ATLAS

Articulated **T**ransporter for **L**ocal **A**cquisition and **S**torage

Final Oral Review

April 20th, 2020

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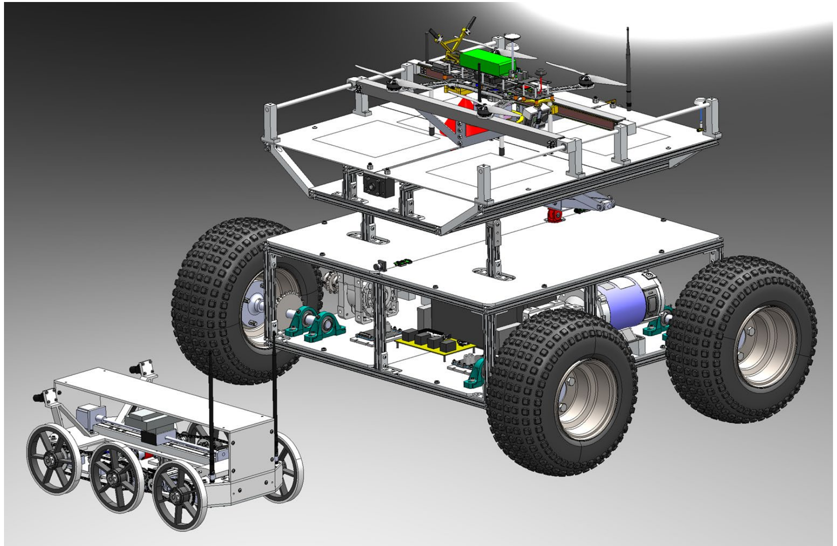
Presentation Outline

I. Project Purpose and Objectives
II. Design Description
III. Test Overview
IV. Test Results
V. Systems Engineering
VI. Project Management

Project Purpose and Objectives

Mission Statement

ATLAS shall provide the capabilities to deploy, retrieve, and store the child scout rover while maintaining the capabilities of heritage projects



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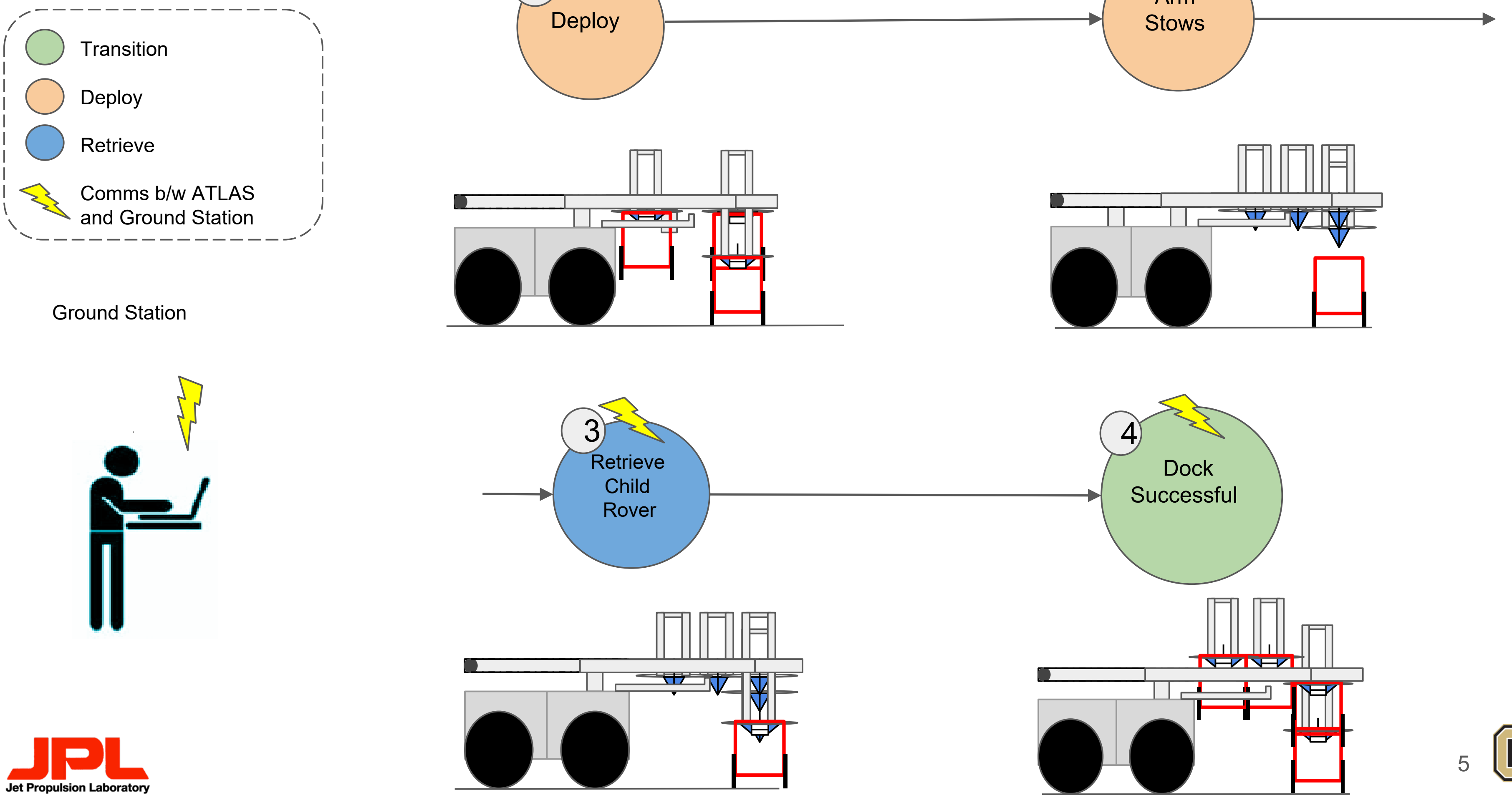


Transition
Deploy
Retrieve
Comms b/w ATLAS and Ground Station
Ground Station
1
Deploy
2
Arm Stows
3
Retrieve Child Rover
4
Dock Successful

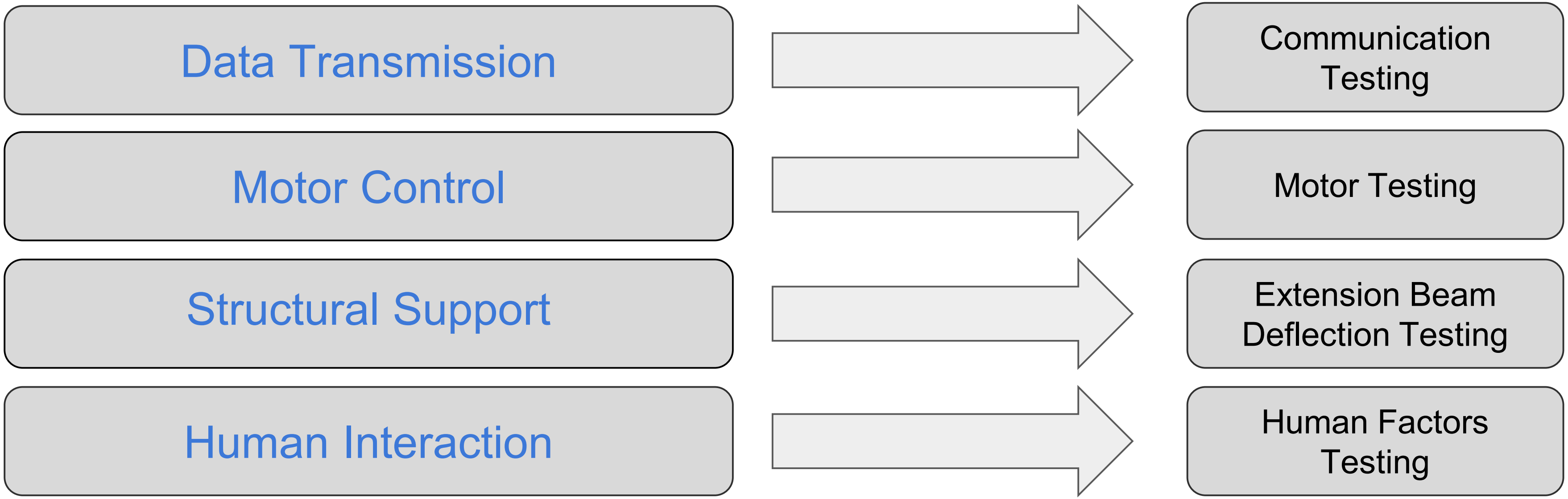
Levels of Success

Tested | Predicted

Criteria	Structure	Control	Communication	Sensors
Level 1	Deploy/retrieve the CSR on flat ground.	Control laws move motors in an intended direction.	The ground station communicates with ATLAS while 0 meters away.	Sensors provide one view of the CSR.
Level 2	Deploy/retrieve the CSR on a flat plane and carry the CSR on a flat plane	Control laws move motors, in an intended direction, with a latency less than 1 second.	The ground station communicates 250 meters away from ATLAS with 0 trees per acre.	Sensors provide visual data (100°) of the CSR from two angles (above CSR and from the MR POV)
Level 3	Deploy/retrieve the CSR on a flat plane and carry the CSR on planes between -20° and +20°.	Control laws allow for joint stationkeeping. Controls move motors, in an intended direction, with a latency less than 1 second.	The ground station communicates 250 meters away from ATLAS with ~100 trees per acre.	Sensors provide visual data (100°) of the CSR from two angles (above CSR and from the MR POV). Limit switches prevent damage by preventing frames from extending outside their operational zone.
Level 4	Deploy/retrieve the CSR on a flat plane (+/- 5° from the horizon) and carry the CSR on planes between -20° and +20°.	Control laws allow for joint stationkeeping. Control laws move motors, in an intended direction, with a latency less than 300 milliseconds.	The ground station communicates 250 meters away from ATLAS with ~170 trees per acre.	Visual camera has 120° with overlaid guidelines to guide the driving of the CSCA. Limit switches prevent damage by preventing frames from extending outside their operational zone.

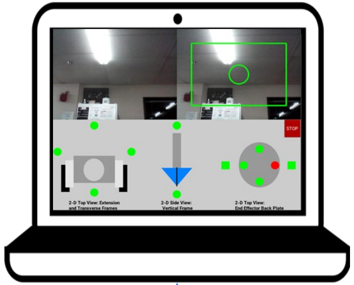
Design Description

Critical Project Elements

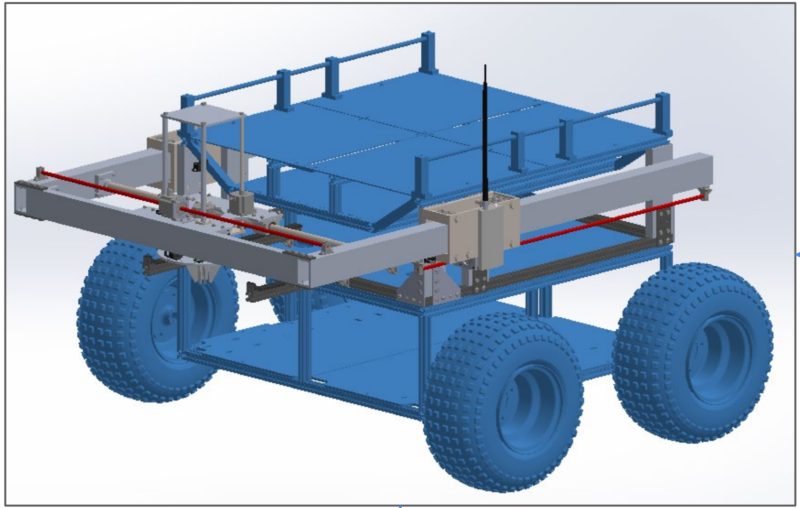


Design Overview: System Interface

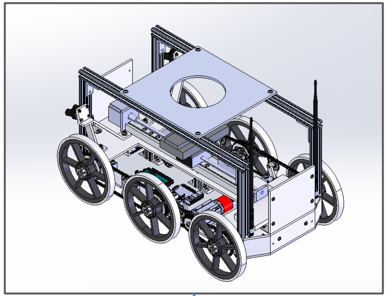
GS



MR and ATLAS



CSR w/ Interface Plate



GS Software

GS Comm. System

ATLAS Comm. System

ATLAS Software

CSR Interface Plate

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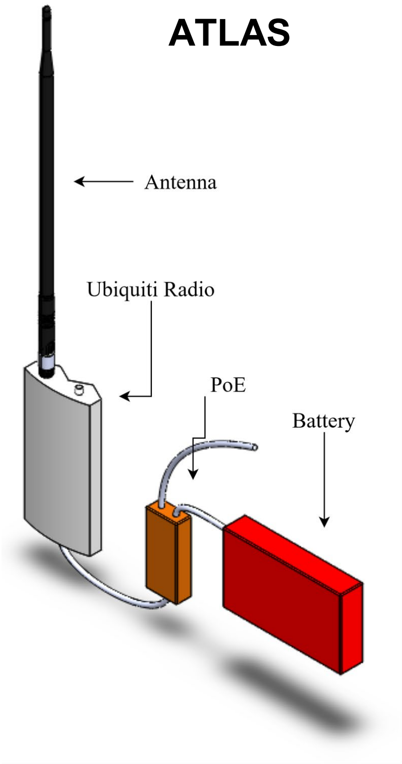
Design Overview: Communications

Purpose:

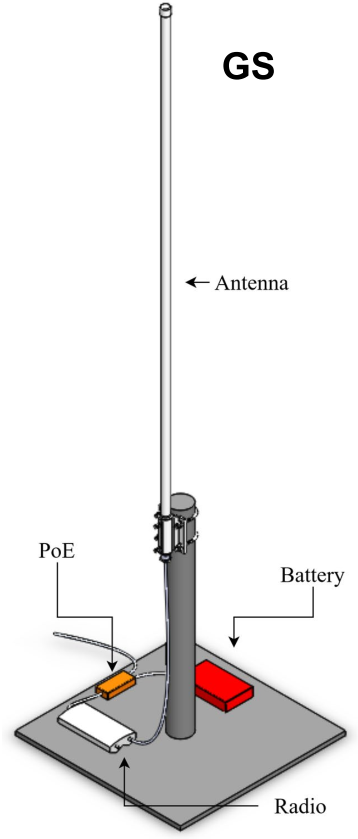
- Transmits video, sensor data, and commands between ATLAS and GS
- Enable human operator to control ATLAS

- **Radio (Ubiquiti Rocket M900)**
- **ATLAS Antenna**
- **GS Antenna**
- **Software**

ATLAS

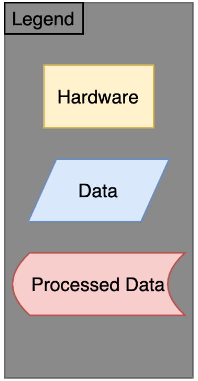


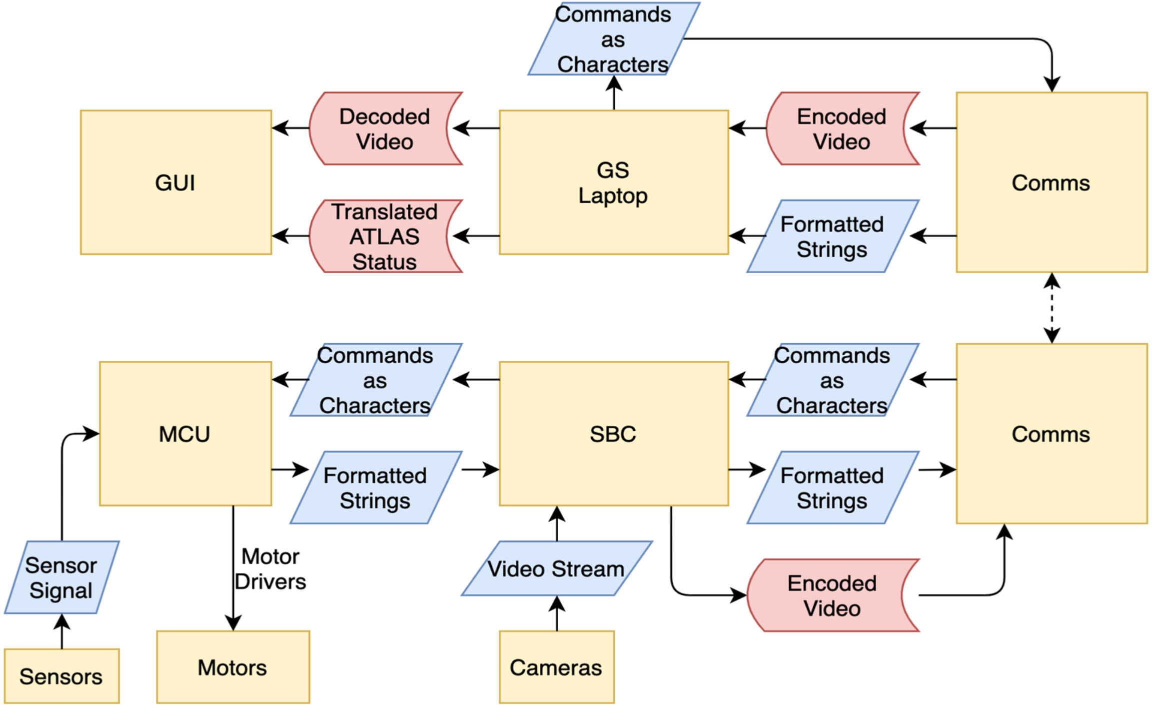
GS



Design Overview: Data Flow Diagram

- Diagram shows how commands/video are handled between hardware components, and where data is processed.





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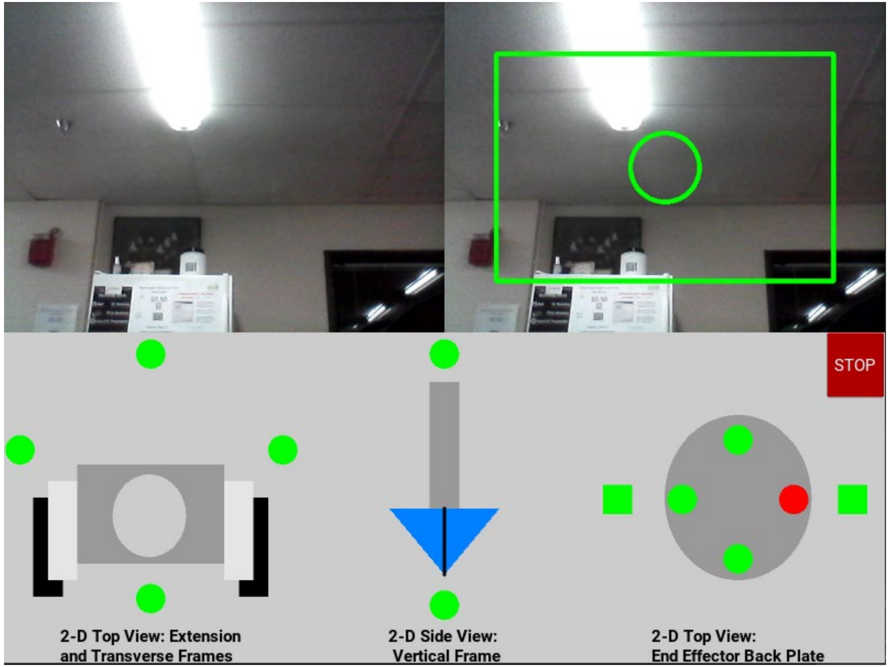
Design Overview: Human Interaction

Purpose:
- Takes user input
- Displays Status and video

- Python Kivy, Socket
- Video with guidelines
- Animated arm/CSR positions



ATLAS Ground Station User Interface

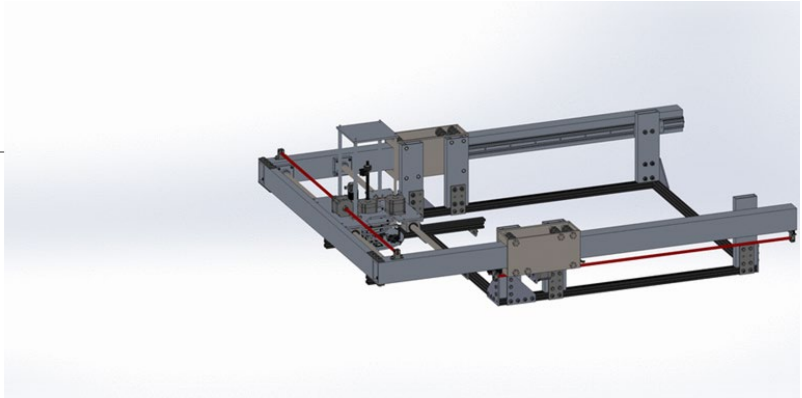
Design Overview: Hardware

Purpose:

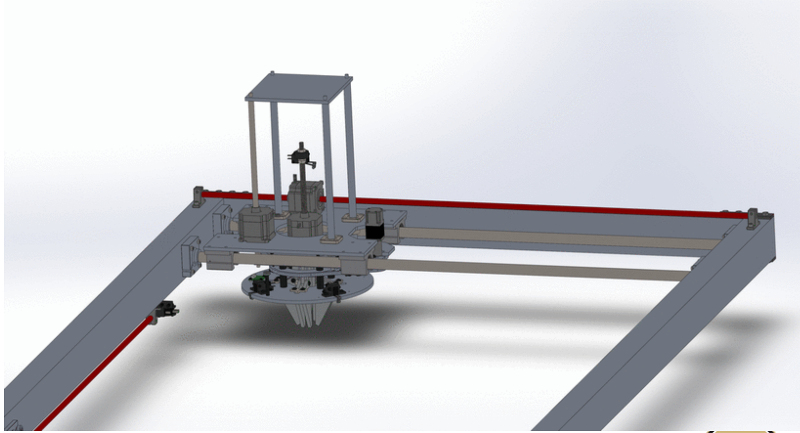
- 4 DOF
- Ability to deploy and retrieve
- Docking Location

Motor: NEMA 23 Non-Captive Motor

Frame	Weight (lb)	Size (in)	Reach (in)
Extension	95	59x43x3	40
Transverse	10	11x3x41	26.918
MR Interface	--	37x37x9.5	--
Latching Mechanism	1.248	16x1x22	15



Extension Frame



Transverse Frame

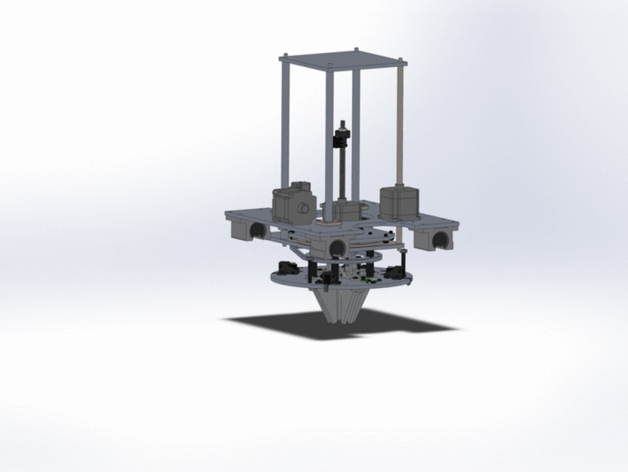
Design Overview: Hardware

Purpose:

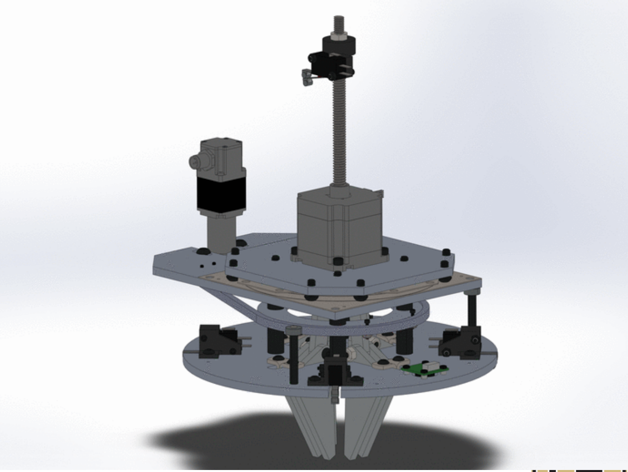
- 4 DOF
- Ability to deploy and retrieve
- Docking Location

Motor: NEMA 23 Non-Captive Motor

Frame	Weight (lb)	Size (in)	Reach (in)
Vertical & End Effector	16	12x11x18	12

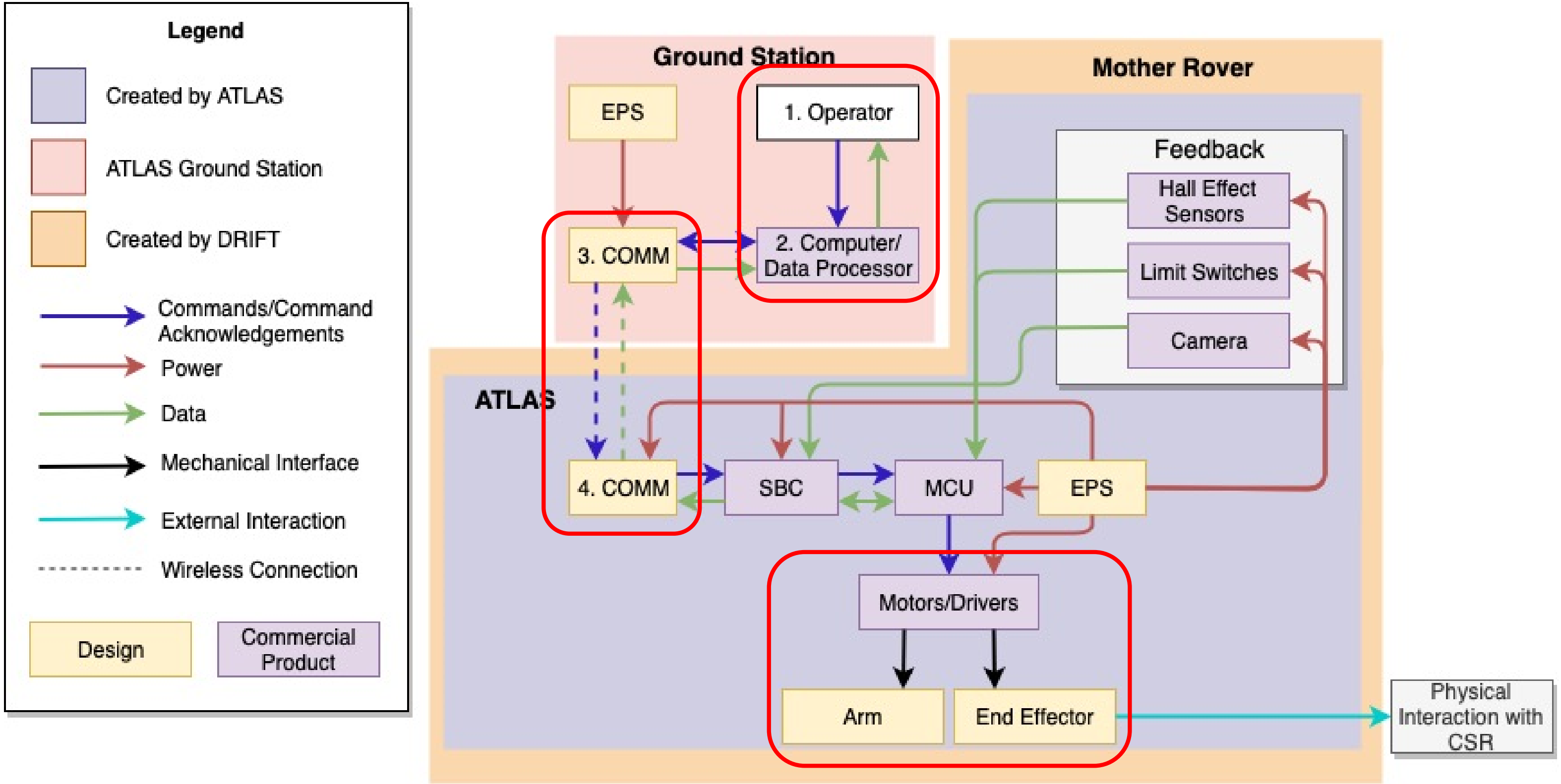


Vertical Frame



End Effector

Functional Block Diagram



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Test Overview

Completed Tests

Component Testing 2/1/2020 - 2/21/2020	Subsystem Integration & Testing 2/24/2020 - 3/20/2020
Motor Testing ❑ Motor response testing ❑ Component fit testing **Software Unit Testing** ❑ SBC Functionality ❑ Camera Transmission ❑ Arduino Functions **Sensor/Electronics Testing** ❑ Camera Resolution ❑ FOV Camera ❑ Camera FPS ❑ Limit Switches ❑ Hall Effect **Communications Testing** ❑ Ubiquiti Functionality	**Software Testing** ❑ Commands to MCU ❑ Camera Resolution/FPS **Communications Testing** ❑ Range of Communication

Planned Tests

Subsystem Integration & Testing 2/24/2020 - 3/20/2020	System Integration and Full-System Testing 3/22/2020 - 4/10/2020
Hardware Frame Testing Software Motor/GUI Testing Sensing/Electronics Integration Testing	Hardware System Testing Software System Testing Sensing/Electronics System Testing Day-in-the-Life Test

Structural Support: Extension Beam Deflection Testing

Purpose:

- Validate predicted deflection model
- Validated general assumptions
- **Tip deflection less than 0.2"**

Description:

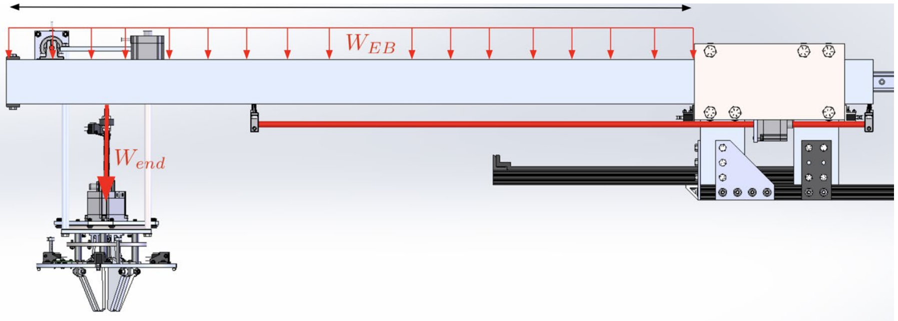
- Tip deflection at points up to 40” of extension
- Level camera
- Overlay deflection grid

Location:

- Two phases of testing
  - Unweighted
  - Weighted

Project Success:

- Safety of hardware during retrieval/deployment
- Motors able to actuate



Data Transmission: Range Test

Purpose:

- **ATLAS shall engage in two way wireless radio communication with the GS.**

Description:

- Range: 250 meters (every 10 meters)
- Video Latency
- Signal Strength
- Video Quality
- Data rate

Location:

- East Campus Walkway

Project Success:

- Level 2 Communication Success
- Baseline for Vegetation Attenuation Test

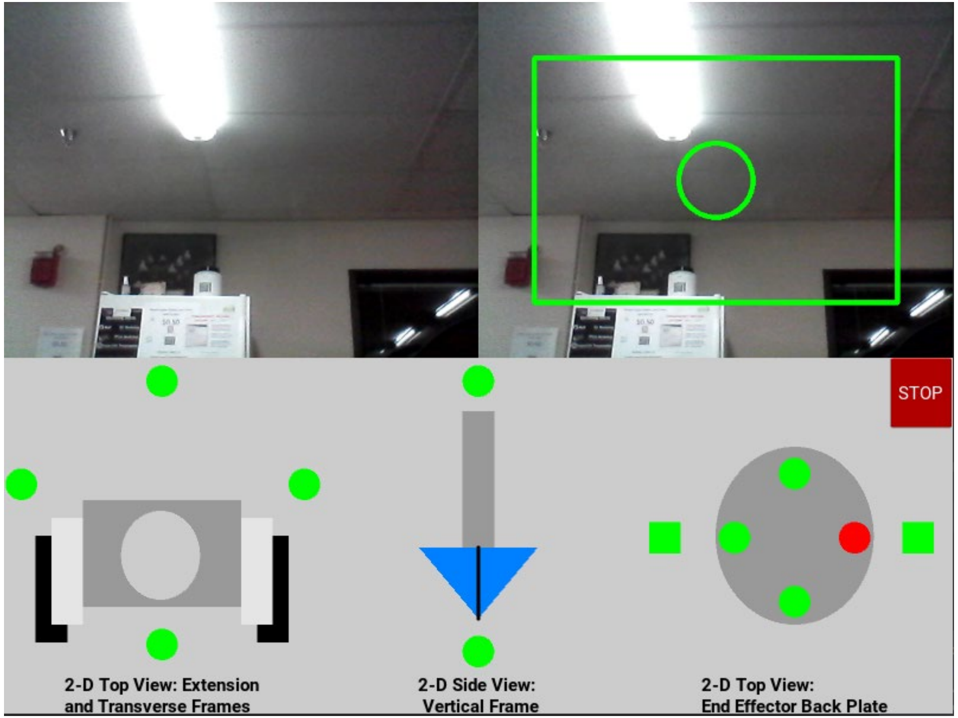
Ground Station Antenna

Human Interaction: Survey & Feedback

Purpose:
- Readability of the GUI
- **ATLAS shall perform commands that are received from the GS.**

Description:
- Laptop running Windows 10
- 10+ test subjects
- Subjective feedback

Project Success:
- Predicts Human Operator Success
- Improvements to GUI



Motor Control: Motor Component Test

Purpose:

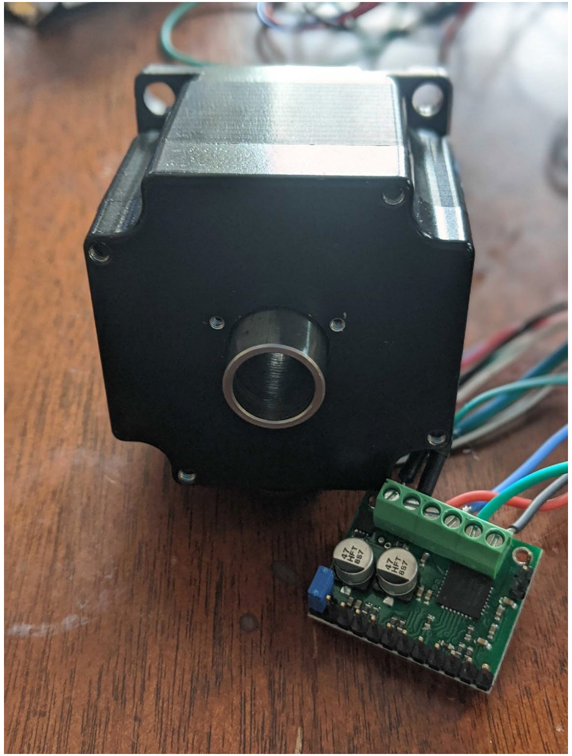
- Verify motors respond to arduino commands correctly
- **ATLAS shall deploy the CSR**

Description:

- Arduino Due, NEMA 23 Stepper motor
- Binary motor movement test
- Motor speed and direction

Project Success:

- Correct motor response to commands allows accurate and predictable control of ATLAS



NEMA 23 motor & motor driver

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Test Results

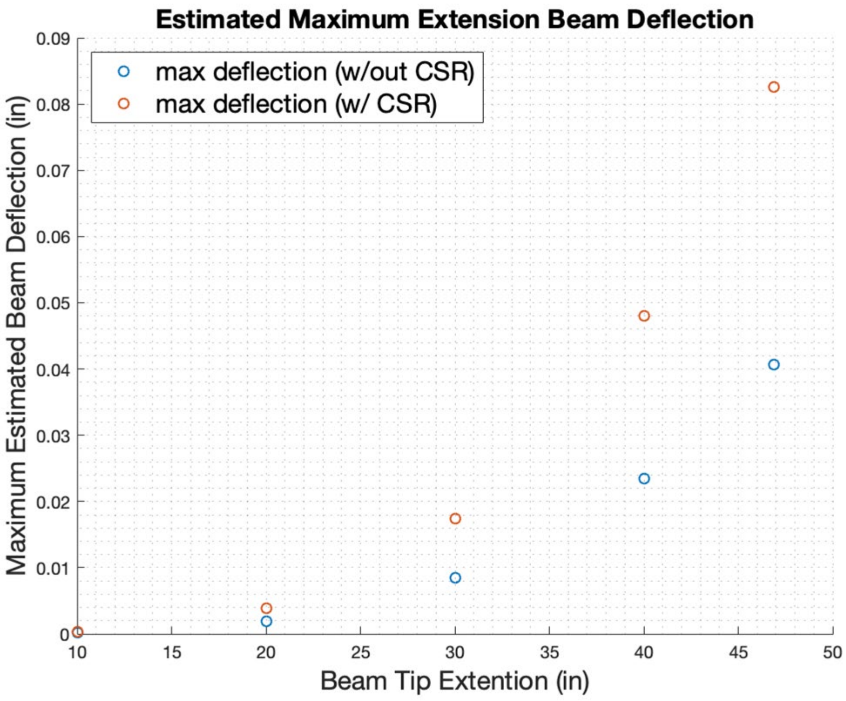
Structural Support: Extension Beam Deflection Testing

Procedure:
- Instrumentation: camera

Data to be collected:
- Tips deflection at various extensions
    - Weighted and unweighted

Requirements to be validated:
- **Deploy and retrieve the CSR**
- **Tip deflection less than 0.2"**

Models to be validated:
- Predicted deflection from beam bending analysis



Structural Support: Extension Beam Deflection Testing

	Unweighted			Weighted		
Tip Extension	Requirements	Expected	Result ± uncertainty	Requirements	Expected	Result ± uncertainty
10”	<0.2”	0.0001”		<0.2”	0.0003”	
20”	<0.2”	0.0019”		<0.2”	0.0039”	
30”	<0.2”	0.0085”		<0.2”	0.0175”	
40”	<0.2”	0.0235”		<0.2”	0.0480”	
46.875” (max)	<0.2”	0.0406”		<0.2”	0.0826”	

Key: Not yet Performed

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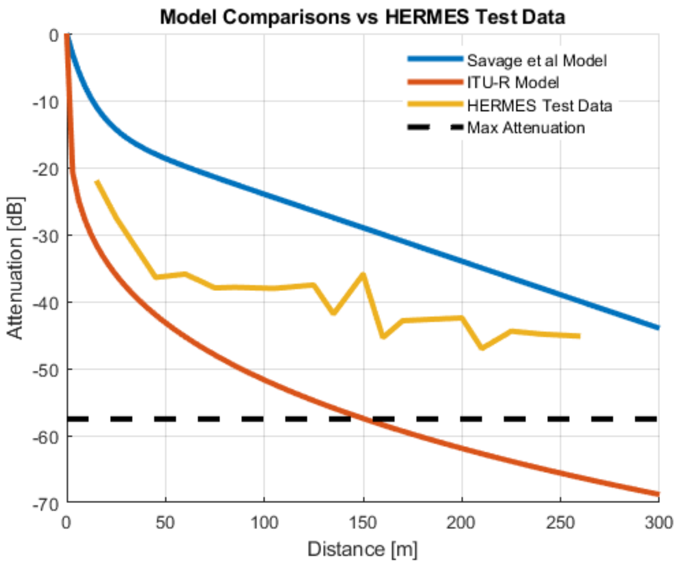
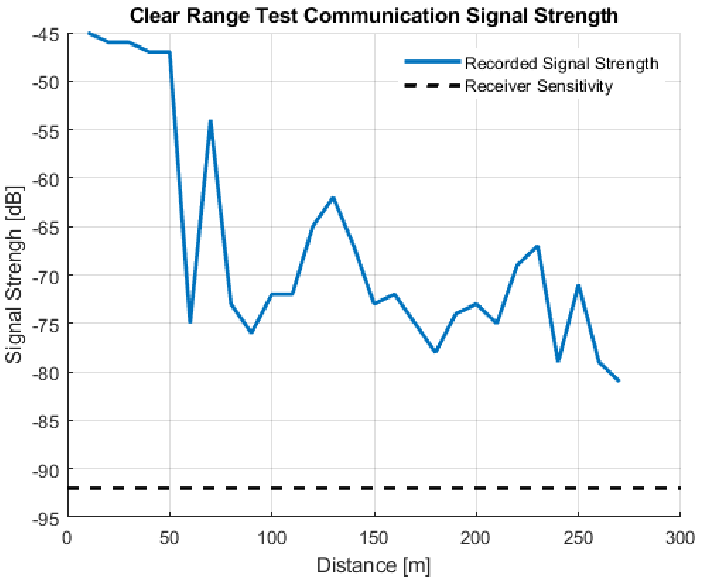
Data Transmission: Attenuation Model

- Vegetation attenuation modeled
- Compared to Heritage data
- *Attenuation = Clear Signal Strength - Vegetation Signal Strength*





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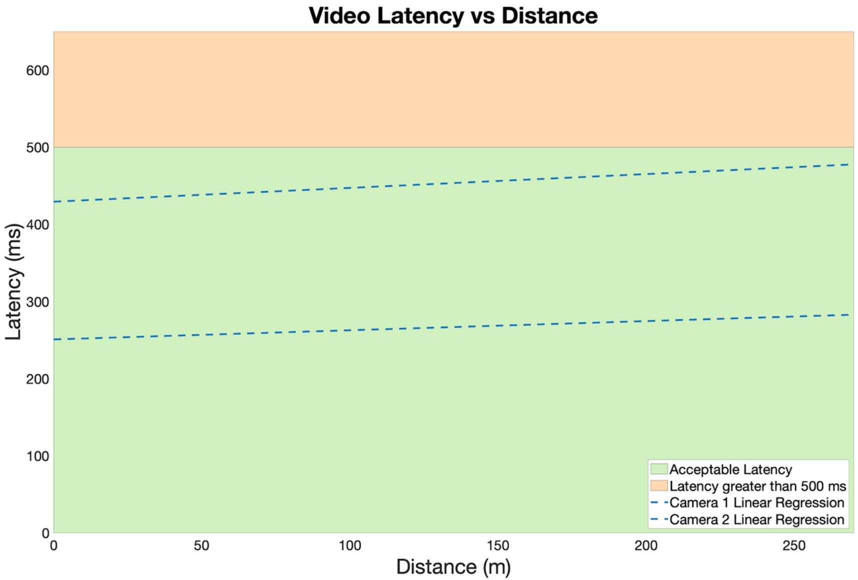
Data Transmission Expected Data

- 70 ms of resolution due to camera frame rate
- Positive correlation between distance & latency



Expected Data

Data Transmission: Range Test

	No Vegetation			Vegetation		
	Requirement	Expected	Result ± uncertainty	Requirement	Expected	Result ± uncertainty
Signal Strength	>8 dB Margin	>8 dB Margin	New Data needed	> 8 dB Margin	> 8 dB Margin	
Video Latency	<500 ms	<300 ms	New Data needed	<500 ms	<500 ms	
Command Latency	<500 ms	<300 ms	11.6 ± 16.5 ms	<500 ms	<500 ms	
Maximum Data Rate	<6 Mbps	<6 Mbps	2.74 ± 0.32 Mbps	<6 Mbps	<6 Mbps	

Key:

Not yet Performed	Satisfied	Not Satisfied

Human Interaction: Survey & Feedback

Procedure:

- Tutorial for subjects
- Interact with GUI

Data:

- Verbal Subjective Feedback

Requirements:

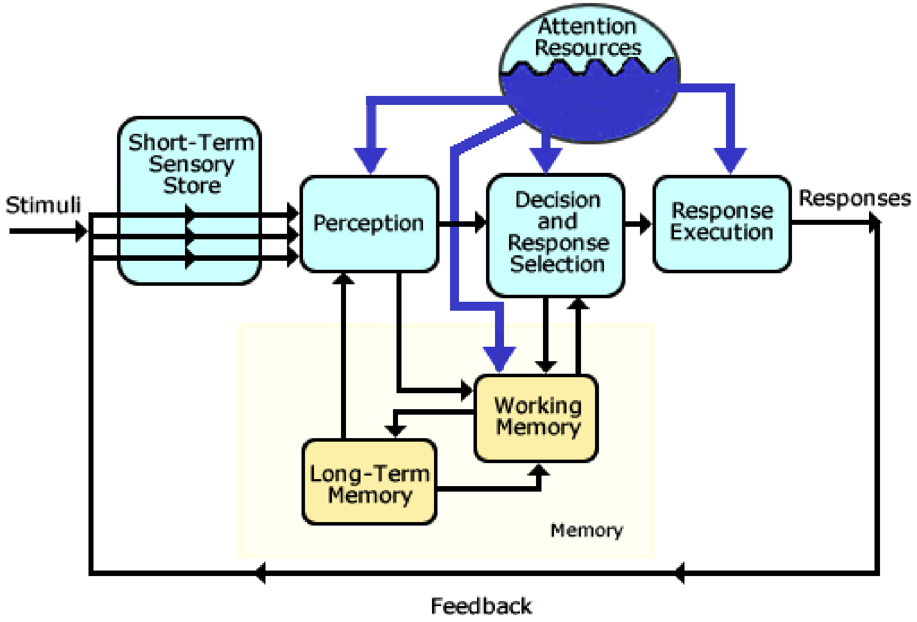
- **The ground station shall have a user interface.**

Models Validated:

- Human Info. Processing
- Guidelines for Selective-Attention Tasks

Engineering reasoning:

- Human Factors in Engineering & Design
- Performance and training in human-machine systems



Human Factors in Engineering & Design 7th Edition

Motor Control: Vertical Fram

Procedure:

- Instrumentation: Accelerometer, stop watch

Data:

- Motor speed

Requirements:

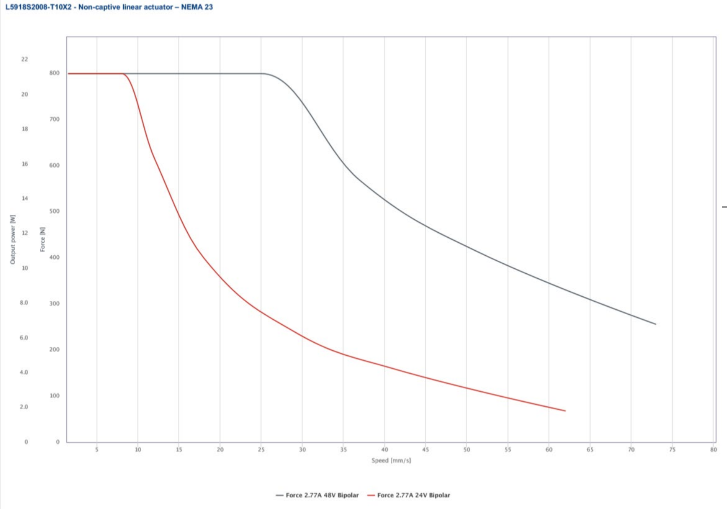
- **ATLAS shall be able to retrieve and deploy the CSR**

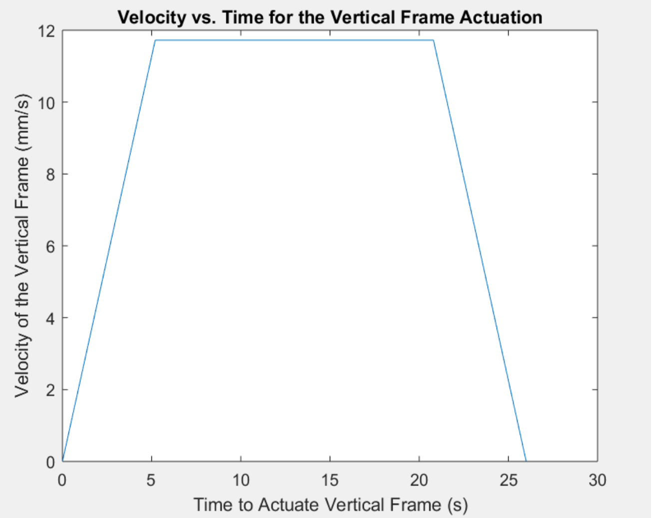
Models Validated:

- Predicted speed curves

Engineering reasoning:

- Motors running within safe force and speed bounds
- Long motor life





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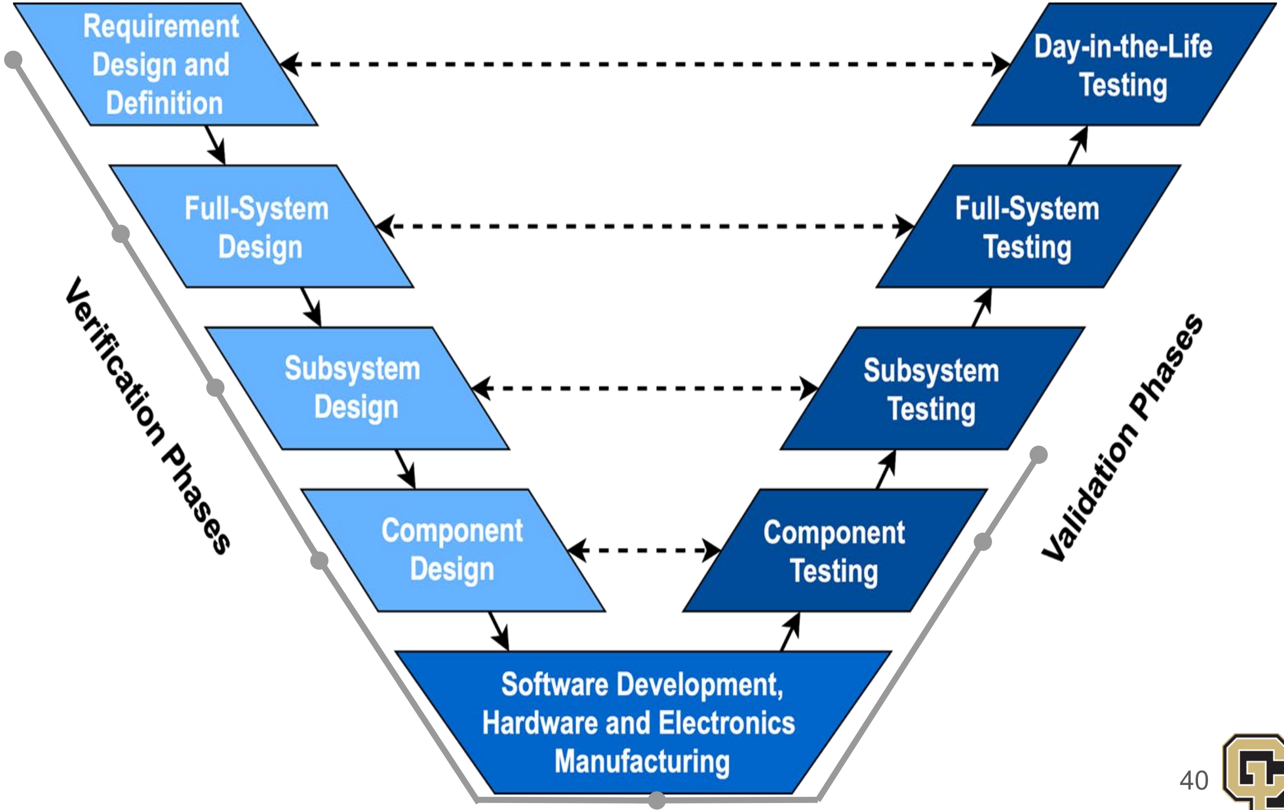
Motor Control: Vertical Frame Test

	Unweighted			Weighted		
Total Time to Actuate (s)	Requirement (max velocity, mm/s)	Expected (max velocity, mm/s)	Result ± uncertainty	Requirement	Expected	Result ± uncertainty
26	N/A	11.72	[redacted]	N/A	11.72	[redacted]
30	N/A	10.16		N/A	10.16	

Systems Engineering

Trade Studies and Requirements

- Trade Studies
  - Types of Arms
  - End Effector
  - Communications
  - Software
  - Human Interaction
- Requirements
  - Several permutations
  - Ran draft requirements by customer and PAB to improve them

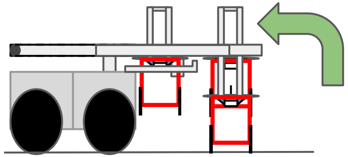


Requirement Evolution

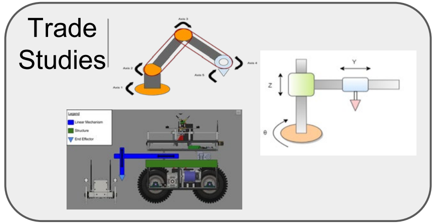
Level 0 - Mission

Mission Statement: ATLAS shall provide the capabilities to deploy, **retrieve**, and store the child scout rover while maintaining the capabilities of heritage projects

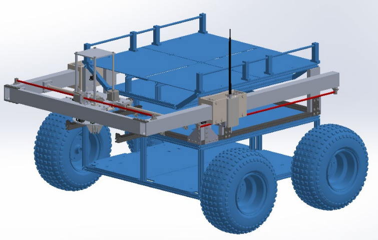
Level 1 - Functional



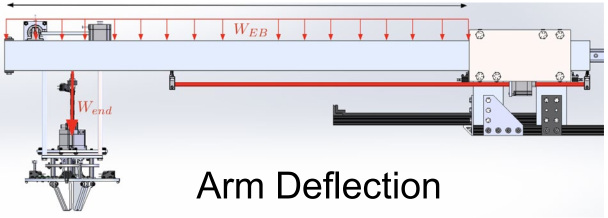
Level 2 - Subsystem



Result



Level 3 - Component



Arm Deflection

Required	Actual
< 0.2”	0.12”

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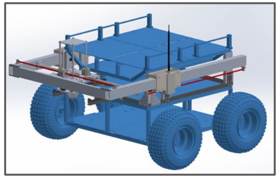
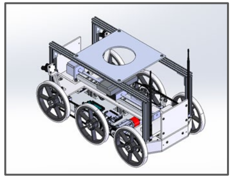
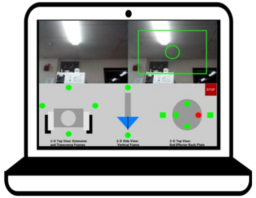
MR - Mother Rover
CSR - Child Scout Rover
GS - Ground Station
MCU - Microcontroller Unit
SBC - SIngle Board Computer

Interfaces

Hardware	Software	Communication
ATLAS to MR ATLAS to CSR Component mounts Cables, voltage and current regulators, electrical housing  	Arduino (MCU) & Tinkerboard (SBC) Tinkerboard to GS Python	Motors to GS Limit Switches to GS Cameras to GS GS commands to ATLAS 

CDR Risks

Risk	Description	Mitigation	Encountered (Yes/No)	Effect on the Project
SE-4	Damage to electronics through ESD	Wiring diagrams required before assembly	Yes	Arduino DUE destroyed by accidental wire connection, replacement ordered
MH-9	Lead time and shipping times will affect team schedule	Shipping >2 wks limited to essential components	Yes	Motor delivery longer than anticipated
SE-23	Temporary loss of connection between GS and ATLAS requires reset of SBC.	Adjust antenna settings to maximize transmission	No	Communications system never encountered a long enough interruption in signal to require SBC reset

Systems Requirements Lessons Learned

Challenges	Lessons Learned
Cross-subsystem requirements	• Make clear which requirements affect each subsystem. • Individuals take ownership of whole project, not just subsystem
Writing testable requirements	• Clear, objective requirements • Numerical requirements • Realistic testing capabilities
Unconscious bias	• Realistic weights for decision matrix

Project Management

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Approaches and Results

Semester	Fall	Spring
Approach	● Separate subteam meetings ● Stand-ups ● Individual quad charts ● Tasks assigned by leads ● Clickup Tasks to see the Progress	● Fewer meetings, more manufacturing ● Quad charts by team leads ● Few individual stand ups ● Internal deadlines for assignments
Result	● Subteam meetings successful ● Individual quad charts inefficient ● Subteams completed assigned tasks	● Manufacturing on schedule ● Lead quad charts helpful ● Internal deadlines = more revision

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Challenges and Lessons Learned

Challenges	Lessons Learned
Schedule (Subteams Waiting on each other, revision time)	● Increase interaction between subteams ● Backup plan when subteams waiting ● Earlier internal deadlines
Leadership Structure	● Co-leadership worked out well ● Clarity of leadership improved
Writing Requirements	● Simple and clear ● Beware of overlapping requirements
Communication across subteams	● Increase interaction between subteams

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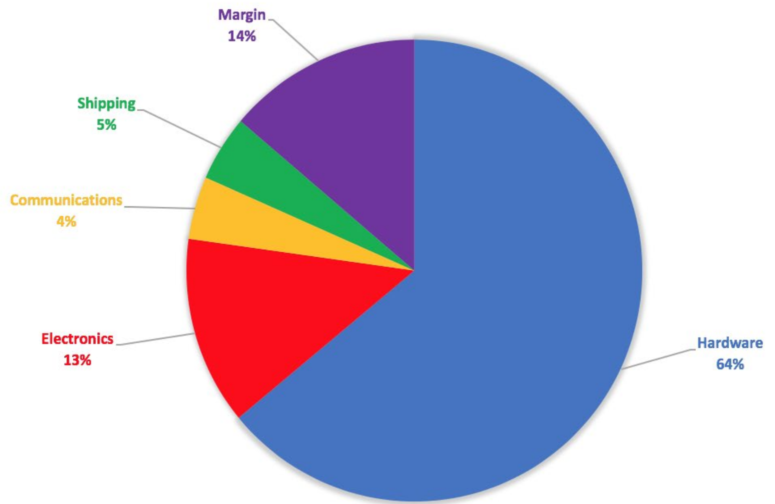
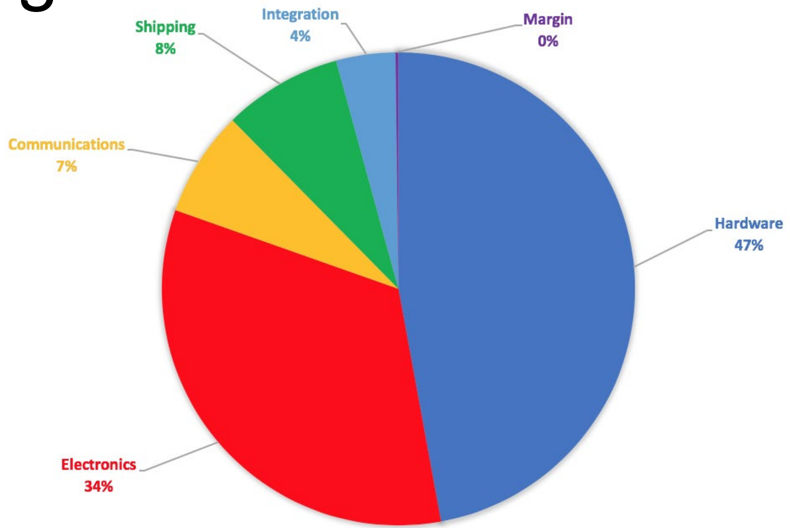
Planned budget vs. Actual budget





Planned Budget:
(Before EEF Funding)

Hardware:	$3200
Electronics:	$660
Communications:	$220
Shipping:	$230
Margin:	$690
Total:	**$5,000**

Actual Budget:
(Including EEF Funding of $1,024 for total budget of $6,024 available.)

Hardware:	$2838.28
Electronics:	$2005.06
Communications:	$435.19
Shipping:	$489.72
Integration:	$243.72
Total:	**$6,011.97**

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“Industry” Cost

- Based off the TimeSheets, approximately **4,285 hours** of labor have been put into this project since September 1st across **12 people**

- Assuming entry level of $65,000 salaries for 2,080 hours of labor per person results in $31.25/per hour, and a total direct labor cost of **$133,906.25** for this project

- Material list (with shipping plus taxes) was **$6,011.97**

- Including an overhead rate of 200% based off direct labor costs results in an overhead cost of **$267,812.50**

Based off the direct labor, materials, and an overhead cost with the assumptions being valid would result in a total first time “Industry” cost of approximately **$407,730.72** for the customer of this project

Acknowledgments

- Professor Koster
- Barbara Streiffert, Brian Campuzano & JPL Advisors
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- Matt Rhode
- Bobby Hodgkinson
- Trudy Schwartz
- Aaron Johnson
- Professor Jelliffe Jackson
- PAB

Backup Slides

Electronics Challenges vs. Lessons Learned

Challenges	Lessons Learned
Protect Hardware	• Double check connections • Always power off to connect/disconnect

Software Challenges vs. Lessons Learned

Challenges	Lessons Learned
	• Incr
	• Co-leadership
Requirement Writing	• Make as simple as possible • Beware of repeating requirements
	• Increase interaction between subteams

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Hardware Challenges vs. Lessons Learned

Challenges	Lessons Learned
Trade Studies	● Identify realistic options ● Group consensus on weighting and outcomes
Working Professionally	● Establish a code of conduct early ● Address problematic behavior quickly and respectfully
Requirement Writing	● Verify that requirements are realistic ● Reevaluate requirements
Design Process	● Don’t get hung up on small details early on ● Establish overall design first ● Ensure participation and agreement of entire team

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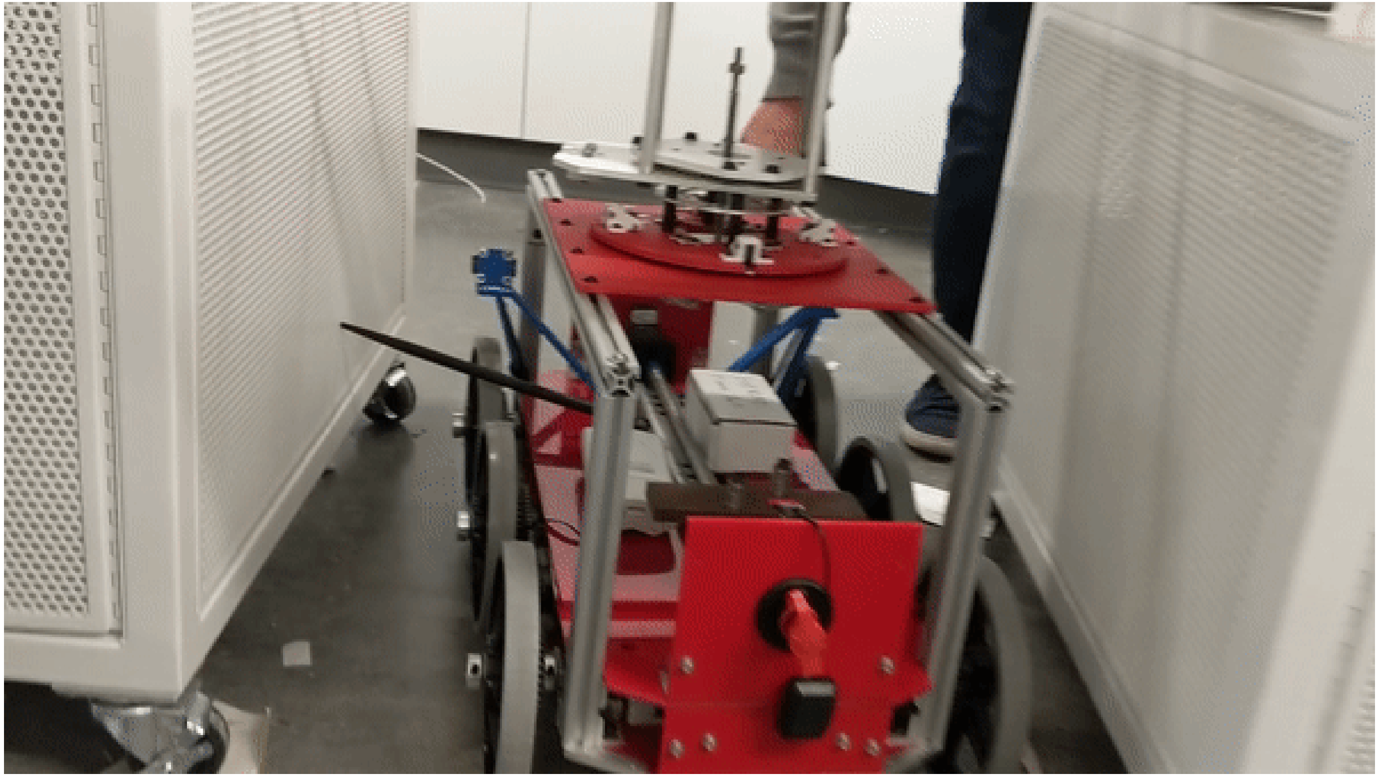
Structural test - clamping/end effector video



Subsystem: Petal Force Testing

Procedure:

- Protractor/Ruler

Data:

- Iterative test to determine maximum allowable petal angle to acquire CSR

Requirements:

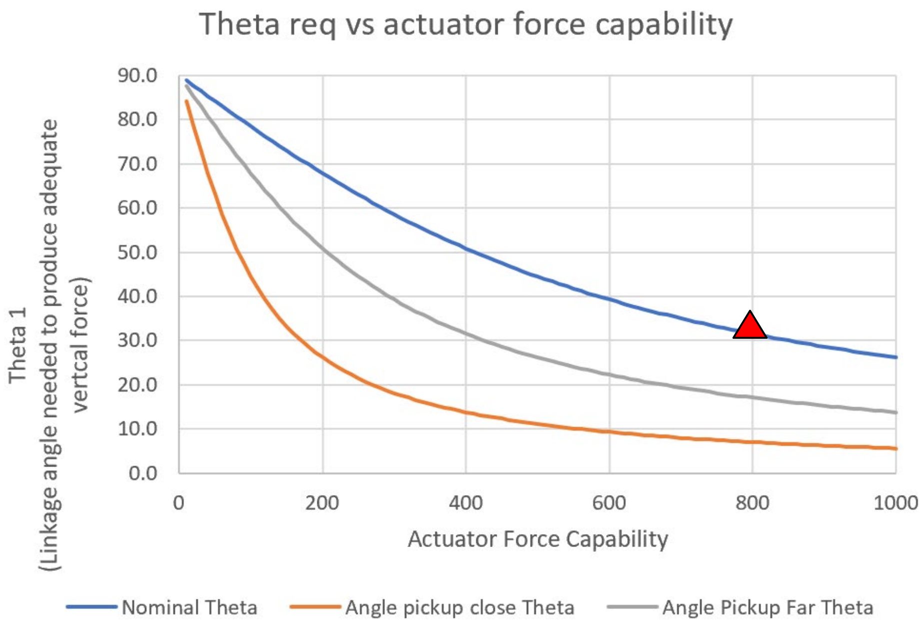
- Acquisition of CSR on relative slope

Models Validated:

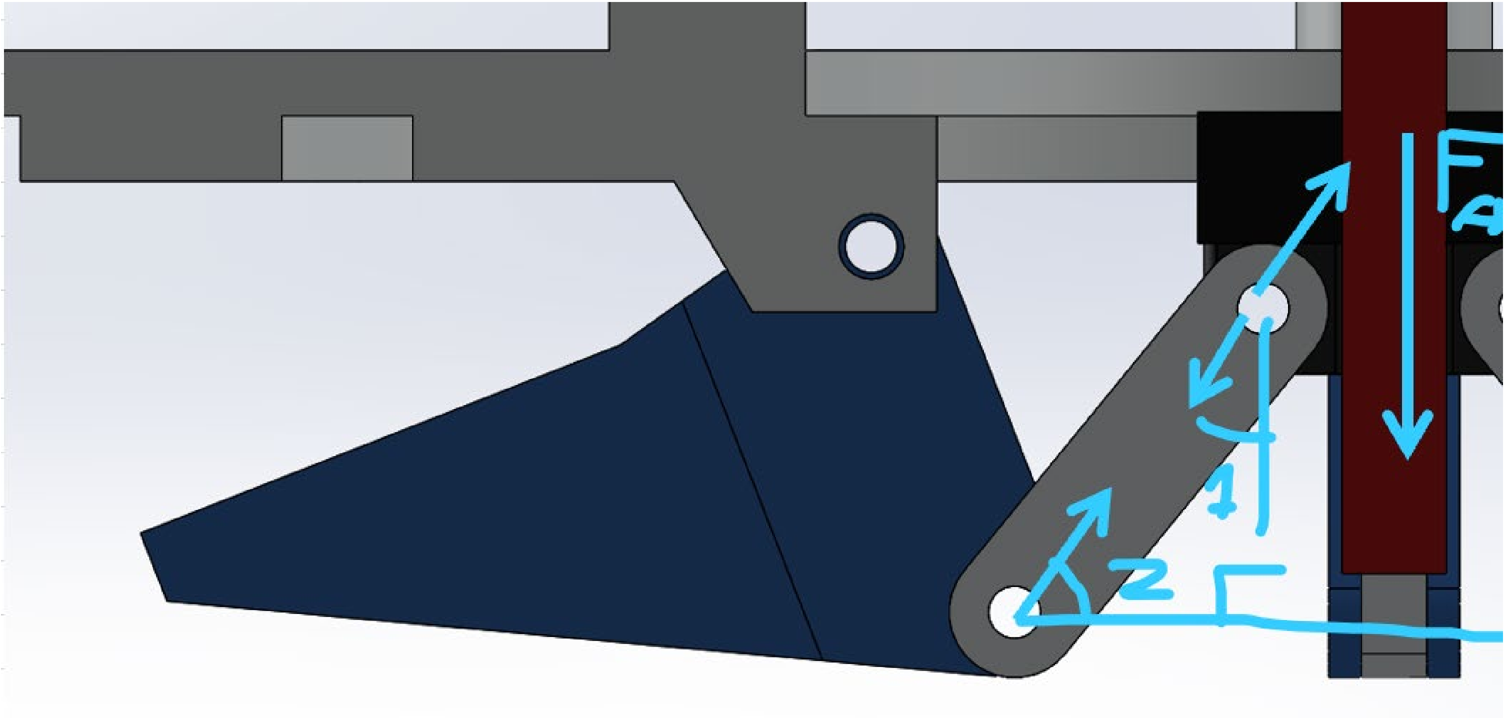
- End effector petal force models
- Predicted Angle: 31.5°

Engineering reasoning:

- Free Body Diagram



Petal Force Diagram



Integration Testing

List of Heritage/Integration tests

- Interference Tests
  - Landing Pad sweep
  - ATLAS range of motion
  - MR FOV testing
  - Ground clearance
  - Landing Platform airspace
- Slope traversal testing
- CSR lift topple testing

Structures: Vibration Testing

Purpose:

- Validate predicted vibration model
- **The CSR shall oscillate with an angular velocity less than .159 Hz during transportation on the MR.**

Description:

- Acceleration
- Natural frequency

Location:

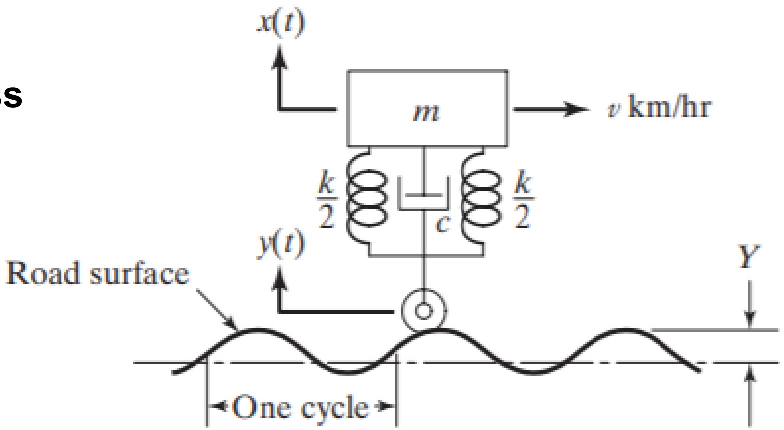
- Two phases of testing
  - Indoors
  - Outdoors

Project Success:

- Safety of hardware during transportation

Models to be validated:

- Base Excitation Frequency: .373 Hz
- Natural Frequency: 0.0747 Hz
- Frequency Ratio: 4.985



$$\omega = 2\pi f$$

$$\omega_n = \sqrt{\frac{k}{m}}$$

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Test Schedule

Component Testing 2/1/2020 - 2/21/2020	Subsystem Integration & Testing 2/24/2020 - 3/20/2020	System Integration and Full-System Testing 3/22/2020 - 4/10/2020
Motor Testing ❑ Motor response testing ❑ Component fit testing **Software Unit Testing** ❑ SBC Functionality ❑ Camera Transmission ❑ Arduino Functions **Sensor/Electronics Testing** ❑ Camera Resolution ❑ FOV Camera ❑ Camera FPS ❑ Limit Switches ❑ Hall Effect **Communications Testing** ❑ Ubiquiti Functionality	**Hardware Testing** ❑ CSR Docking ❑ End Effector Petal Clamping ❑ End Effector Rotation ❑ Vertical/Transverse/Extension Frame Actuation ❑ Vibration Test **Software Testing** ❑ Commands to MCU ❑ Motor Performance ❑ Camera Resolution/FPS ❑ GUI Output as Expected **Sensing/Electronics** ❑ Limit Switches ❑ Data/Command Transmission ❑ Data Rate **Communications Testing** ❑ Range of Communication	**Hardware** ❑ Integrated Actuation ❑ Pick-up Test ❑ Angle of Retrieval Test **Software** ❑ Atlas Performs Commands ❑ Stationkeeping ❑ GUI Display **Sensing/Electronics** ❑ Tolerance ❑ Limit Switch Display/Signal **Day-in-the-Life Test**

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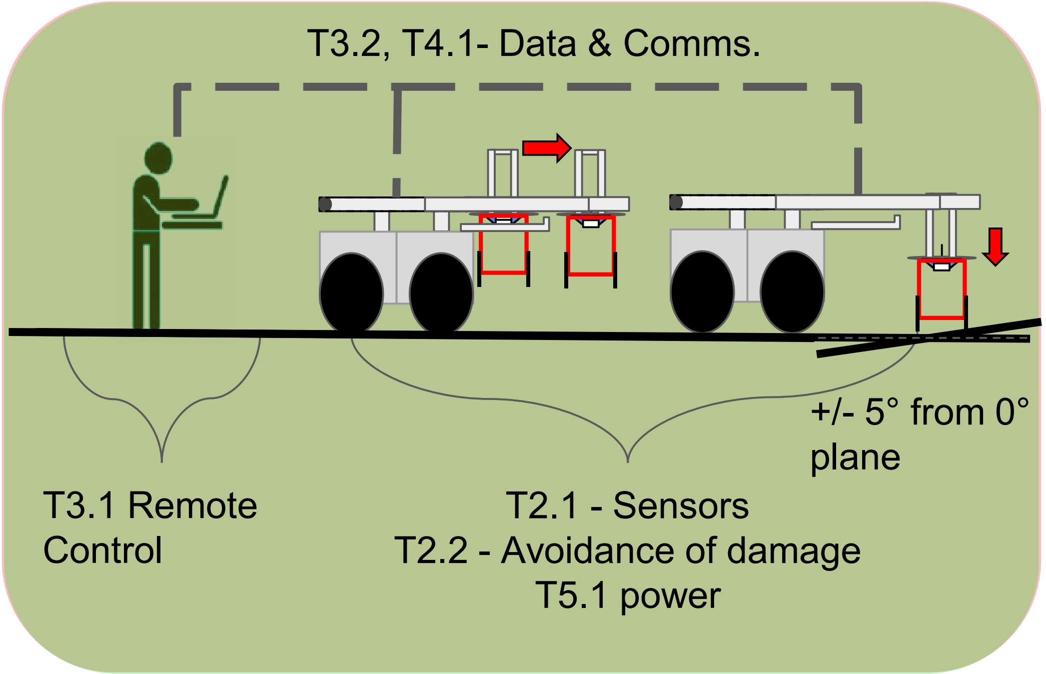
*Completed

Full-System Test - Deployment T1.2

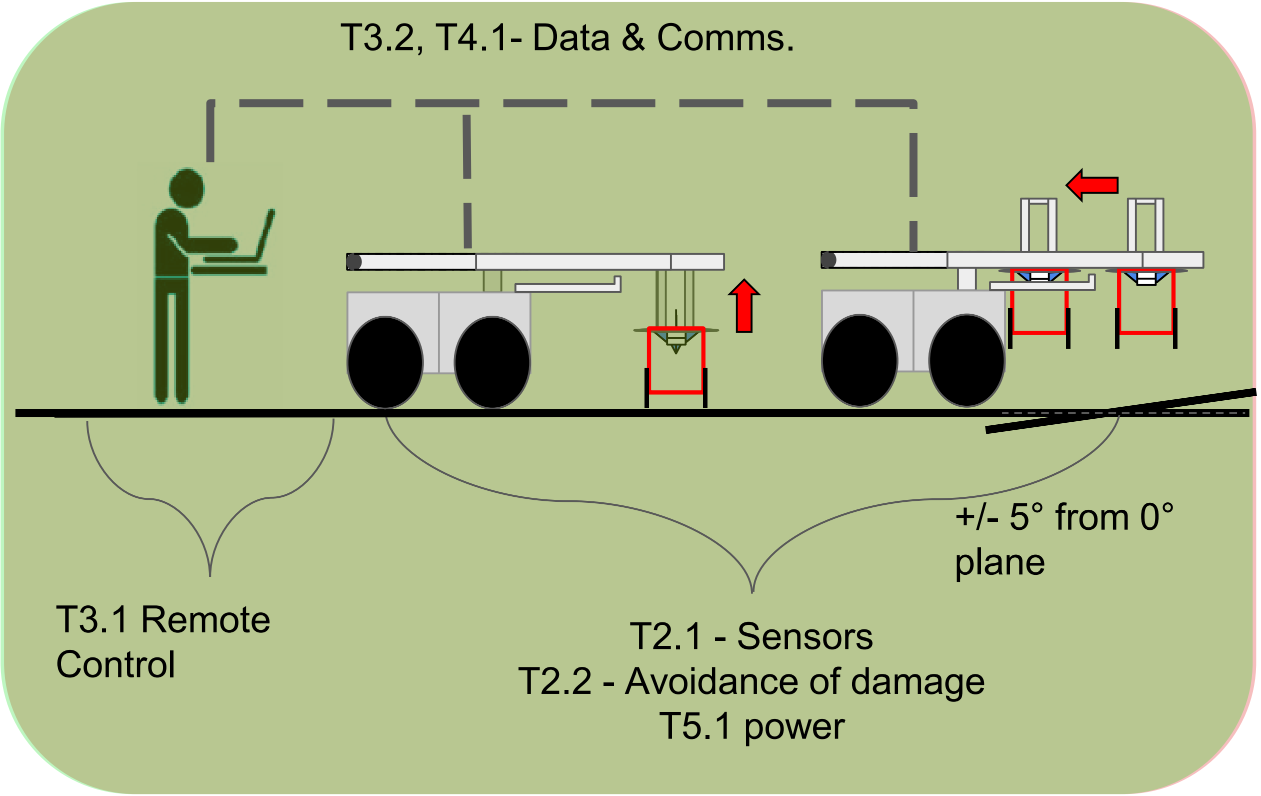
- **Objective:** Validate functional requirements in lab environment and real environment
- **Success Criteria:**
  - Complete full system tests, meet functional requirements.
  - Validate all related models from CDR.
- **Risk Mitigated:** Reduces risk for potential failures during the real mission.
- **Status:**
  - March 23 - April 4 (Margin until April 10th)
  - Will have premade checklist
  - Performed near field near Aero. Building



Full-System Test - Retrieval T1.3

Lab environment

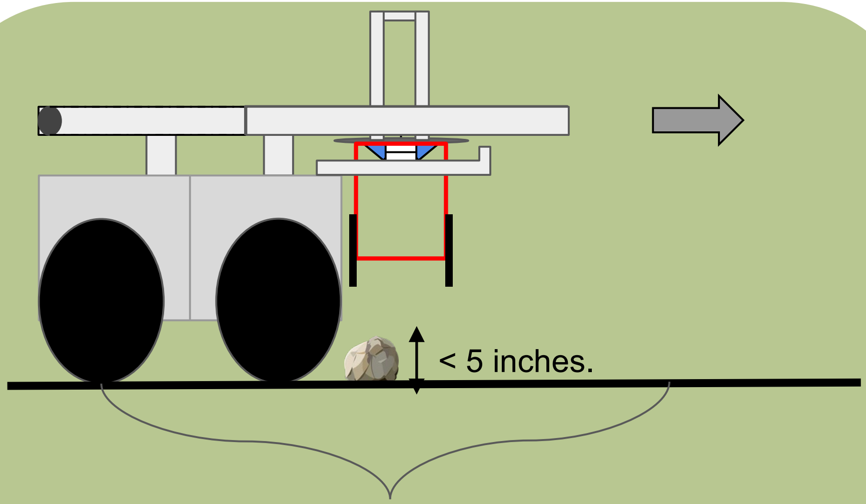
Real Environment



Full-System Test - Storage T1.1 & T1.4

Lab environment

Real Environment



- **T1.1.1 Secured CSR**
  - T1.1.1.2 End Effector Clamping
  - T1.1.1.3 Pin Shear Force
  - T1.1.1.4 Interface Plate Bending
- **T1.4.1 Vibration Test**

Subsystem: Motor Integration and Test

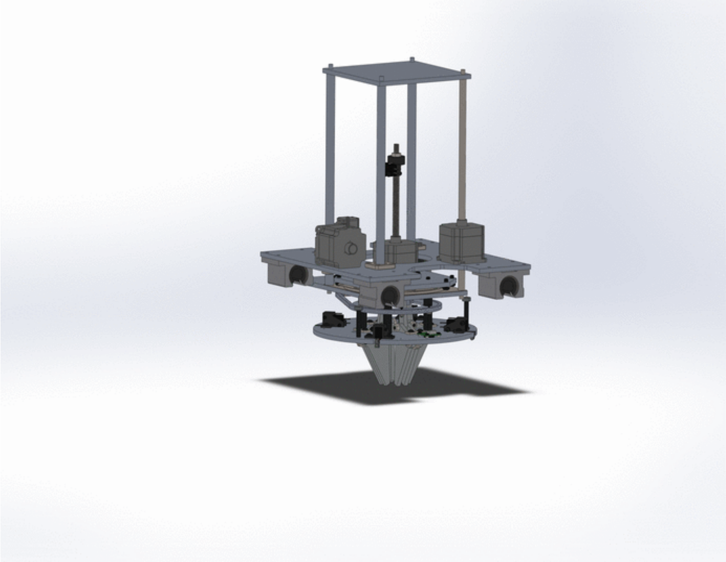
Objective:

- Verify that the motors are functioning as predicted (compare predicted speeds with actual)
- Verify that the software and motor drivers are interacting with the motors correctly (compare commanded speeds with actual)
- Validate requirements associated with motor

Success Criteria:

Commanded speed should match the measured velocity.

- Performance characterized by how closely commanded velocity matches expected RPM and linear velocity under load of CSR



Requirements Validated:

T1.3	The CSCA shall retrieve the CSR when it is in operational position.
T1.2	The CSCA shall deploy the CSR.

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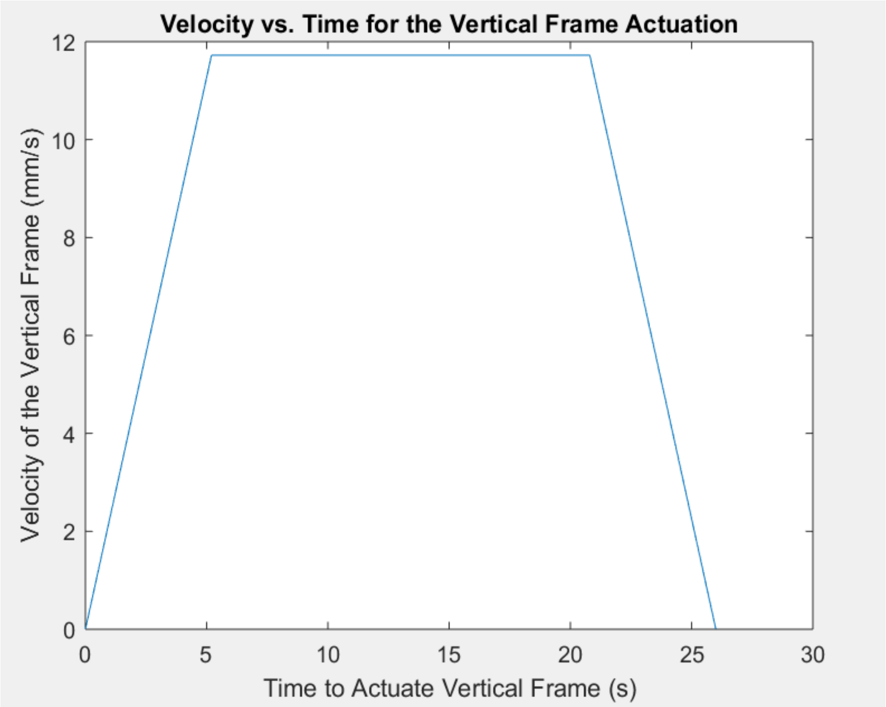
Subsystem: Predictive Motor Models to Validate

Risk Mitigation:
Measure of expected speed improves ability to accurately control ATLAS

Testing for: Motor Linear Velocity under load

Key Variables: Software mode (commanded speeds)

Level of Success Achieved:
Structures - Level 2
Control - Level 1



Subsystem: Hardware Integration Test Design

Procedure:

- Mount vertical frame to test stand
- Secure CSR on end effector
- Upload software to arduino
- Connect motor controllers and motor
- Command motor drivers to actuate the motors at various set speeds
- Measure time to fully actuate the vertical frame at each commanded speed
- Compare the measured speed with the speed defined to the motor drivers
- Compare measured speed with performance prediction plots

	Weighted	Unweighted
1 mm/s		
3 mm/s		
6 mm/s		
9 mm/s		
12 mm/s		

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Phase I: Backup Component & Subsystem Testing

Component Testing: Batteries

TalentCell 3000mAh Batteries:

- **Planned Testing:**
  - Endurance test to find if meets mission duration
  - Tested by powering Arduino Due and Tinkerboard
- **Can be used to test motor drivers/stepper motors**

WindyNation 100Ah Batteries:

- **Planned Testing:**
  - Endurance test to monitor temperature and heating of motor drivers/motors

Component Tests Backup

Motors component tests

- Motor drivers tested with smaller motors initially to prove functionality
- NEMA 23 motors tested with drivers once motors arrived (prolonged shipping)
    - Deals with requirements T3.1.2 and T3.1.3
- Limit switches tested with single motor, verified that motors can be stopped within an acceptable amount of time
    - Requirement T3.2.1
- Hall effect sensor verified to send data to user when activated, not done with motor yet

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Phase II: Backup Subsystem Integration & Testing

Subsystem: SBC, Comms, and Video Transmission

Objective: Determine GUI FPS impact on video latency and video quality

Requirements being Validated: T2.1.3, T2.1.4, T4.1.4

Success Criteria: Consistent video quality and video latency reduced to acceptable levels.

Risks Mitigated: Operator cannot operate ATLAS if video latency is too high or video quality prevents vision of operational area.

Status: Planned for March 4th

	GUI 5 FPS	GUI 15 FPS	GUI 30 FPS	GUI 60 FPS	GUI 120 FPS	GUI 240 FPS
Video Latency	Link	Link	Link	Link	Link	Link
Video Artifacts	Link	Link	Link	Link	Link	Link
Packet Latency	Link	Link	Link	Link	Link	Link
Packet Loss	Link	Link	Link	Link	Link	Link

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Subsystem: Communication Subsystem Test

Purpose:

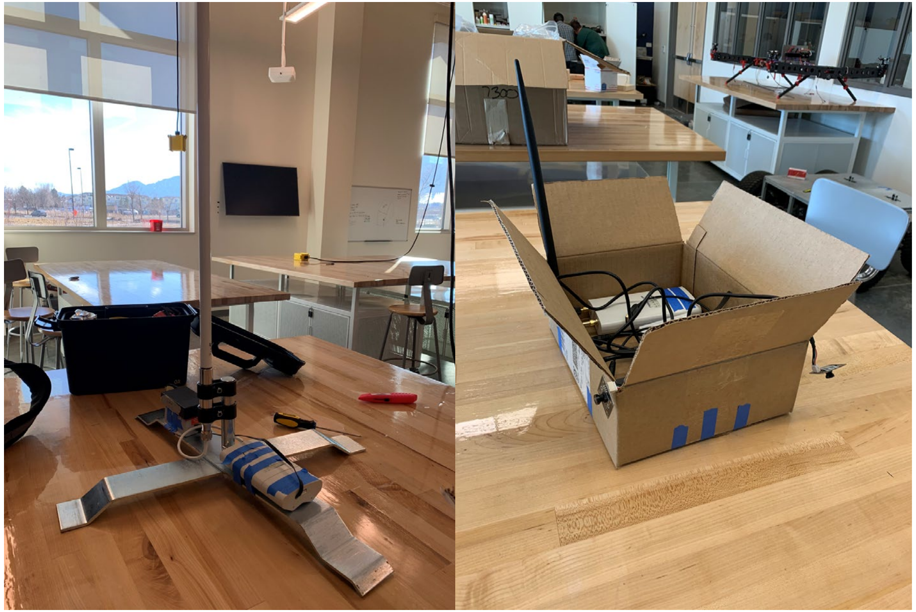
To test that the assembled communication system can transmit data and video the distance required.

Requirements being Validated:

T4.1.1	**The ATLAS communication subsystem shall communicate up to distance of 250 meters with the GS.**

Procedure:

Setup the SBC to transmit video to the GS. Record data with ping commands and video latency with synchronized stopwatches at incremental distance up to 260 meters.



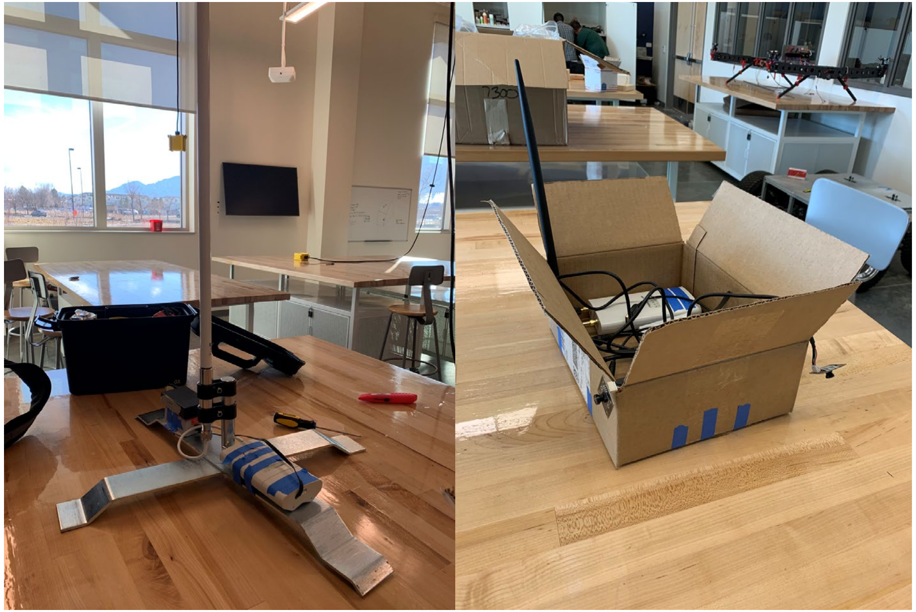
Subsystem: Communication Subsystem Test

Results:
- Battery Power Issue
- Unstable video latency
- Unacceptable video quality

Diagnostics:
- Outdoor temperature draining battery charge
- Signal Interference at short range

Potential Issues:
- Antenna Interference
- SBC/Comms System Damaged
- Code Issue

Next Steps:
- Vary fixed parameters to isolate issue
- Ensure batteries are kept warm during future testing in cold weather



Limit Switch Testing

- Individual limit switch tested with stopping motor upon activation
  - Primarily for reqt. T2.2.1/T3.2.1, component test successful
  - Next test will be to integrate onto hardware and test with hardware config.
- Implementation of limit switches (and hall effect sensors) to prevent mechanical damage to the CSCA
- Testing will verify that both physical limit switch is working and software limit switch logic is working as expected

Subsystem: Motor Testing

- Purpose: Test functionality and motor performance under load. Important test to verify that components of the CSCA respond as expected and stay within expected current limits.
- General procedure:
  - Power on arduino, motor drivers, and ground station/means of commanding motors
  - Command motors controlling extension, transverse, vertical, rotation, and end effector components individually
  - Monitor temperature and current during test to determine if motor drivers are performing within their specified limit
  - Verify motors can actuate under mission-equivalent load
- Requirements Verified
  - T3.1.1, T3.1.2, T3.1.3
- Status
  - Will be completed week of 3.9.20
- Test will provide info on motor/driver performance over time

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Phase III: Backup System Integration and Full-System Testing

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Hardware Integration & Full System Tests

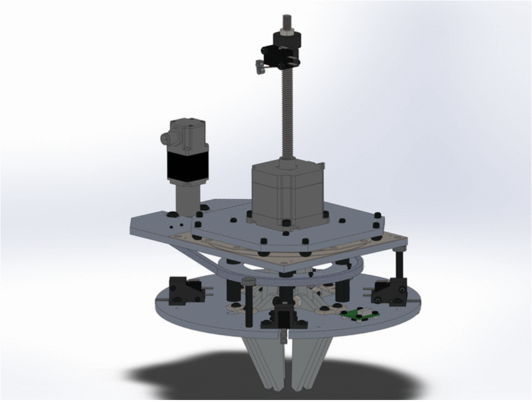
Hardware full system tests not covered in main slides- link to day in the life tests - and main hardware tests linked to requirements

- Hardware Integrated Actuation
    - Show and go over general test plan, V&V, etc.
- Angle of Retrieval
    - Show and go over general test plan, V&V, etc.
- Pick Up Test
    - Show and go over general test plan, V&V, etc.

Hardware Angle of Retrieval Test

- **Risk:** Reduces risk for potential docking failures during the real mission.
- **Procedure:**
  - Orient CSR in non-nominal orientation
  - Reorient CSR to acceptable docking position(Parallel to MR)

- **Validation of Models (Most Critical):**
  - Rotational Motor Analysis
  - Grasping Mechanism
    - Petal Deflection
    - Clamping Force



Requirements

- T1.1
  - T1.1.5
- T1.3

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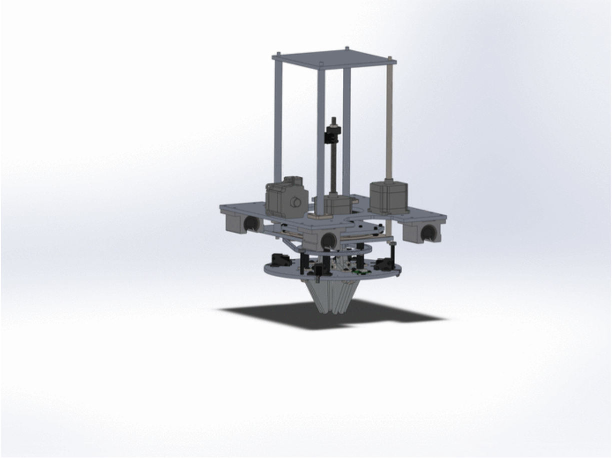
Hardware Pick Up Test

- **Risk:** Reduces risk for potential docking failures during the real mission.
- **Procedure:**
  - Orient CSR underneath of vertical frame
  - Actuate vertically to interface and grasp CSR
  - Lift CSR into upper docked position

- **Validation of Models (Most Critical):**
  - Vertical Motor Analysis
  - Grasping Mechanism
    - CSR Clamp Interface



Requirements
- T1.1
  - T1.1.1
- T1.3.1.3
- T1.4

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