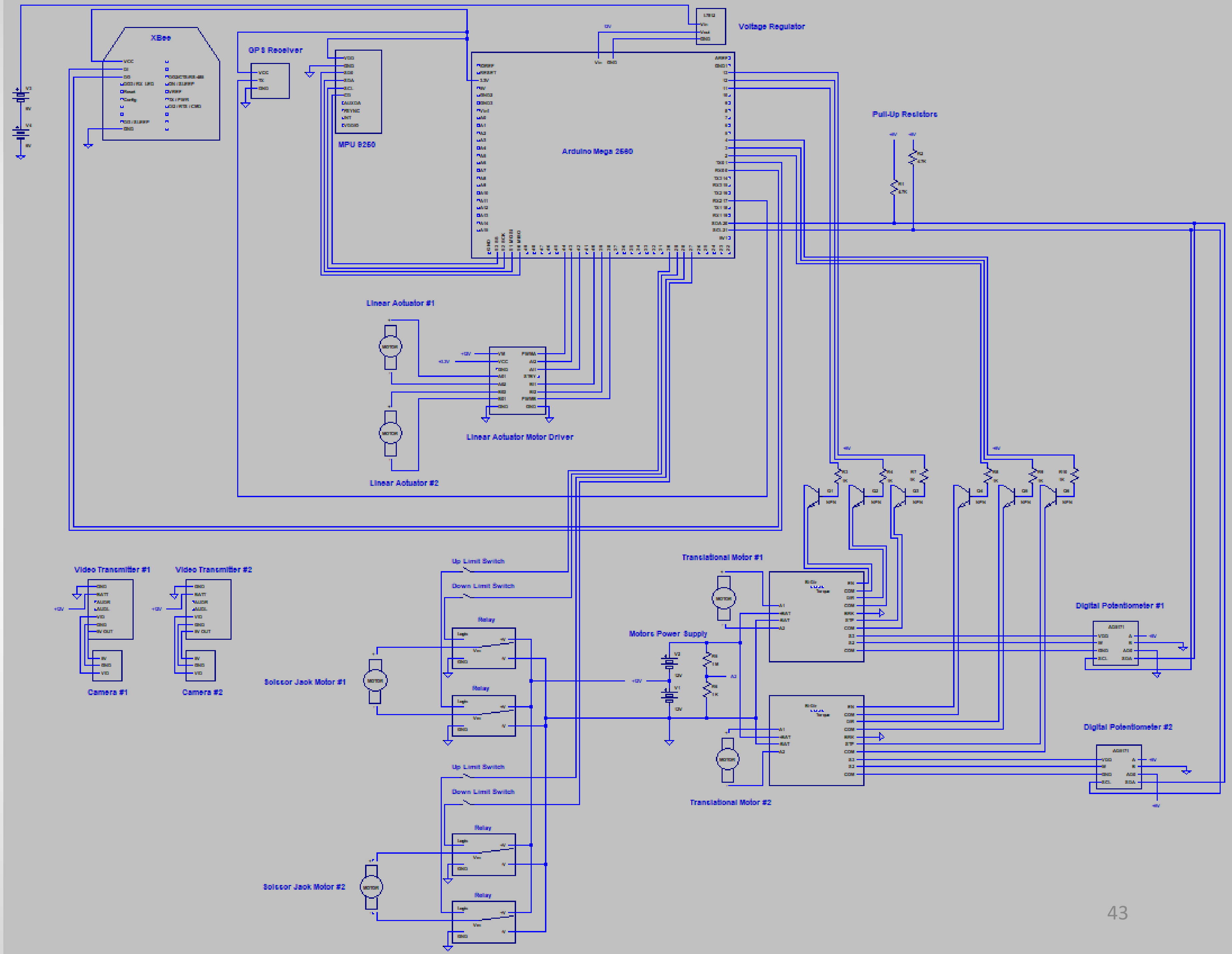
Xbee Pro S3B

- Allows creation of custom messages
- Has RP-SMA connector, allowing interchangeable antennae in case of damage

General Control for Rover

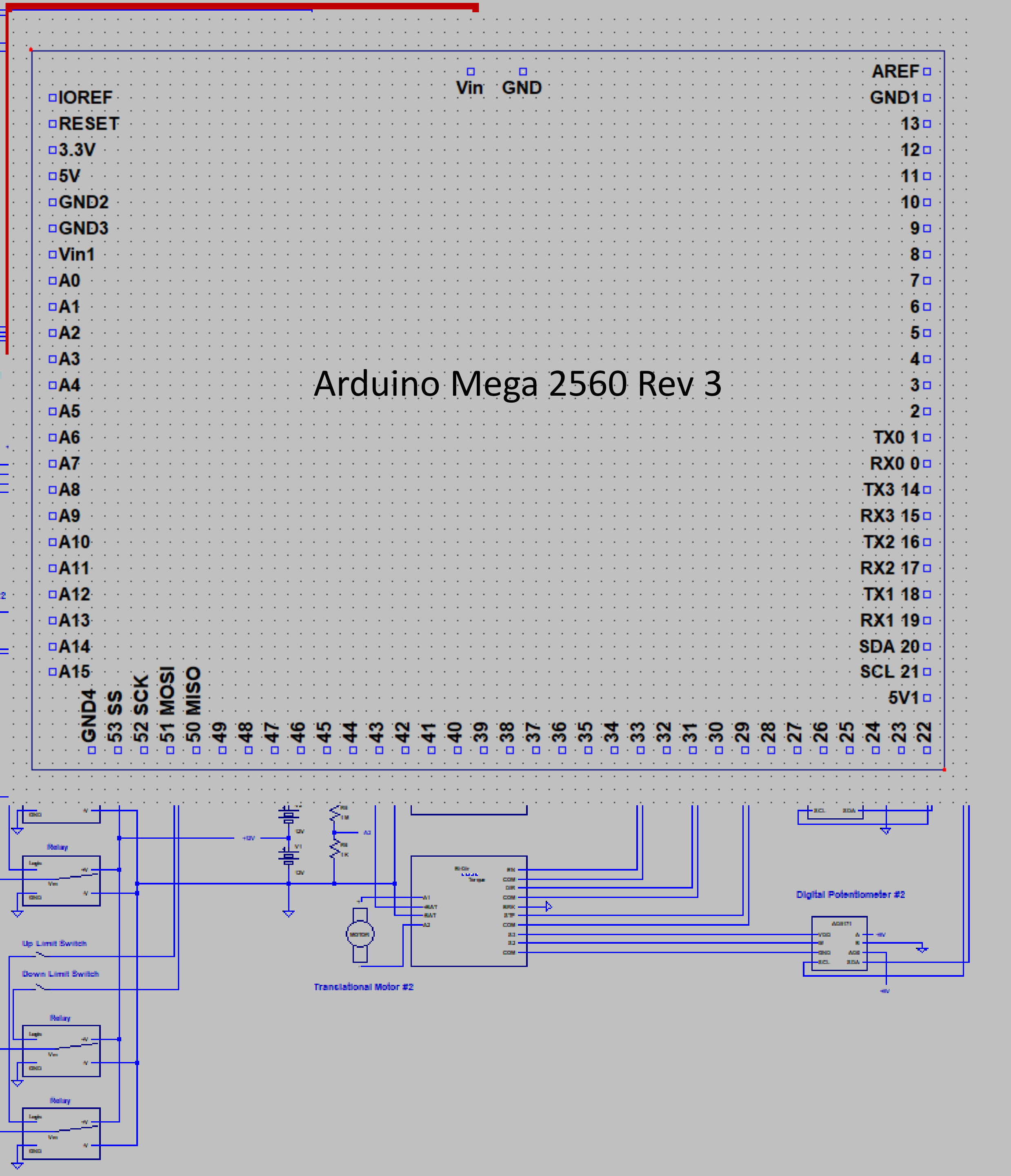


Design Solution for Electronics & Communications: Schematic



Microcontroller

Major Considerations	Arduino Mega 2560 Rev 3
16 x 5V – DIO Pins	54 x 5V DIO Pins
1 x Analog Input Pin	16 x Analog Input Pins
2 x TX/RX Channels	4 x TX / RX Channels
SPI	SPI
I2C	I2C
ADC	10-Bit ADC
3.3V Power Supply	3.3V Power Supply
5V Power Supply	5V Power Supply



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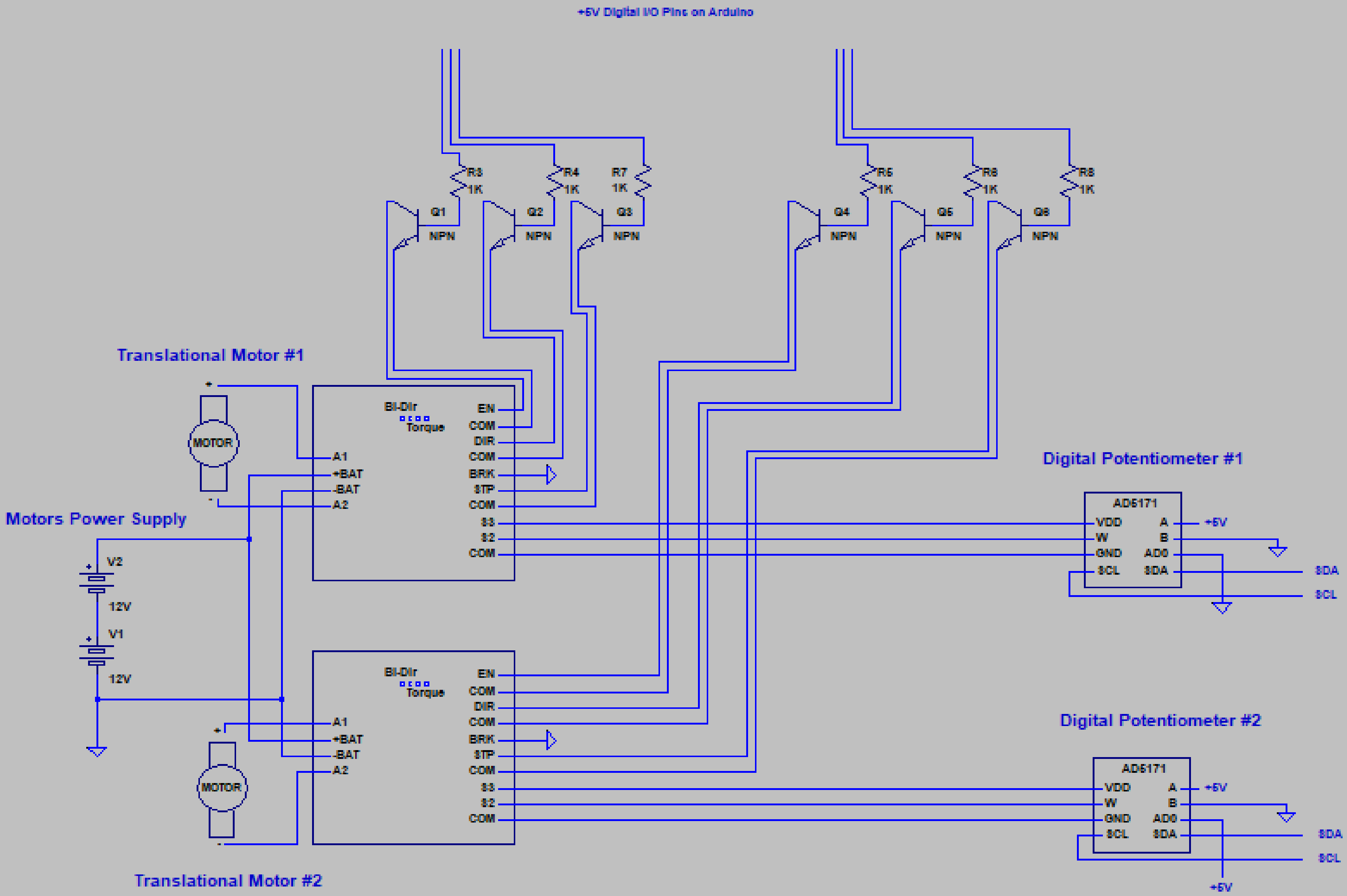
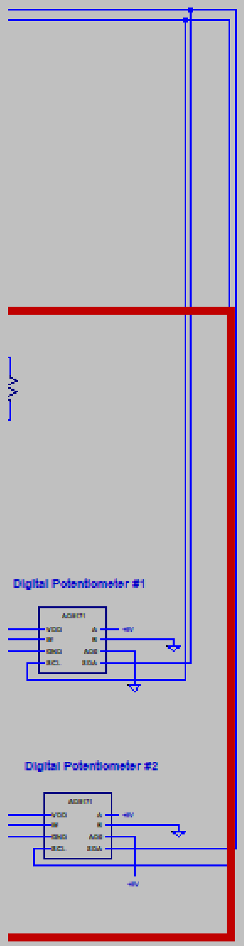
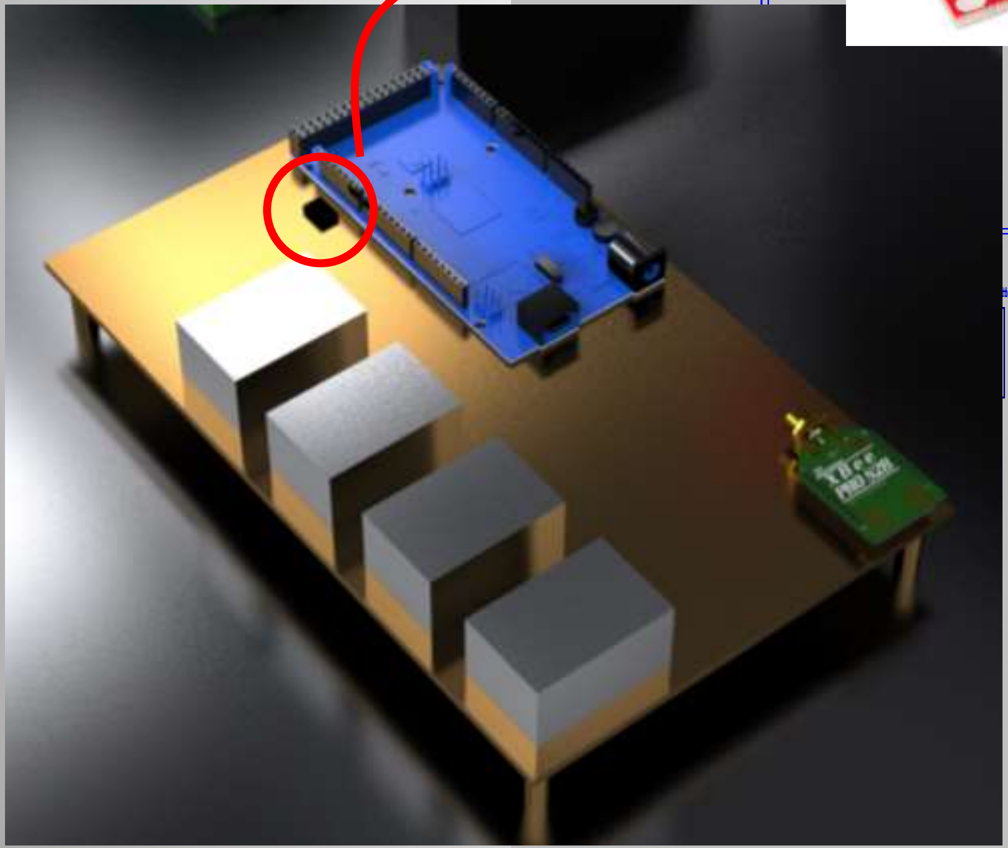


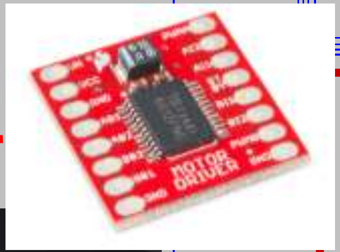
+5V Digital I/O Pins on Arduino
R3
1K
R4
1K
R7
1K
R5
1K
R6
1K
R8
1K
Q1
NPN
Q2
NPN
Q3
NPN
Q4
NPN
Q5
NPN
Q6
NPN
Translational Motor #1
MOTOR
Bi-Dir
Torque
EN
COM
DIR
COM
BRK
STP
COM
S3
S2
COM
A1
+BAT
-BAT
A2
Motors Power Supply
V2
12V
V1
12V
Translational Motor #2
Digital Potentiometer #1
AD5171
VDD
W
GND
SCL
A
B
AD0
SDA
+5V
SDA
SCL
Digital Potentiometer #2
AD5171
VDD
W
GND
SCL
A
B
AD0
SDA
+5V
SDA
SCL
+5V

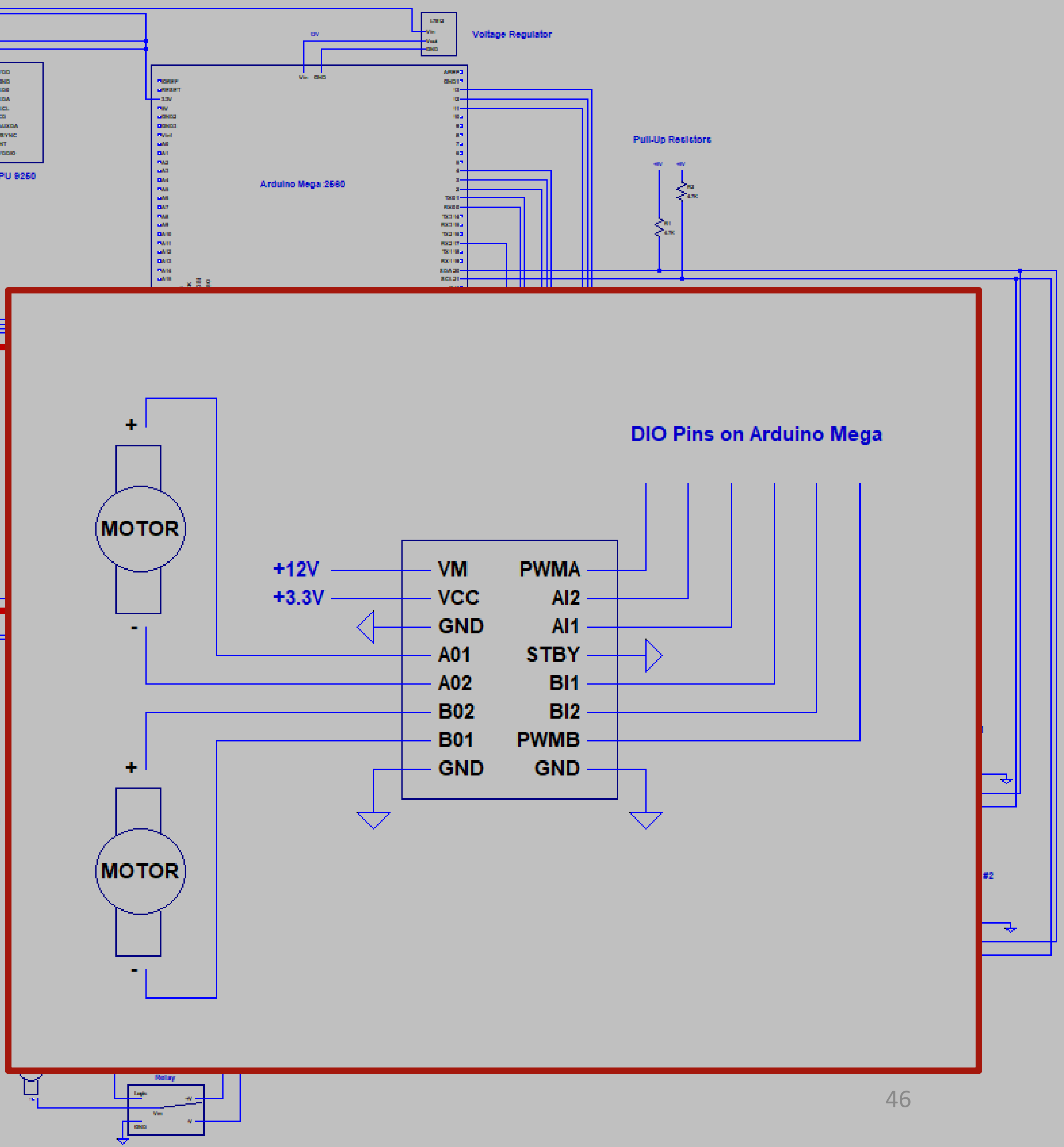


Digital Potentiometer #1
Digital Potentiometer #2

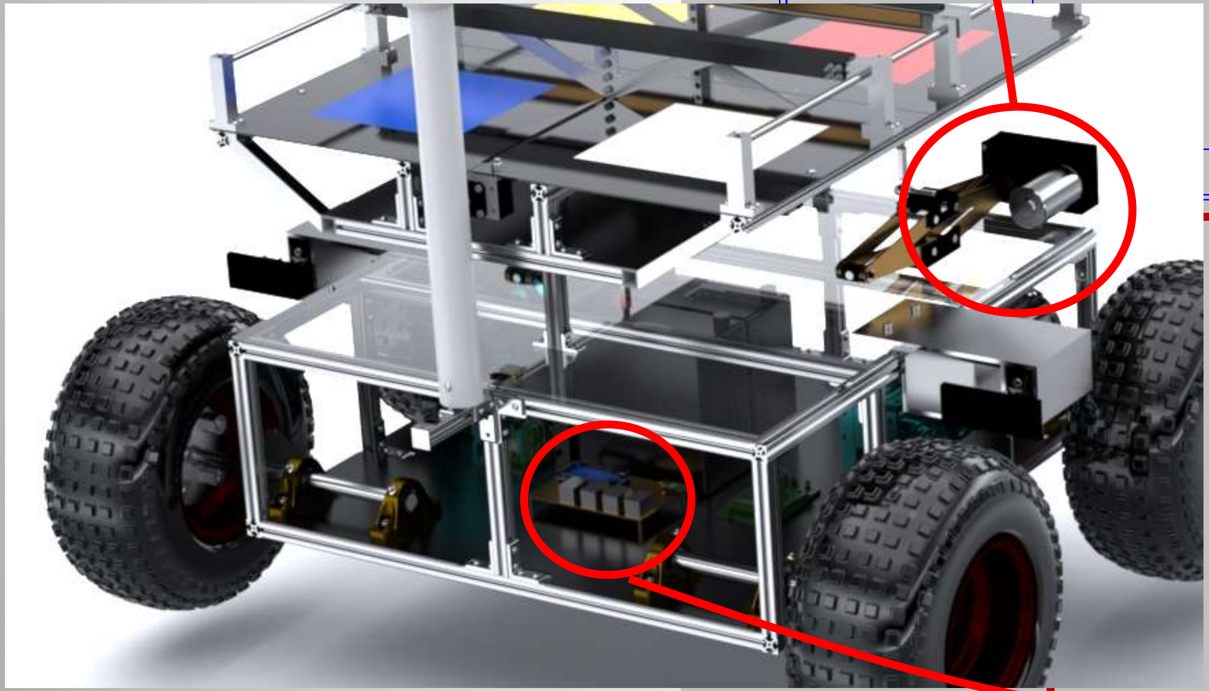
Linear Actuator Wheel Locking Mechanism

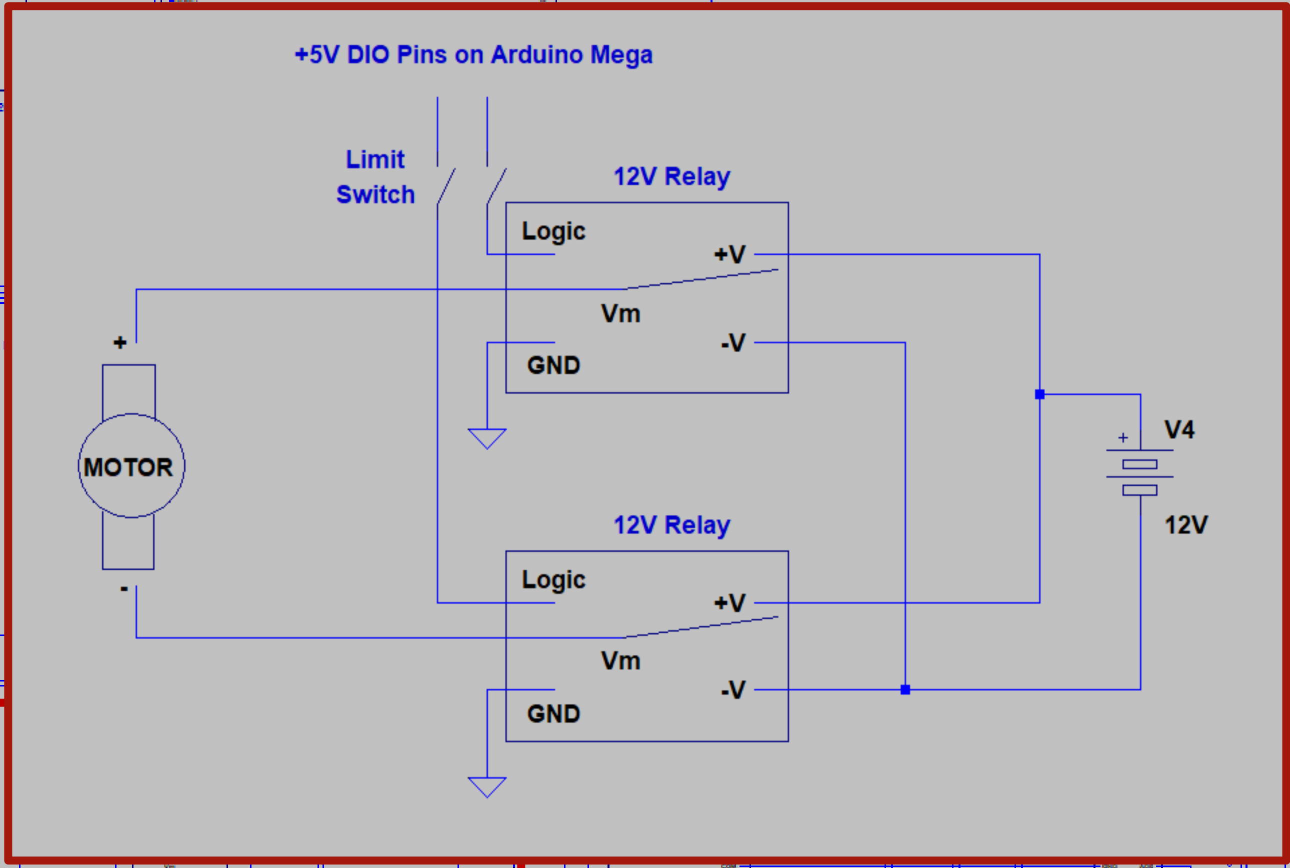




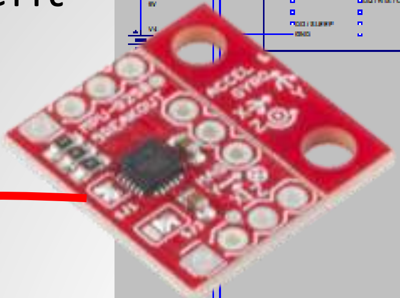


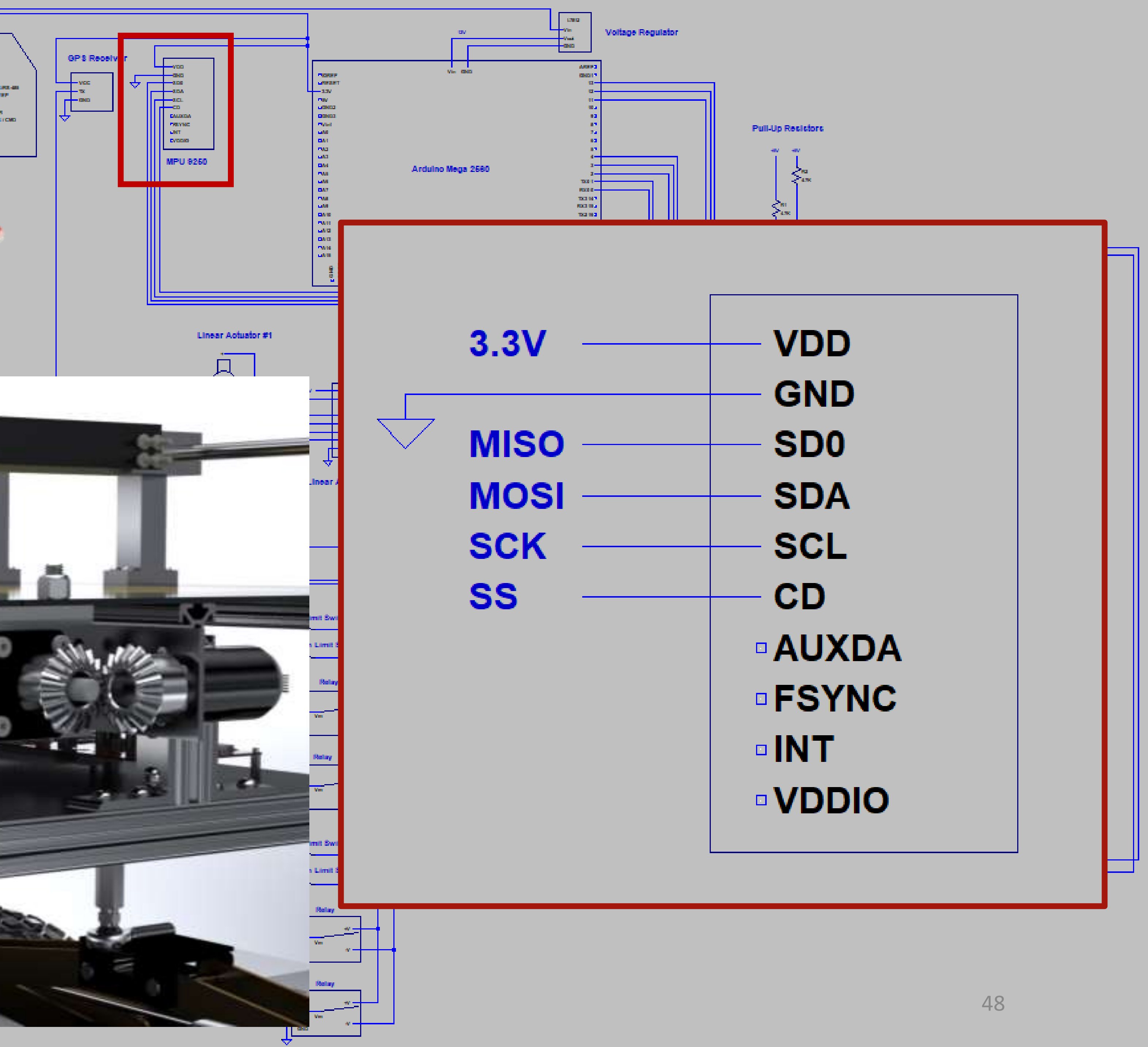
Scissor Jack Leveling System

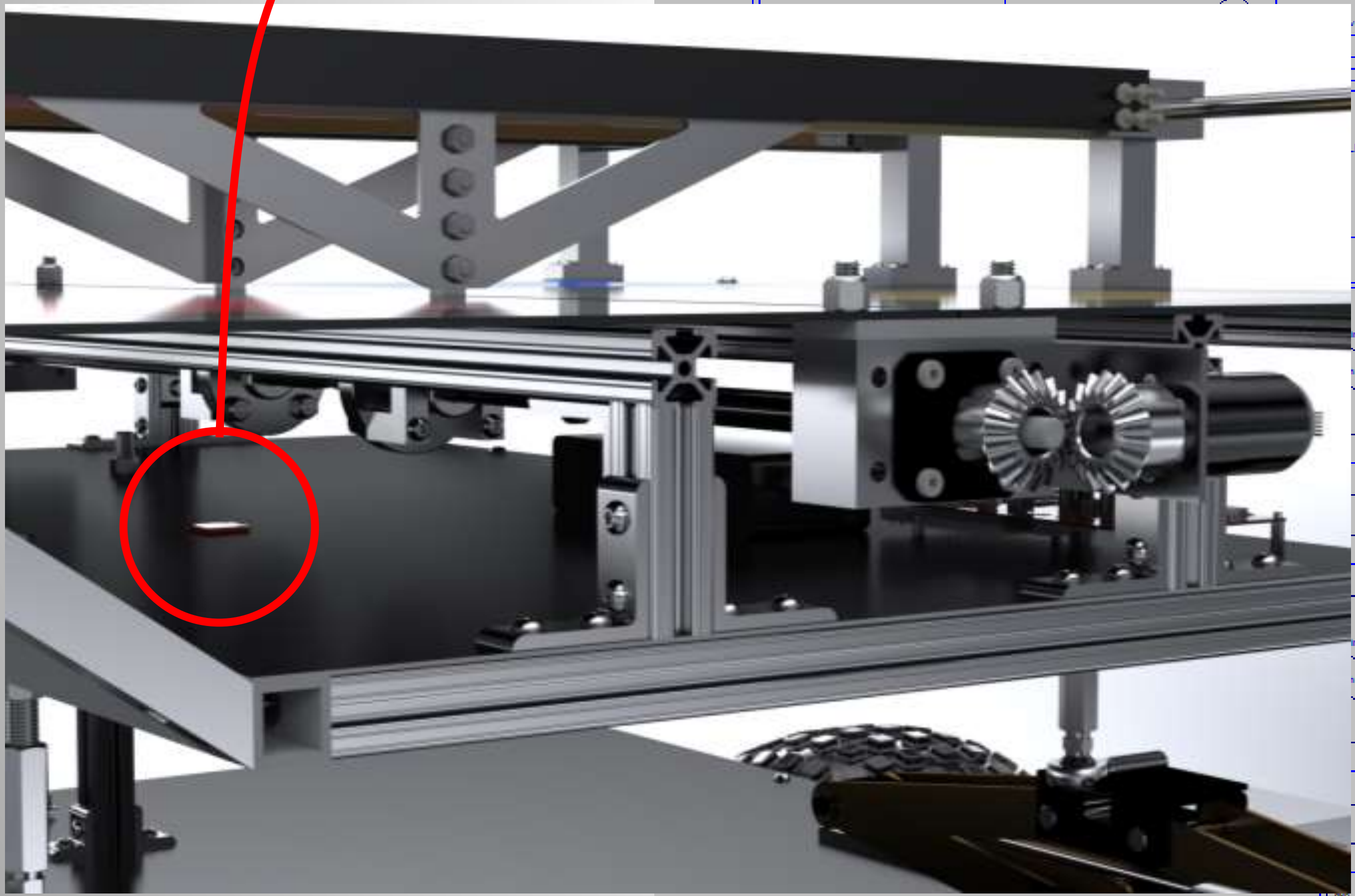




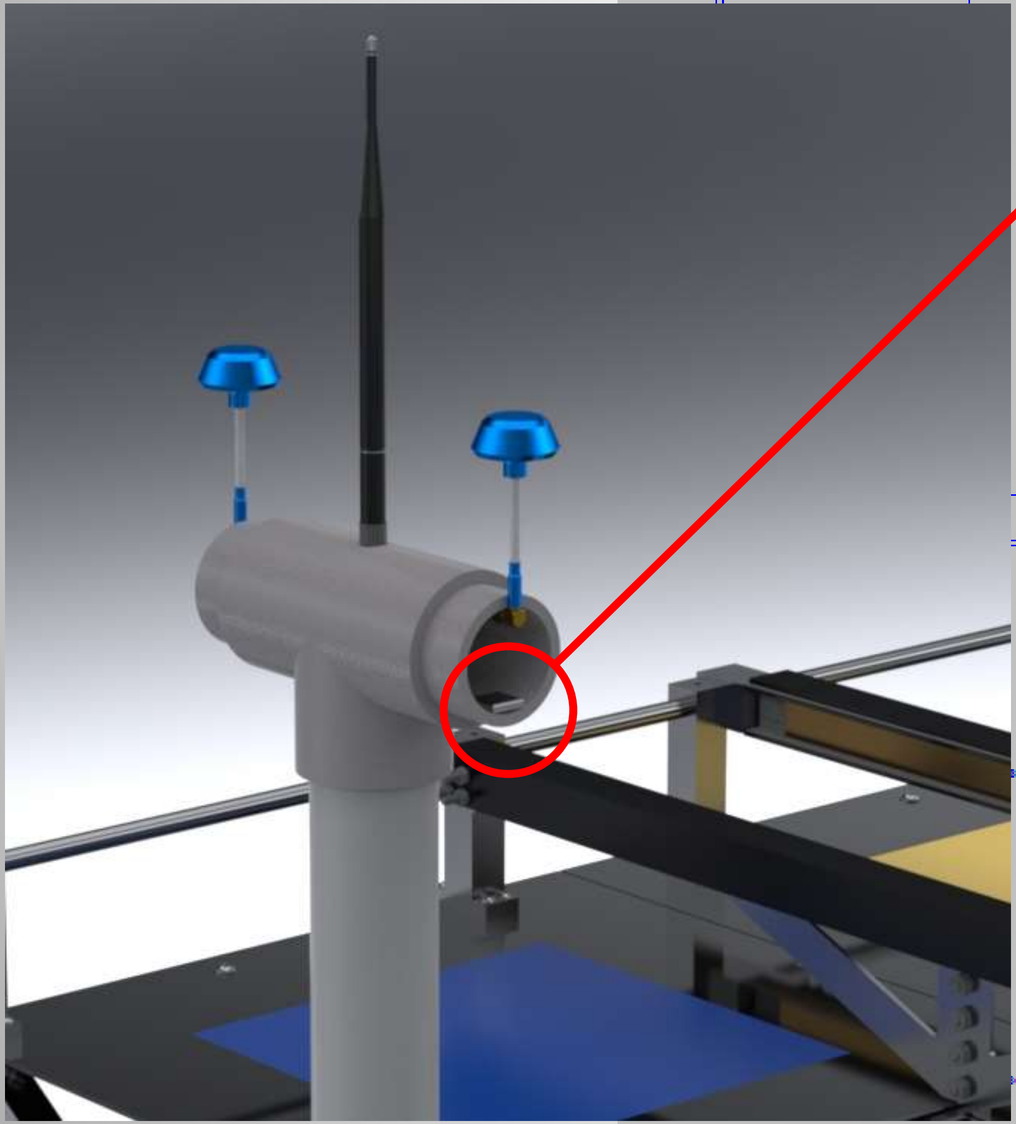
Inertial Measurement Unit (IMU)

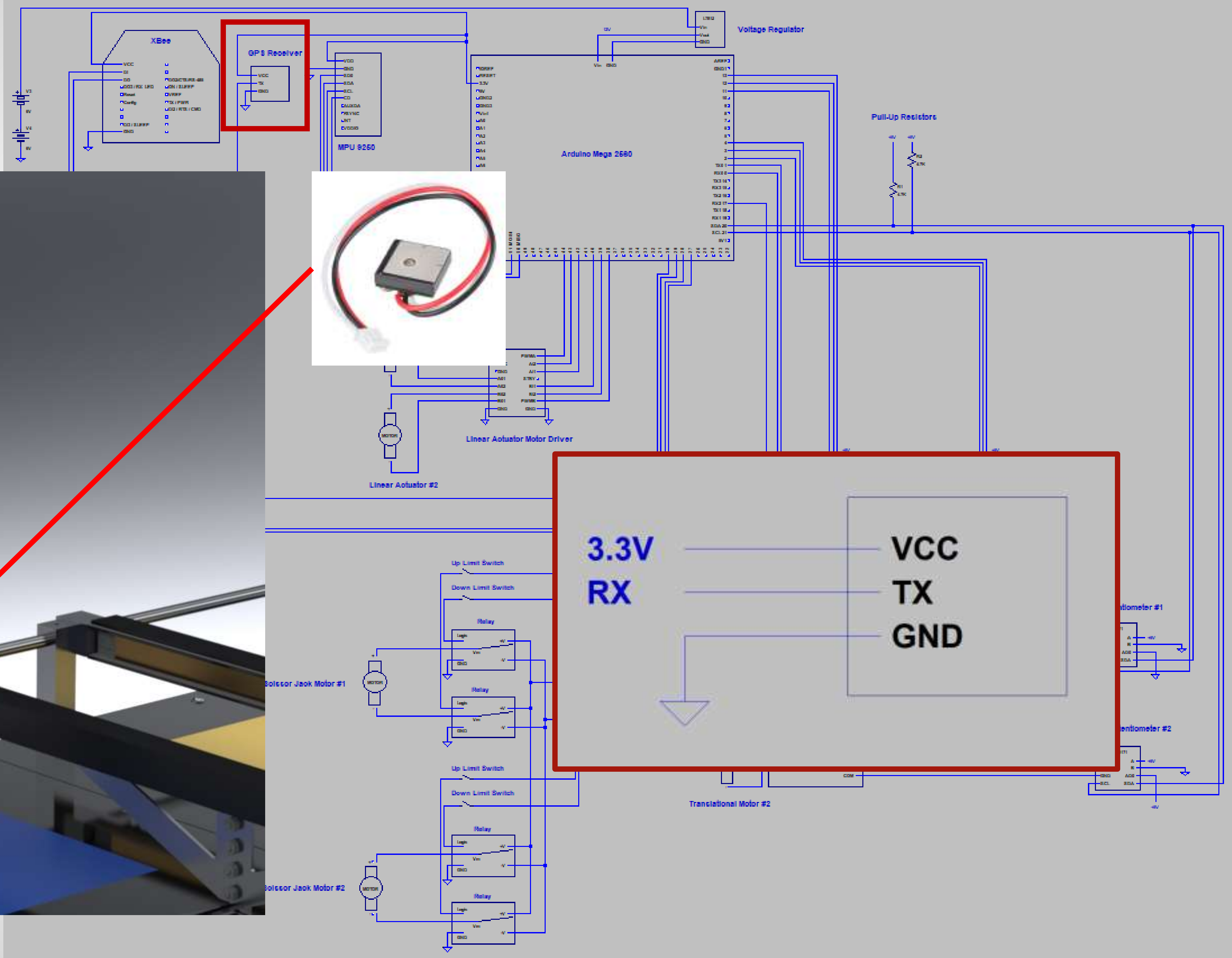




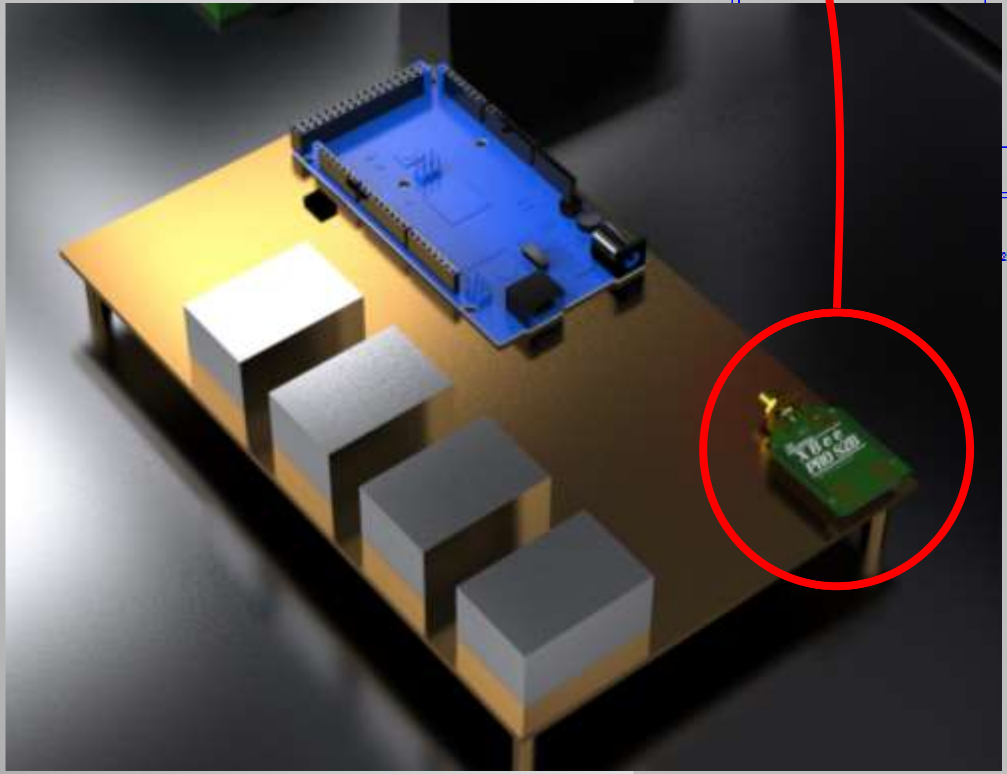


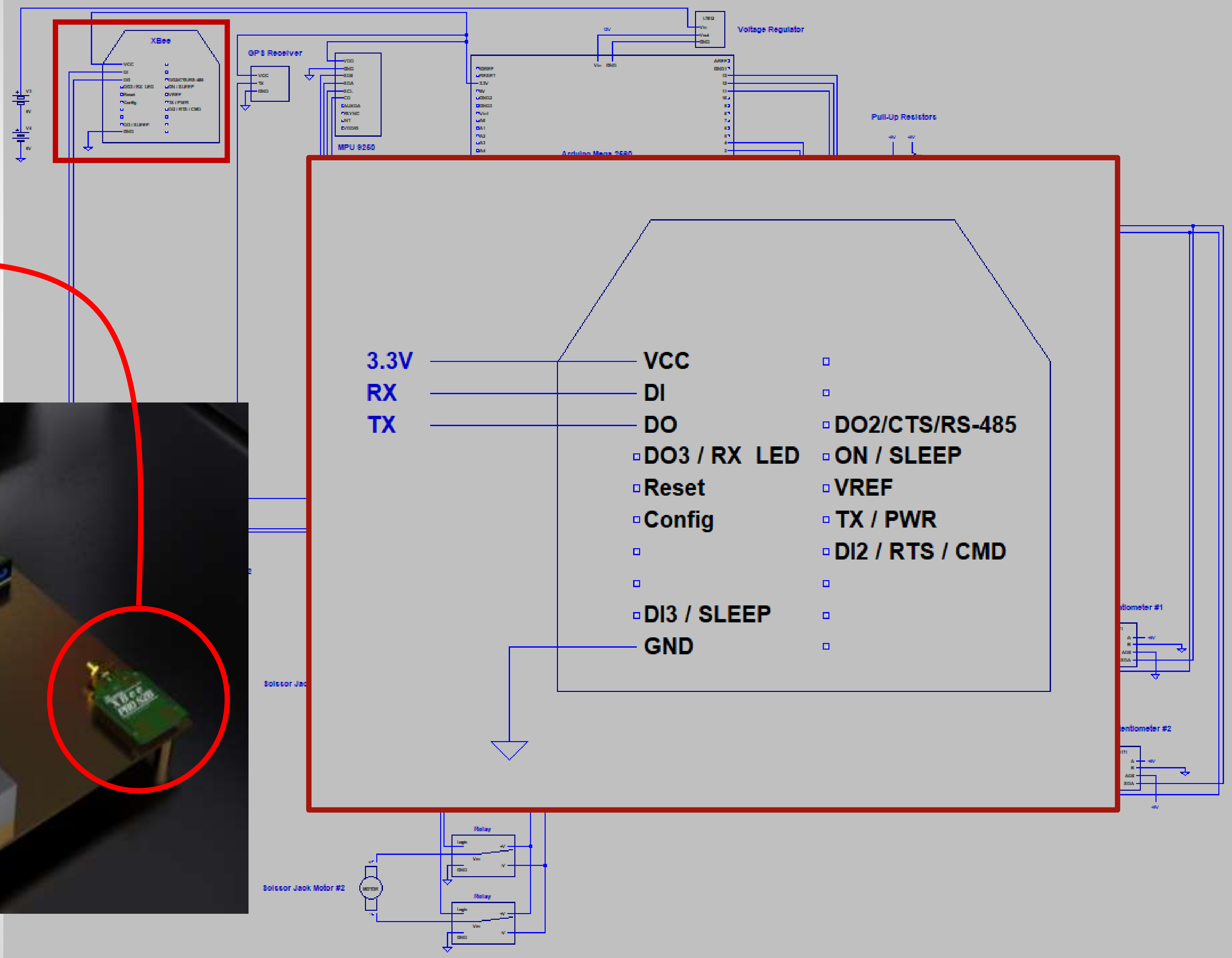
GPS



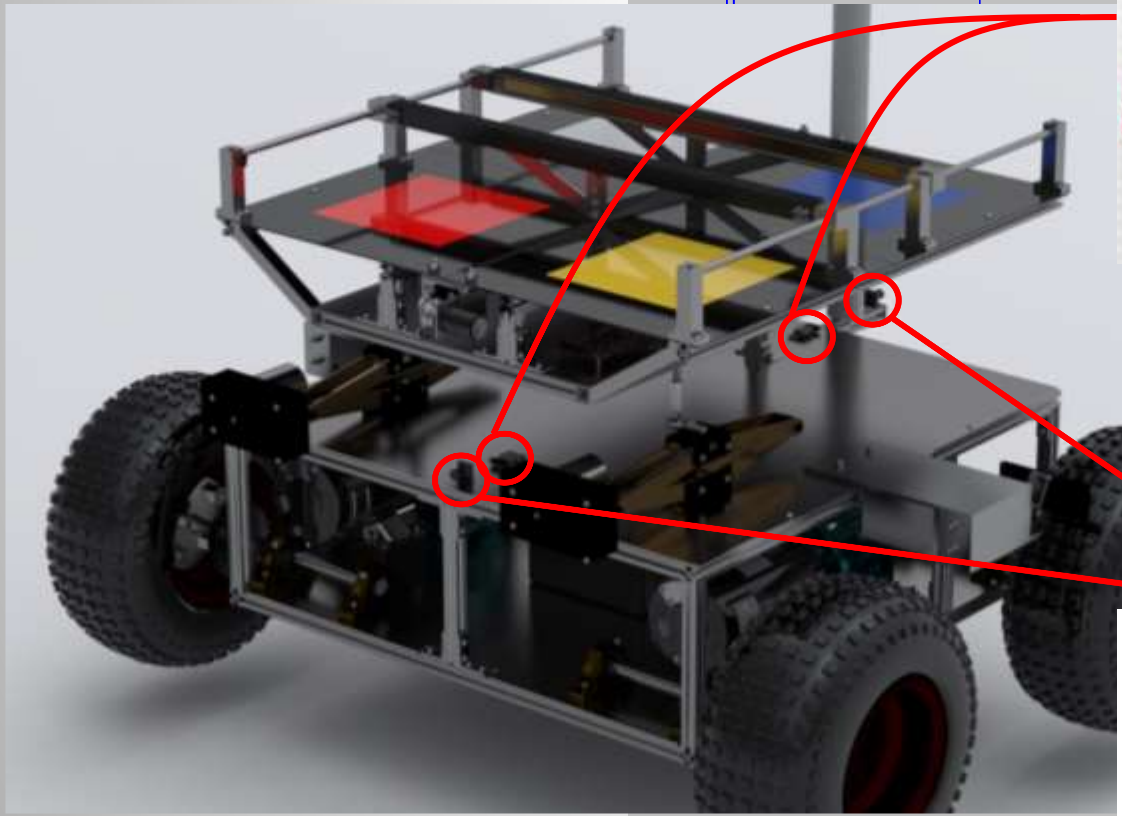

XBee
GPS Receiver
MPU 9250
Arduino Mega 2560
Voltage Regulator
Pull-Up Resistors
Linear Actuator Motor Driver
Linear Actuator #2
Up Limit Switch
Down Limit Switch
Relay
Scissor Jack Motor #1
Scissor Jack Motor #2
Translational Motor #2
3.3V
RX
VCC
TX
GND

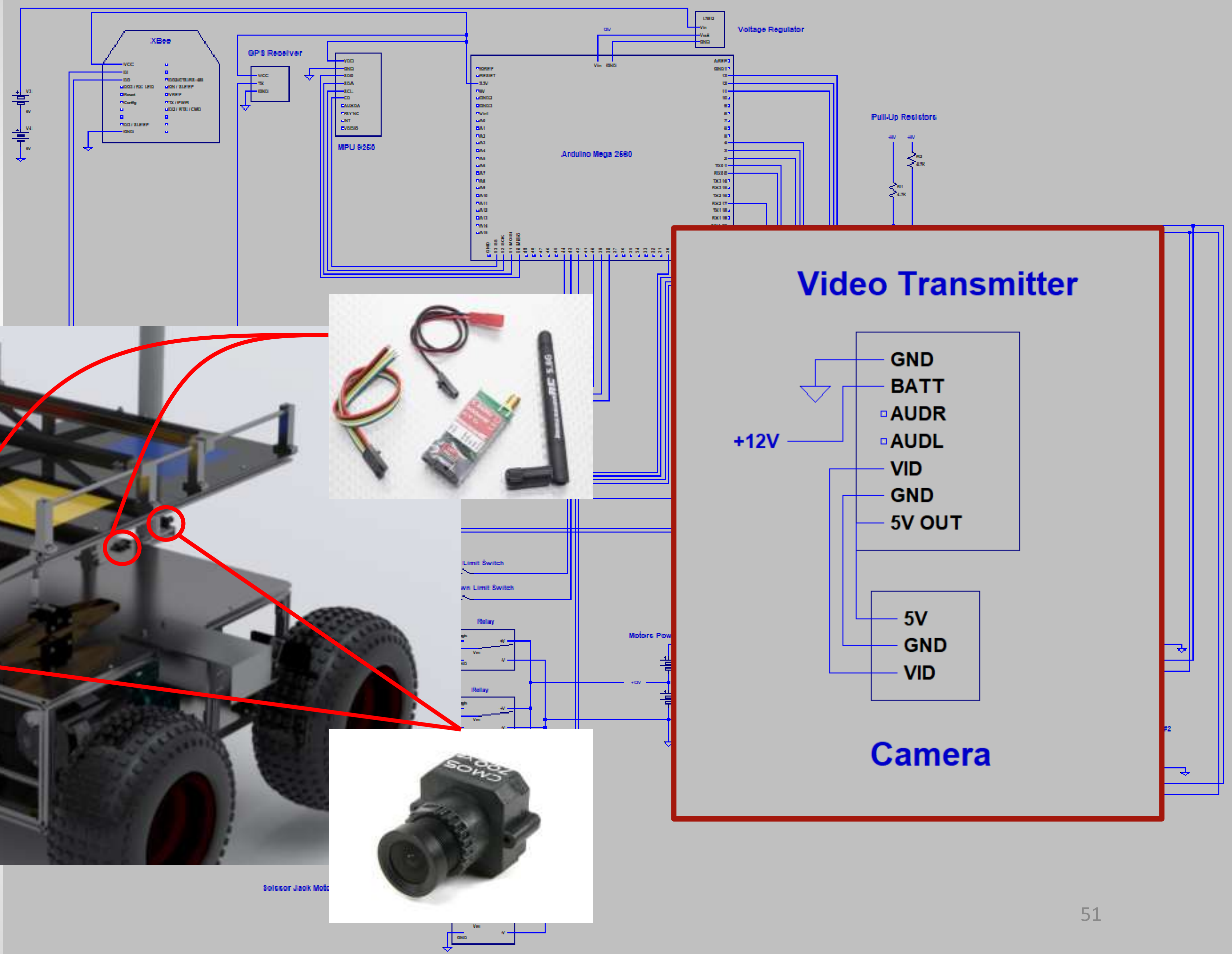
Communications





Hazard Camera System





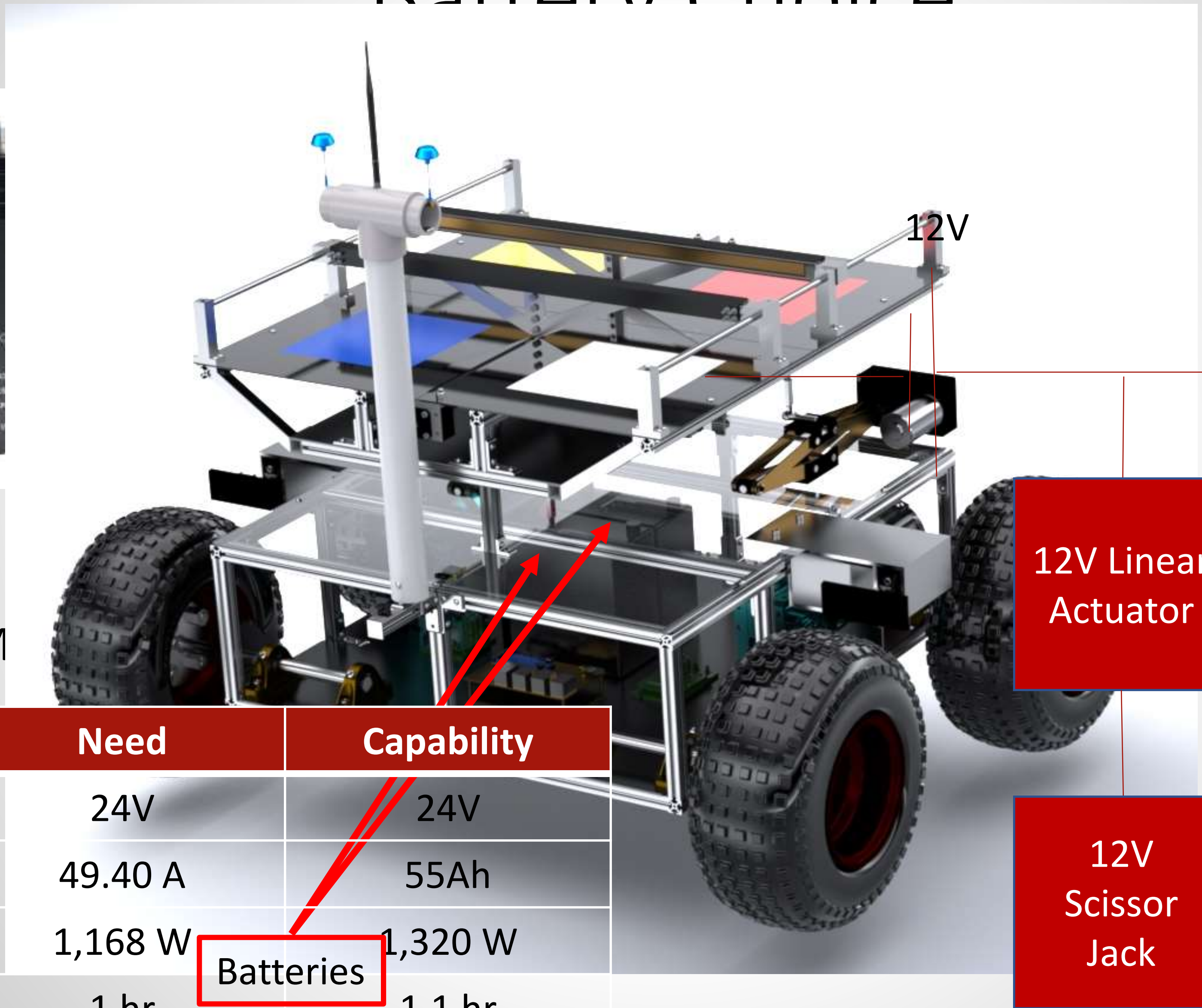
Mechanical Systems Power Budget

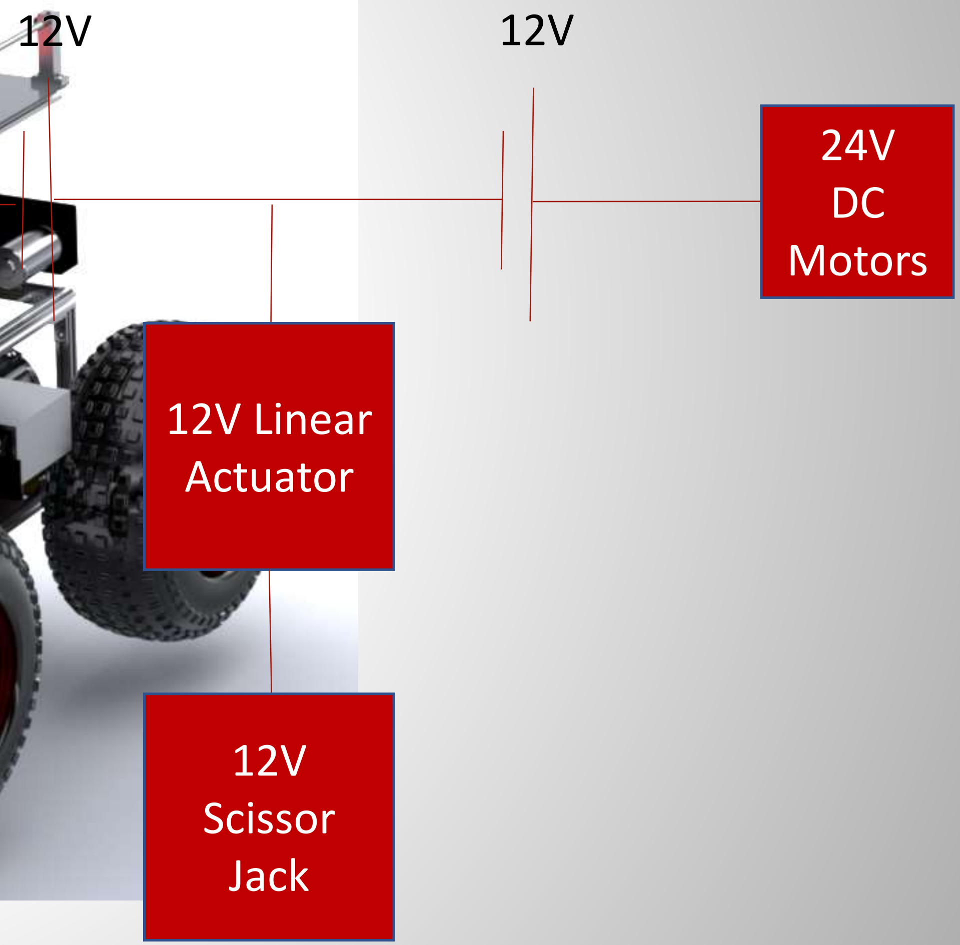
Part Name	Part Description	Quantity	Total Current Draw (A)	Total Power Draw (W)	Voltage (V)	Manufacturer
Brushed DC Gear Motor	Translational Motion Motor	2	40	960	24	Brother
Electric Scissor Jack	Leveling Mechanism Motor	2	1	12	12	Buffalo Tools
Linear Actuator	Braking System Motor	2	0.167	2.00	12	Windy Nation
			41.17 A	974.00 W		
	Accounting for 20% inefficiency		**49.40 A**	**1,152 W**		

Assumptions:

- Linear actuator runs for a total of 2 minutes for the duration of the mission
- Electric scissor jack runs for a total of 3 minutes for the duration of the mission
- Accounts for inefficiency when battery reaches below 20%

Battery Choice





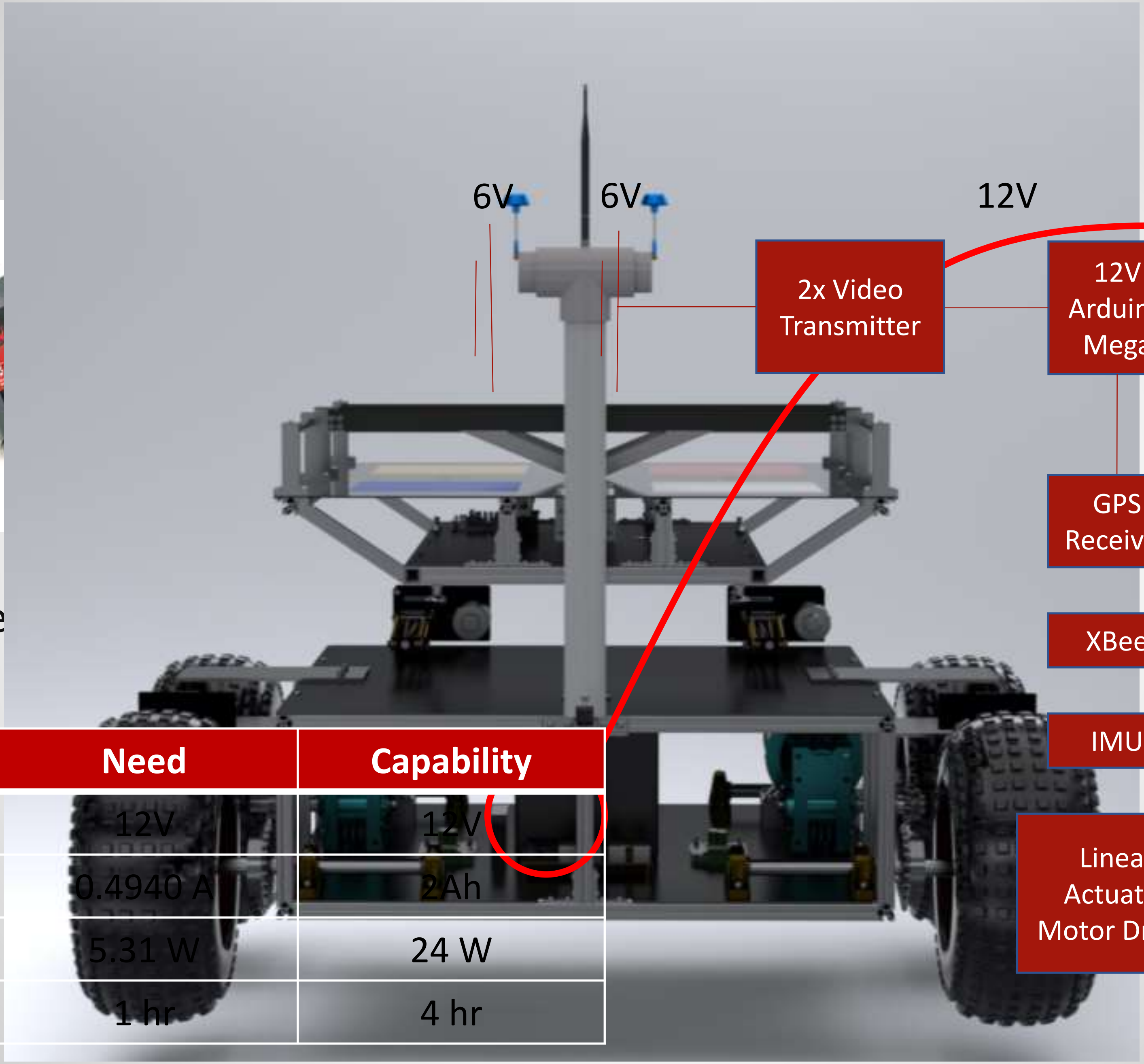
12V 55Ah
M

	Need	Capability
Voltage	24V	24V
Current	49.40 A	55Ah
Power	1,168 W	1,320 W
Time	1 hr	1.1 hr

Sensors Power Budget

Part Name	Part Description	Quantity	Total Current Draw (A)	Total Power Draw (W)	Voltage (V)	Manufacturer
SparkFun IMU Breakout - MPU-9250	Inclination and Heading of the MR	1	0.00074	0.002442	3.3	Sparkfun
Immersion RC 5.8 GHz Audio/Video Transmitter	Transmitter for MR Video Feed	2	0.1	1.2	12	ImmersionRC
XBee Pro S3B	Transmitter for MR Data Transmission	1	0.026	0.0858	3.3	DigiKey International
FatShark 700TVL CMOS Camera	Hazard Camera	2	0.12	0.6	5	FatShark
Arduino Mega 2560 R3	Microcontroller	1	0.040	0.48	12	Sparkfun
GPS Receiver: GP-20U7	GPS Receiver for GPS Location	1	0.040	0.132	3.3	Sparkfun
SparkFun Motor Driver - Dual TB6612FNG	Linear Actuator Motor Driver	1	0.002	0.0066	3.3	Sparkfun
DC60-4Q Dual Motor Driver	Translational Motors Motor Driver	2	0.080	1.92	24	Minarik Drives
10K Digital Potentiometer	Variable Speed for Translational Motors	2	0.000002	0.000010	5	Sparkfun
			0.409 A	**4.43 W**		
	Accounting for 20% inefficiency		**0.491 A**	**5.31 W**		

Tene



	Need	Capability
Voltage	12V	12V
Current	0.4940 A	2Ah
Power	5.31 W	24 W
Time	1 hr	4 hr

Validation and Verification

Requirements and Test Breakdown

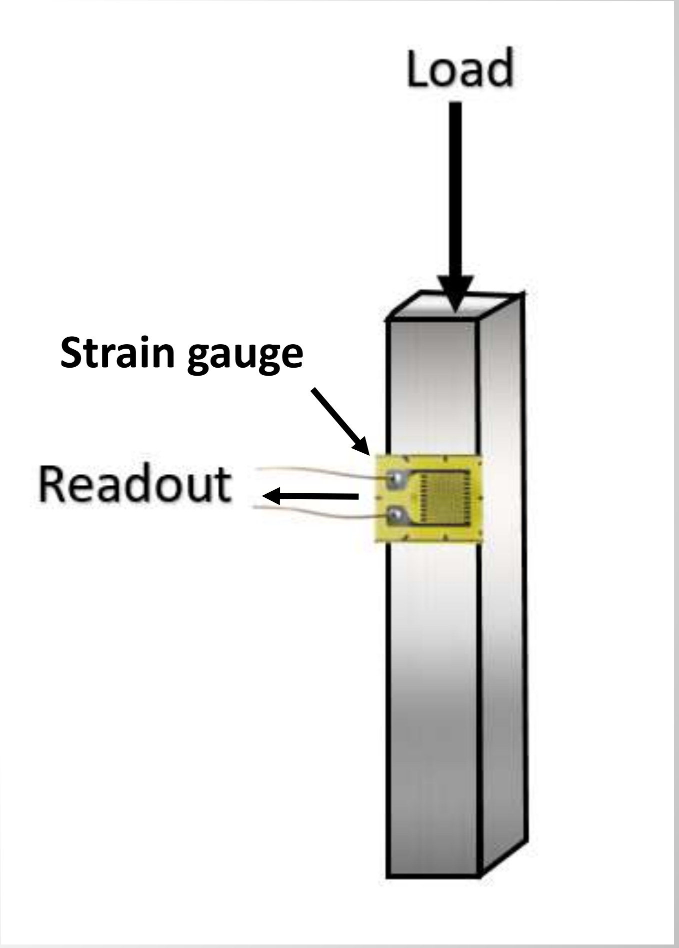
Functional Requirement	Description	Tests Involved in Verification
FR1.0	The MR shall integrate with the attached landing platform such that it is permanently fixed and securely carries the CD without tipping while traversing the defined rough terrain	Check deformation after distance test, obstacle test and slope test.
FR2.0	The MR shall receive commands from the GS at a rate of 5 Hz.	Communications Test Distance Test
FR3.0	The MR shall transmit data to the GS at a rate of 30 HZ	Communications Test Distance Test
FR4.0	The MR shall traverse 500 meters away from the GS to a specified GPS location over rough terrain defined by varying slopes and obstacles which require the MR to navigate over and around them. The MR shall return to the GS after the mission is complete.	Slope and Leveling Test Maneuverability Test Obstacle Test Distance Test GPS Test
FR5.0	The MR shall position itself for the CD to take-off and land safely such that it is able to be secured by the MR's securement mechanism	Slope Test

Test Plan

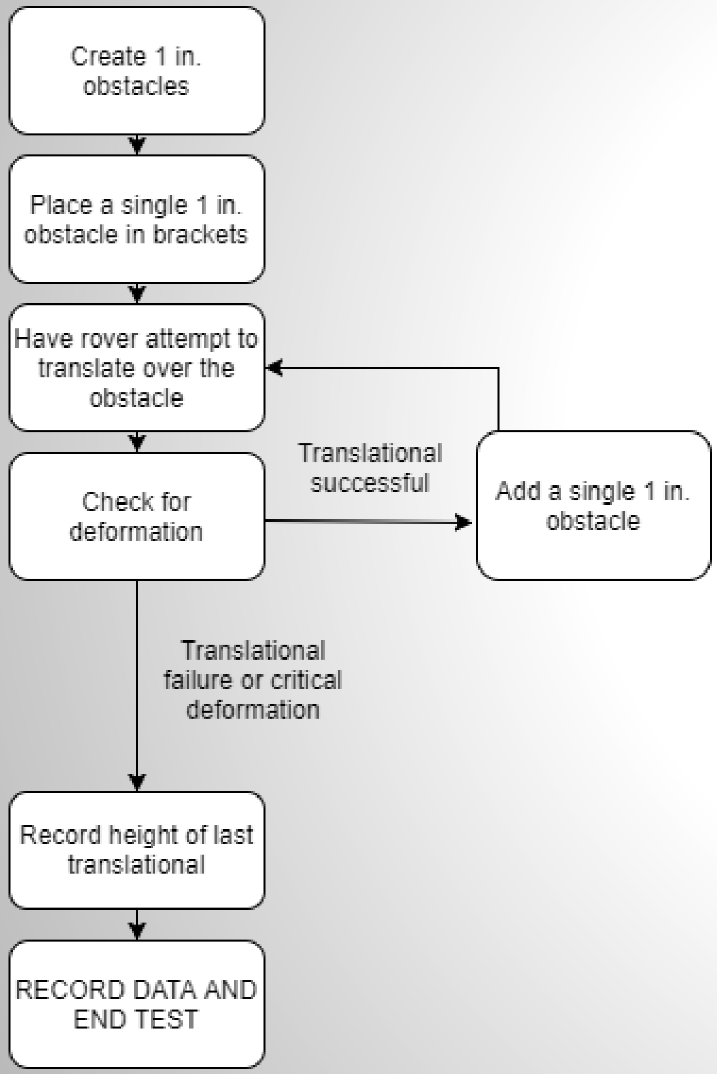
- Test in environment similar California hillside.
  - Switzerland Trail
- Weather unpredictable
  - Need for outdoor and indoor options
- Full mission simulation will be performed
  - Subsystem/Other tests to verify design requirements
- Model Verification Tests
  - Tipping model/Center of Mass Verification
  - Traction Model Verification
  - Software/Camera Verification
  - Structural Deformation Model.
- FR and DR Verification Tests
  - Communications Test
  - Distance Test
  - Slope Capability and Leveling Test
  - Obstacle Clearence Test
  - Maneuverability Test
  - GPS Test

Structural Model Verification

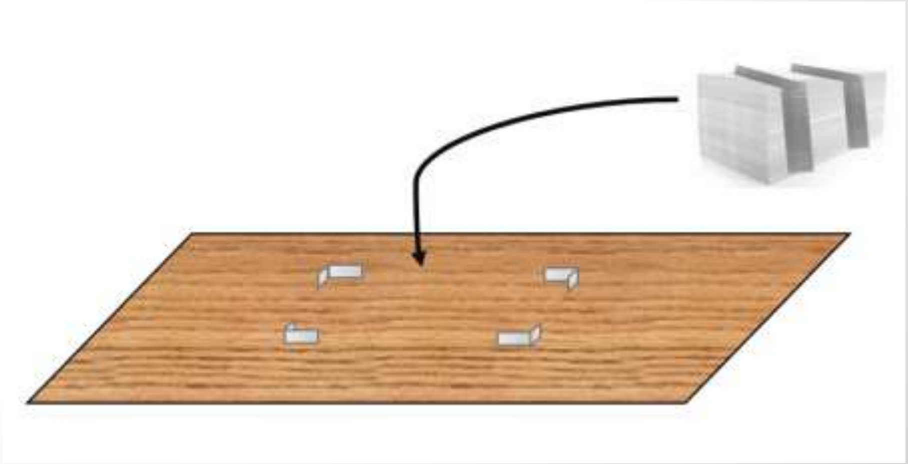
- Before construction:
  - take one of the beams to be used to support the rover.
- Apply a load of known value on the beam by placing a known mass on the beam while the beam is stabilized.
  - A strain gauge shall be used to measure the strain experienced on the beam under the load.
- Use the model to predict the strain under the load and compare to the strain experienced.
- Measure the difference of the two strains
  - Greater than or less than the predicted?



Obstacle

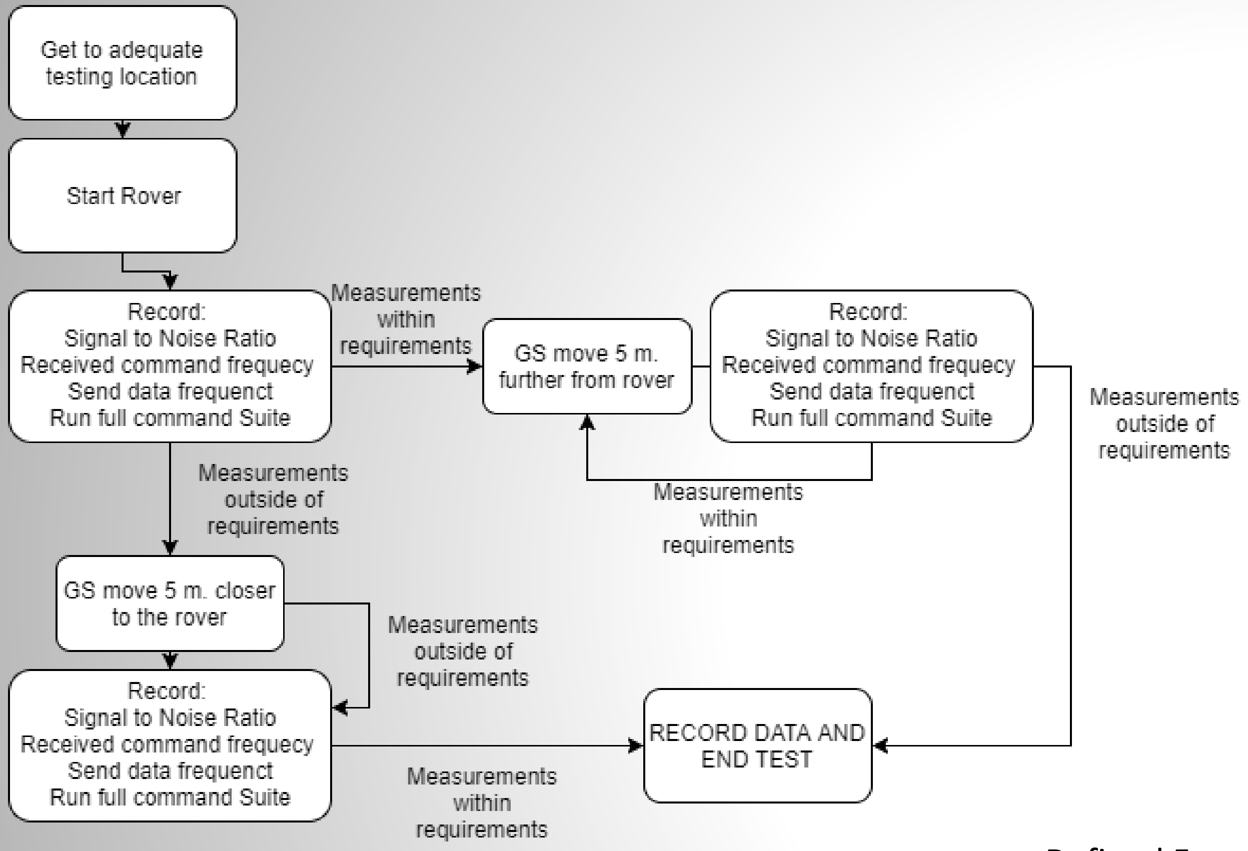


- From **Requirements 4.6**
- Outside and inside test has similar procedure
  - Outdoor utilizes Switzerland Trail potentially with apparatus or obstacles on site
  - Indoor utilizes an apparatus that involves 90 degree corner joints, a plywood board, and stacks of printer paper and duct tape.
- Height changed until max height of possible translation found.

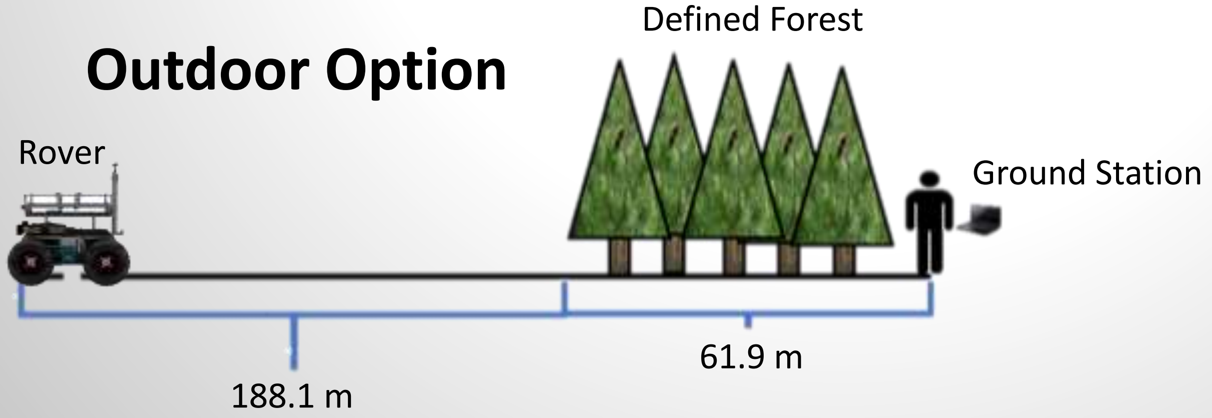


Communications Test

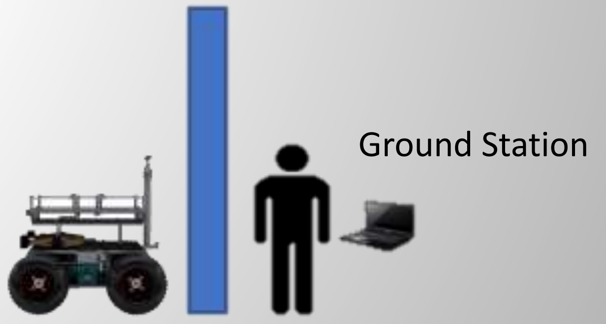
- Requirement **FR 2.0**
- Flowchart: Outdoor Test
- Indoor
  - Limited to Verification
  - Create a shield of similar attenuation levels to the described forest environment.
  - Early indications 1.70 in. of concrete likely candidate.
  - Measure if communications can send data at required frequency.
  - Measure over 1 hr and find success time vs failure time.



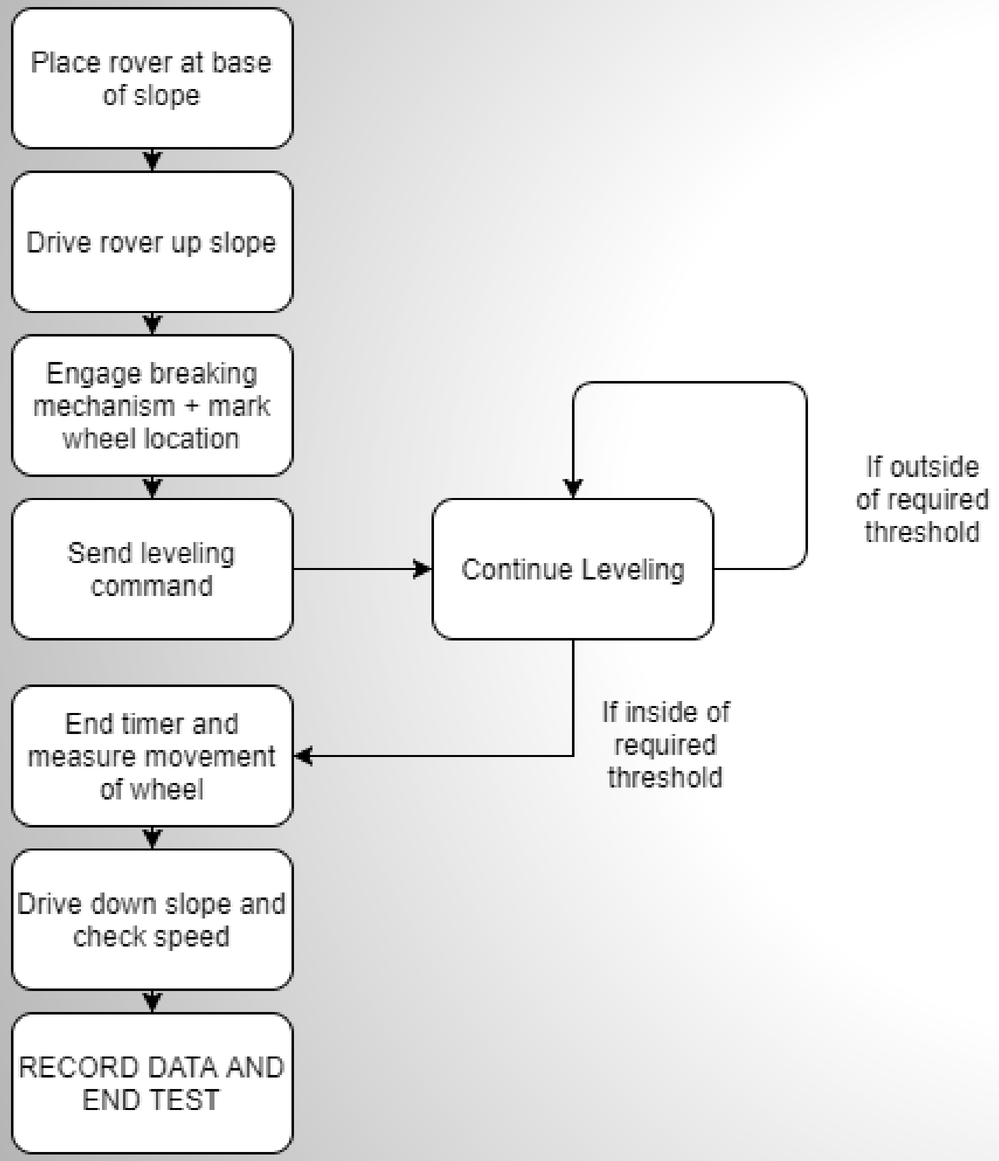
Outdoor Option



Indoor Option

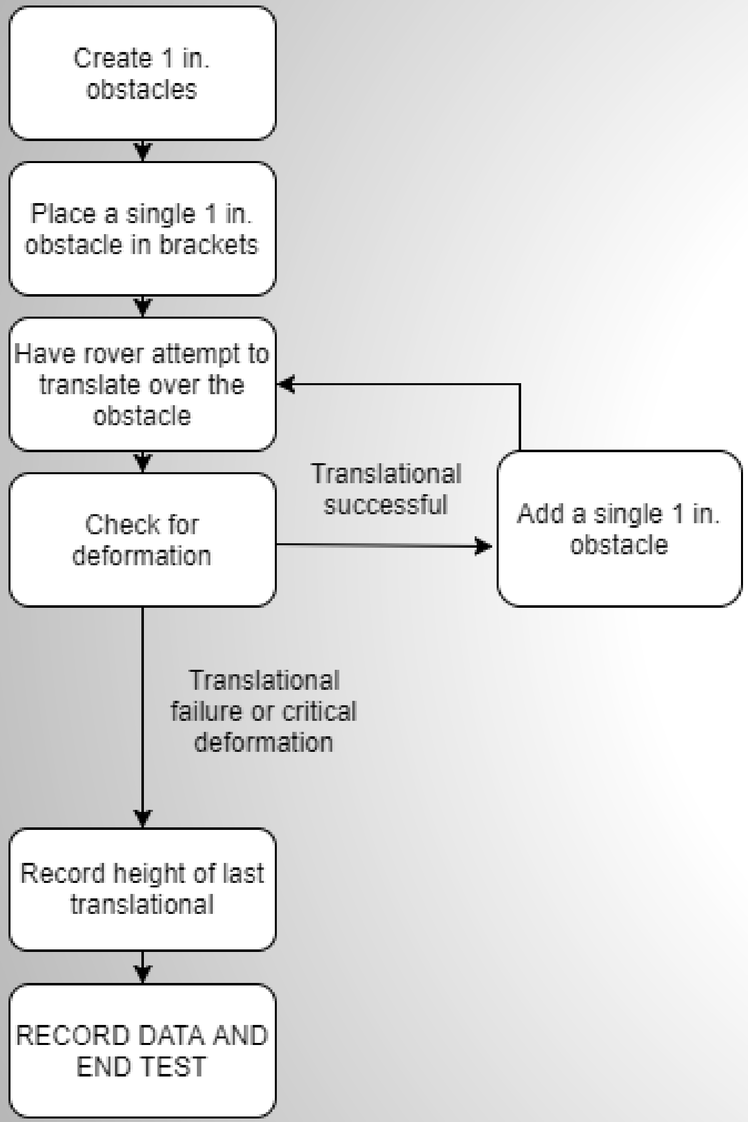


Slope and Leveling Test



- From **Requirements 4.5, 5.1, and 5.2.**
- Outside and inside test has similar procedure
  - Outdoor utilizes Switzerland Trail
  - Indoor utilizes ramp system shown. Constructed of plywood sheet, 2x4 supports and dirt to model terrain. Constructed at a 20 degree slope.
- Tests slope, leveling accuracy, leveling time, and speed on braking mechanism.

Obstacle



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- Outside and inside test has similar procedure
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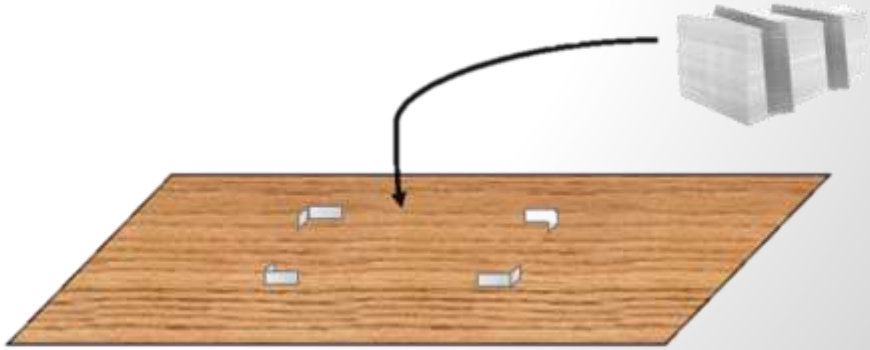


Outdoor Testing Location – Switzerland Trail

- Accommodates all tests needed.
- No permission required. (Run by USFS)
- Challenging terrain still in scope
- Wide range of slopes .
  - Measured slopes varied from 5 degrees to 24 degrees.
- Easily accessible
- Have back up outdoor locations given weather problems and indoor plan given extensive weather restrictions

5 inch and other size obstacles

Ample parking and room for turning

One of the smaller hills available

Project Risks

Project Overview | Design Solution | Critical Elements | DRs and Satisfaction | Validation and Verification | **Project Risks** | Project Planning | Conclusion

Risks and Risk Mitigation

	Risks
R1	Structural Deformation/Breakage of Drive Shaft
R2	Wheel Slippage
R3	Wheel Lock Failure
R4	Shearing/Shifting of connections to LP
R5	Leveling system control failure
R6	Instability of the leveling connections to MR
R7	Instability of the leveling connections to LP
R8	Communication signal loss
R9	Overheating of the Motor
R10	Motor Overloads
R11	Back Drive
R12	Short Circuit
R13	Battery dies during mission
R14	Overheated components

Pre-Mitigation Risk Matrix

Likelihood \ Severity	1	2	3	4	5
5	R2			R11, R12	
4			R7		R3
3			R6, R14	R4,R8, R10	R13
2			R5	R9	R1
1					

	Risks
R1	Structural Deformation/Breakage of Drive Shaft
R2	Wheel Slippage
R3	Wheel Lock Failure
R4	Shearing/Shifting of connections to LP
R5	Leveling system control failure
R6	Instability of the leveling connections to MR
R7	Instability of the leveling connections to LP
R8	Communication signal loss
R9	Overheating of the Motor
R10	Motor Overloads
R11	Back Drive
R12	Short Circuit
R13	Battery dies during mission
R14	Overheated components

Post-Mitigation Matrix

Likelihood \ Severity	1	2	3	4	5
5					
4	**R2**				
3			**R13**		
2		**R5,R10**	**R8,R11, R14**	**R12**	**R3**
1		**R6,R7**	**R4,R9**		**R1**

	Risks
R1	Structural Deformation/Breakage of Drive Shaft
R2	Wheel Slippage
R3	Wheel Lock Failure
R4	Shearing/Shifting of connections to LP
R5	Leveling system control failure
R6	Instability of the leveling connections to MR
R7	Instability of the leveling connections to LP
R8	Communication signal loss
R9	Overheating of the Motor
R10	Motor Overloads
R11	Back Drive
R12	Short Circuit
R13	Battery dies during mission
R14	Overheated components

Project Planning

Project Overview | Design Solution | Critical Elements | DRs and Satisfaction | Validation and Verification | Project Risks | **Project Planning** | Conclusion

Organizational Chart

- **Customer: JPL** Barbara Streiffert
- **Director:** Dr. Lawrence
- **Advisor:** Dr. Jackson

- **Project Manager:** Samantha Growley
- **Systems Lead:** Syamimah Anwar Deen
- **Test:** Kelsey Owens
- **Safety:** Nur Abd Rashid
- **CFO** Daniel Collins

- **Electrical:** Amber Bishop
- **Software:** Brandon Cott
- **Manufacturing:** Pierce Lieberman
- **Mechanical:** Matt Stoffle, Anthony Stanco
- **Modeling:** Nick Wiemelt

Work Breakdown

Translational System	Leveling System	Communications	Integration and Test	Fall Semester Deliverables	Spring Semester Deliverables
Preliminary Design	Preliminary Design	Flowcharts for Leveling, Control, and Steering	Test Planning	Project Definition Doc	Manufacturing Status Review
Component Selection	Component Selection	Develop Code Prototypes	Secure Testing Facilities	Conceptual Design Doc	Test Readiness Review
Structural Analysis	Structural Analysis	Test Code Prototypes	Subsystem Tests	Preliminary Design Review	Spring Final Review
Finalized Drawings	Finalized Drawings	Code on Microcontroller	Full System Integration	Critical Design Review	Project Final Report
Manufacture and Order Parts	Manufacture and Order Parts	Tested Code	Full System Testing	Fall Final Report	Senior Design Symposium
Components Integration	Components Integration				AIAA Paper

Work Plan (Gantt Chart)

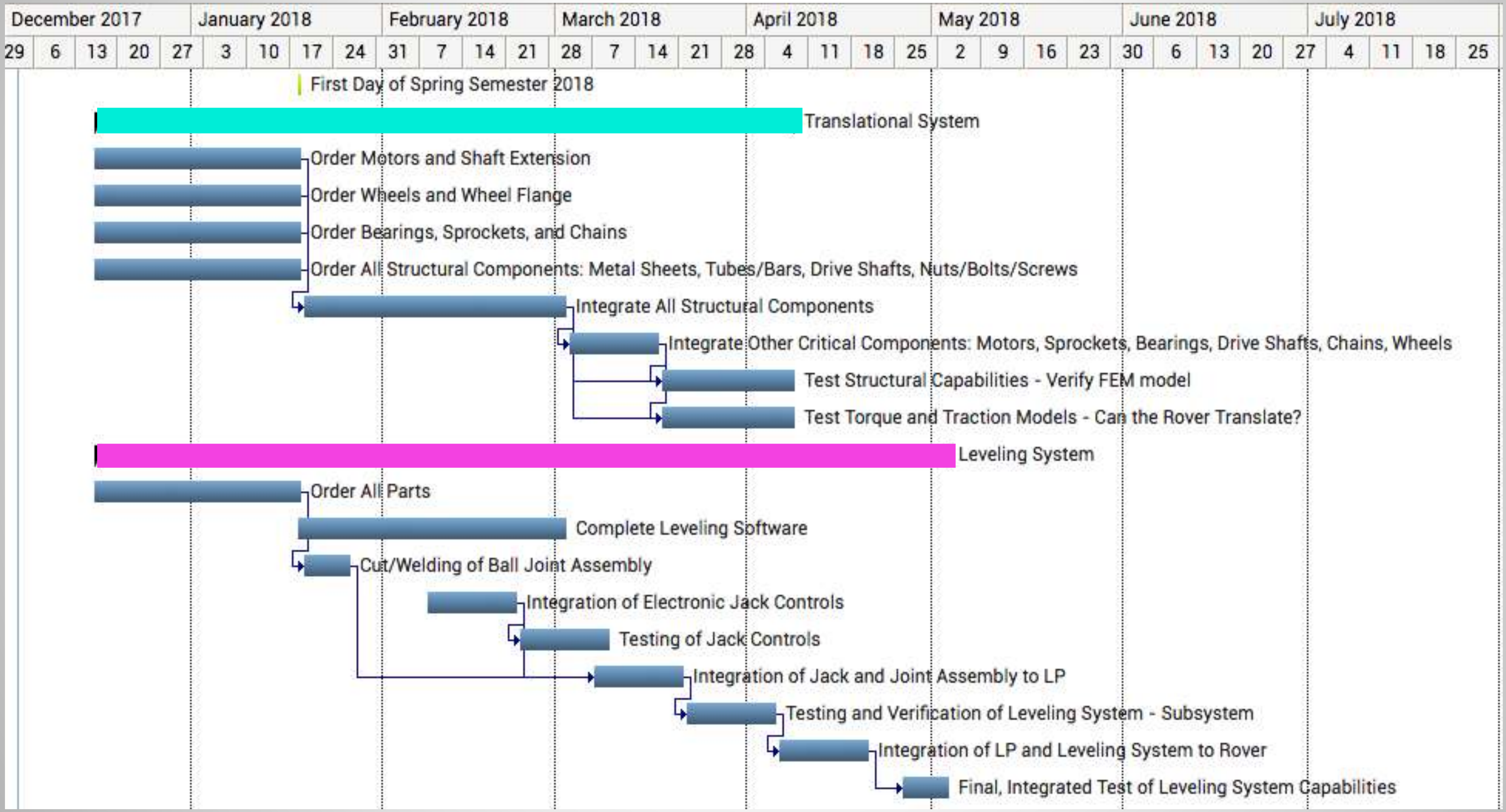
First Day of Spring Semester 2018	1day	01/16/2018	01/16/2018
⊟ **Translational System**	82days	**12/14/2017**	**04/06/2018**
Order Motors and Shaft Extension	24days	12/14/2017	01/16/2018
Order Wheels and Wheel Flange	24days	12/14/2017	01/16/2018
Order Bearings, Sprockets, and Chains	24days	12/14/2017	01/16/2018
Order All Structural Components: Metal Sheets, Tubes/Bars, Drive S	24days	12/14/2017	01/16/2018
Integrate All Structural Components	31days	01/17/2018	02/28/2018
Integrate Other Critical Components: Motors, Sprockets, Bearings, D	11days	03/01/2018	03/15/2018
Test Structural Capabilities - Verify FEM model	16days	03/16/2018	04/06/2018
Test Torque and Traction Models - Can the Rover Translate?	16days	03/16/2018	04/06/2018
⊟ **Leveling System**	98days?	**12/14/2017**	**05/01/2018**
Order All Parts	24days?	12/14/2017	01/16/2018
Complete Leveling Software	32days?	01/16/2018	02/28/2018
Cut/Welding of Ball Joint Assembly	6days?	01/17/2018	01/24/2018
Integration of Electronic Jack Controls	11days?	02/06/2018	02/20/2018
Testing of Jack Controls	11days	02/21/2018	03/07/2018
Integration of Jack and Joint Assembly to LP	11days	03/05/2018	03/19/2018
Testing and Verification of Leveling System - Subsystem	11days	03/20/2018	04/03/2018
Integration of LP and Leveling System to Rover	11days	04/04/2018	04/18/2018
Final, Integrated Test of Leveling System Capabilities	6days	04/24/2018	05/01/2018

⊟ **Communications/Software**	94days?	**12/14/2017**	**04/24/2018**
Order All Parts	24days?	12/14/2017	01/16/2018
Begin Software for Leveling System	32days?	01/16/2018	02/28/2018
Begin Coding for Translational System	32days?	01/16/2018	02/28/2018
Begin Coding Main	32days?	01/16/2018	02/28/2018
Once Leveling System Constructed, Integrate Software and Test	22days?	03/01/2018	03/30/2018
Once Translational System Constructed, Integrate Software and Tes	22days?	03/01/2018	03/30/2018
Set Up and Test All Commands from Ground Station	6days?	04/02/2018	04/09/2018
Once All Code Completed on Subsystem Level, Bug Testing	5days?	04/10/2018	04/16/2018
Communications Testing (Accuracy of Messages, Any Improvement	6days?	04/17/2018	04/24/2018
⊟ **Electronics**	94days	**12/14/2017**	**04/24/2018**
Order All Parts	24days	12/14/2017	01/16/2018
Wire GPS Receiver and Test Functionality	6days	01/16/2018	01/23/2018
Receive All Parts	11days	01/16/2018	01/30/2018
Wire IMU and Test Functionality	5days	01/30/2018	02/05/2018
Wire Translational Motors and Motor Drivers and Test Functionality	15days	01/30/2018	02/19/2018
Wire Linear Actuators and Motor Drivers and Test Functionality	15days	01/30/2018	02/19/2018
Wire Scissor Jack Motors and Associated Components and Test Fur	6days	02/19/2018	02/26/2018
Wire Video Transmitters and Cameras and Test Functionality	7days	02/26/2018	03/06/2018
Begin Integration of All Components	19days	03/07/2018	04/02/2018
Construct, Test, and Time the Battery Depletion	16days	04/03/2018	04/24/2018

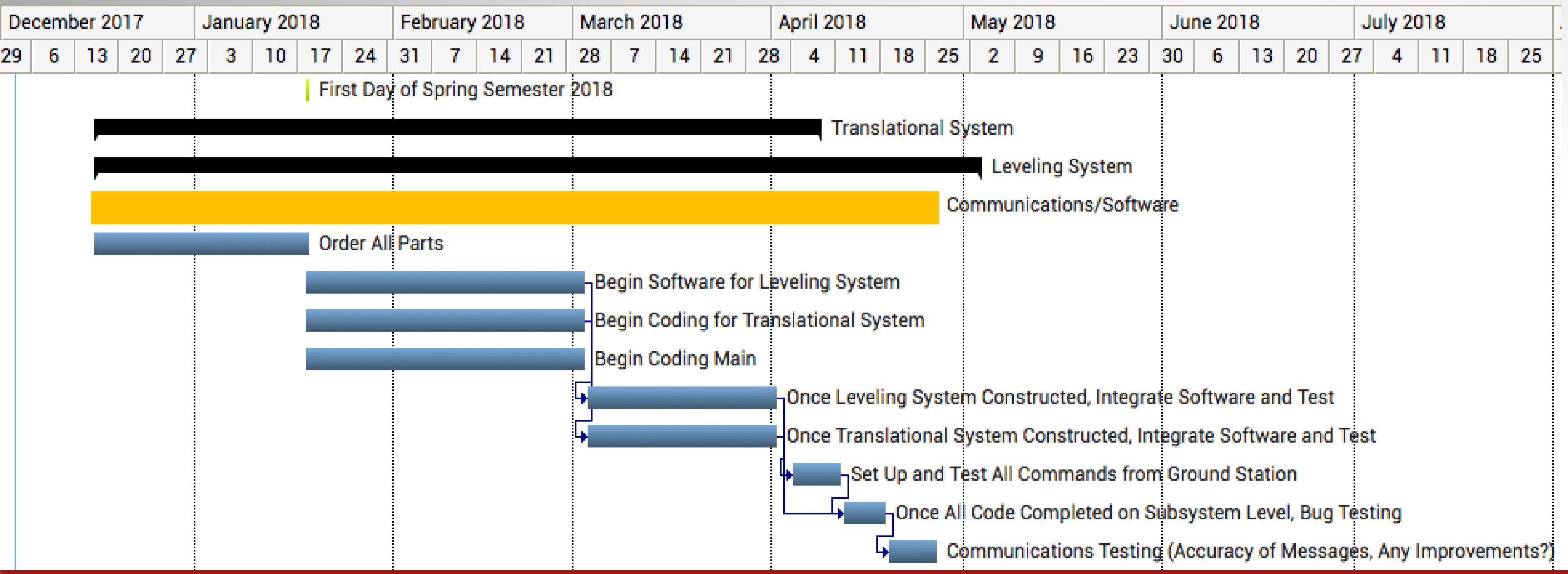
Work Plan Continued

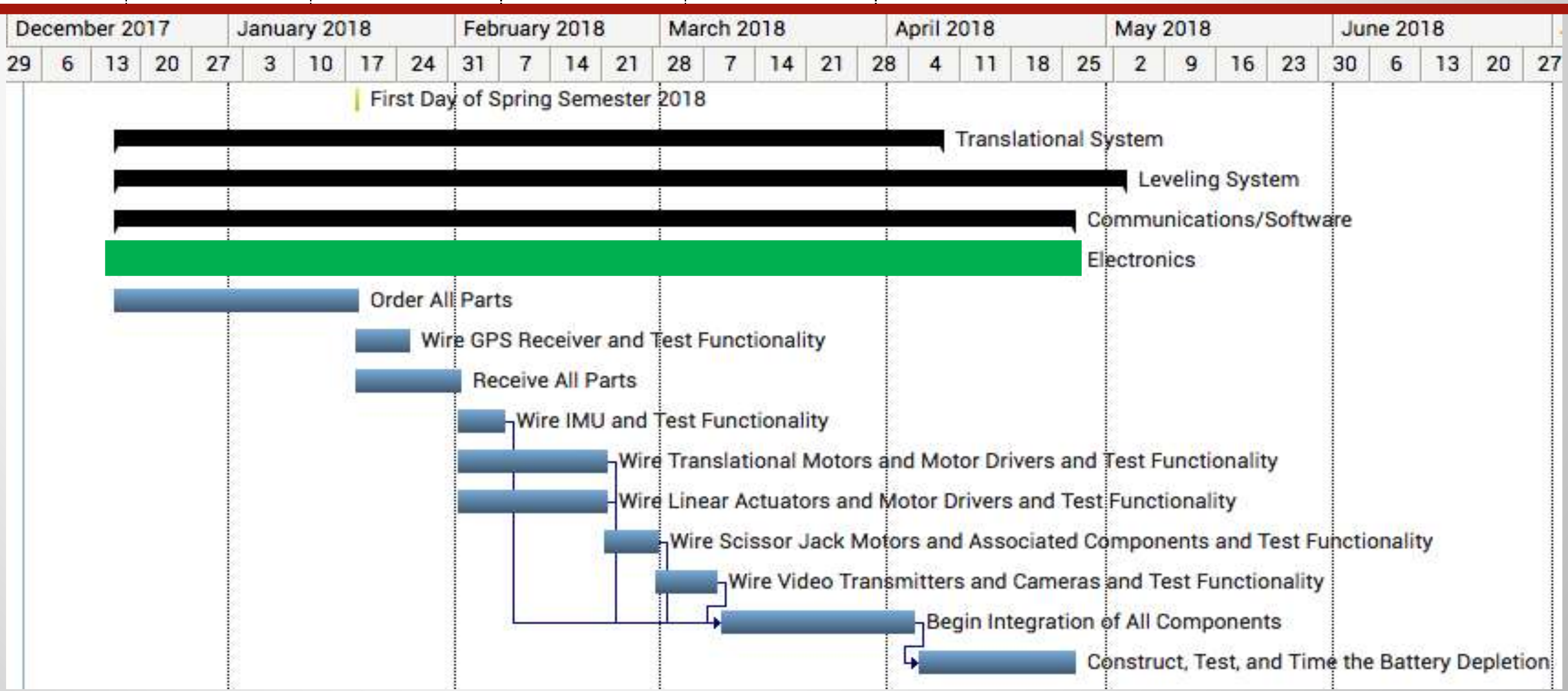
Manufacturing	96days	12/14/2017	04/26/2018	
Order All Parts	24days	12/14/2017	01/16/2018	
Map Out Manufacturing Plan for Each Subsystem	28days	12/14/2017	01/22/2018	
Begin Machining and Fabricating in House Parts and Attachments	50days	01/23/2018	04/02/2018	44,
Begin Manufacturing of Systems As Per Mapped in Plan	50days	01/23/2018	04/02/2018	44,
Pass Manufactured Systems to Testing	6days	04/03/2018	04/10/2018	45,,46,
Integration of Verified Systems	12days	04/11/2018	04/26/2018	47,
Test	22days	04/02/2018	05/01/2018	
Finalize Dates/Weather/Locations of Testing Facilities	11days	04/02/2018	04/16/2018	
Communications Test	6days	04/16/2018	04/23/2018	
GPS Test	6days	04/16/2018	04/23/2018	
Slope and Leveling Test	6days	04/24/2018	05/01/2018	51,
Obstacle Test	6days	04/24/2018	05/01/2018	51,
Distance Test	6days	04/24/2018	05/01/2018	51,
Last Day of Classes Spring 2018	1day?	05/09/2018	05/09/2018	

Gantt Chart: Translational and Leveling System

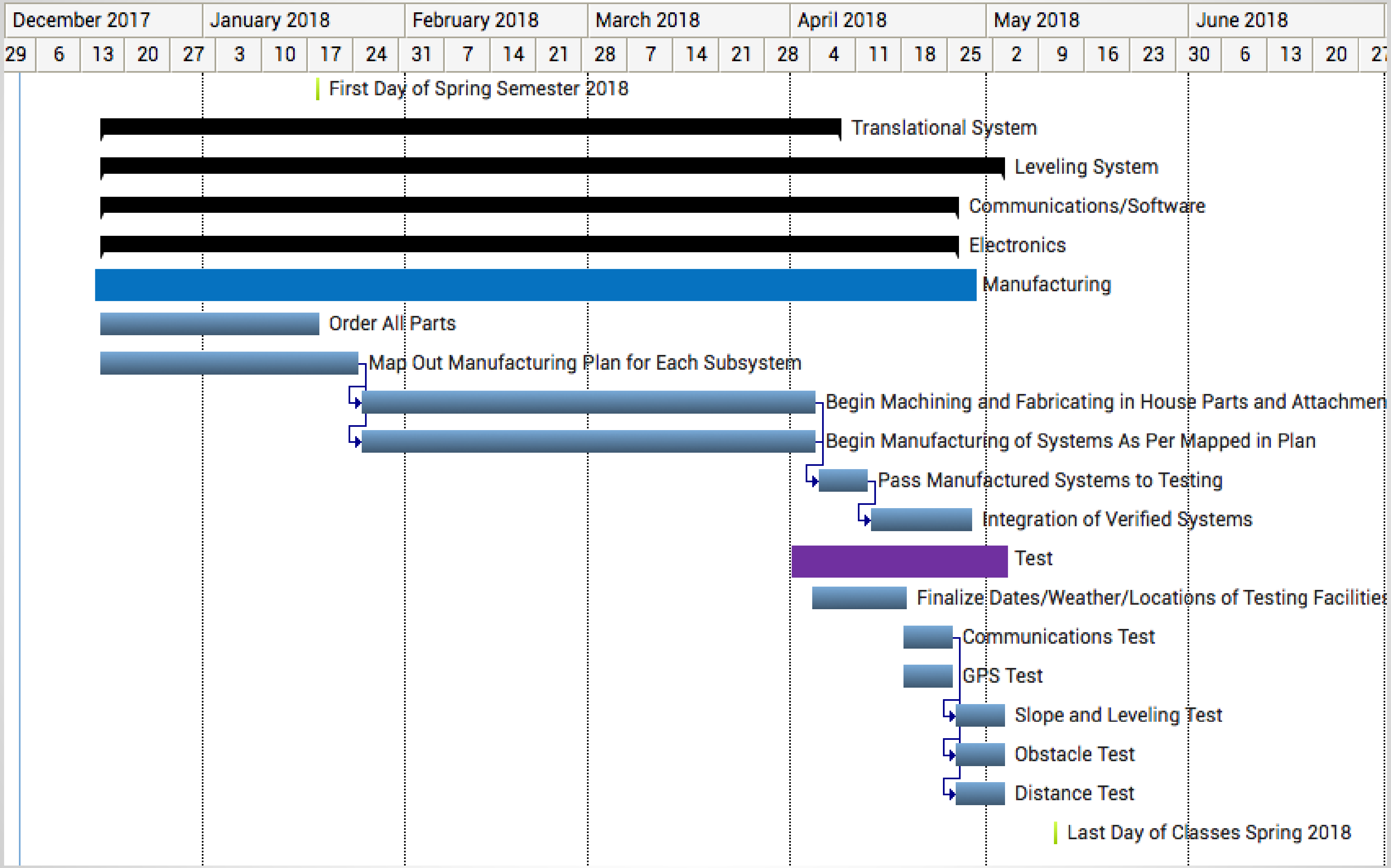


Gantt Chart: Communications/Software & Electronics

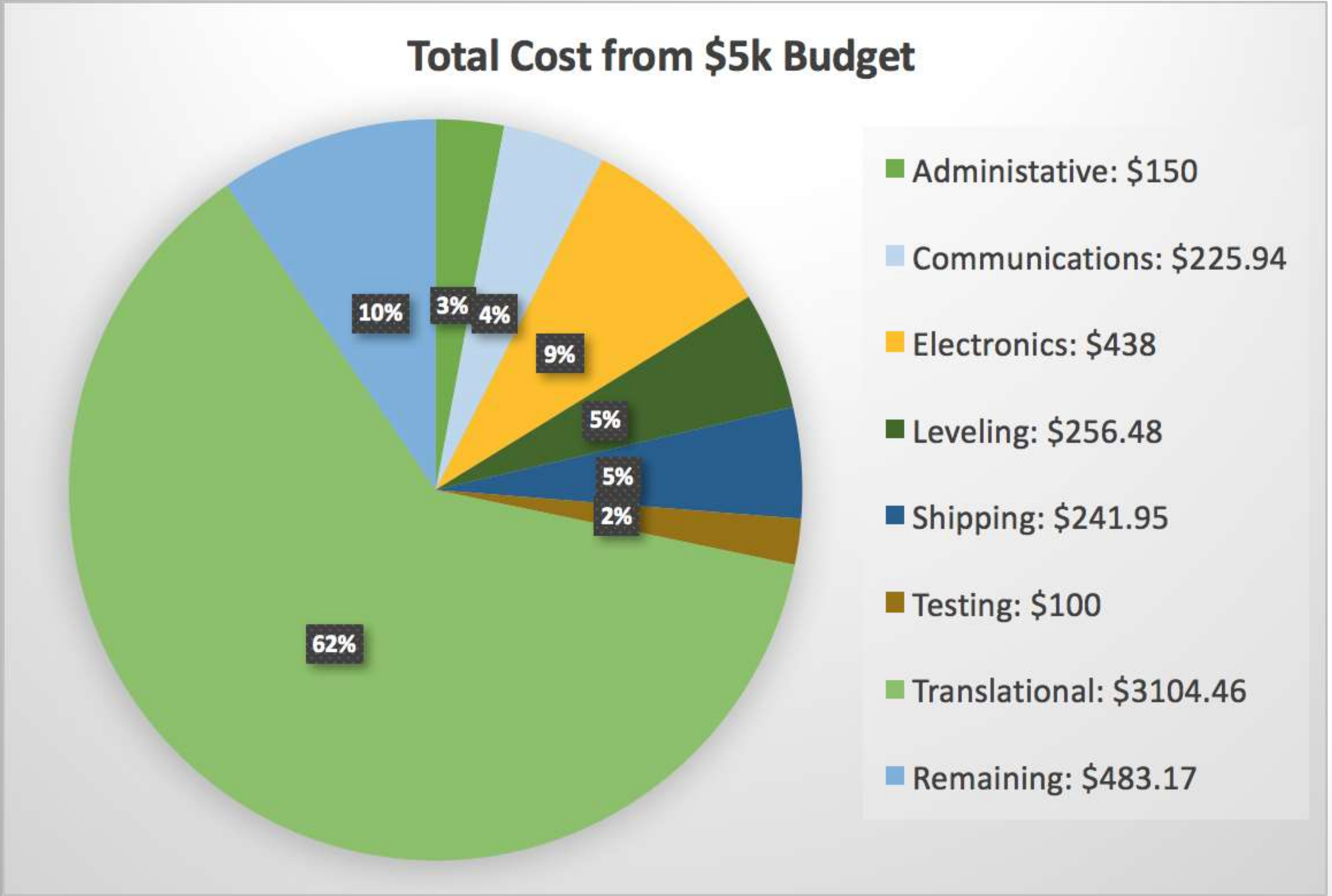




Gantt Chart: Manufacturing



Cost Plan (Financial Budget)



Projected Total Amount:
$4,516.83

Budget Busters

- **Electronics**
  - 2 12VDC Batteries: $198.00
- **Translational**
  - Motors: $1,052.10
  - Motor Drivers: $439.60
  - Wheels & Tires: $303.35
  - Al 6061 Plates: $255.01
  - Wheel Sprockets: $222.56
  - Bracket Connections: $210.60

Cost Plan (Savings)

PDR Adjustment Savings

- Cameras
  - PDR Price: $298.00
  - CDR Price: $47.72
  - Savings: **$250.28**
- Structural Metal Bars
  - PDR Price: $214.50
  - CDR Price: $144.11
  - Savings: **$70.39**
- 5.8GHz & 900GHz Antennas
  - PDR Price: $104.98
  - CDR Price: $33.82
  - Savings: **$71.16**
- Rocker Bogie Differential
  - PDR Price: $225.00
  - CDR Price: $0.00
  - Savings: **$225.00**
- Battery (250m vs. 500m)
  - 500m Price: $420.00
  - 250m Price: $220.00
  - Savings: **$200.00**

Educational Discounts

- Motors
  - Orig. Price: $1,421.00
  - Disc. Price: $1,052.10
  - Savings: **$368.90**
- Motor Drivers
  - Orig. Price: $675.00
  - Disc. Price: $439.60
  - Savings: **$235.40**

Total Savings: $1421.13

Conclusion

Project Overview → Design Solution → Critical Elements → DRs and Satisfaction → Validation and Verification → Project Risks → Project Planning → **Conclusion**

Conclusion

- Mother Rover will secure, carry, and level the Child Drone to a desired GPS location
- **Fixed-Chassis** Translational System will allow Mother Rover to traverse:
  - Defined rough terrain – lawn grass, small gravel, and fine dirt
  - 5 in obstacle
  - 20 degree slope
- **Leveling Jacks** will allow Landing Platform to be leveled within 3.5^{o}
  - Allows for autonomous takeoff and landing of CD
- **Electronics and Communications** allow for:
  - Power distribution to all critical components
  - Communication from Mother Rover to Ground Station-navigation, video, etc.
  - Communication from Ground Station to Mother Rover- translational motion, leveling, etc.

Thank you!

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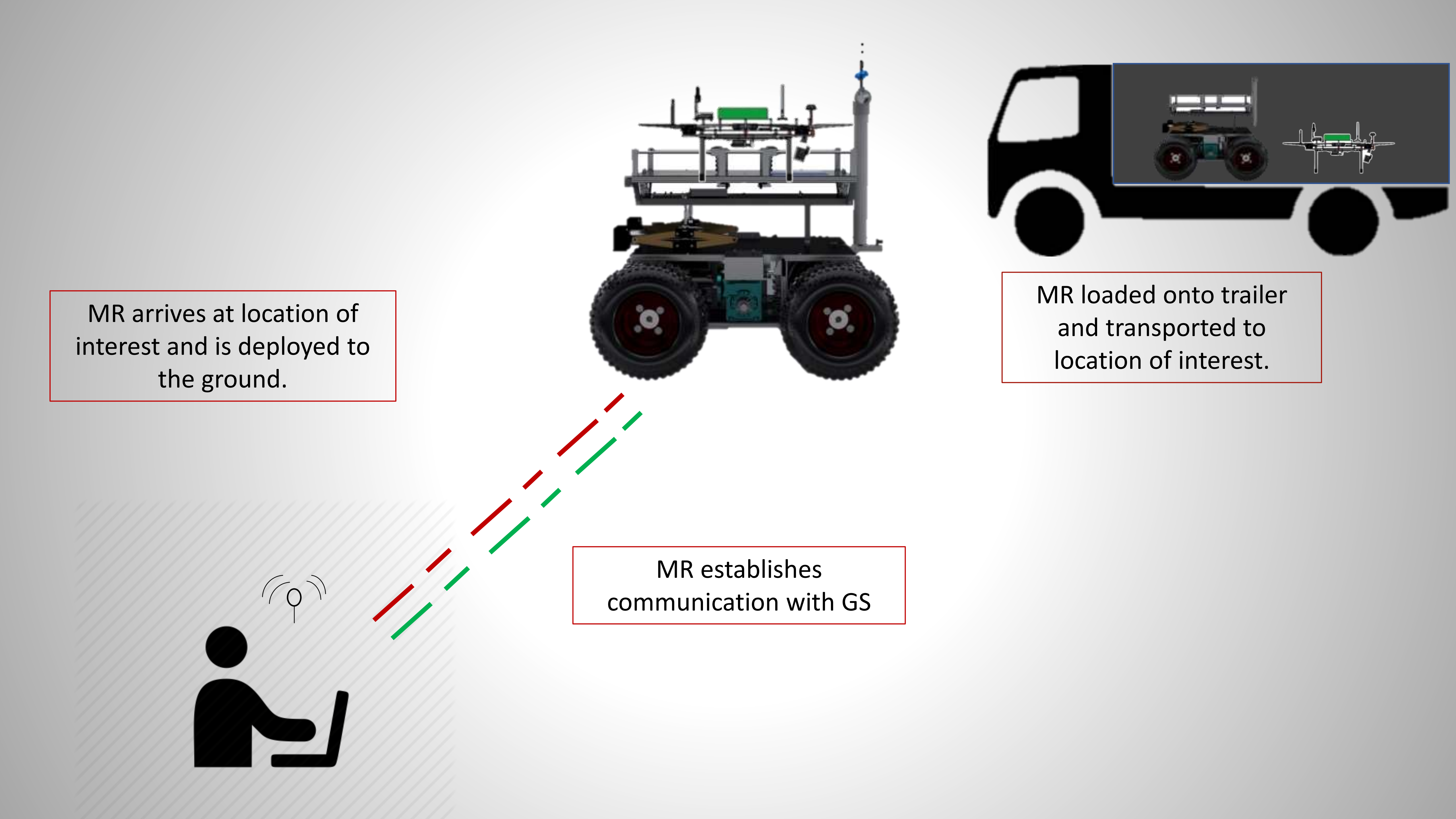
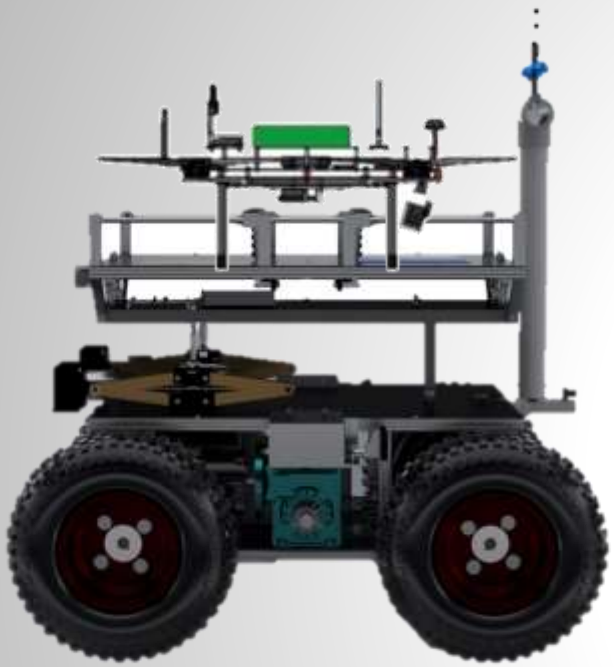
Backup Slides

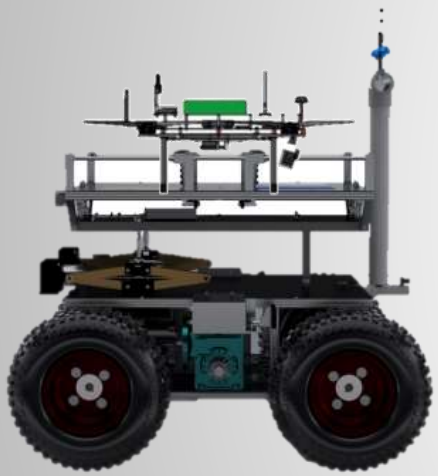
CONOPS Animation


MR loaded onto trailer and transported to location of interest.
MR arrives at location of interest and is deployed to the ground.
MR establishes communication with GS



MR traverse around obstacles up to 5” tall

MR speed :
0 m/s – 0.5 m/s



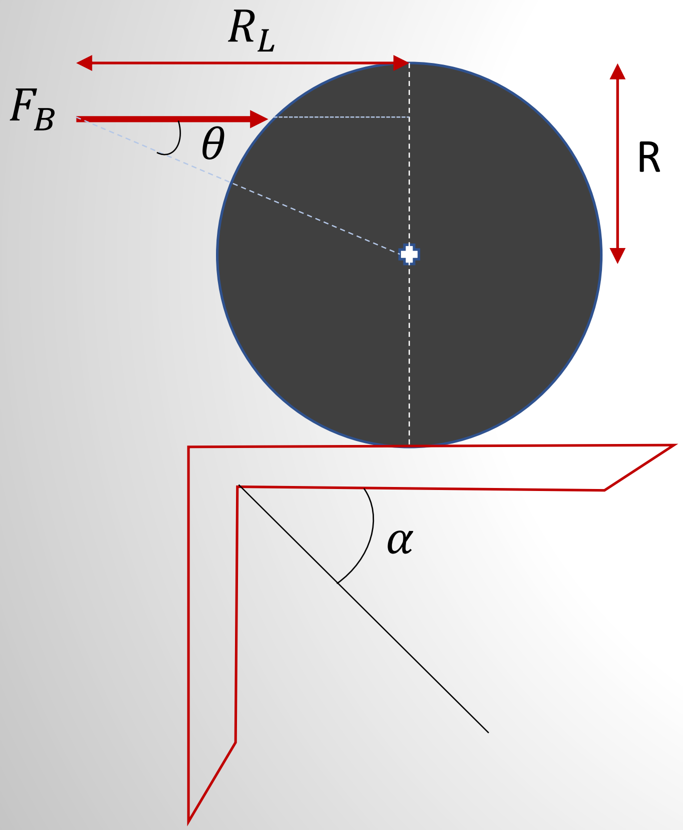
MR maneuver around obstacles greater than 5”

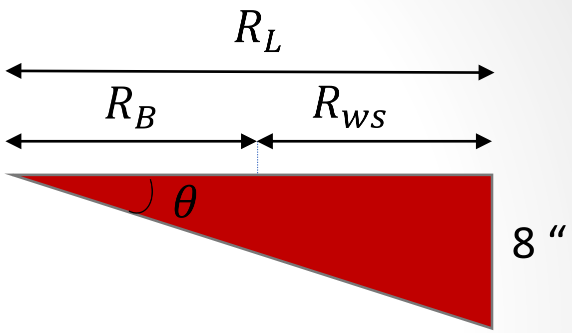
Translational Subsystem

Wheel Locking Mechanism

- Housing
  - Material: Al 6061 – ¼ inch thick
  - Bolted to top of MR, corners welded
- Linear Actuators
  - Windy Nation LIN-ACT1-02
    - 2-inch stroke
    - Rated load up to 225 lbs (900 N)
- Brake Pad
  - Materials:
    - Al 6061 – ¼ inch thick
    - Neoprene Rubber 60A – ¼ inch thick

Wheel Locking: Model





R_B = the length of the linear actuator
R = radius of the wheel
R_{ws} is found using triangle equation
F_B = Braking force needed

Assumptions:

- Mass of the rover the treated as a single point
- α is set at the highest inclination = 20°

Wheel Locking: Equations

- $\sum F_x = F_B + f_{friction} - Mgsin(\alpha)$ ------------- 1
- $\sum M_o = \tau + f_{friction} - F_B sin(\theta) \cdot R_L$ ------------- 2

Set equation 2 = 0 and solve for N

- $\tau = Mg\ sin(\alpha) \cdot R$
- $f_{friction} = \mu N$

- $N = \frac{F_B sin(\theta) \cdot R_L - Mgsin(\alpha) \cdot R}{\mu R}$ ------------- 3

- Substitute equation 3 into 1 and solve for F_B by setting it to 0

$$\boxed{F_B = \frac{2MgRsin(\alpha)}{R + (R_L \cdot \sin(\theta))}}$$

Parameters :

M = 180 kg

R = 0.2286 m

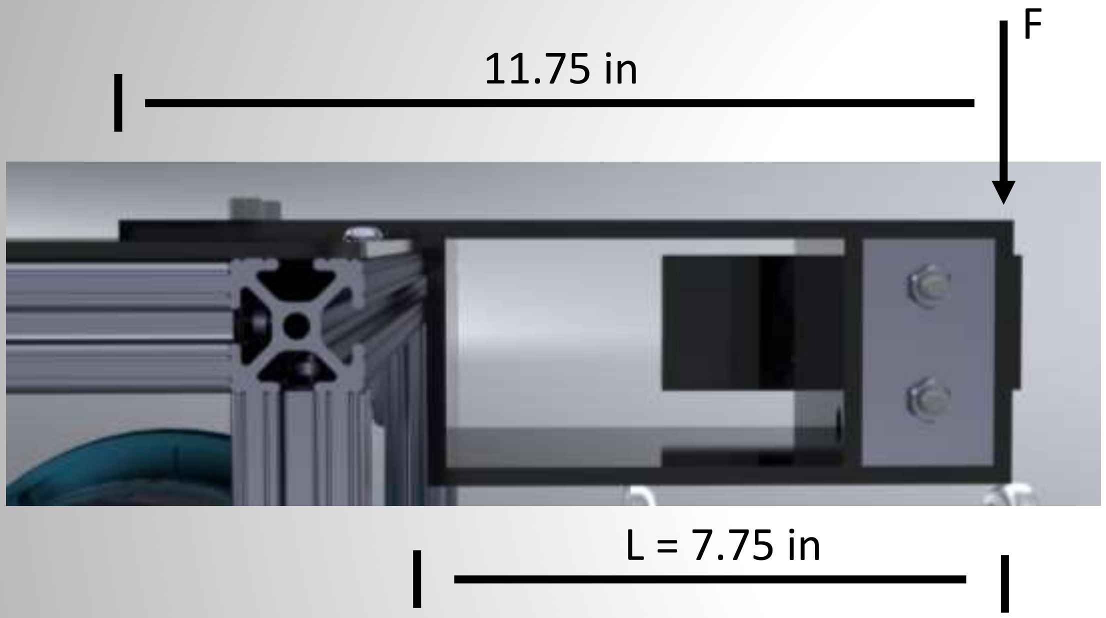
R_L = 0.2604 m

θ = 37.97°

α = 20°

$$\boxed{F_{B_{Total}} = 710.23\ N}$$

Wheel Lock: Bending Moment & Deflection



<u>Parameters</u>

L = 7.75in = 0.19685m
b = 7.5in = 0.1905 m
E = 68.9 GPa
h = .25 in = 0.00635 m
F = mg sin(20) = 302N

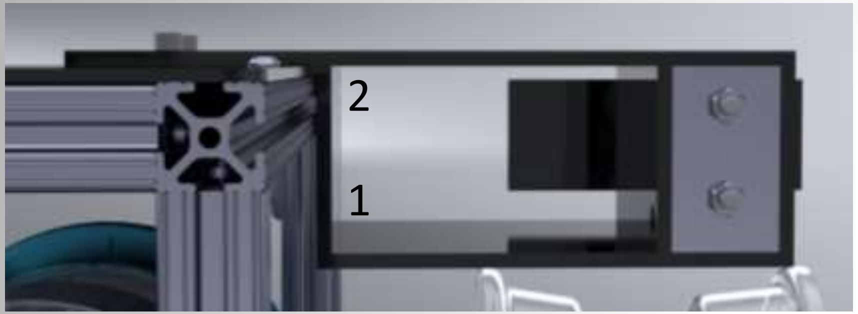
2^{nd} Order Method Equations :

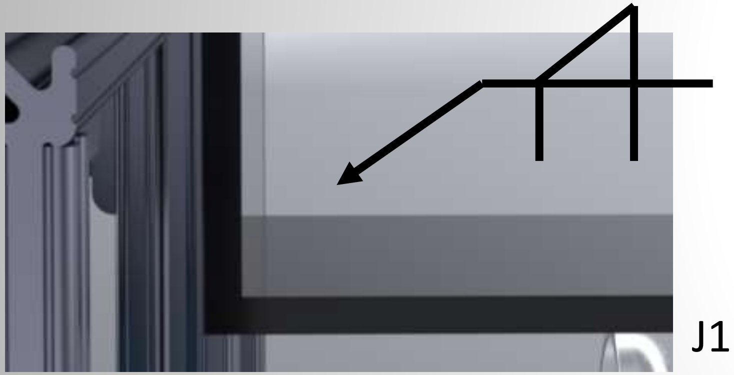
- $M_z(x) = -Fx \quad where \quad EI_{zz}v''(x) = M_z(x)$
- $v(x) = \frac{-FL^3}{6EI_{zz}}(x^3 - 3L^2x + 2L^3)$
- $I_{zz} = \frac{bh^3}{12} = 4.0648 \times 10^{-9}\, m^4$

Inserting Parameters :

- $M_{z_{root}} = -(301N)(.19685m) = 59.25Nm$
- $v_{tip} = \frac{-FL^3}{6EI_{zz}}\left((L)^3 - 3L^2(L) + 2L^3\right) = -2.73\text{mm}$

Wheel Locking Model: Weld Analysis





J1

J2

Joint 1: Butt & Fillet Welds

$\sigma_b = \frac{My}{I_c}$ where $M = 59.25$ N, $y = 0.003175\, m,\ I_c = \frac{bh^3}{12} = 4.06 \times 10^{-9} m^4$

- For welds, can assume 75% of material Tensile Strength
- Al 6061 Yield Tensile Strength $= 276\ MPa \rightarrow\ .75(276) = 207 MPa$

$$\boxed{\sigma_b = 46.5 MPa \quad \rightarrow \quad FOS = \frac{207\ MPa}{46.5\ MPa} = 4.45}$$

Joint 2: Double Fillet Weld

$\sigma_b = \frac{My}{I_c}$ where $M = 59.25$ N, $y = 0.003175\, m,\ I_c = \frac{bh^3}{12} = 4.06 \times 10^{-9} m^4$

$\sigma_t = \frac{F}{A_x}$ where $F = 302\ N,\ A_x = bh = 0.001169\ m^2$

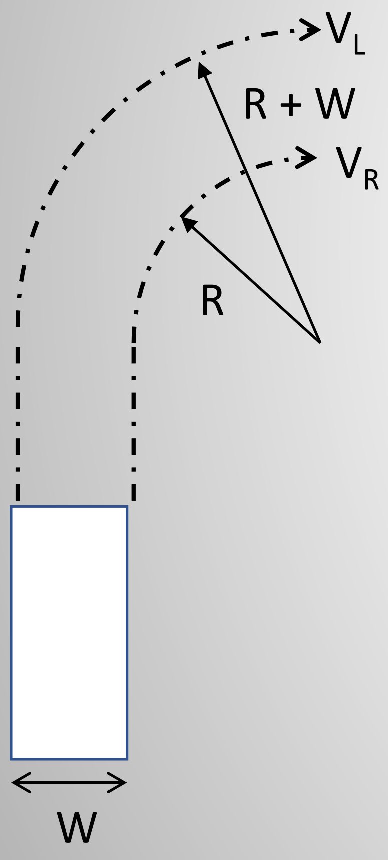
- For welds, can assume 75% of material Tensile Strength
- Al 6061 Yield Tensile Strength $= 276\ MPa \rightarrow\ .75(276) = 207 MPa$

$$\sigma_b = 46.5\ MPa\ \&\ \sigma_t = 258.3\ kPa$$

$$\boxed{FOS = \frac{207\ MPa}{46.5 MPa + 258.3 kPa} = 4.42}$$

Motor RPM Calculation for Turning in Radius

RIGHT TURN



$$V_L = \frac{2\pi(R+W)}{t} = \omega_L\, r_{wheel}$$

$$V_R = \frac{2\pi(R)}{t} = \omega_R\, r_{wheel}$$

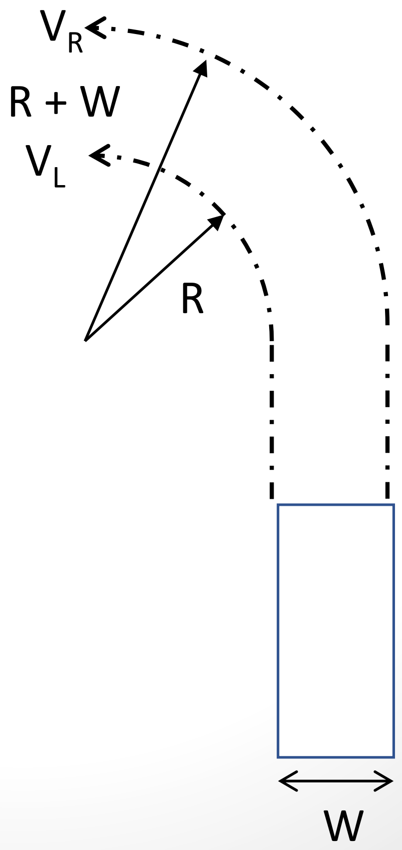
$$RPM_L = \frac{2\pi(R+W)}{t\, r_{wheel}} \frac{2\pi}{60}$$

$$RPM_R = \frac{2\pi(R)}{t\, r_{wheel}} \frac{2\pi}{60}$$

$$V_R = \frac{\tau \cdot RPM \cdot R}{I\, \eta} \frac{60}{2\pi}$$

$$V_L = \frac{\tau \cdot RPM \cdot L}{I\, \eta} \frac{60}{2\pi}$$

LEFT TURN



$$V_R = \frac{2\pi(R+W)}{t} = \omega_R\, r_{wheel}$$

$$V_L = \frac{2\pi(R)}{t} = \omega_L\, r_{wheel}$$

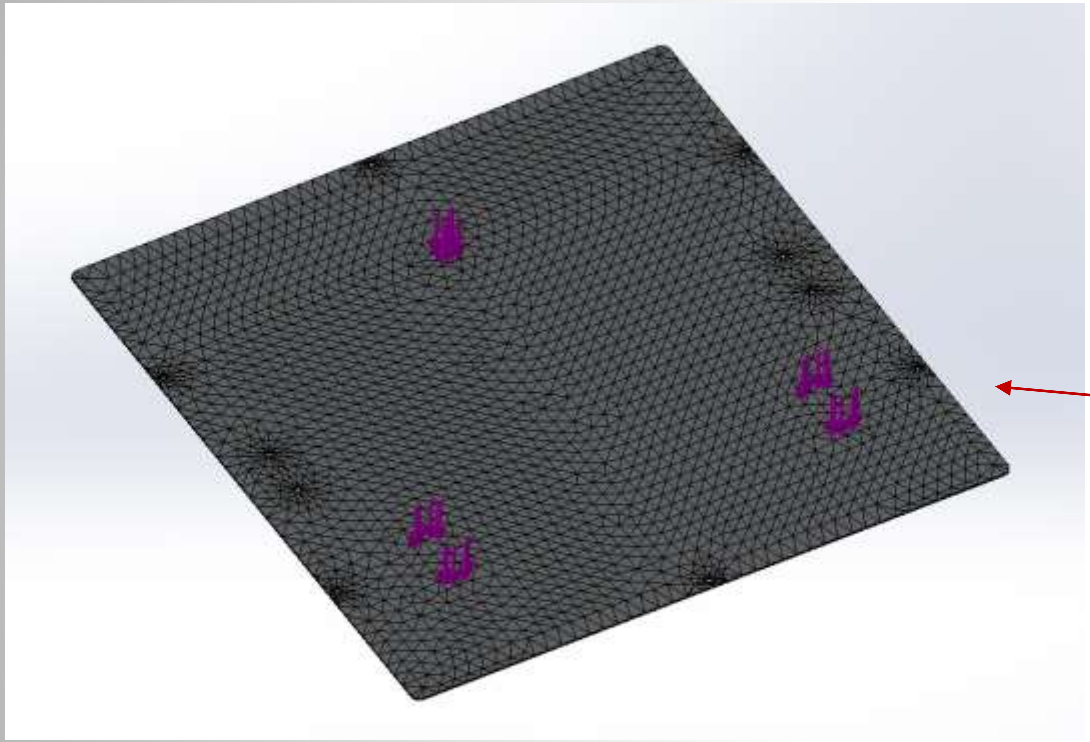
$$RPM_R = \frac{2\pi(R+W)}{t\, r_{wheel}} \frac{2\pi}{60}$$

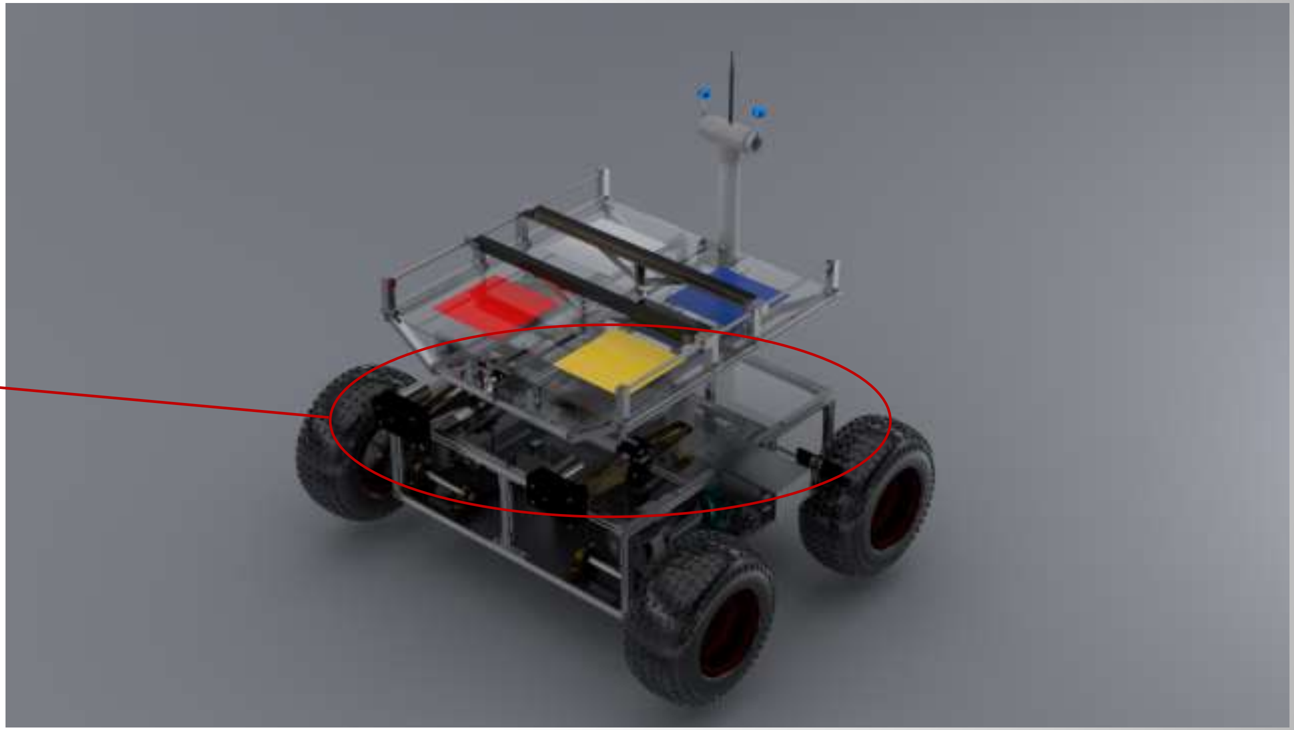
$$RPM_L = \frac{2\pi(R)}{t\, r_{wheel}} \frac{2\pi}{60}$$

$$V_R = \frac{\tau \cdot RPM \cdot R}{I\, \eta} \frac{60}{2\pi}$$

$$V_L = \frac{\tau \cdot RPM \cdot L}{I\, \eta} \frac{60}{2\pi}$$

Finite Element Analysis – Top Sheet





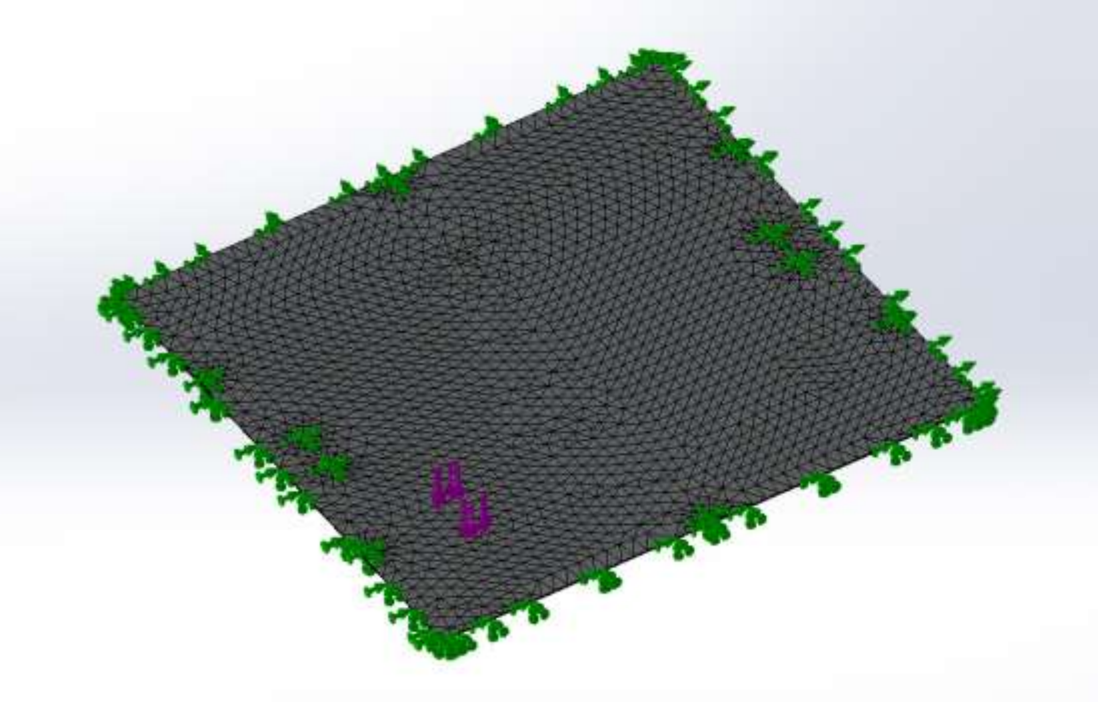
<u>Assumptions</u>

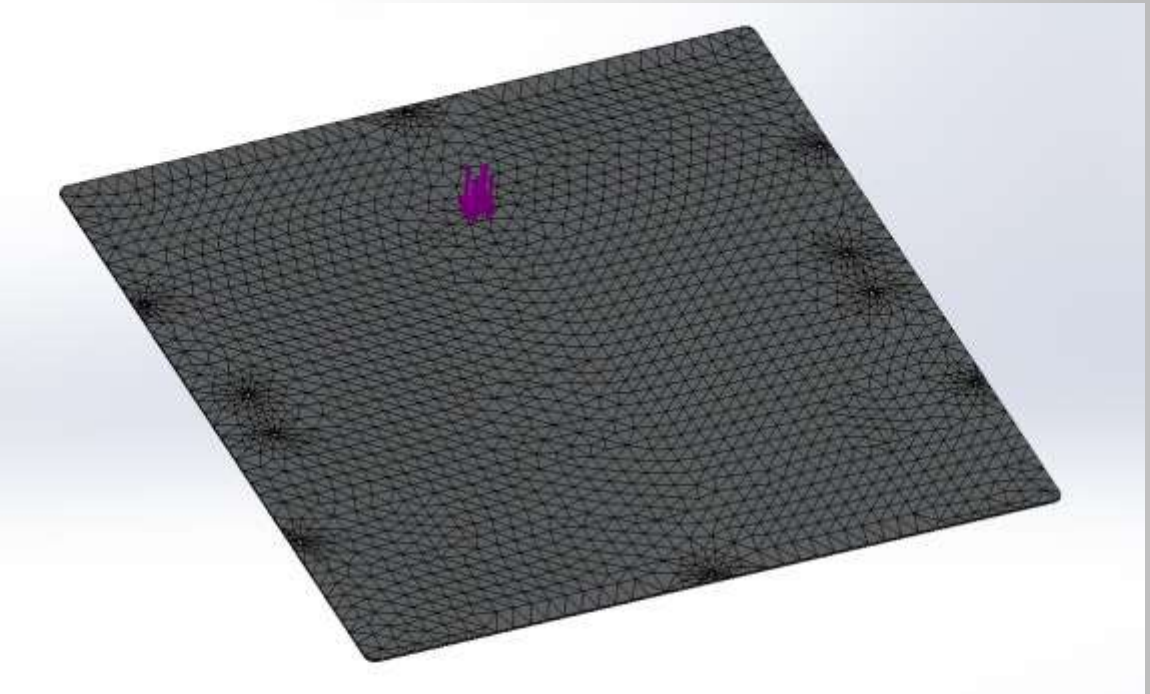
- Force is applied at the contact points of the two scissor jacks and the forward point
- Force is equally distributed over the surfaces
- Force is normal to the top surface of the sheet

<u>Parameters</u>

- Weight of the landing platform/child drone create distributed load in a static state
- Load over each surface is 20 lbf
- Material: 6061 Aluminum
- Holes are fixed geometries

Finite Element Analysis – Worst Case Scenarios





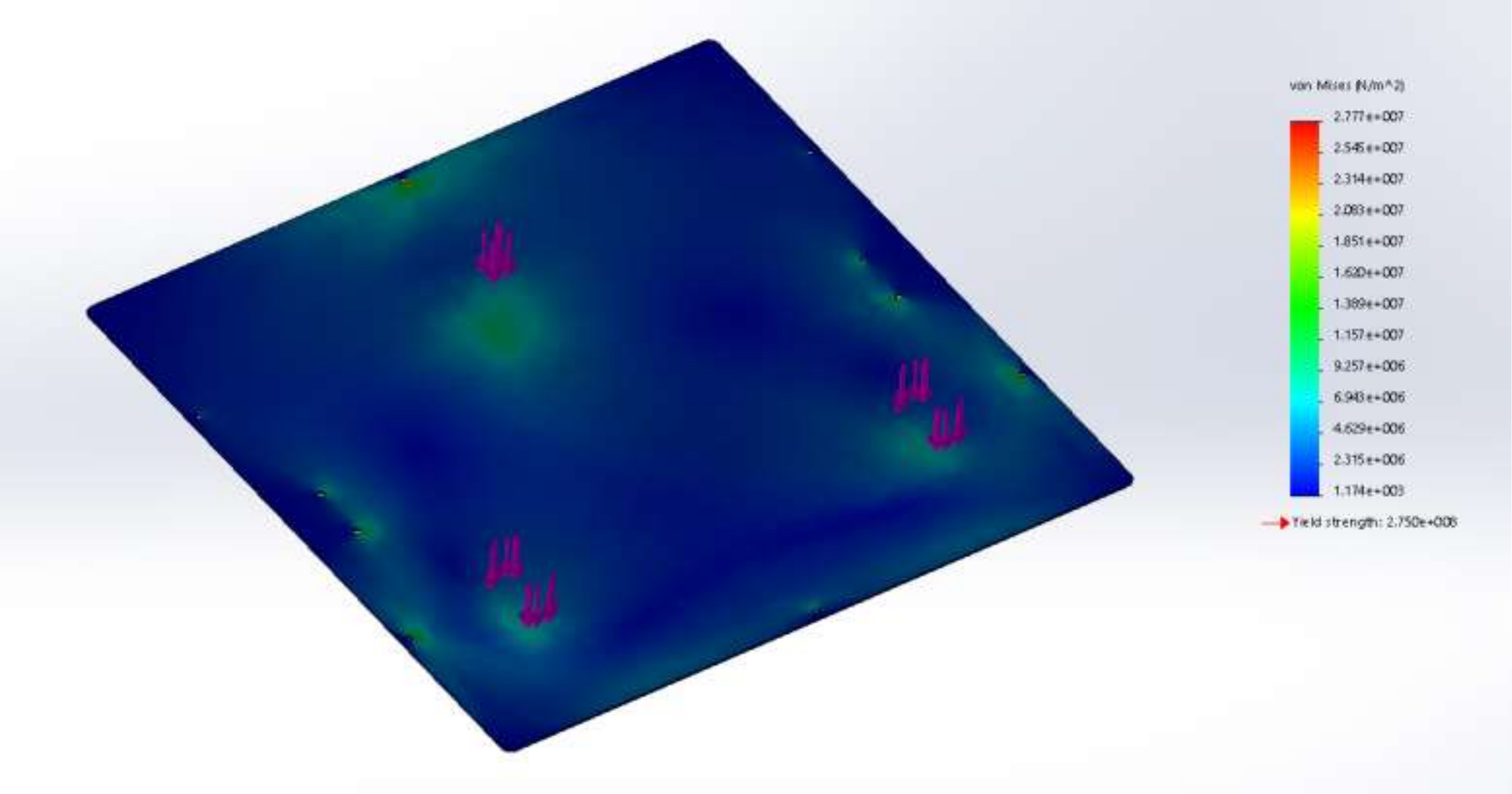
Assumptions

- Force is applied over one contact point
- Force is equally distributed over the surface
- Force is normal to the top surface of the sheet

Parameters

- Weight of the landing platform/child drone create distributed load in a static state
- Load over the surface is 60 lbf
- Material: 6061 Aluminum
- Holes are fixed geometries

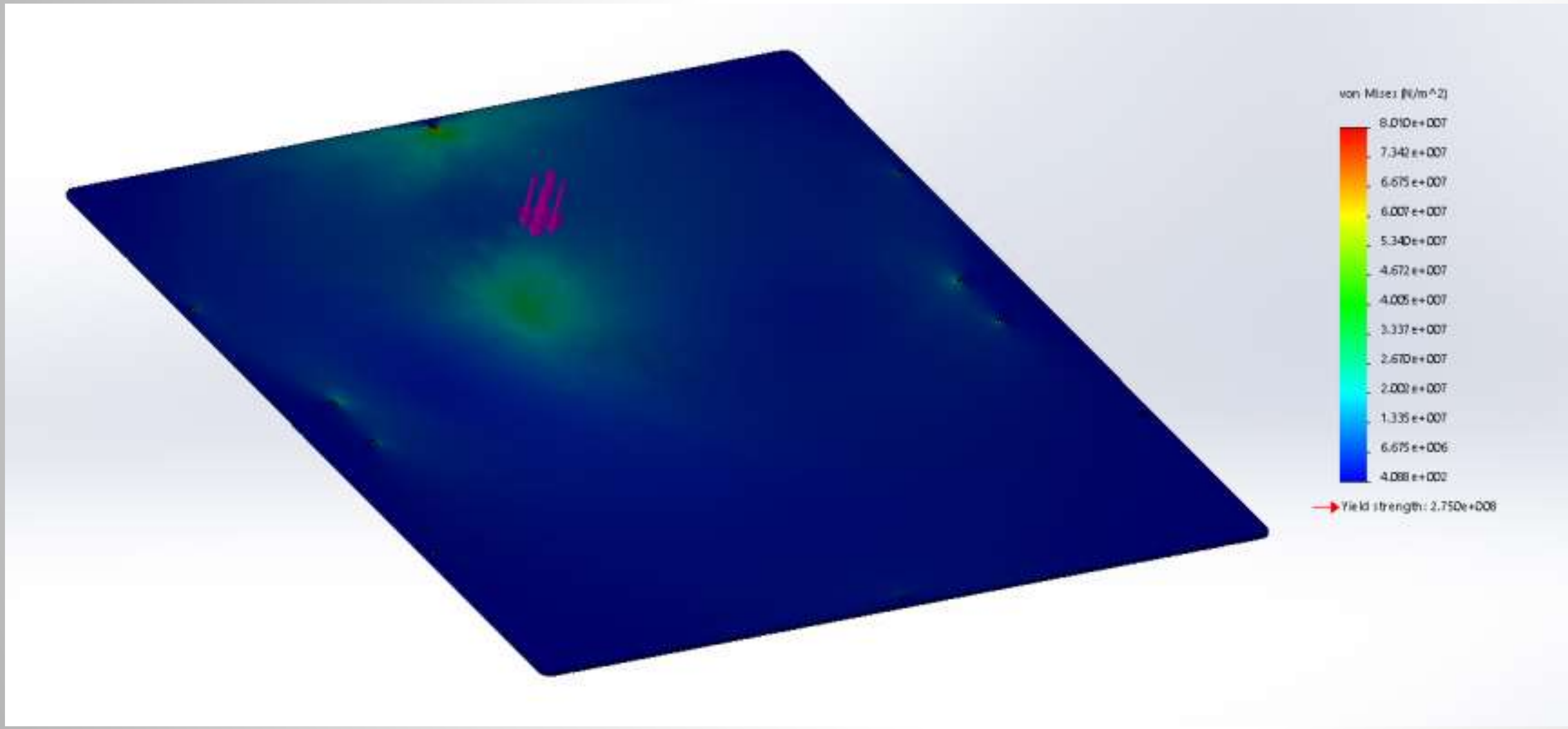
Stress Contours



Results

- Maximum stress occurs at the front bolt hole
- Maximum stress: $2.777E7\frac{N}{m^2}$

Stress Contours – Scenario 1



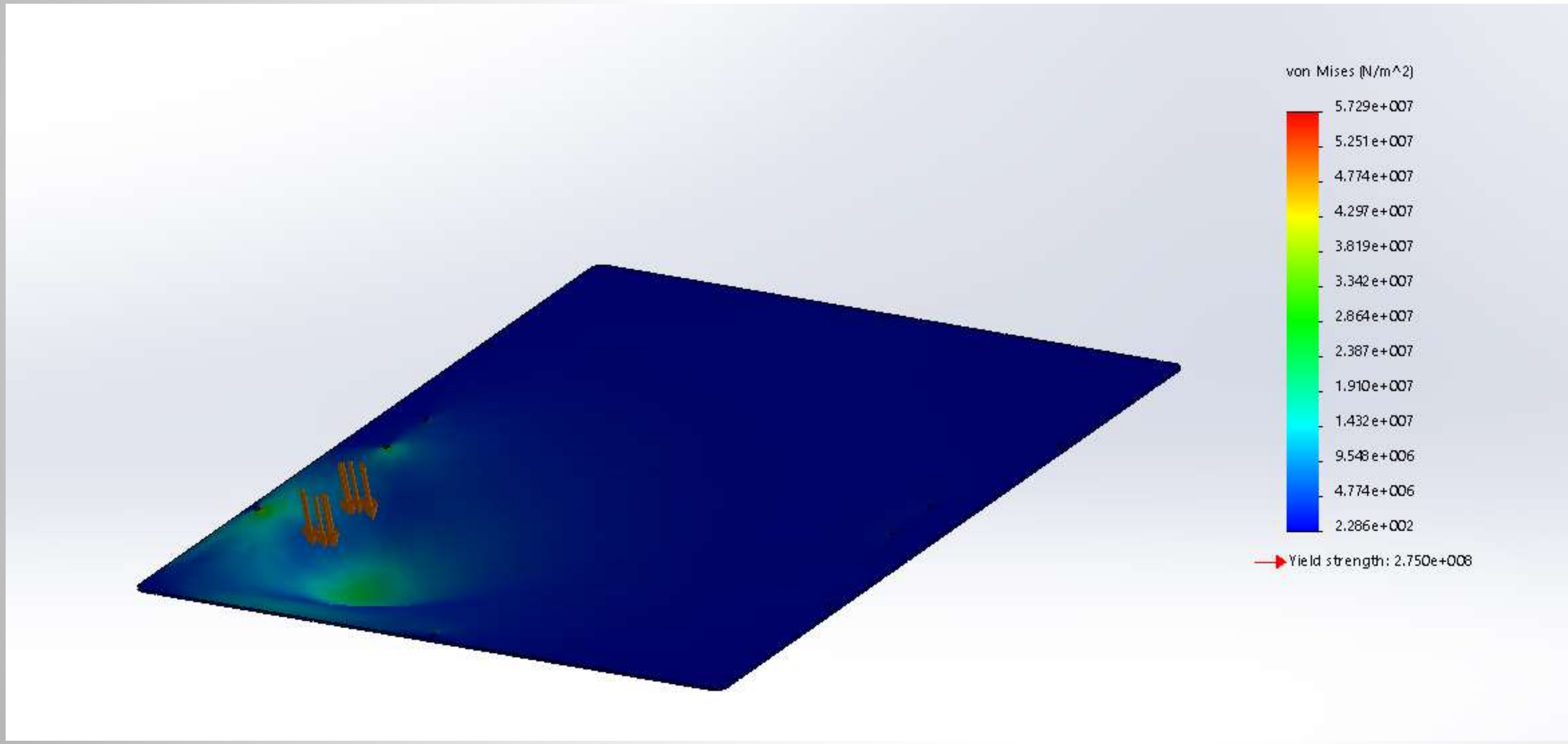
<u>Scenario 1</u>

All of the weight of the landing platform and child drone is applied at the forward pivot point

<u>Results</u>

- Maximum stress occurs at the front bolt hole
- Maximum stress: $8.01\text{E}7\frac{N}{m^2}$

Stress Contours – Scenario 2



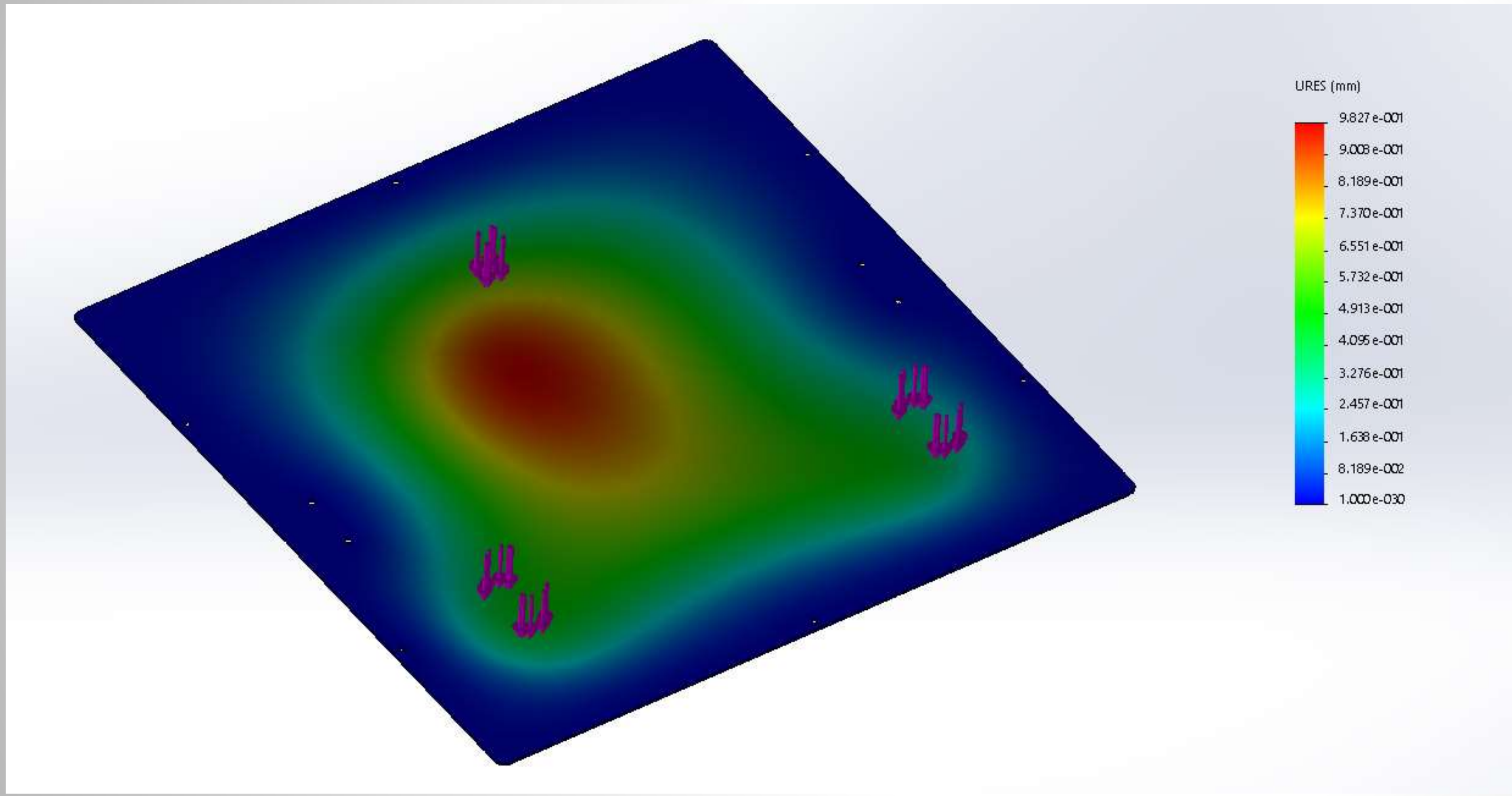
Scenario 2

All of the weight of the landing platform and child drone is applied at one of the scissor jacks

Results

- Maximum stress occurs at the back left bolt hole
- Maximum stress: 5.729E7 $\frac{N}{m^2}$

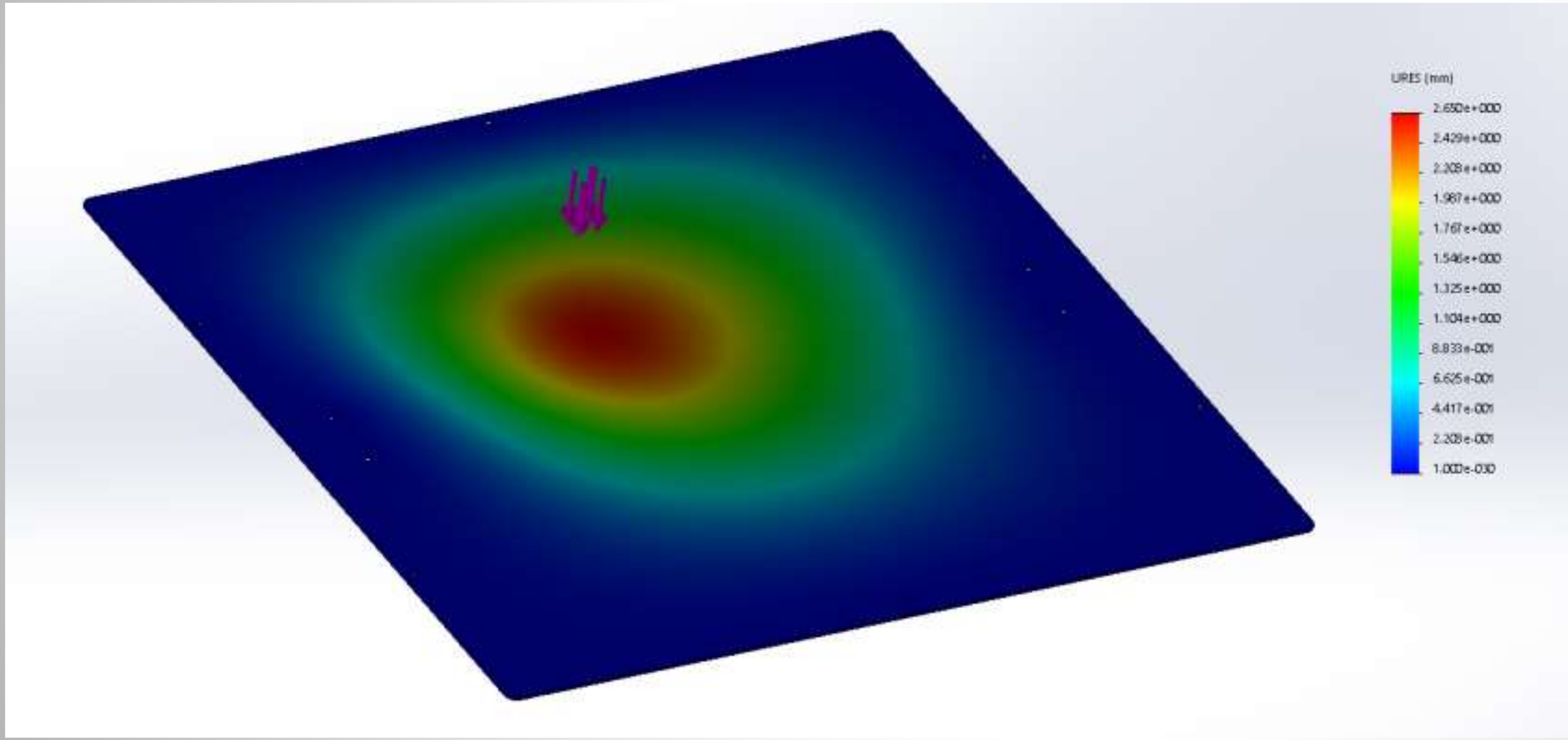
Deflection Contours



<u>Results</u>

- Maximum deflection occurs in the center 20'' from the back side of the rover
- Maximum deflection: 0.9827 mm
- Adding support bars will mitigate this deflection

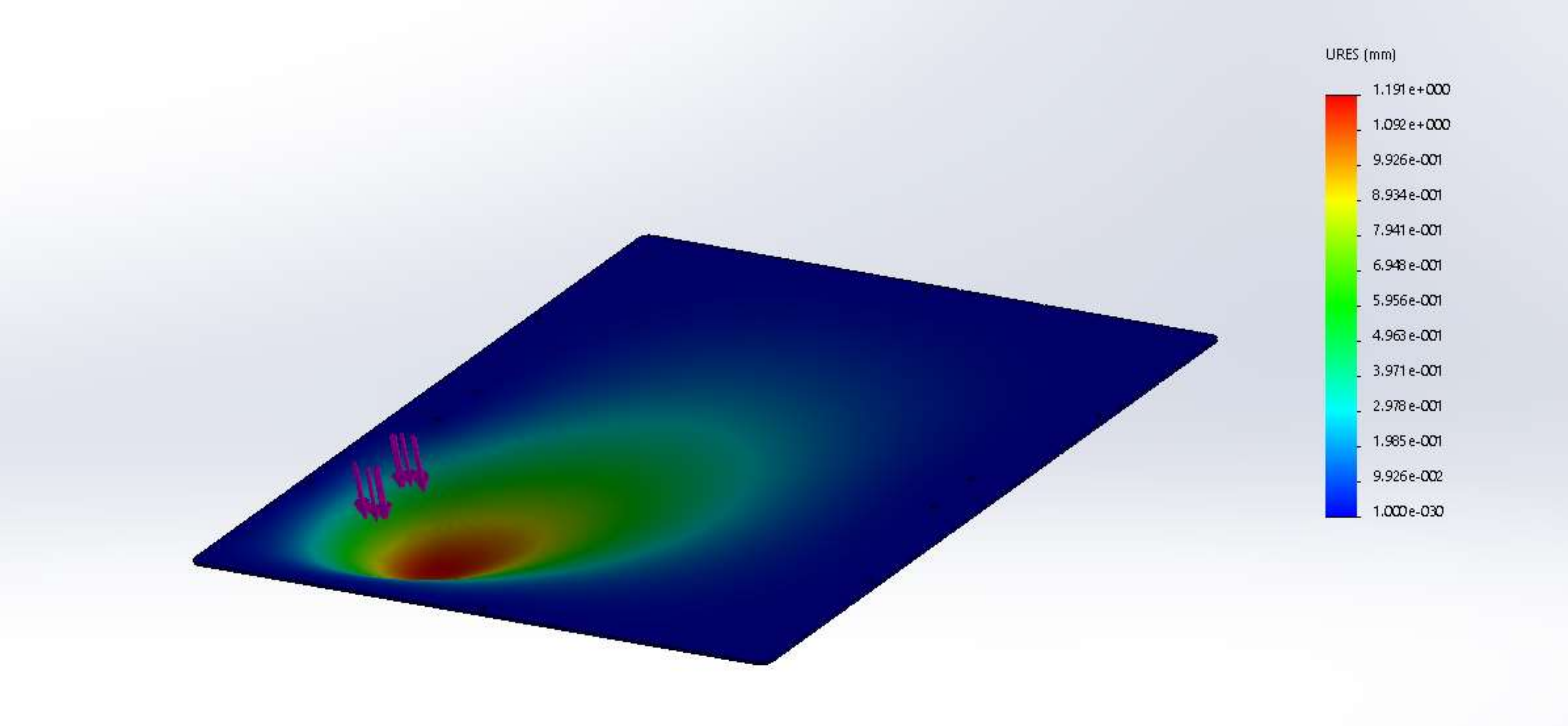
Deflection Contours – Scenario 1



<u>Results</u>

- Maximum deflection occurs in the center 21'' from the back side of the rover
- Maximum deflection: 2.65 mm

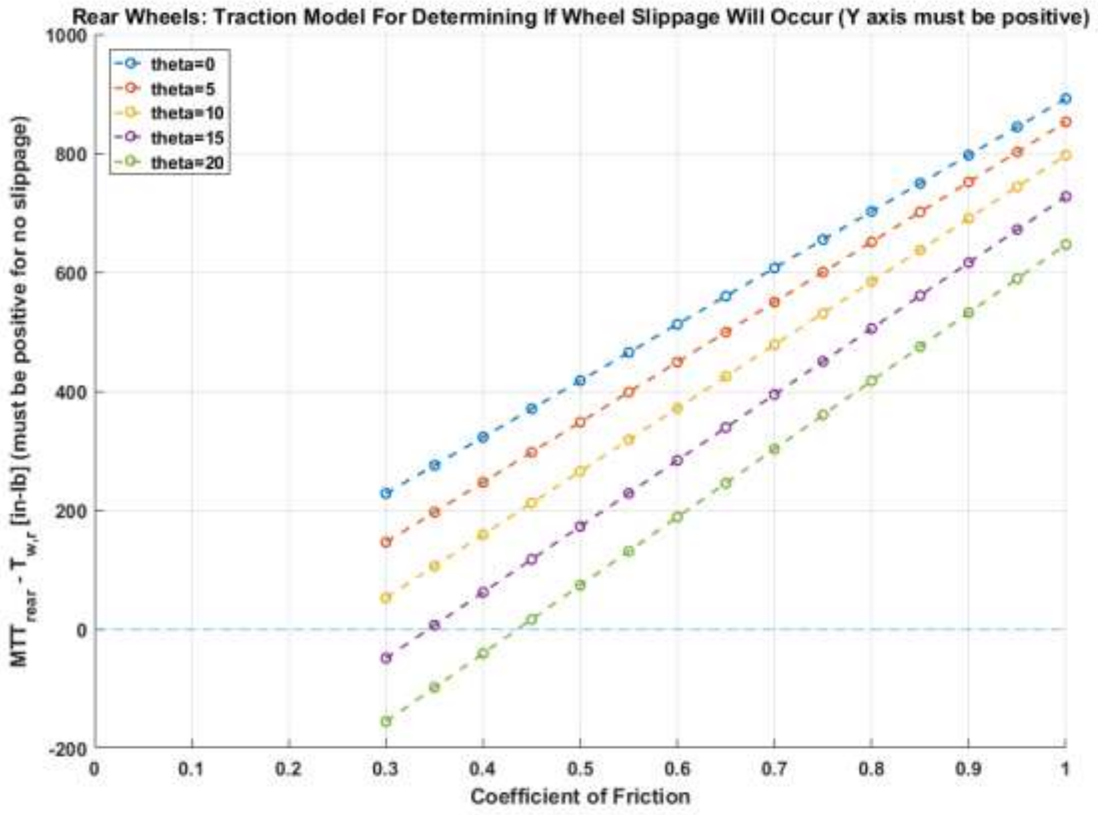
Deflection Contours – Scenario 2

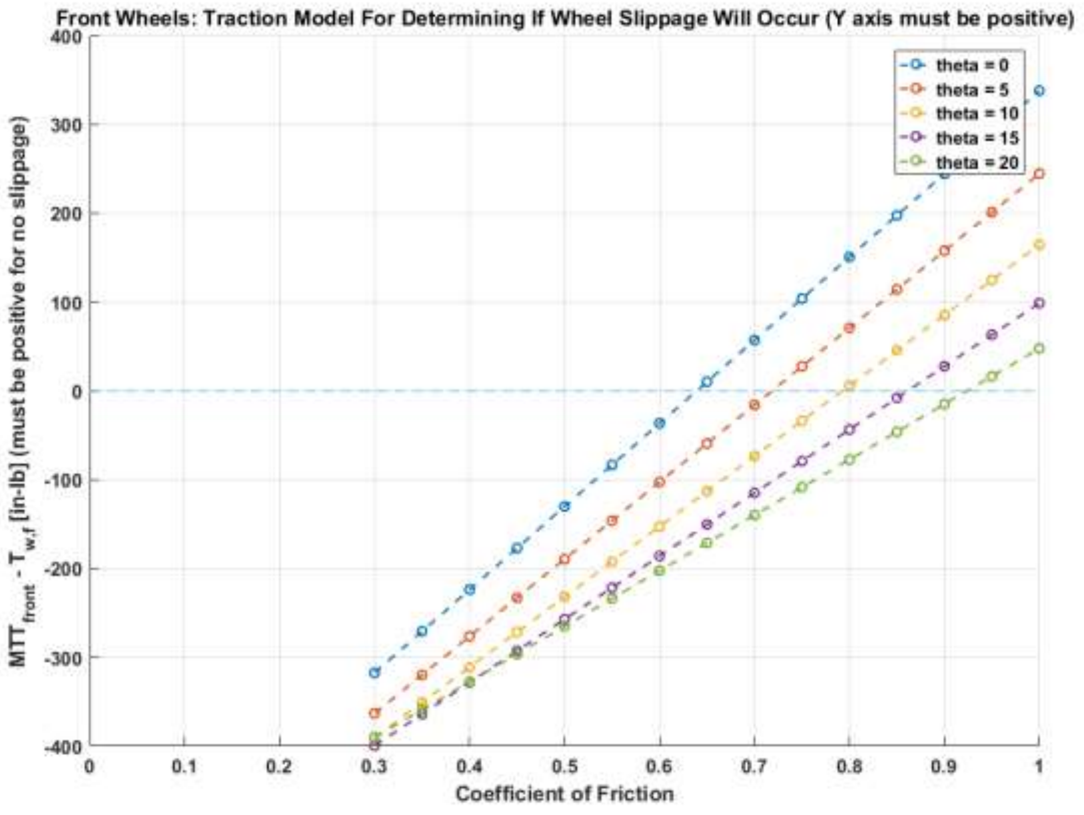


<u>Results</u>

- Maximum deflection occurs 8'' from the left side of the rover and 7'' from the back side of the rover
- Maximum deflection: 1.191 mm

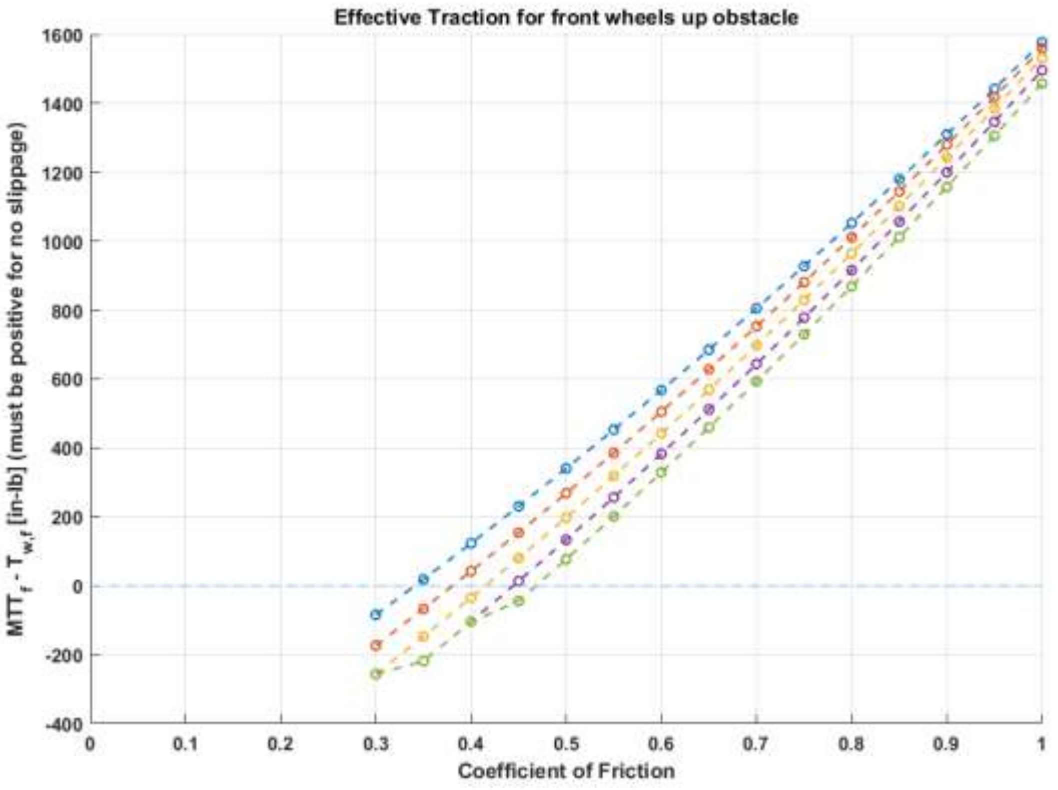
Traction Analysis: 5 Inch Obstacle

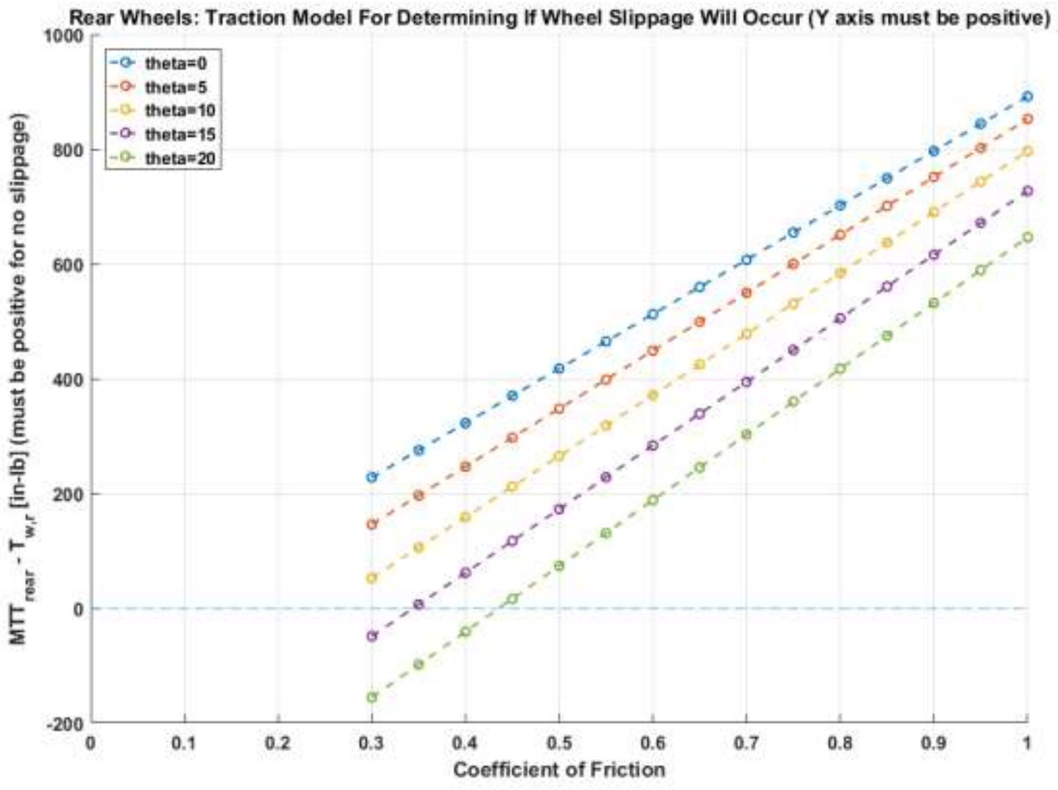




Assuming the angle seen between the contact point of the wheel and the ground and obstacle can be seen as a constant slope ramp. This slope may be too steep for the wheel to surpass itself. The other wheel may have excessive potential traction force the ground can provide to the wheel, which it can utilize and translate it into a force into the wheel needing to get up the obstacle as additional normal force and frictional force, therefore providing additional effective traction.

Traction Analysis: 5 Inch Obstacle





Electronics Subsystem

AD5171 Digital Pot. & DC60 – 4Q Motor Driver

Arduino Mega

Digital Potentiometer

Motor Driver

Motor

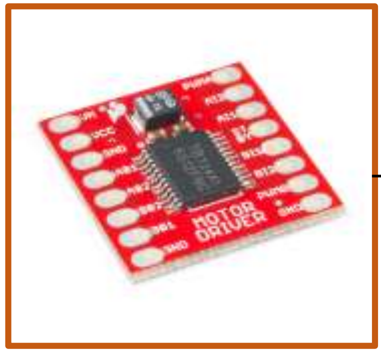
<u>Specifications:</u>

- Motor Input Voltage & Current = 24V and 60A max (30A constant)
- Motor Driver Current Draw = 40 mA
- Motor driver requires 5V logic through the Arduino Mega I/O pins via an NPN transistor
- 10KΩ digital potentiometer for variable speed control utilizing I2C through Arduino Mega which requires +5V supplied by Arduino Mega

Sparkfun Motor Driver – Dual TB6612FNG (1A)

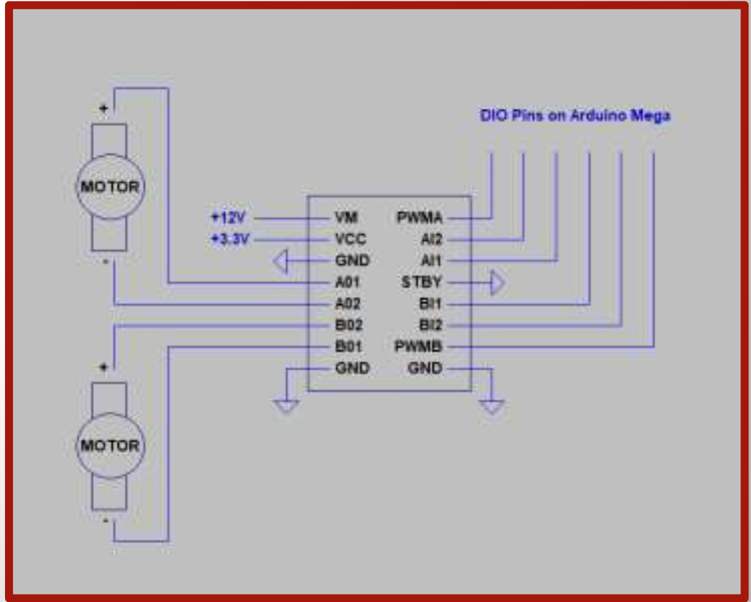
Arduino Mega

Motor Driver



Linear Actuator

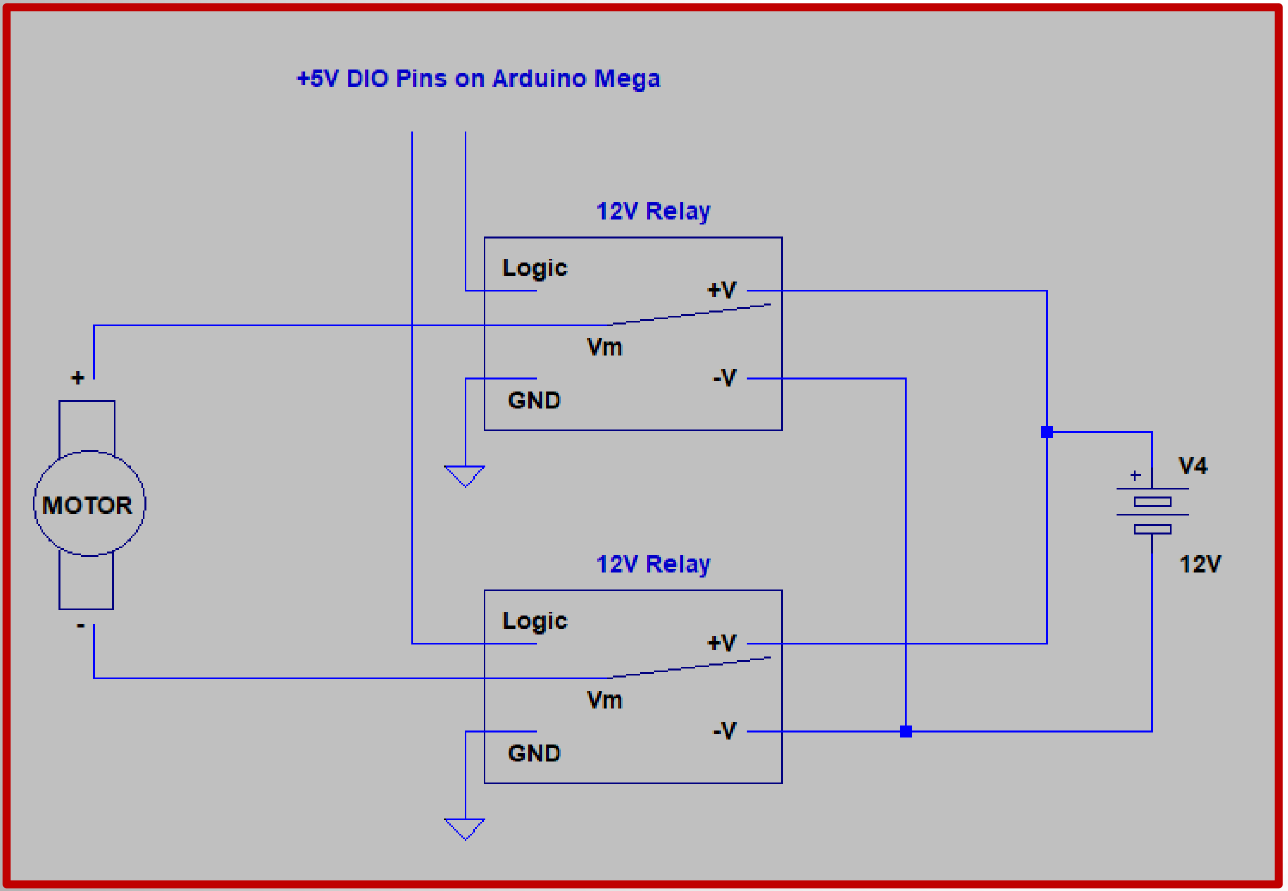
Schematic:



Specifications:

- Motor Driver Input Voltage = 3.3V
- Motor Driver Output Current = 1.2A constant (3.2A Peak)
- VM = motor voltage = 12V
- Pulse Width Modulated DC Signal & Input Logic supplied by digital I/O pins on Arduino Mega

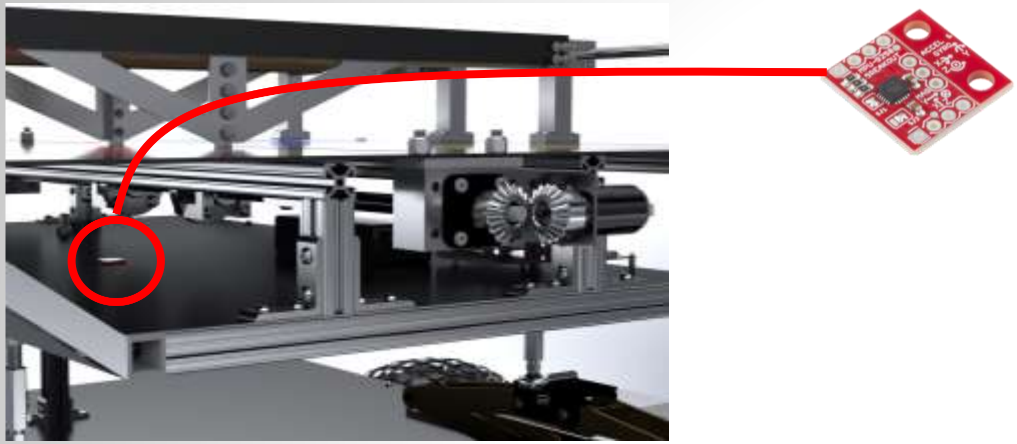
Scissor Jack System



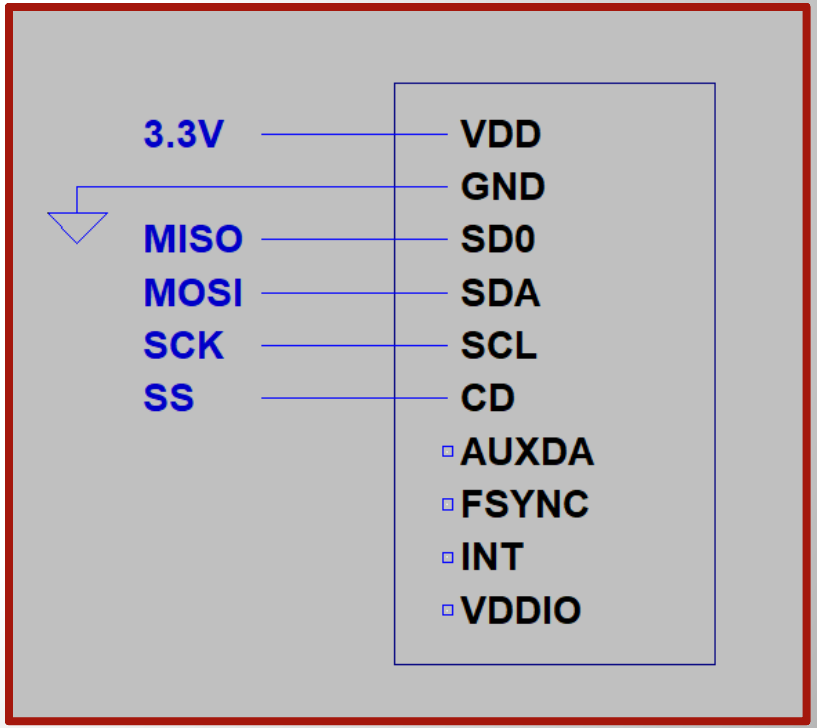
Specifications:

- For each scissor jack motor, two relay switches are wired together to provide positive or negative 12V DC to control the movement of the scissor jack (up or down)
- 5V logic from the digital I/O pins of the Arduino Mega control the relays

Sparkfun IMU Breakout



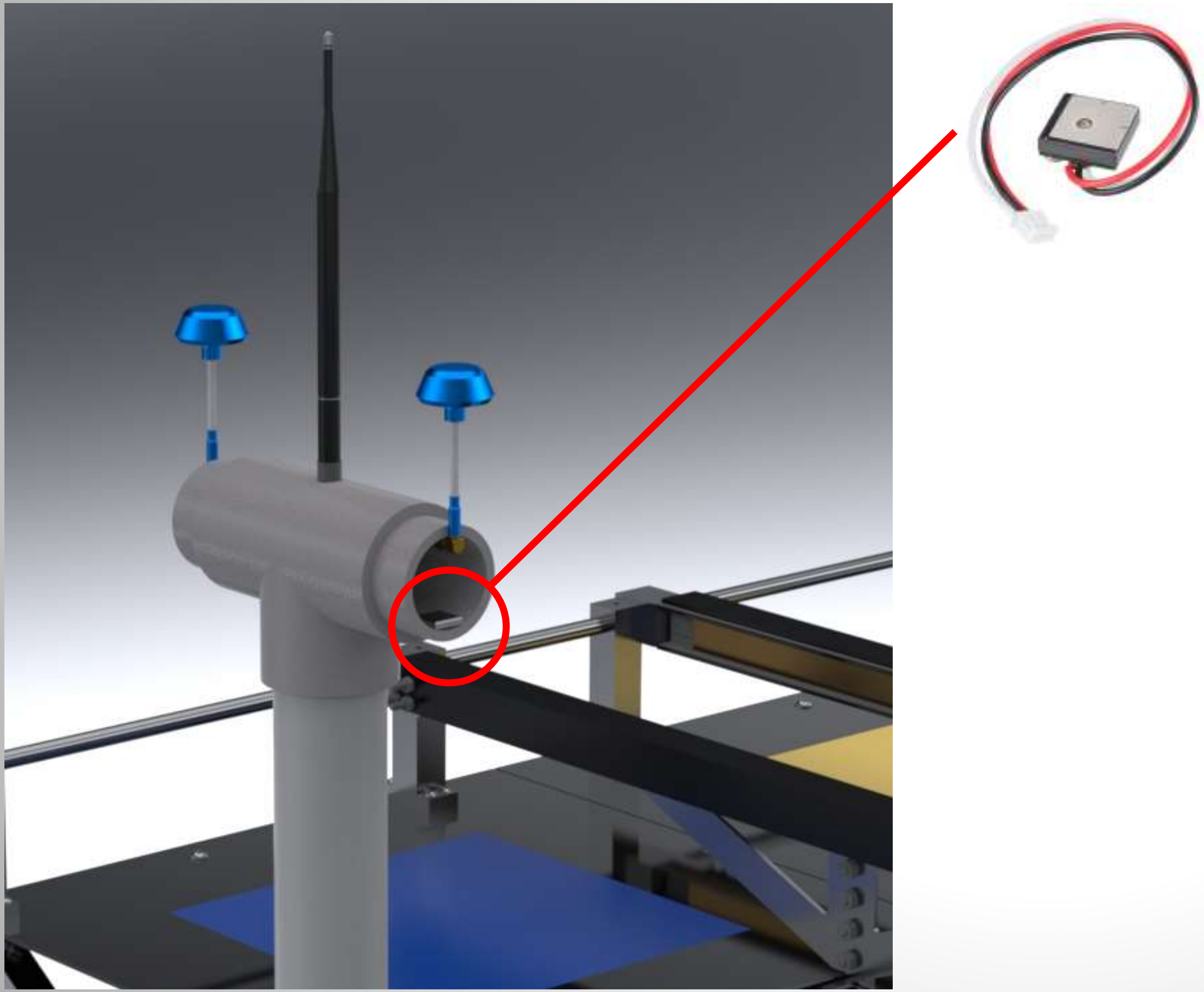
Schematic:

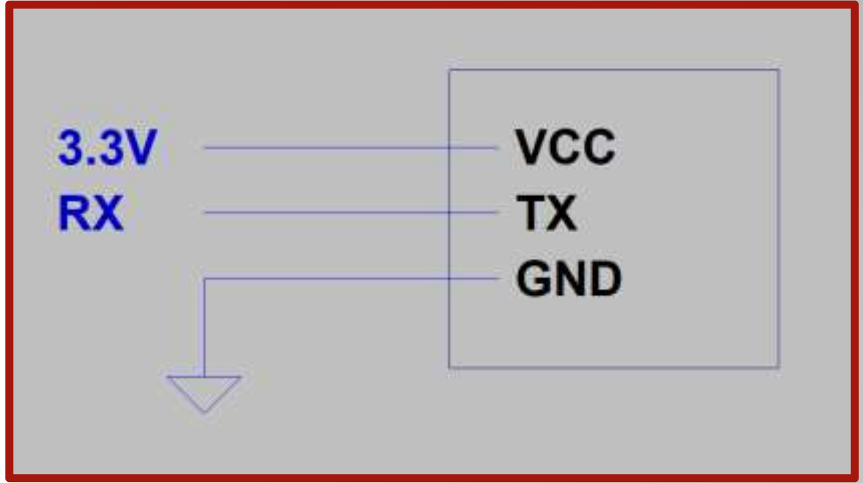


Specifications:

- Input Voltage = 2.4 – 3.6V – going to supply 3.3V
- Current Draw = 740 μA from Accelerometer & Magnetometer Only
- 3-Axis Magnetometer
- 3-Axis Accelerometer
- 3-Axis Gyroscope
- Internal 16-bit ADC
- Accelerometer Full-Scale Range = ± 2g
- Magnetometer Full-Scale Range = ±4800 μT
- Utilizes I2C or SPI – going to use SPI
- Accelerometer Resolution:

GPS

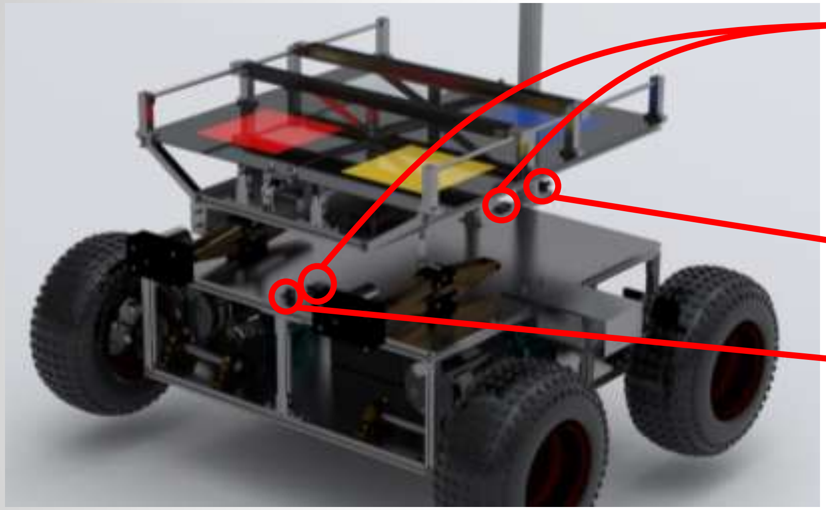




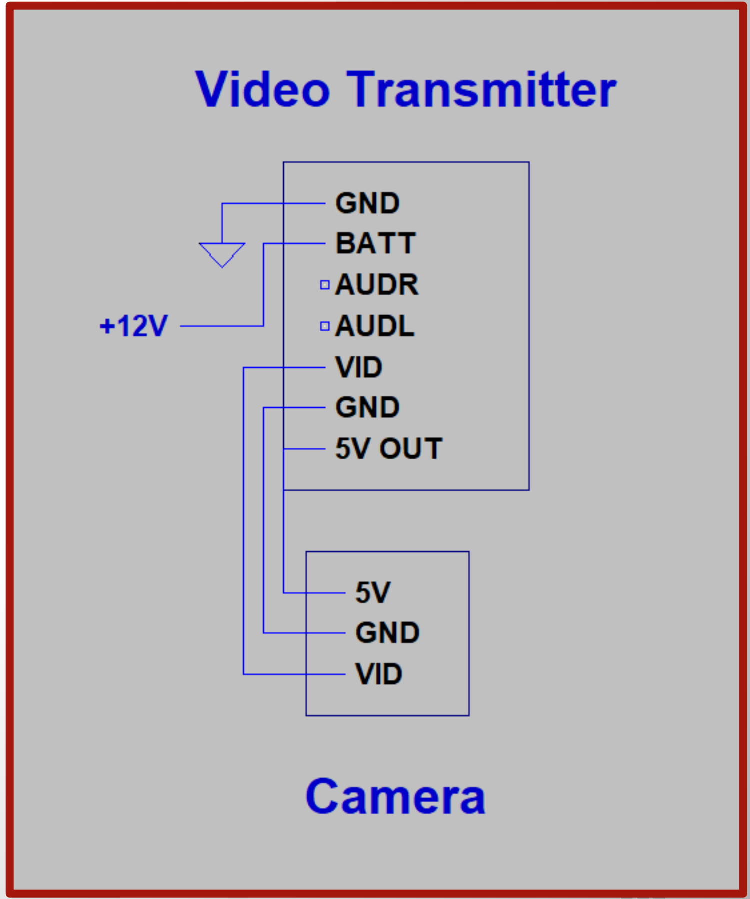
Specifications:

- 40 mA at 3.3V (max)
- 2.5 m positional accuracy
- 56 channel GPS module
- Onboard antenna
- -162 dBm tracking sensitivity
- NMEA – 0183 & Ublox 7 Protocol
- Cold start: 29 s
- Velocity 0.1 m/s

Hazard Camera & Video Transmitter



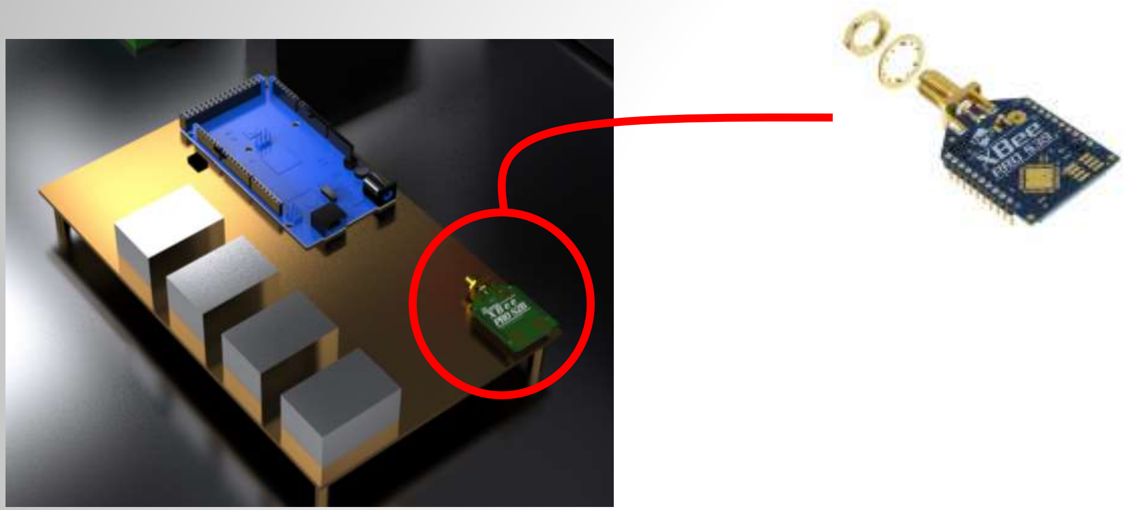
Schematic:



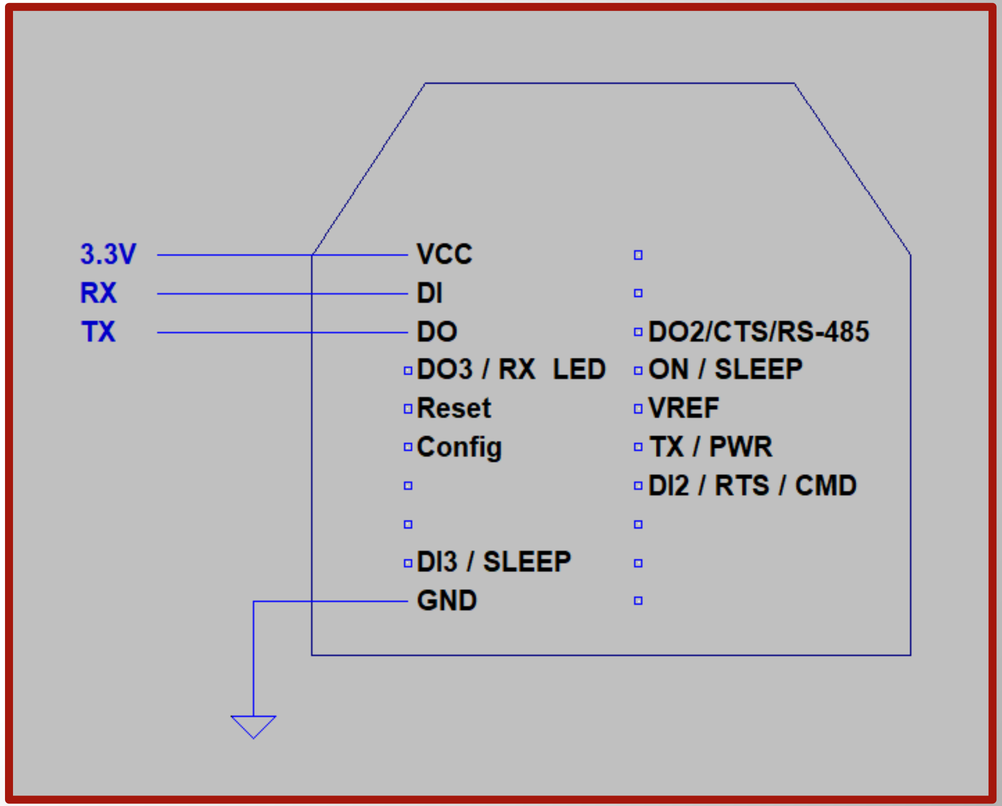
Specifications:

- FatShark 700TVL CMOS FPV Camera
- Immersion RC Audio / Video Transmitter
- Transmitter Input Voltage = 7 – 25V, 12V will be supplied
- Transmitter Output Current & Voltage = 300 mA at 5V
- Camera Input Current & Voltage = 60 mA at 5V
- Camera FOV = 726 (H) x 582 (W)

Xbee Pro S3B



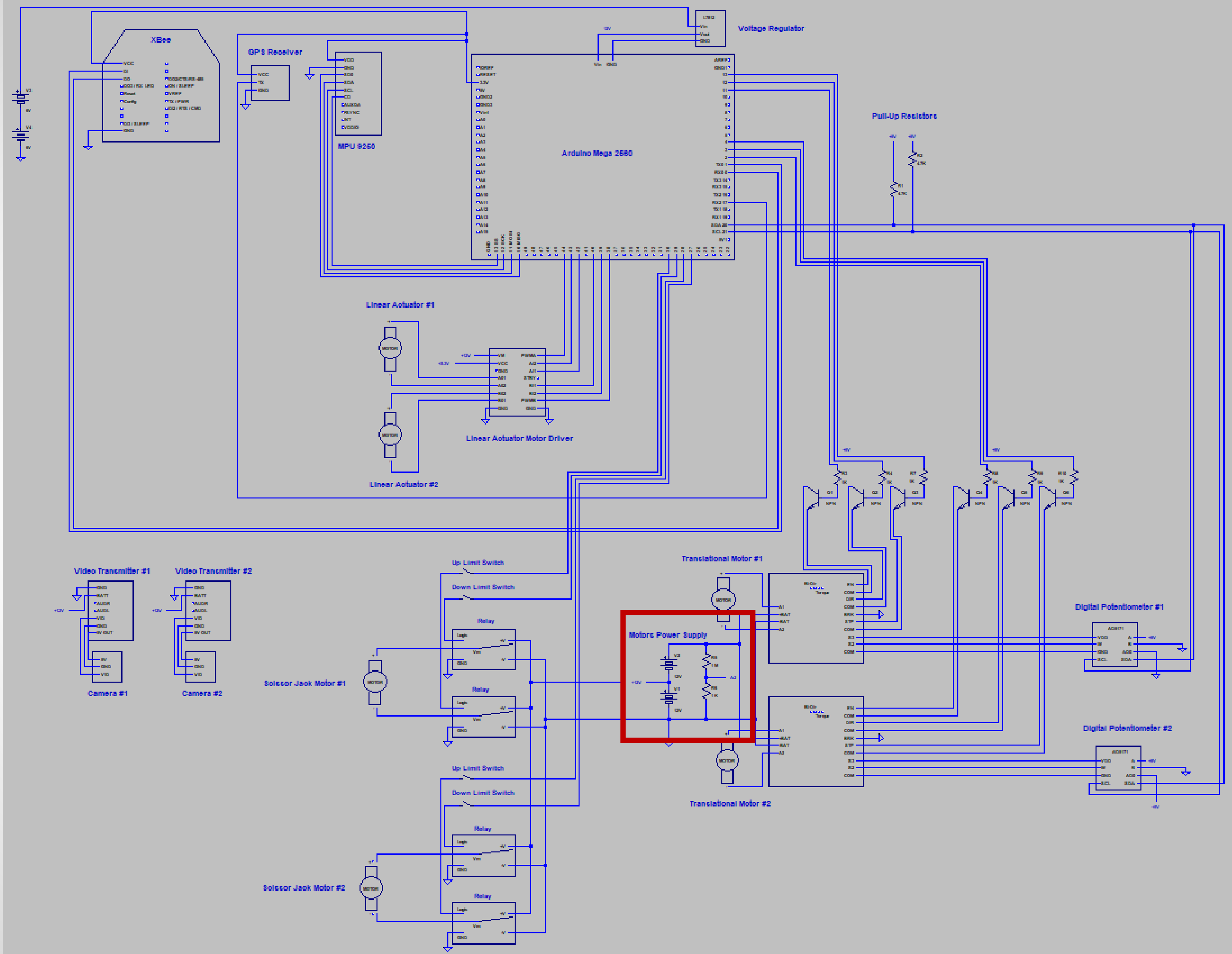
Schematic:



Specifications:

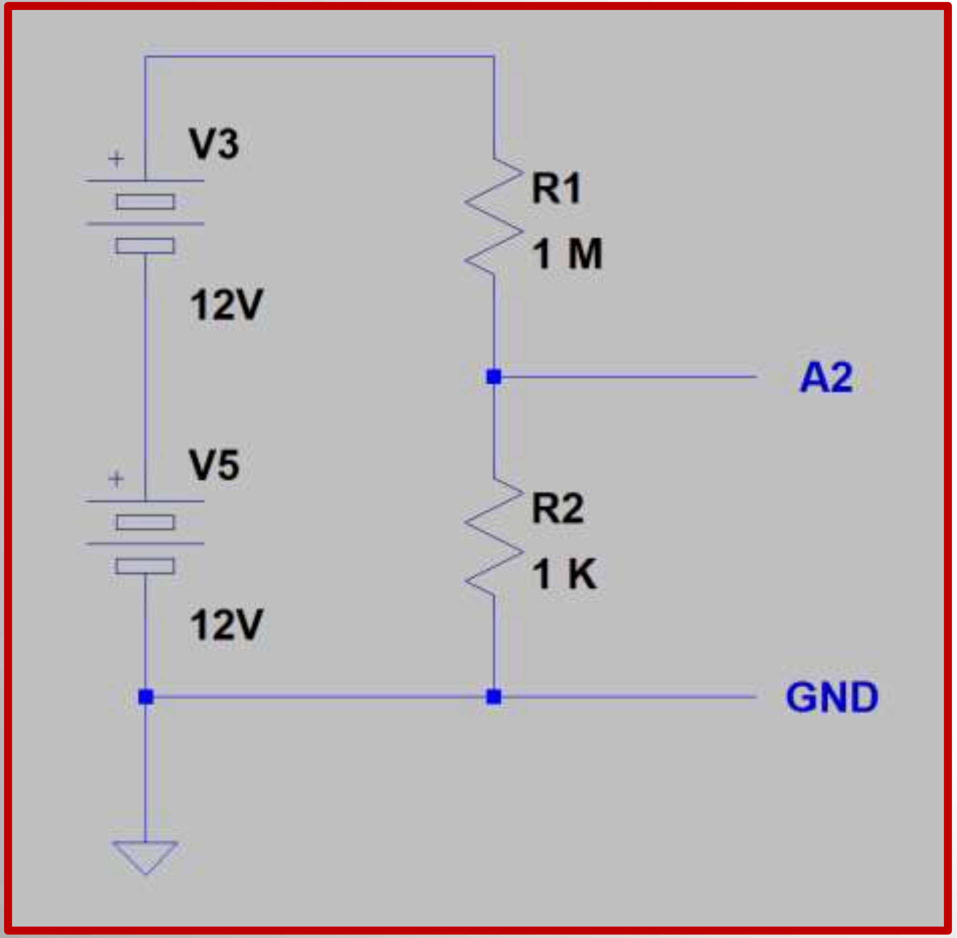
- Input Voltage & Current Draw = 26 mA at 3.3V
- Data Rate = 20 kbps
- Frequency = 900 kHz
- Power Output = 24 dBm
- Communication with Arduino Mega via TX/RX

Battery Monitoring System



Battery Monitoring System

Schematic:



Purpose: To monitor the current voltage of the translational power system in order to reduce risk of running out of power and not being able to retrieve the mother rover

Specifications:

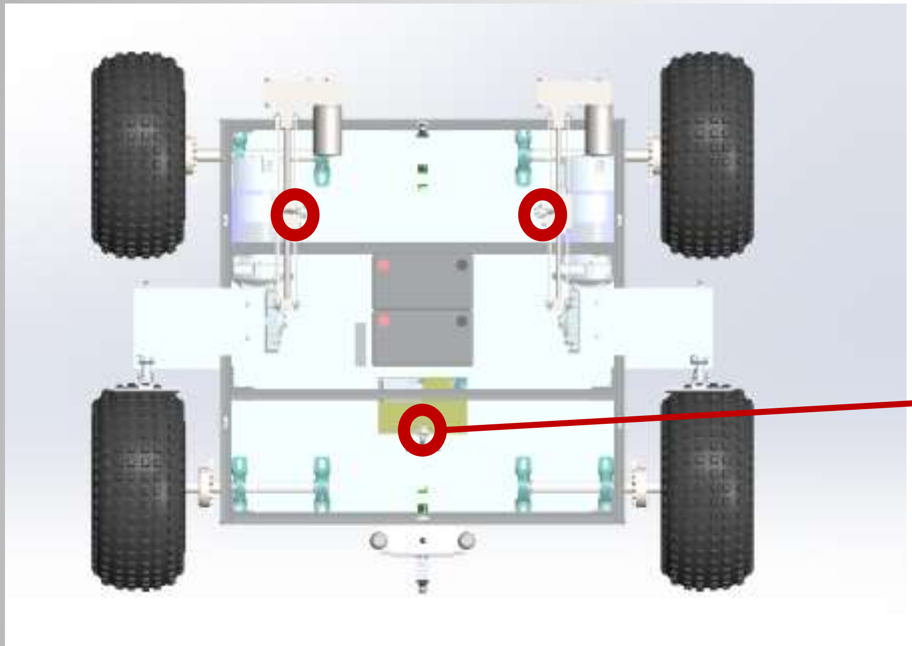
- Simple voltage divider circuit necessary to send voltage that is 5V or below to the Arduino Mega
- 10-bit ADC converts the voltage to a digital value and the value can be used to calculate the voltage using the following formula

$$V_{in} = \frac{(R_1 + R_2)V_{out}}{R_2}$$

- 1 MΩ resistor used to reduce the current flow so less power is wasted in the circuit

Leveling Subsystem

Connections of Components

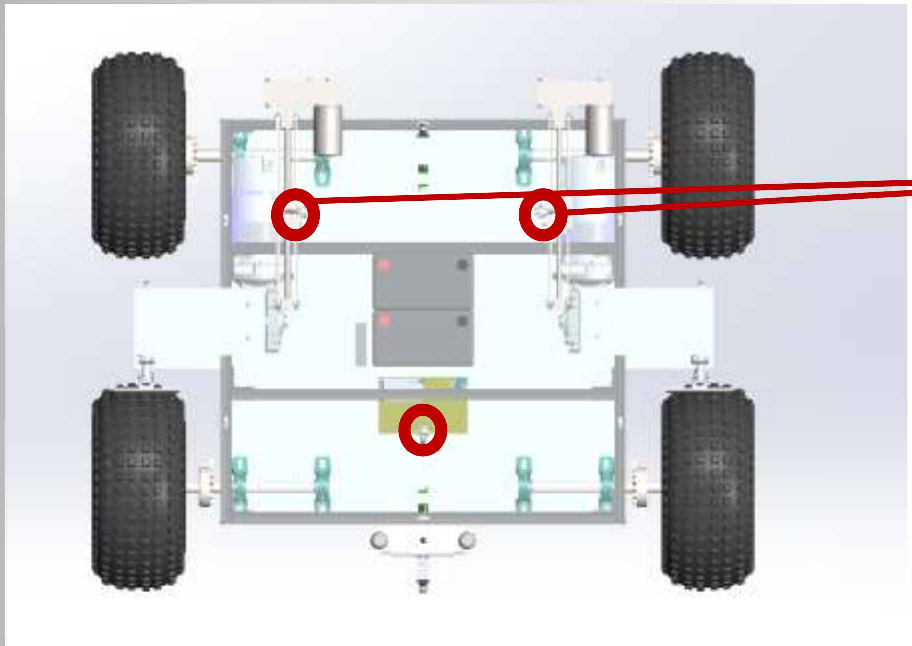


Top view of rover with connections to the LP circled in red

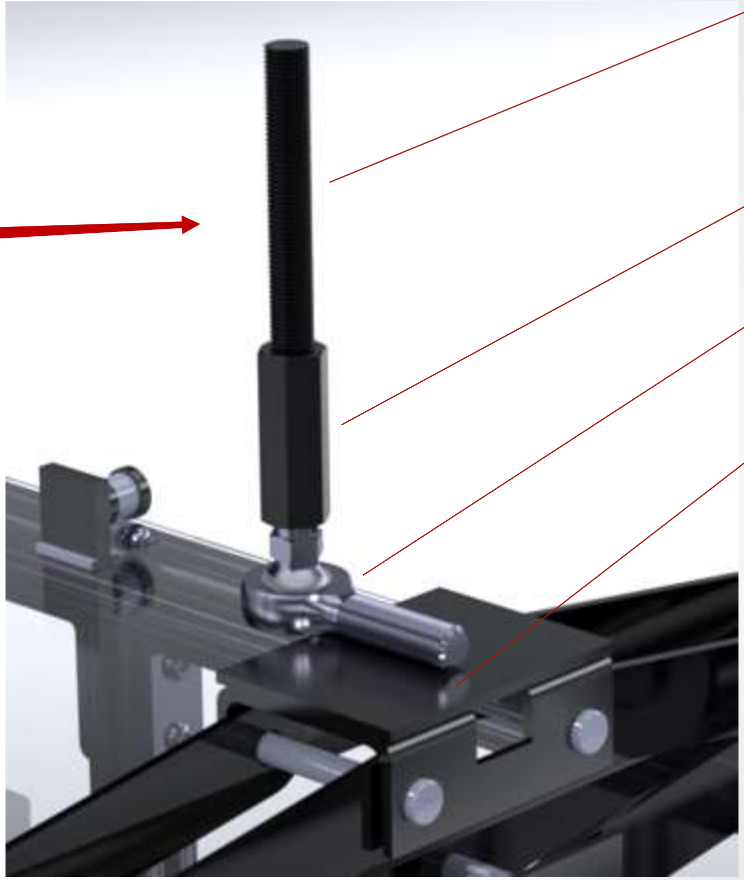
Ball joint is welded to a plate atop a section of T-slotted framing. The ball joint is mounted directly into the square tubing of the LP base.

Raised forward pivot point about which the jacks will rotate the LP

Connections of Components



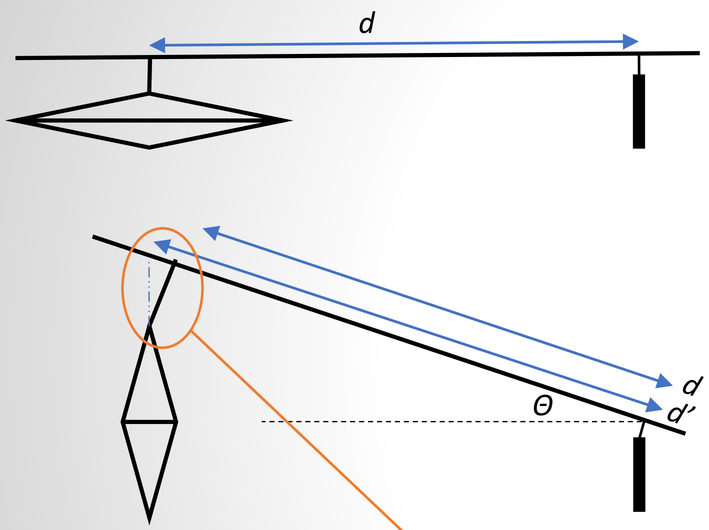
Top view of rover with connections to the LP circled in red

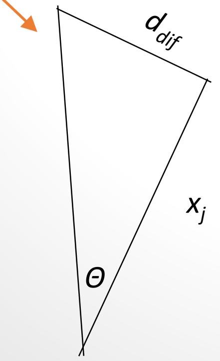


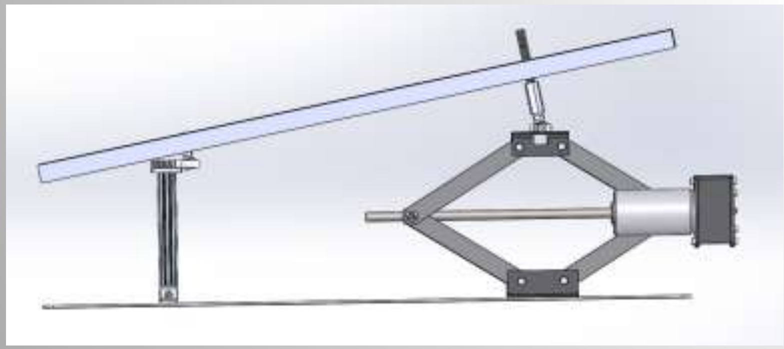
Ball joint assembly attached to the leveling jacks. Coupling nut and threaded rod provide necessary x_j distance and a means of connecting to the LP

Ball joint is welded directly to the top of the scissor jacks. The couple nut is threaded to the base of the ball joint thread, and the threaded rod into the remainder of the nut. The threaded rod is mounted into the square tubing of the LP base.

Determination of Assembly Size







- As the platform levels, the bolt assembly and LP support bar must remain perpendicular
- For this to happen, the assembly must extend past the pivot point
- The length of this extension x_j is determined through the maximum leveling angle *Θ* and the associated translational distance d_{dif} between the contact point at the jack and the LP

$$d = 21.9285\ in \qquad \Theta = 20\ degrees$$

$$d' = \frac{d}{\cos\Theta} = 23.3358\ in$$

$$d_{dif} = d' - d = 1.4073\ in$$

$$x_j = \frac{d_{dif}}{\tan\theta} = 3.8666\ in$$

Component Strength of Attachments to LP

With only three connection points to the LP, the ball joint assemblies will be subjected to large shear stresses.

Assumptions:

- Rover travelling initially at 0.5 m/s
- Deceleration in 0.1 s
- Entire weight of rover applied to single attachment

Parameters:

- Shear force on bolts at ball joints and LP connection of **332.1 lbf**
- Area of 7/16" diameter bolt is **0.15033 in^2**
- Shear stress on bolts of **2209.138 psi**

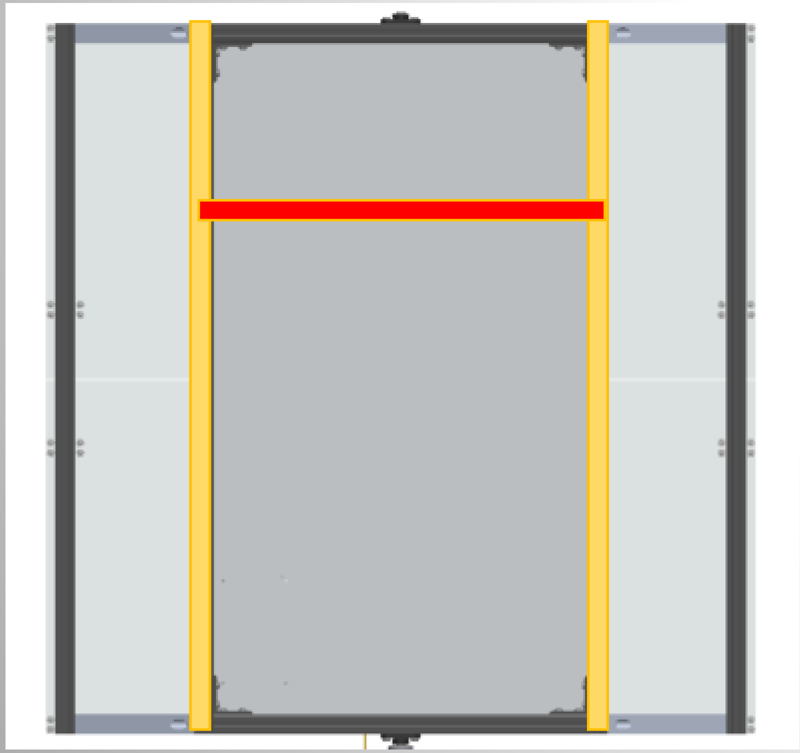
Component	Shear Rating	Safety Factor
7/16”-20 Bolts	55,000 psi	24.9
Coupling Nut	120,000 psi	54.3
Ball Joints	1,150 lb.	3.5

Results:
Components integrating the LP and rover are sufficiently strong to mitigate concerns about shearing at connections in event of sudden deceleration.

Replacement of T-slotted Framing on LP

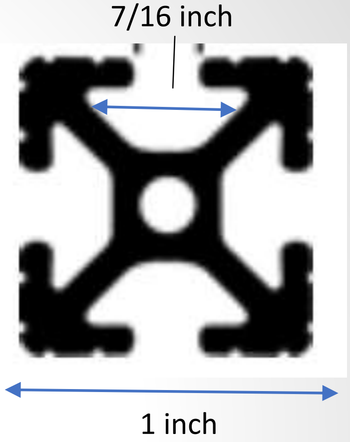
With only three points of contact, a strong connection between the LP and the leveling jacks is required.

Underside of LP

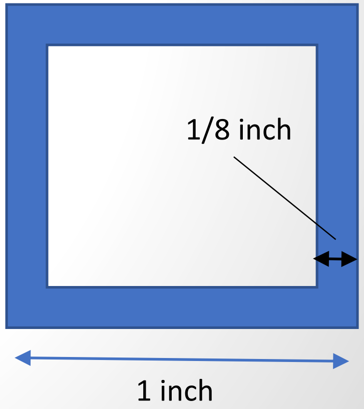


Gold bars represent bars that will be changed from T-slotted framing to square tubing.

The red bar is square tubing that will be added to the LP frame



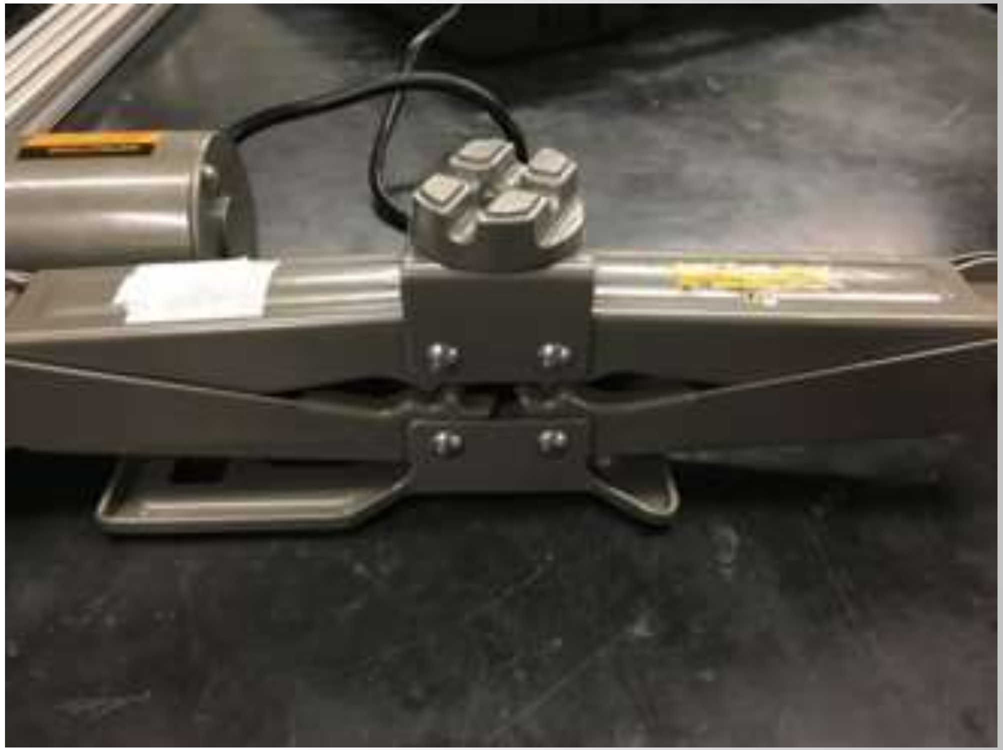
Currently used – T-slotted Aluminum Framing: 7/16" bolts drilled through compromises structural integrity



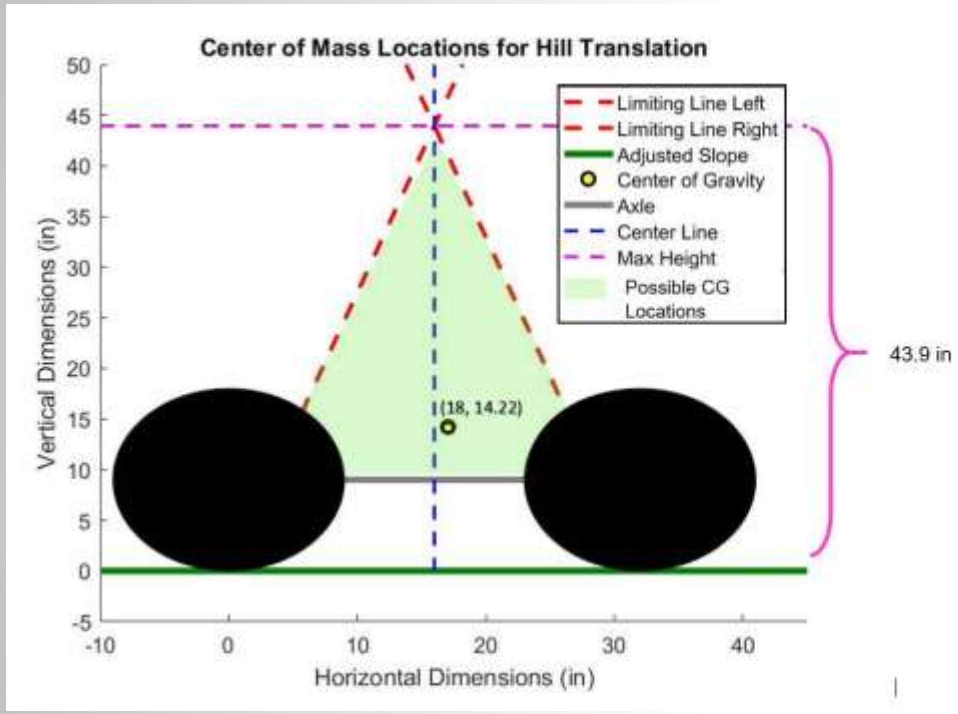
Solution - 1/8" thick Aluminum 6061 Square Tubing to reduce damage caused by drilling

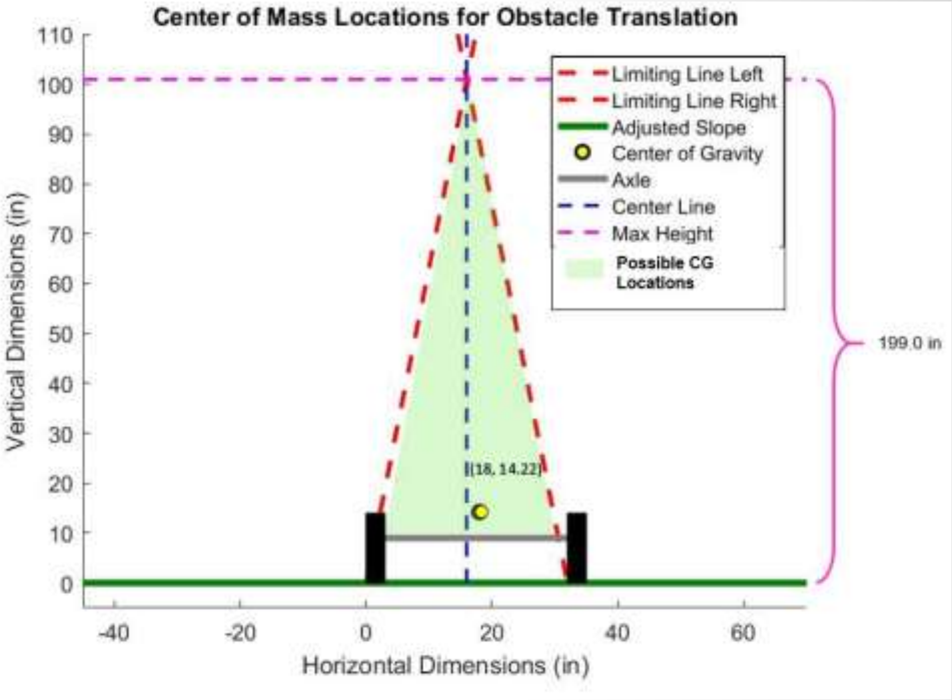
Protection of Screw From Particulates

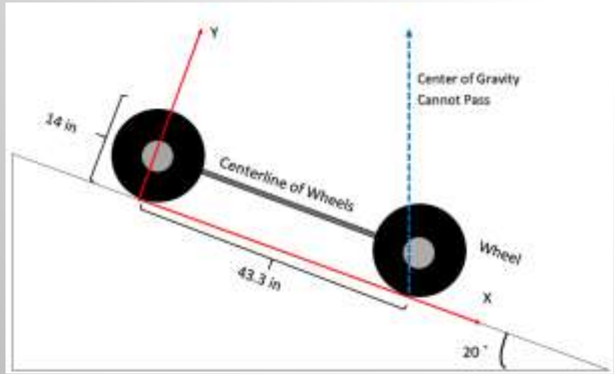
The rover will move only with the jacks at their minimum height. When collapsed, the jacks encapsulate the screw, protecting it from dust and other particulates that could adversely affect performance.

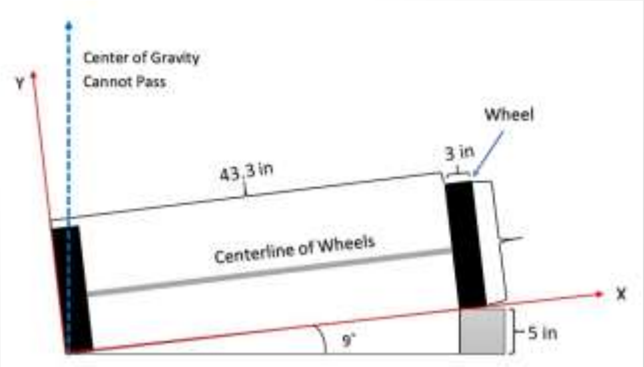


Tilting Analysis – Other Cases





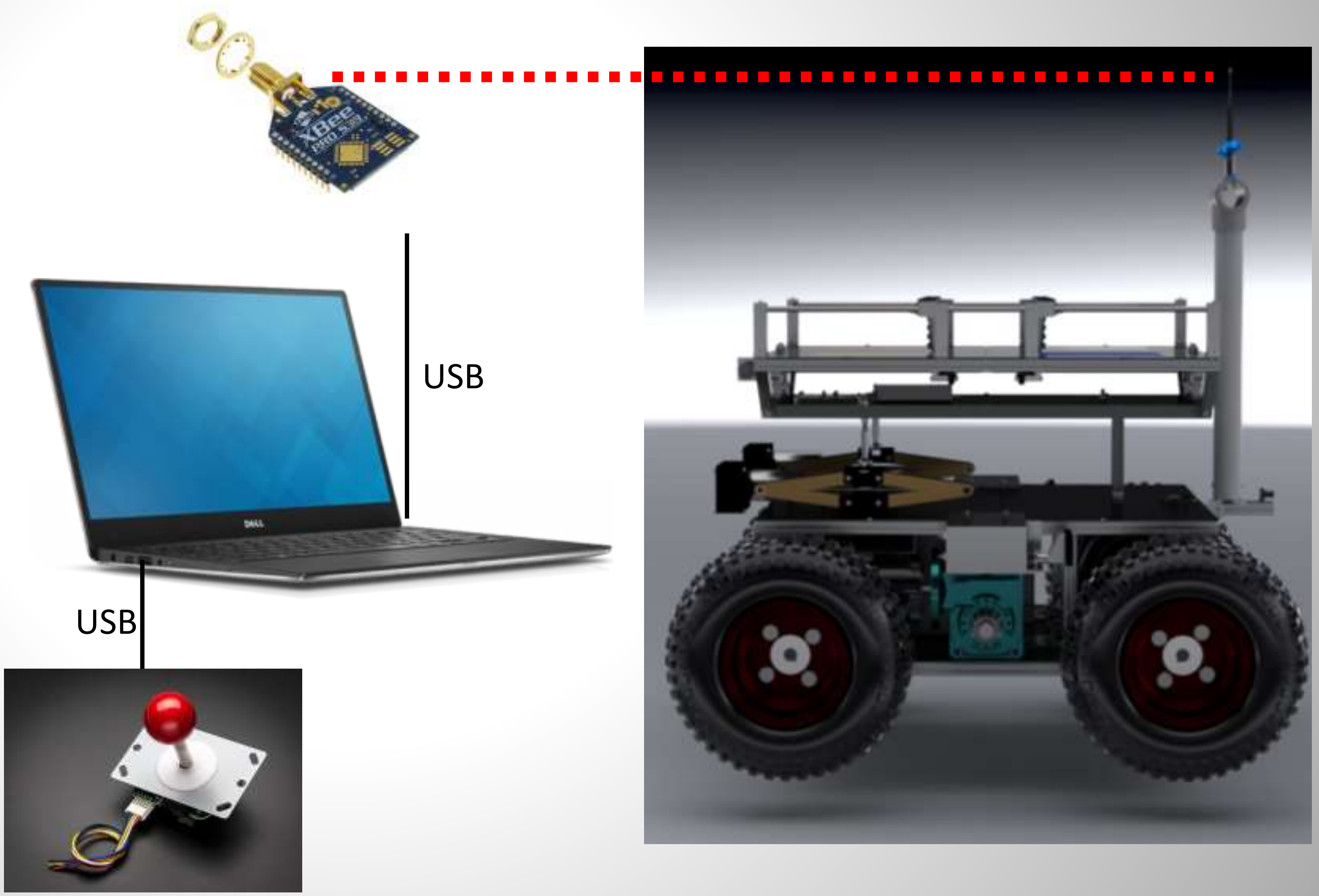




Communication Subsystem

Ground Station for Controls

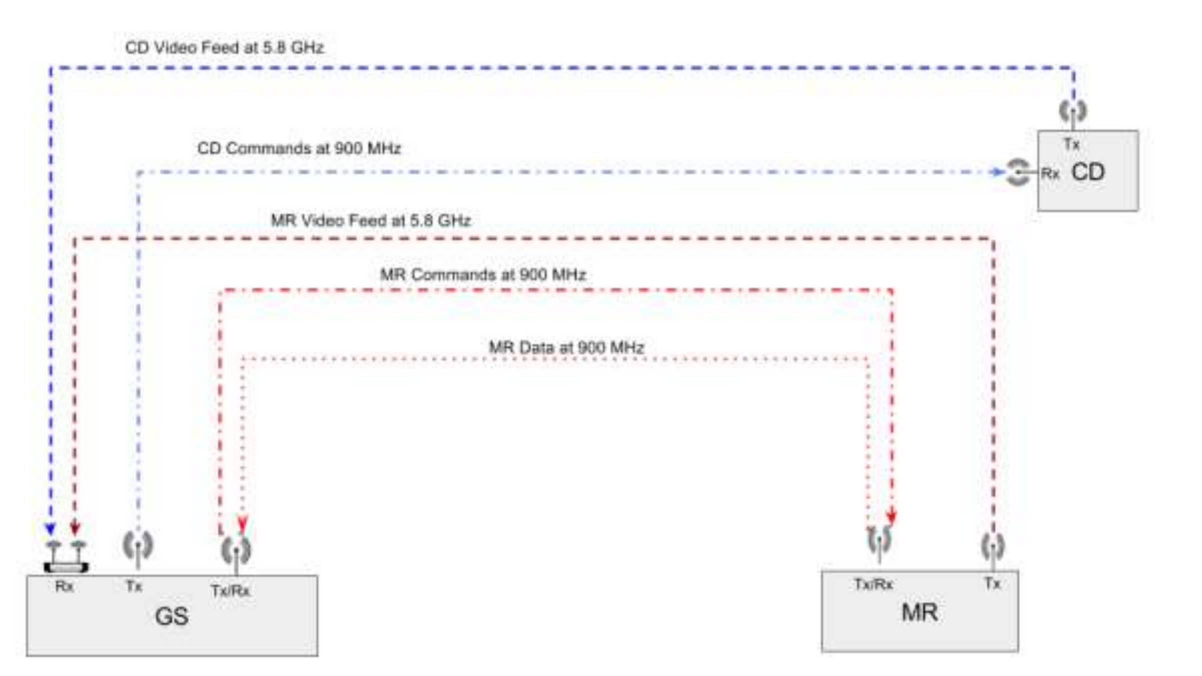
- XBee sends commands to the rover
- Commands are a combination of input from ground station computer and joystick
- All other commands and video transmission are taken care of by ground stations created by previous teams



Communications Feasibility

Baseline Design

- Existing Lines
  - CD Video Feed
  - CD Commands
- New Lines
  - MR Video Feed
  - MR Commands
  - MR Data



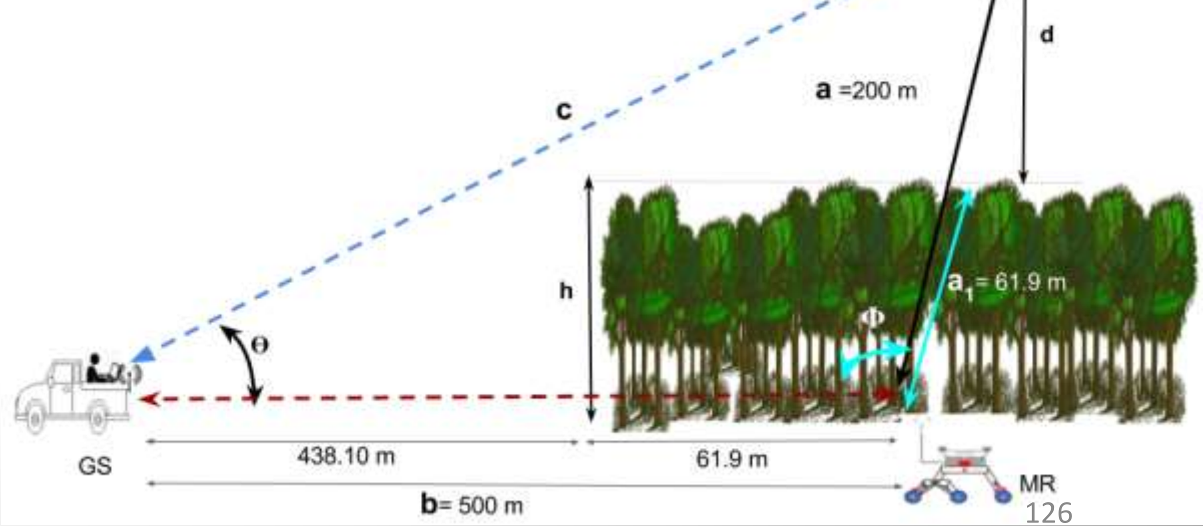
Assumptions

- The CD is high enough so that signal loss through the trees is minimal
- The MR signal is travelling partially through open space, and partially through trees

h	ϕ	ϴ	d
20 m	161.2 deg	5.35 deg	44.6 m
40 m	139.7 deg	11.2 deg	89.1 m

$$\phi = 180 - \sin^{-1}\left(\frac{h}{a_1}\right) \qquad \theta = \cos^{-1}\left(\frac{b^2+c^2-a^2}{2bc}\right)$$

$$c = \sqrt{a^2 + b^2 - 2ab\cos(\phi)} \qquad d = c\sin(\theta) - h$$



Results from Link Budget

		LINK MARGIN	COST
CD Video Feed	Downlink	35.24 dB	Antenna - $25
MR Video Feed	Downlink	38.16 dB	Antenna - $25
MR Command	Uplink	58.65 dB	XBee Pro S3B - $45 Antenna - $15
MR Data	Downlink	60.65 dB	XBee Pro S3B - $45 Antenna - $15

- **Signal loss due to 61.9 m of trees : 32.16 dB**

  - Using experimentally created models, loss due to foliage estimated to be –163.43 dB (averaged between models for similar frequencies) for 500m, not including path loss

Nonzero Gradient Model from *Radio Science Vol. 38 Iss. 5*

$$L_{tree} = R_{\infty} d + k\left(1 - e^{-\frac{(R_0 - R_{\infty})}{k} d}\right)$$

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What Is Feasible?

Possible Forest Distance?

- Link budget for 5.8 GHz at 500m produces link margin of 38.16 dB
- Radio Science's model, using link margin, and constant values for 2 GHz and 11.6 GHz, shows forest range can be from **62.3 m to 86.9 m**

5.8 GHz Band Limiting Factor

- Trees will produce a signal loss of –163.42 dB, not including free space loss.
- Free space loss of –163.43 dB occurs at range of 610.9 km, meaning a system would have to be found with an effective range of 610.9 km

Equation for free space loss:

$$L_s = 20\log\left(\frac{\lambda}{4\pi R}\right)$$

Improvements?

- Antenna array to increase gain
  - surpasses the budget restrictions
  - takes far too long to construct
- Higher power version of current system
  - Increases gain by 60+ dB
  - Pricing much higher than budget

Risks

R1 : Structural Deformation/Breakage of Drive shaft

- **Description :**
  4 drive shafts will be used to hold the entire structure and drive the entire structure. If these were to break, they could cause complete failure of the project as the system will not be able to drive.

  Likelihood : 2 **Severity** : 5 **Total :** **10**

- **Mitigation(s) :**
  1. A larger drive shaft preferably between 0.75”-1.0” is used

  Likelihood : 1 **Severity** : 5 **Total :** **5**

R2 : Wheel Slippage

- **Description :**
  The rover is required to drive over surfaces with loose gravel and steep inclines where slippage may occur and may act as an obstacle to the mission's success.

  Likelihood : 5 **Severity** : 1 **Total** : **5**

- **Mitigation(s) :**
  1. Using larger diameter wheels in order to traverse over small obstacles easily
  2. Use wheels with deep treads in order to penetrate soft surfaces
  3. Find a different route if path is too slippery

  Likelihood : 4 **Severity** : 1 **Total :** **4**

R3 : Wheel Lock Failure

- **Description :**
  The motors used for the rover system have a "locking" mechanism to hold the wheels in place when no power is supplied, but vibrations can free the motors and the wheels will roll with no way of stopping especially on a slope.

  Likelihood : 4 **Severity** : 5 **Total** : **20**

- **Mitigation(s) :**
  1. The front wheels will have linear actuators pressed against the front tires to hold the wheels in place so that they cannot rotate.

  Likelihood : 2 **Severity** : 5 **Total :** **10**

R4 : Shearing or shifting of connection to LP

- **Description :**
  Shifting or deformation of connections to LP, either through bending of joint assemblies or connection itself.

  Likelihood : 3 **Severity** : 4 **Total** : **12**

- **Mitigation(s) :**
  1. Replacing T-bars on LP with Square aluminum tubing of 1/8" to drill and screw through
  2. Ball joints of much higher strength than needed, rated for 1150 lb

  Likelihood : 1 **Severity** : 3 **Total :** **3**

R5 : Control Failure for leveling

- **Description :**
  Software, electrical, or instrumentational error leading to an inability to properly level the LP.

  Likelihood : 2 **Severity** : 3 **Total** : **6**

- **Mitigation(s) :**
  1. Writing safeguards into code to prevent over extension or retraction of jacks
  2. Set limits on what inclination leveling system can activate in

  Likelihood : 2 **Severity** : 2 **Total :** **4**

R6 : Instability of connection to MR

- **Description :**
  Wobbling of jacks or shearing of connections to platform.

  Likelihood : 3 **Severity** : 3 **Total** : **9**

- **Mitigation(s) :**
  1. Jacks are mounted around structural strong points
  2. Use additional and oversized bolts tightly fastened to prevent movement

  Likelihood : 1 **Severity** : 2 **Total :** **2**

R7 : Instability of connections to LP

- **Description :**
  Tilting or shifting or inaccuracy of leveling due to instability of joint assemblies.

  Likelihood : 4 **Severity** : 3 **Total** : **12**

- **Mitigation(s) :**
  1. Three contact points with ball joints prevent rotation or tilting without the shearing of the connections

  Likelihood : 1 **Severity** : 2 **Total :** **2**

R8: Communication Signal Loss

- **Description :**
  Messages are interrupted or misinterpreted during transmission or do not arrive at all to the MR.

  Likelihood : 3 **Severity** : 4 **Total** : **12**

- **Mitigation(s) :**

  Likelihood : 2 **Severity** : 3 **Total** : **6**

R9 : Overheating of the Motor

- **Description :**
  The DC motors used produce a lot of heat and cause the system to overheat and eventually could lead to the internal system of the motor to melt.

  Likelihood : 2 **Severity** : 4 **Total** : **8**

- **Mitigation(s) :**
  1. Leave sides of the rover body open on all sides to allow the heat from the motors to self regulate

  Likelihood : 1 **Severity** : 3 **Total** : **3**

R10 : Motor Overloads

- **Description :**
  Too much of power sent to the motor can cause the motor to overload thus destroying the internal systems.

  Likelihood : 3 **Severity** : 4 **Total** : **12**

- **Mitigation(s) :**
  1. Use motor driver that will regulate the amount of current sent to the motor

  Likelihood : 2 **Severity** : 2 **Total :** **4**

R11 : Back Drive

- **Description :**
  If the motor spins when power is not applied, the motor turns into a generator and sends current backwards into the system.

  Likelihood : 5 **Severity** : 4 **Total : 20**

- **Mitigation(s) :**
  1. Use motor driver to send back the power to the batteries during back drive

  Likelihood : 2 **Severity** : 3 **Total : 6**

R12 :Short Circuit

- **Description :**
  Wires to come apart and connect in inappropriate and unexpected places causing current to be supplied in incorrect places or directions

  Likelihood : 5 **Severity** : 4 **Total : 20**

- **Mitigation(s) :**
  1. Ensure that all connections are seal and shrink tubing is utilized.
  2. Ensure that all wire routes do not pose risk of cutting the wire by covering the structure in rubber where the wires will contact the structure.
  3. Ensure there is no wires being smashed by the motion of the scissor jack.

  Likelihood : 2 **Severity** : 4 **Total : 8**

R13 : Battery ran out

- **Description :**
  If the components draw more amps during the mission than calculated, the battery may be drawn dead and no power will be supplied to the system

Likelihood : 3 **Severity** : 5 **Total** : **15**

- **Mitigation(s) :**
  1. Constantly monitor the battery power of the system and relay that information back to the ground station.

Likelihood : 3 **Severity** : 3 **Total** : **9**

R14 : Overheated components

- **Description :**
  Components such as motors and linear actuators may overheat when they draw an excessive amount of current for a long period of time, due to a large load placed on the component

Likelihood : 3 **Severity** : 3 **Total** : **9**

- **Mitigation(s) :**
  1. Consult data sheet of component for limits on the maximum amount of time that the device may draw the maximum amount of current

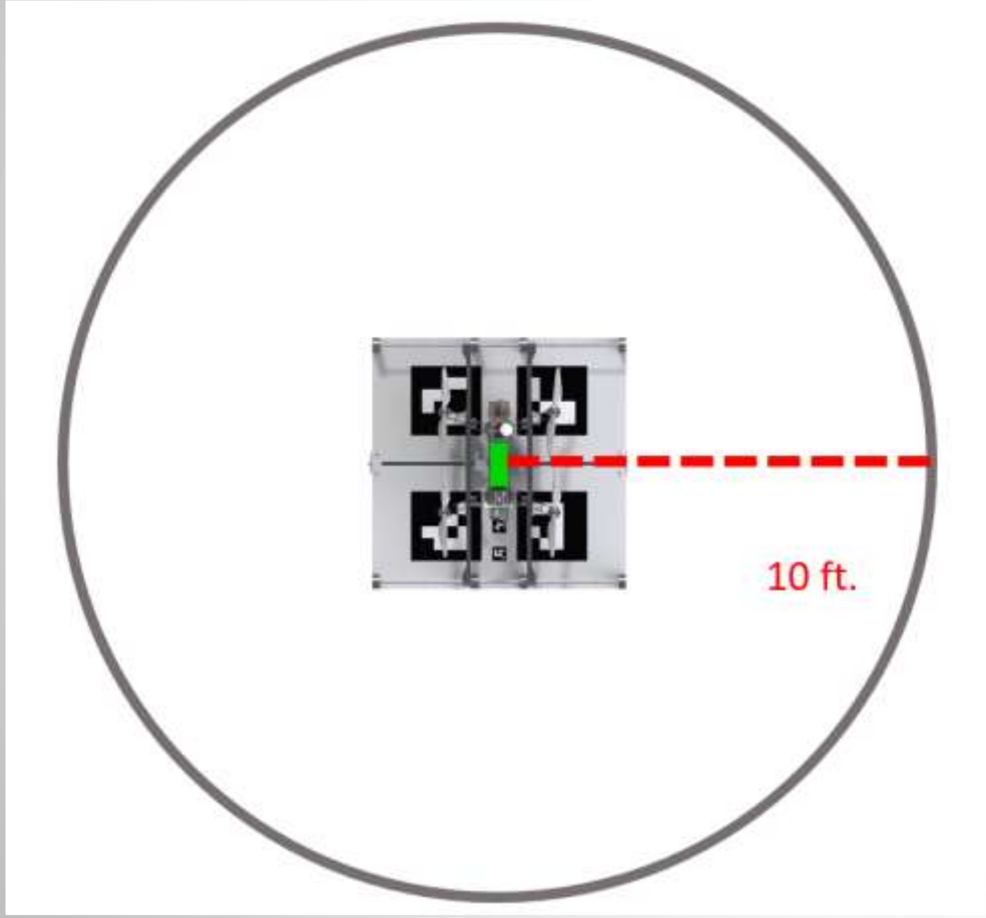
Likelihood : 2 **Severity** : 3 **Total** : **6**

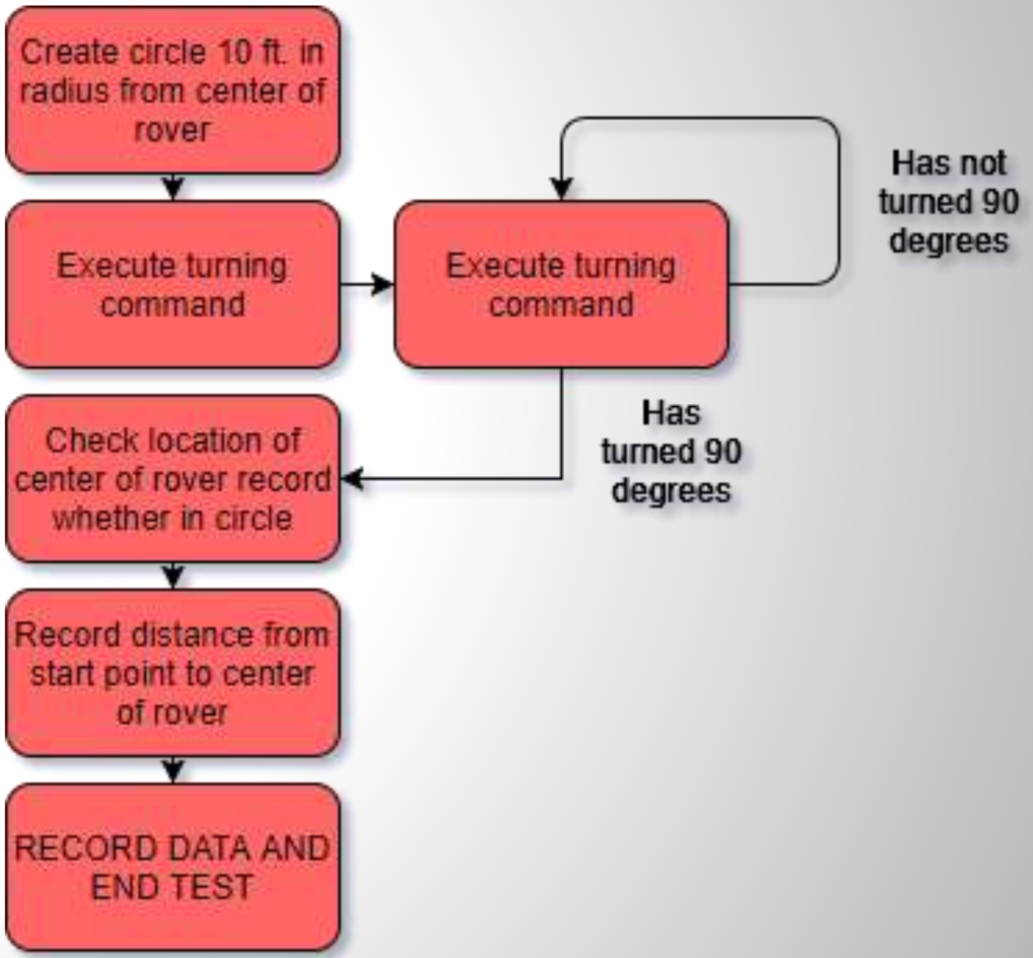
Testing

Tipping/Center of Mass Model

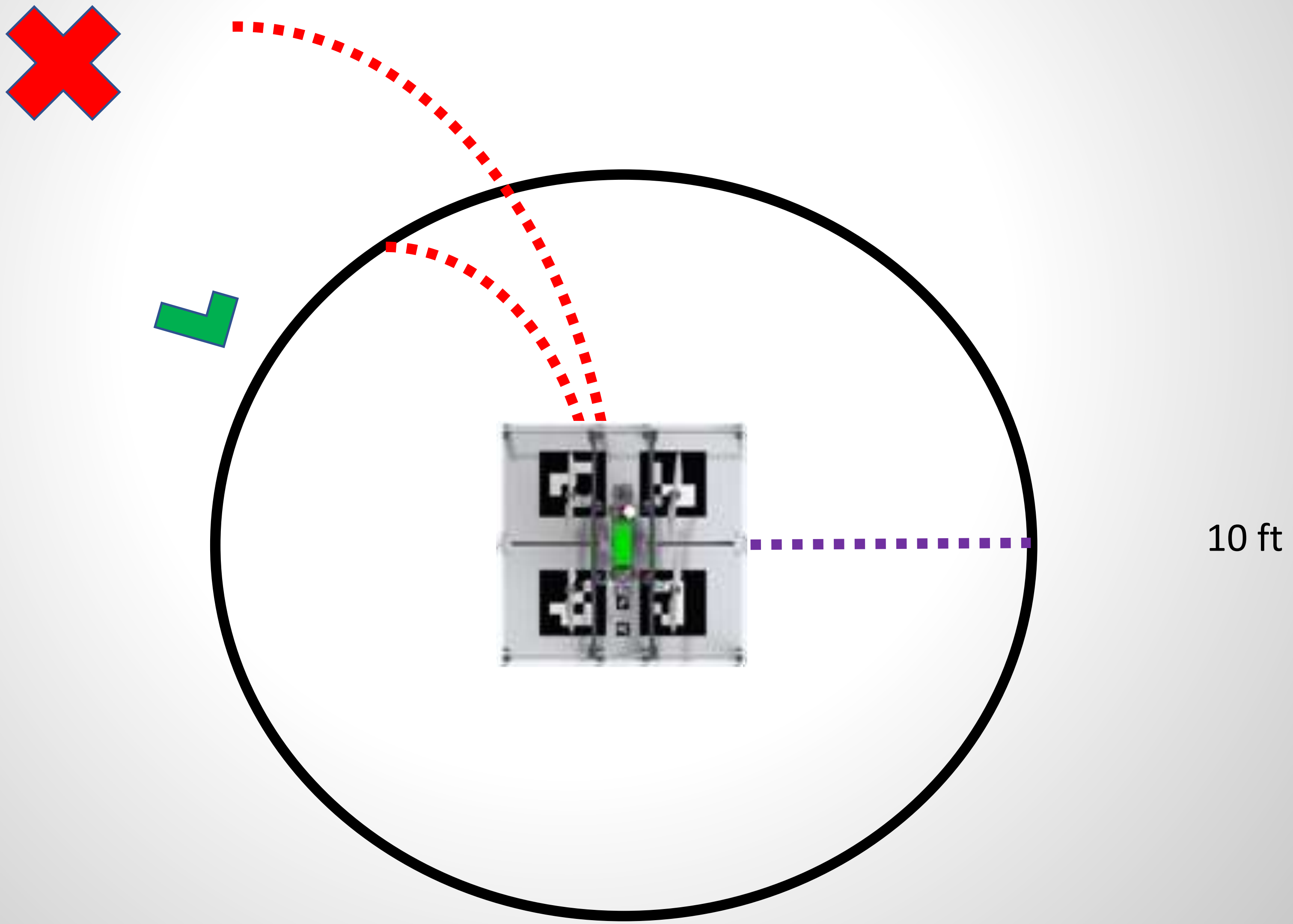
- Slowly move the rover up a 20 degree hill verify no tipping.
- Move the rover onto a 5 inch obstacle on the hill.
- Have team members with hands on the rover ready to apply a small force back toward the hill if tipping begins as only small restoring force needed to stop tip at beginning of tipping motion.
- Have team members on edges and some cushioning in the center so in case tipping cannot be stopped team members can effectively move and have the rover fall onto the cushioning.
- Verify that the 5 inch obstacles and 20 degree slope will indeed not cause a tip.

Maneuverability Test Plan

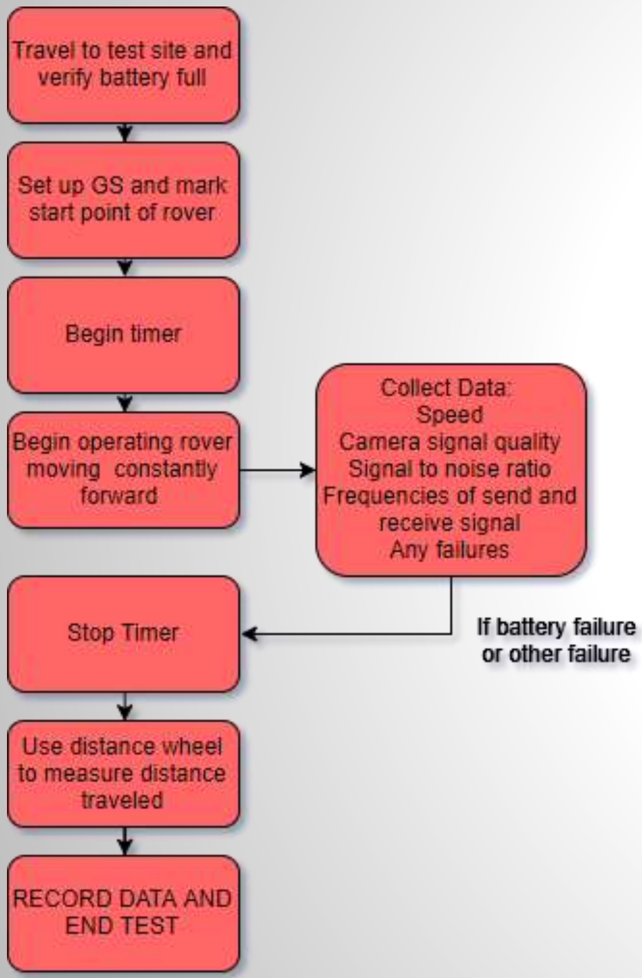




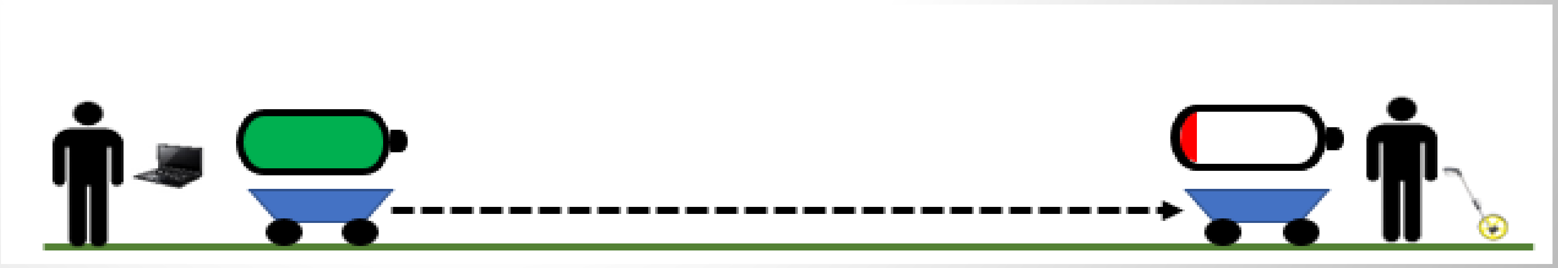
Maneuverability Animation Example



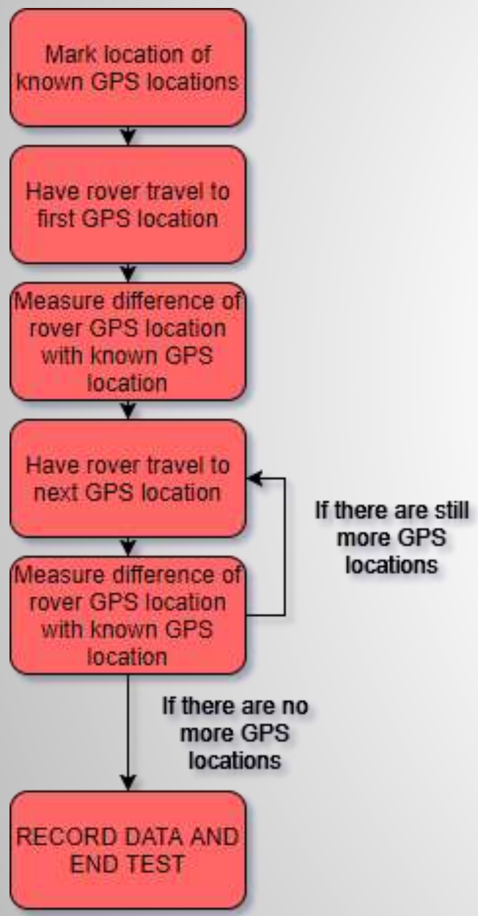
Distance



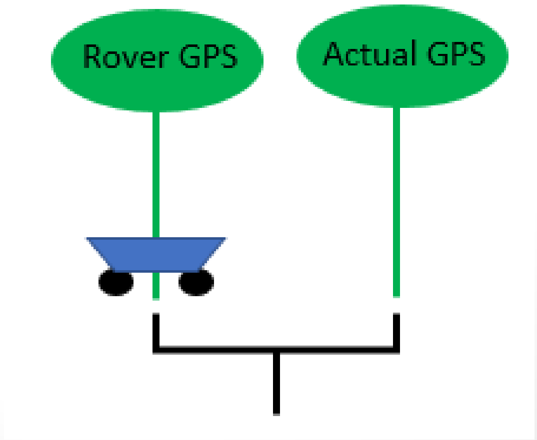
- Comes from Requirements 4.2
- Outside and inside test has similar procedure
    - Outdoor utilizes XX
    - Indoor utilizes some indoor area capable of fitting the rover. Hallways in the engineering center are a potential option and essentially any indoor area wide enough to fit the rover could work.
- Many data points taken such as speed, camera quality, signal to noise ratio (potentially dependent on indoor location), frequency of signals.



GPS Test



- Comes from Requirements 3.1
- Inside test unlikely due to GPS restriction.
- Involves finding GPS locations and comparing with the rover's GPS reading. Multiple points measured.
- Likely involve looking up precise locations using the internet and then comparing to GPS of the rover.
- Needs to be within 5m, but accuracy for many points measured to more accurately describe the accuracy of the system.



Software Verification

- Open the software and verify that the cameras are operational and interfacing with the software.
- Go through the control scheme of the rover and verify that each of the commands that can be sent are received and has the proper response.
- Find source of any error in command if they occur, and find a fix.
- Begin Test again.

Finance

Translational - $3,104.46

Part Name	Description	Manufacturer	Cost	Quantity	Discount	Shipping	Total Cost
TracGard N766 TURF Bias Tire 18X9.50-8 B/4 Ply	Tires for translation, 18 x 9.50 - 8	From Walmart	$29.83	4	0.00%	$0.00	$119.32
DWT .125 Aluminum Blue Label Wheel	Wheels for translation, 8x8	motosport	$48.99	4	0.00%	$0.00	$195.96
LIN-ACT1-02	Wheel lock linear actuator, free shipping, comes with 2 & mount bearings	Windynation	$87.99	1	0.00%	$0.00	$87.99
1370N16	Rubber pad for wheel lock	mcmaster-carr	$9.83	1	0.00%	$0.00	$9.83
GQ63-0045-RSB2S-WDE3B and GQ63-0045-LSB2S-WDE3B	gearmotors	Bison Gear & Engineering	$526.05	2	0.00%	$0.00	$1,052.10
DC60-12/24-4Q	Motor drivers	Minarik Drives	$219.80	2	0.00%	$15.75	$439.60
6280K895	motor sprockets	mcmaster-carr	$19.81	4	0.00%	$0.00	$79.24
6280K866	wheel sprockets	mcmaster-carr	$55.64	4	0.00%	$0.00	$222.56
UCP204-12, 3/4" 2-Bolt Pillow Block	mount bearings	Intech bearing inc	$13.58	8	0.00%	$0.00	$108.64
6261K175	chains	mcmaster-carr	$17.94	4	0.00%	$0.00	$71.76
1497K103	keyed shaft	mcmaster-carr	$75.70	1	0.00%	$0.00	$75.70
47065T101	44' of T-slotted bars	mcmaster-carr	$31.59	4	0.00%	$0.00	$126.36
47065T101	T-slotted framing, single rail, silver 1"x1", solid, 5 ft long	mcmaster-carr	$17.75	1	0.00%	$0.00	$17.75
47065T239	Brackets for connecting the T-slotted bars	mcmaster-carr	$5.85	36	0.00%	$0.00	$210.60
Aluminum 6061 plate	36x36 0.25", could go away with scraps	midwest	$99.69	2	0.00%	$57.66	$199.38
Aluminum 6061 plate, brake housing	24x12, 025",	midwest	$55.63	1	0.00%	$0.00	$55.63
91274A244	Bolts for reducer, pack of 25	mcmaster-carr	$8.14	1	0.00%	$0.00	$8.14
92316A552	Bolts for motor, pack of 25	mcmaster-carr	$8.63	1	0.00%	$0.00	$8.63
5537T163	Bolts for motor, pack of 4	mcmaster-carr	$2.71	1	0.00%	$0.00	$2.71
95505A602	Nuts for Reducer, pack of 100	mcmaster-carr	$4.84	1	0.00%	$0.00	$4.84
91030A028	Nuts for motor	mcmaster-carr	$1.93	4	0.00%	$0.00	$7.72
SHIPPING FROM MCMASTER	MCMASTER	mcmaster-carr	$0.00	0	0.00%	$145.00	$0.00

Leveling - $260.88

Part Name	Description	Manufacturer	Cost	Quantity	Discount	Shipping	Total Cost
EJ212 Automatic Jack	Scissor Jack, 5x17x9	Buffalo Tools	$59.79	2	0.00%	$0.00	$119.58
98957A148	Threaded rod for extending ball joint, as needed 7/16-20	mcmaster-carr	$6.23	1	0.00%	$0.00	$6.23
60645K251	Ball Joint	mcmaster-carr	$7.31	3	0.00%	$0.00	$21.93
92327A288	Bolts for base	mcmaster-carr	$2.78	8	0.00%	$0.00	$22.24
90977A190	Coupling Nut	mcmaster-carr	$4.80	3	0.00%	$0.00	$14.40
94758A645	Flange nut for 7/16-20	mcmaster-carr	$7.66	3	0.00%	$0.00	$22.98
6546K21	1/8 t al 6061 square tube 9 ft (6 ft $27.44 and 3 ft $15.92)	mcmaster-carr	$43.36	1	0.00%	$0.00	$43.36
90473A031	3/8 16 nuts 100 count	mcmaster-carr	$5.76	1	0.00%	$0.00	$5.76

Communications - $225.94

Part Name	Description	Manufacturer	Cost	Quantity	Discount	Shipping	Total Cost
5.8GHz Circular Polarized Antenna Set-T and R 90° (SMA)	Antennas for the video transmission feed	HobbyKing	$8.42	2	0.00%	$0.00	$16.84
ImmersionRC 5.8 GHz AUdio/Video TRansmitter	Transmitter for MR Video Feed	HobbyKing	$24.99	2	0.00%	$0.00	$49.98
SHIPPING FROM Hobby King	Hobby King	HobbyKing	$0.00	0	0.00%	$15.78	$0.00
XBP9B-XCST-002	XBee Pro S3B for MR Data Transmission	DigiKey International	$42.00	2	0.00%	$2.77	$84.00
RG58 Patch Cable SMA F to M (2 meter)	Cables to connect video antennas to	Amazon	$6.99	2	0.00%	$0.00	$13.98
2m RP-SMA extension cable	Cable to connect XBee to antenna on rover	?	$6.99	1	0.00%	$0.00	$6.99
ANT0906 900MHz antenna	900MHz 3.5dBi Omni GSM Antenna RP-SMA Male(female pin)	Eightwood	$8.49	2	0.00%	$0.00	$16.98
Thick-Wall Unthreaded PVC Pipe for Water: 48855K23	PVC pipe for pole	mcmaster-carr	$7.80	1	0.00%	$0.00	$7.80
Tee Connector, 2 Pipe Size Socket-Connect Female :4881K113	PVC pipe for pole, thick wall unthreaded pvc	mcmaster-carr	$4.42	1	0.00%	$0.00	$4.42
XBee shield USB dongle	GS Xbee connection	SparkFun	$24.95	1	0.00%	$0.00	$24.95

Electronics - $483.00

Part Name	Description	Manufacturer	Cost	Quantity	Discount	Shipping	Total Cost
SparkFun IMU Breakout - MPU-9250 SEN-13762 ROHS	Calculate the inclination and heading of the MR	SparkFun	$14.95	1	0.00%	$0.00	$14.95
FatShark 700TVL CMOS FPV Camera V2 NTSC/PAL	Video Camera	HobbyKing	$23.86	2	0.00%	$0.00	$47.72
Arduino Mega 2560 R3 DEV-11061 ROHS	Microcontroller Arduino Mega	Arduino	$49.95	1	0.00%	$0.00	$49.95
AD5171 Digital Potentiometer	Digital Potentiometer	Mouser	$3.46	2	0.00%	$4.99	$6.92
SparkFun Motor Driver - Dual TB6612FNG	Linear Actuator Motor Driver	SparkFun	$3.96	1	0.00%	$0.00	$3.96
Miscellaneous			$30	1	0.00%		$30.00
GPS Receiver - GP-20U7	GPS Receiver	SparkFun	$15.95	1	0.00%	$0.00	$15.95
Tenergy 6V 2000mAh NiMH RX Battery Packs	Battery to power Arduino and Sensors	Tenergy	$10.99	2	0.00%	$0.00	$21.98
Tenergy Universal Smart Charger for NiMH/NiCd Battery Packs (6'	Battery Charger	Tenergy	$17.99	1	0.00%	$0.00	$17.99
ML55-12 SLA - 12V 55 Ah	Battery to power translational system	Walmart	$110.00	2	0.00%	$0.00	$220.00
552087807	Battery Charger	Walmart	$8.58	1	0.00%	$0.00	$8.58

Admin, Shipping & Testing - $491.95

Subsystem	Part Name	Description	Manufacturer	Cost	Quantity	Discount	Shipping	Total Cost
Administrative	printing posters, paper, etc	printing	CU	$150.00	1	0.00%	$0.00	$150.00
Testing	Testbed	Testing our Rover	DRIFT	$100.00	1	0.00%	$0.00	$100.00
Shipping	Total of $400, subtracting current estimate from $400	Shipping	Drift	$0.00	1	0.00%	$241.95	$241.95

Subsystem	Part Name	Description	Manufacturer	Cost	Quantity	Discount	Shipping
Translational	DC60-12/24-4Q	Motor drivers	Minarik Drives	$219.80	2	0.00%	$15.75
Translational	Aluminum 6061 plate	36x36 0.25", shipping includes 2 items	midwest	$99.69	2	0.00%	$57.66
Translational	SHIPPING FROM MCMASTER	MCMASTER (22 items)	mcmaster-carr	$0.00	0	0.00%	$145.00
Communications	SHIPPING FROM Hobby King	Hobby King (2 items)	HobbyKing	$0.00	0	0.00%	$15.78
Communications	XBP9B-XCST-002	XBee Pro S3B for MR Data Transmission	DigiKey International	$42.00	2	0.00%	$2.77
Electronics	AD5171 Digital Potentiometer	Digital Potentiometer	Mouser	$3.46	2	0.00%	$4.99

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