2022 Breakthrough, Innovative, Game-Changing (BIG) Idea Challenge

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http://bigidea.nianet.org/

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TRAVELS

Terrapin Rover Allows Versatile Exploration of the Lunar Surface

University of Maryland Entry

NASA 2022 BIG Idea Challenge – Extreme Terrain Access for Mobility Platforms

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Team:

Joshua Martin, Nicholas Limparis, Charles Hanner, Romeo Perlstein, Nicolas Bolatto, Rahul Vishnoi, Daniil Gribok, Christopher Kingsley

Presentation Contents

- Team Breakdown
- Lunar Mobility Difficulties
- TRAVELS System Overview
- Earth-Analogue Prototypes
- Current Status & Future Work

TRAVELS Team Breakdown

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Software

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Software/Team Lead

Romeo Perlstein

Rahul Vishnoi

Hardware

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Hardware Lead

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Hardware Lead

Christopher Kingsley

Nicholas Limparis

Electronics

Daniil Gribok
Electronics Lead

Past Members: Project Proposal and Phase 1 Contributors

- Michael Howe
- Eunice Hong
- Fletcher Smith
- Dominic Manzella

Lunar Mobility Difficulties

- Areas of interest:
  - Polar permanently shadowed regions, sloped craters
  - Rough terrain, geologically interesting formations, e.g. lava tubes
- Different rover mobility modes have different advantages:
  - Driving: efficient over flat terrain, but untenable on slopes and rocky regions
  - Walking: good over high slopes and rough terrains, but inefficient
- A flexible, “ideal” mobility system would combine these advantages

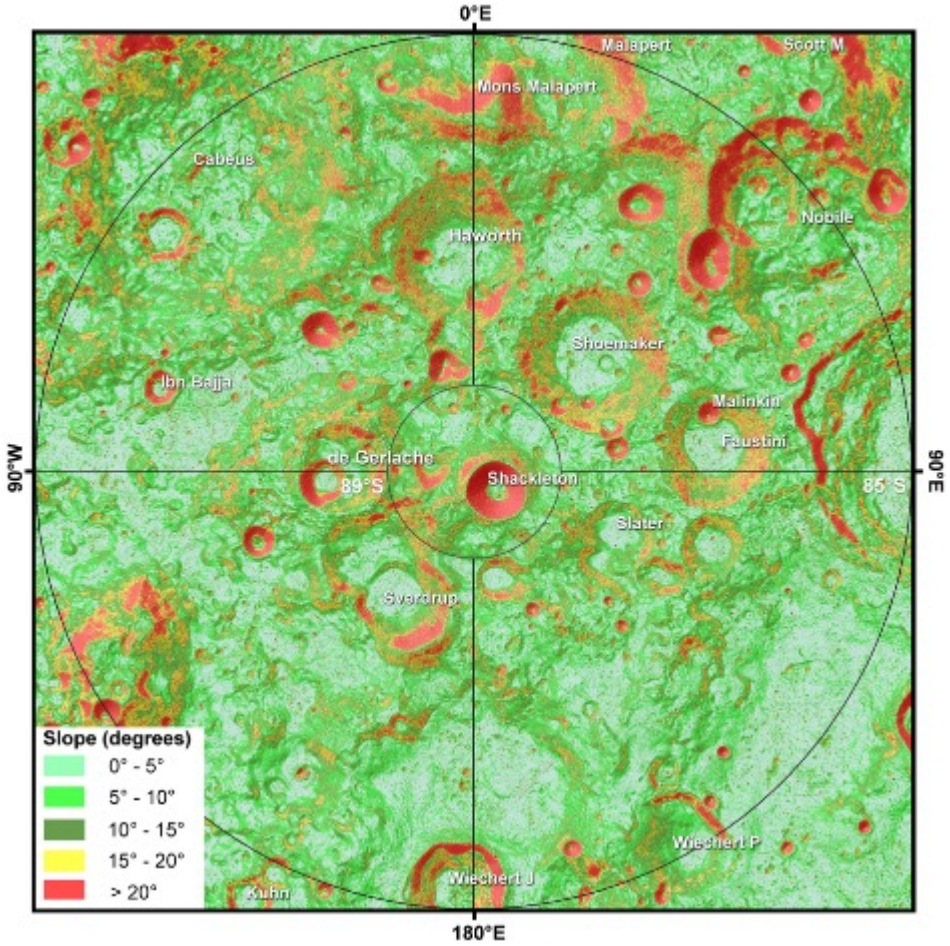


Image from: Harish, Satya, V., Animireddi, K., Barrett, N., undefined, S., Gawronska, A., Gilmour, C., Halim, S., McCanaan, K., Shah, J., et al., “Slope Map of the Moon’s South Pole (85°S to Pole),” , 2019. URL `https://www.lpi.usra.edu/lunar/lunar-south-pole-atlas/`.

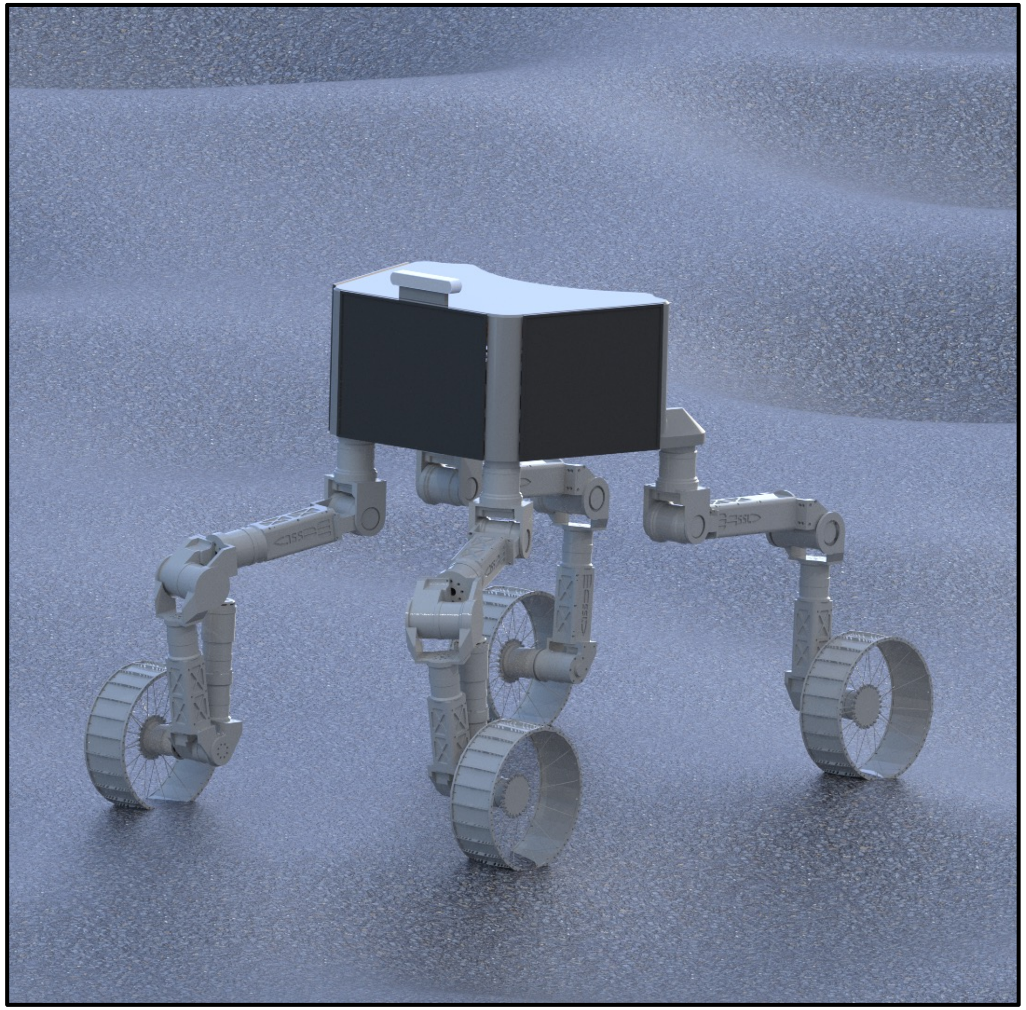
Robot Design Objectives

1. **Efficient motion over flat terrain**
2. **Flexible motion over rough terrain**
3. **Maximum adaptability** to different mission types:
    1. Unexplored terrain navigation
    2. Dexterous full-body manipulation
    3. Scalable hardware architecture

TRAVELS System Overview

TRAVELS: Terrapin Rover Allows Versatile Exploration of the Lunar Surface

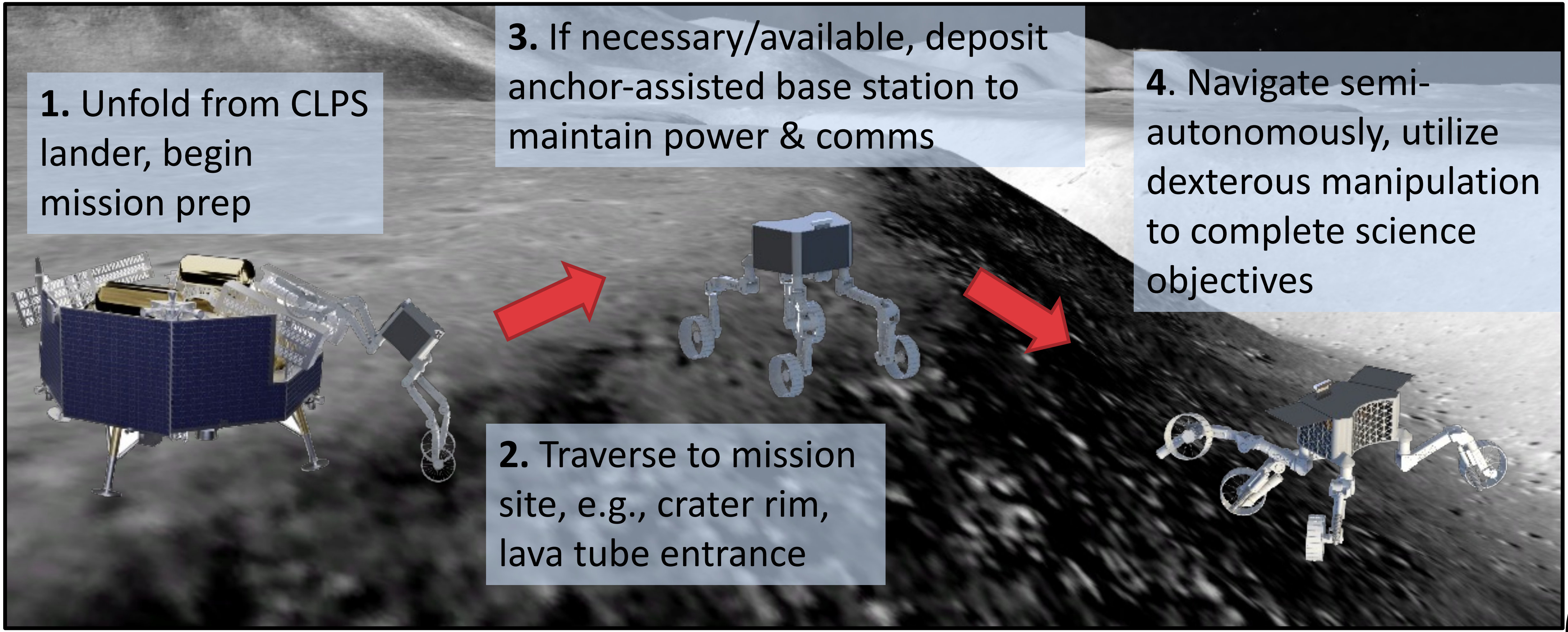
Limbs	4
Degrees of Freedom	28
- Front Limbs	7+wheel
- Rear Limbs	5+wheel
Lunar Mass	200 kg
Payload Capacity (3 contacts)	25 kg
(4 contacts)	100 kg
Limb Reach (to wheel)	0.8 m
(to end effector)	1.1 m



System-Level Requirements

Sys Req #	Requirement
S1	**TRAVELS shall be able to move** in regolith, on flat rock, and **in rough terrain using four wheeled limbs**.
S2	TRAVELS **shall be able to drive in relatively smooth lunar environments of up to 15°** in slope while using its limbs to provide articulated suspension.
S3	TRAVELS **shall be able to walk** using static gaits **in rough and rocky terrain** unsuitable for wheeled driving and slopes of up to 30°.
S4	TRAVELS **shall be able to use a front limbs as manipulators** while supported by its three other limbs to accomplish dexterous tasks.
S5	TRAVELS shall carry secondary science payloads and/or volume and payload mass for samples.
S6	TRAVELS shall utilize modified versions of **existing manipulator architectures** for mobility and manipulation.

System Concept of Operations

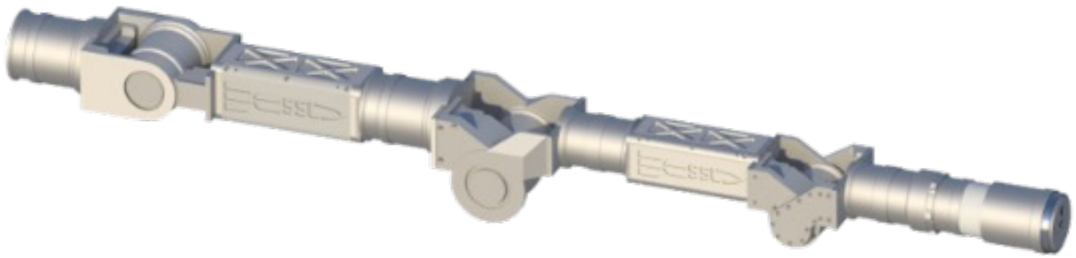


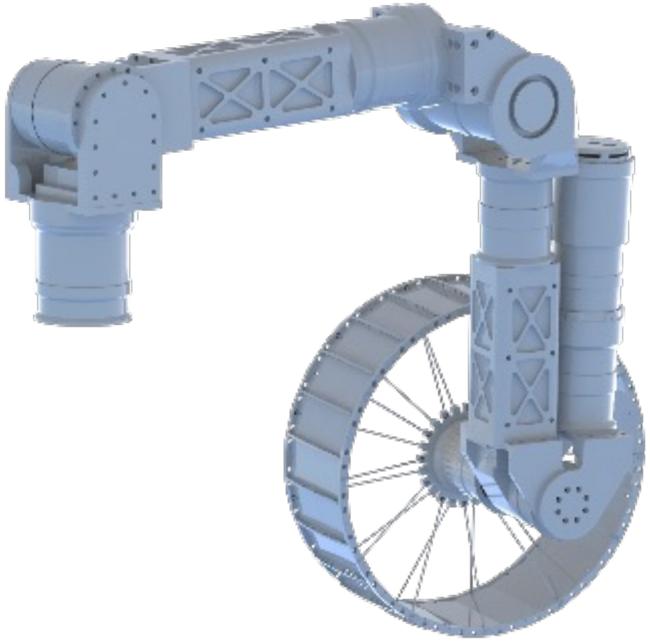
Griffin Lander image courtesy of Astrobotic
Background courtesy of Google Earth, NASA, APL

TRAVELS Earth-Analogue Prototypes

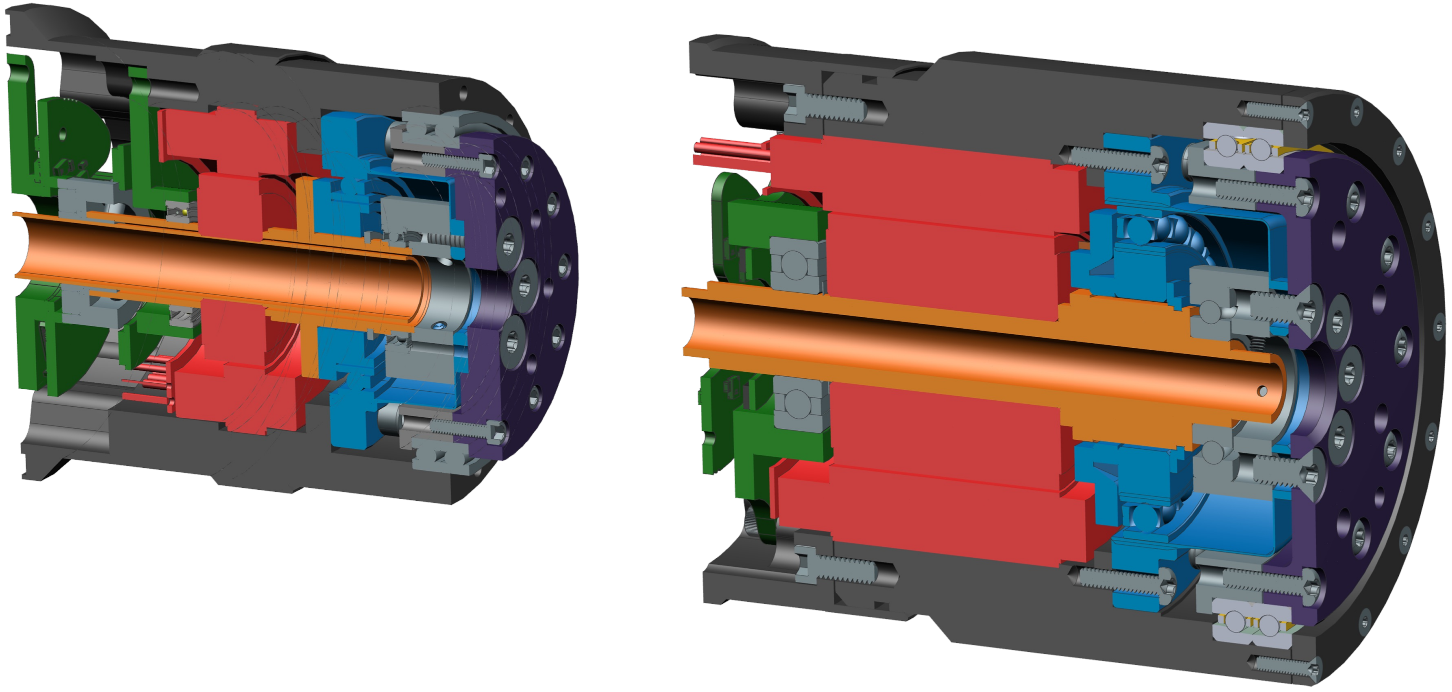
Prototype 1: “DymaFlight” Manipulator

Demonstrating lunar hardware	
Degrees of Freedom	7
Additional Tooldrive Motors	1
Actuators	Custom
Structural Material	Al-6061
Mass	20 kg
Tip Torque	20 Nm
Tip Force, Full Extension, 1g	90 N
Lunar Payload	>60 kg
Limb Reach	1.1 m





Prototype 1: "DymaFlight" Manipulator



Custom DymaFlight Actuator

- Brushless DC motor
- Harmonic Drive gear reducer
- Incremental & absolute encoders

Testing Goals

- Demonstrate hardware used for lunar environments
- Analyze thermodynamic properties in cryogenic conditions
- Investigate torque, speed output of lunar-grade actuator(s)
- Single-manipulator control

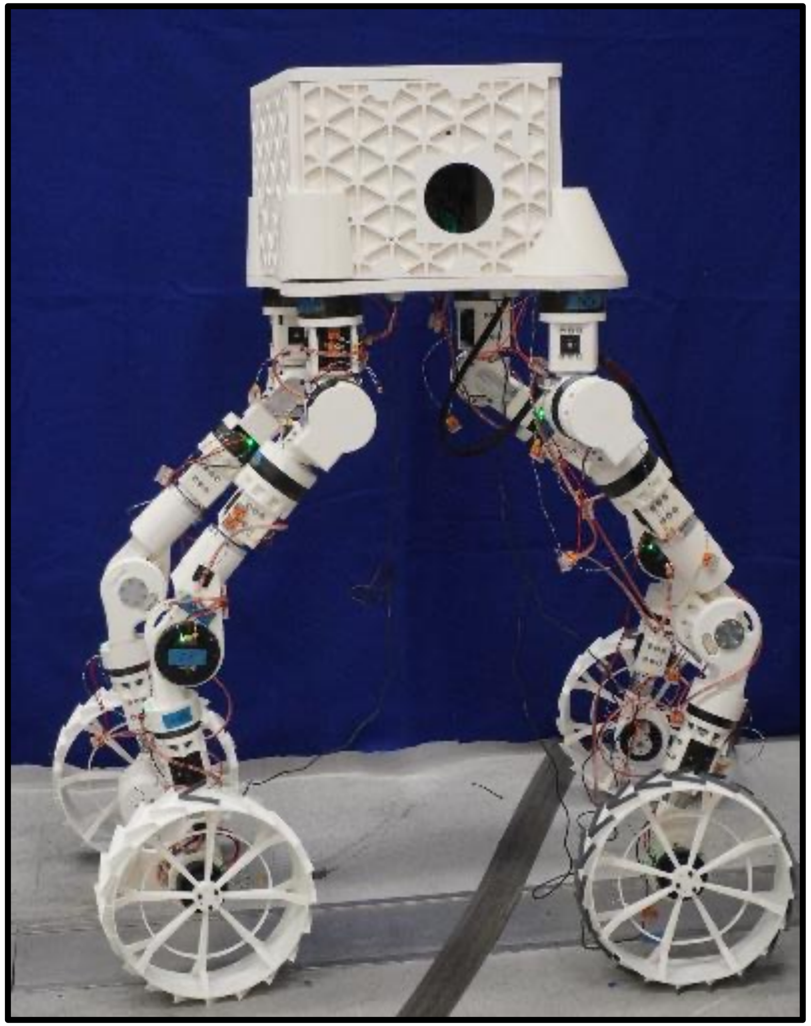
Prototype 1: “DymaFlight” Manipulator

DymaFlight Status

- All drive components arrived, some sensors still in shipping
  - Arrival of components, machining of limb hampered by shipping delays
- Motor housings, structures being machined in-house

Prototype 2: Full-Scale Printable Prototype

Full-System Mobility Demonstration	
Limbs	4
Degrees of Freedom	26
- Front Limbs	6+wheel
- Rear Limbs	5+wheel
Actuators	Commercial
Structural Material	3D printed
Limb Reach (to wheel)	0.8 m
Software	ROS-based custom control



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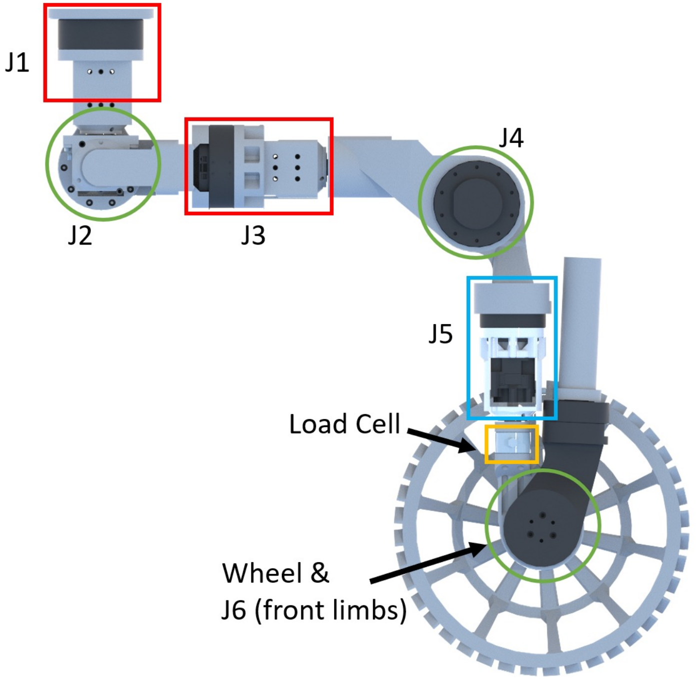
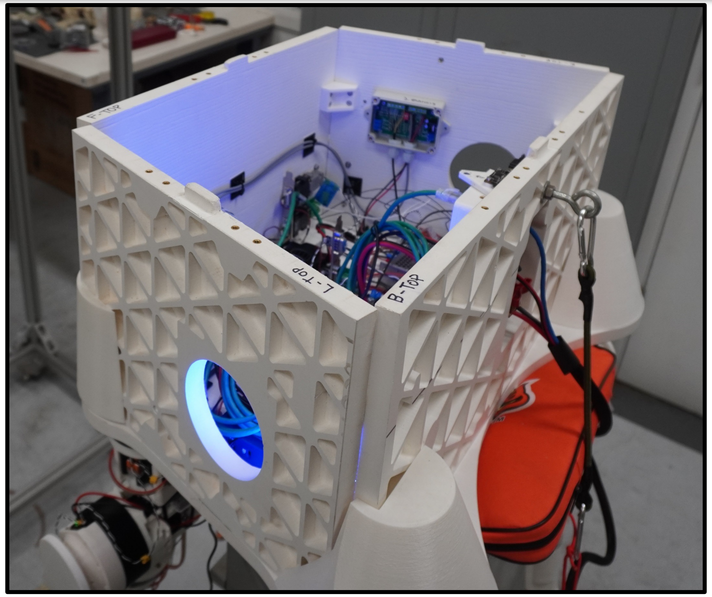
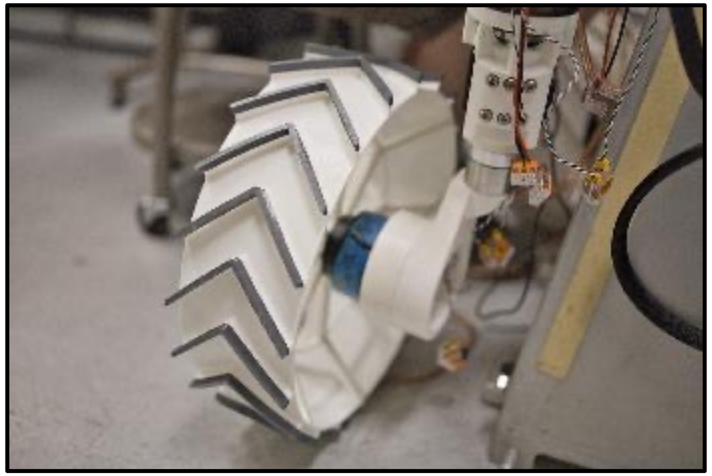
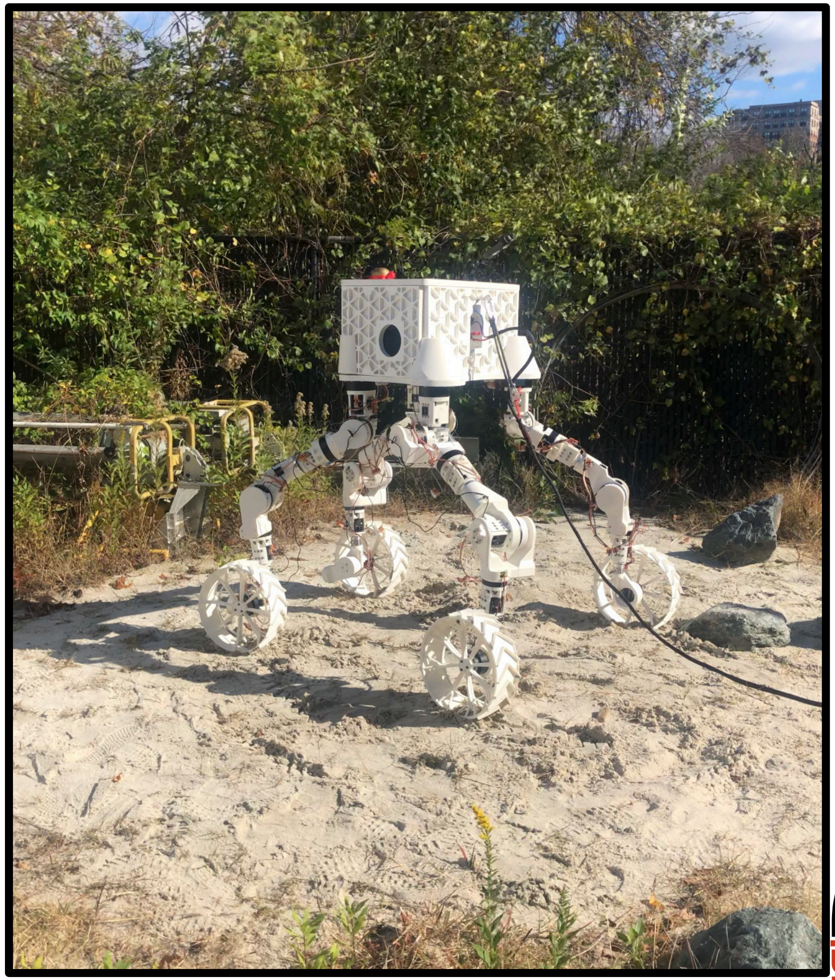




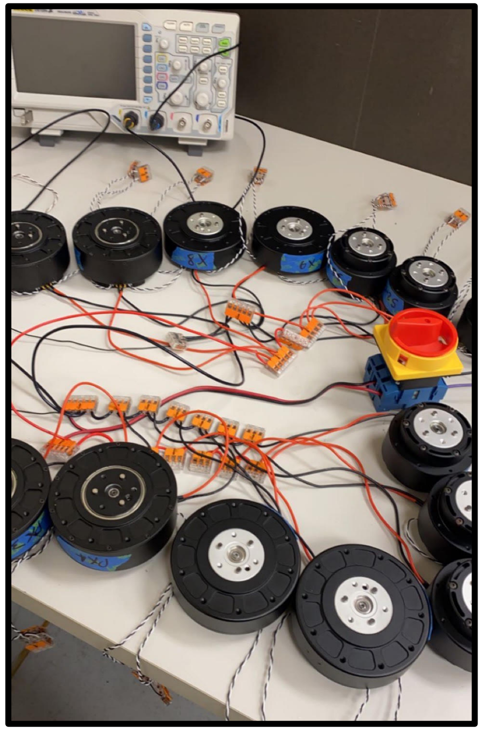




Prototype 2: Full-Scale Printable Prototype

Actuators

- All-in-one integrated brushless motor, controller, encoder, and planetary gearbox
- Controlled via Controller Area Network (CAN) communication protocol)
- 3 different types use by TRAVELS:
  - RMD-X8 Pro
  - RMD-X8
  - RMD-X6-S2



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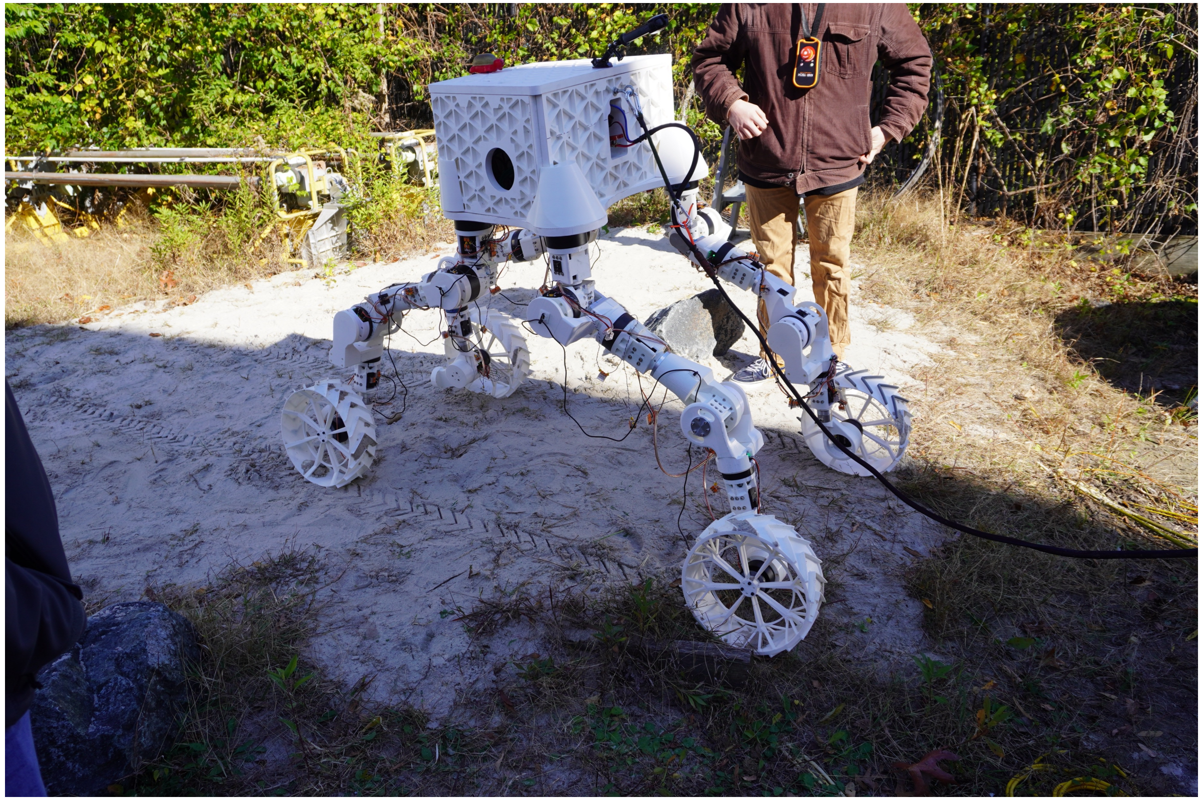


Testing Goals

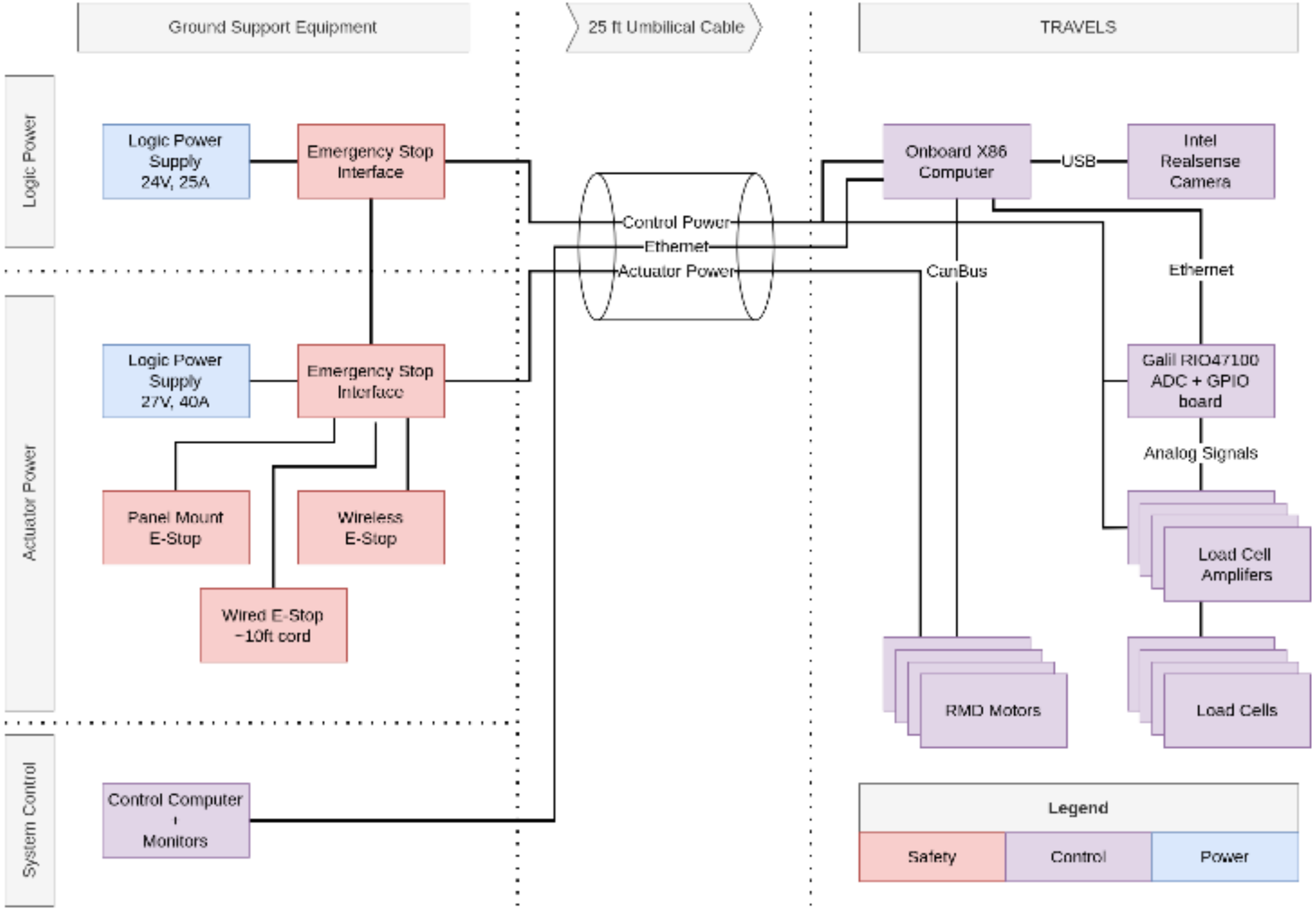
- Earth analogue field testing in different environments
  - Varied slopes
  - Rocky terrain
- Investigating all mobility modes with integrated software
  - Articulated suspension
  - Walking
  - Dexterous manipulation

Rapid-Prototype TRAVELS Test Motions

Electronics

- Early analysis found that including batteries in an earth-analog chassis was not feasible due to weight restrictions
  - An umbilical design was chosen
- Electronics focused on using COTS components to reduce cost and design time
- System was made modular to increase flexibly and lower assembly time
- Particular emphasis was placed in making the power delivery system safe and reliable

Electronics Diagram



UNIVERSITY OF MARYLAND
Space Systems Laboratory
Department of Aerospace Engineering

Ground Support Electronics Gen 1

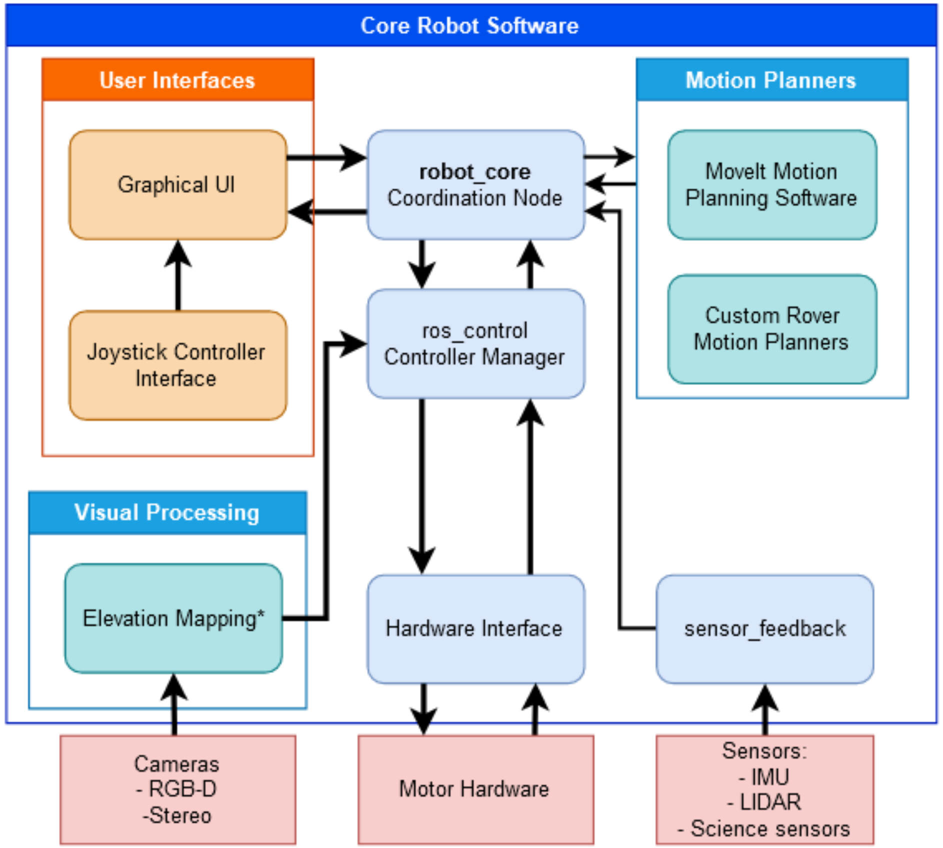
- Gen 1 electronics were based in a 19-inch rack
- Control and actuator power was spilt into two 2U rackmount boxes.
- Rack was nice to have in a lab environment, but was not easily portable

Ground Support Electronics Gen 2

- Moved all functionality into portable cases
- First case contains all active power components
- Second case contains all the control and safety interfaces
- Cases will self-pack all needed interconnect equipment

Common Software and Controls

- Software architecture built on Robot Operating System
  - Open-source packages easily implemented
  - Same software run on hardware, simulation, different prototypes
- Movement modes being explored:
  - Driving with active suspension
  - Static walking gait
  - Dexterous manipulation



Simulation Demo – Turn-in-Place

Simulation Demo – Footprint Adjust

Simulation Demo – High-Slope Driving

Full System Testing

Future Work and Path to Flight

Future Work and Path to Flight

- Hardware:
  - Build three more DymaFlight arms, conduct lunar-grade hardware mobility tests
  - Upgrade electronics to radiation-hardened equivalents
  - Coordinate with stakeholders to integrate potential science/engineering payloads
- Software:
  - Motion planning, more robust obstacle avoidance
  - Fault tolerance, moving in presence of joint failure

Future Work – Mission Specialization

- TRAVELS system uniquely flexible to adapt to different science missions
  - End effectors amenable to interchangeable end effector mechanism for use with different tools
  - DymaFlight actuator design inherently scalable to larger or smaller rovers as needed for a given mission
- Exploration of high slopes:
  - Anchor-winch payload useful to help rover descend into lava tubes/down high-sloped craters, maintain power
  - Payload mass can be allocated to collect samples or carry heavy instruments
- Astronaut and infrastructure assistance:
  - Manipulators useful for preparing landing sites, interacting with other payloads
  - Use by astronauts or pilots on Earth for teleoperated science and engineering tasks

Acknowledgements

- BIG Idea Funding Sources:
  - Maryland Space Grant Consortium
  - National Institute of Aerospace
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- Proposal and Phase 1 Contributing Team Members
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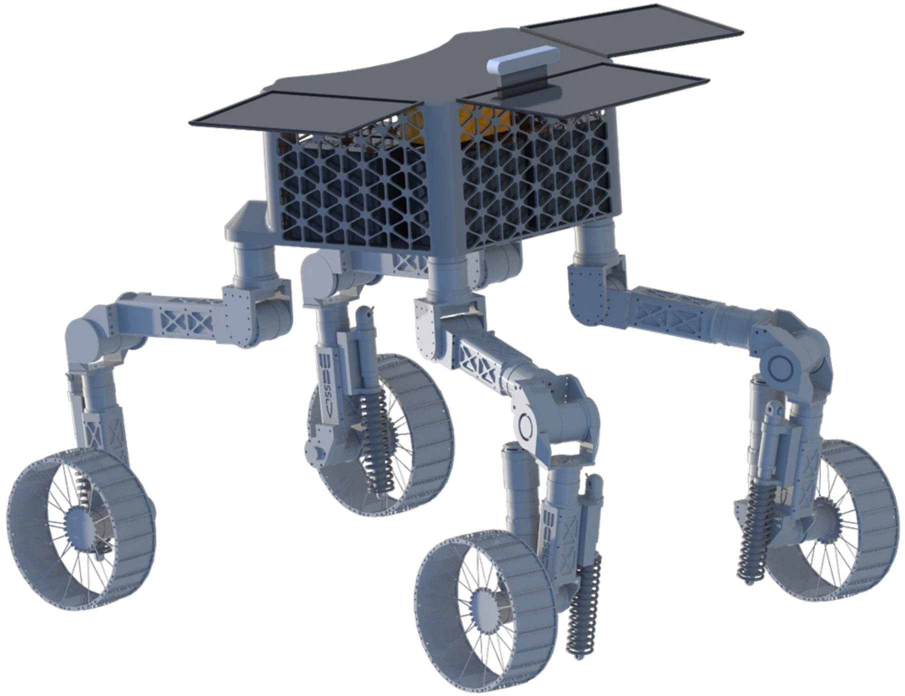
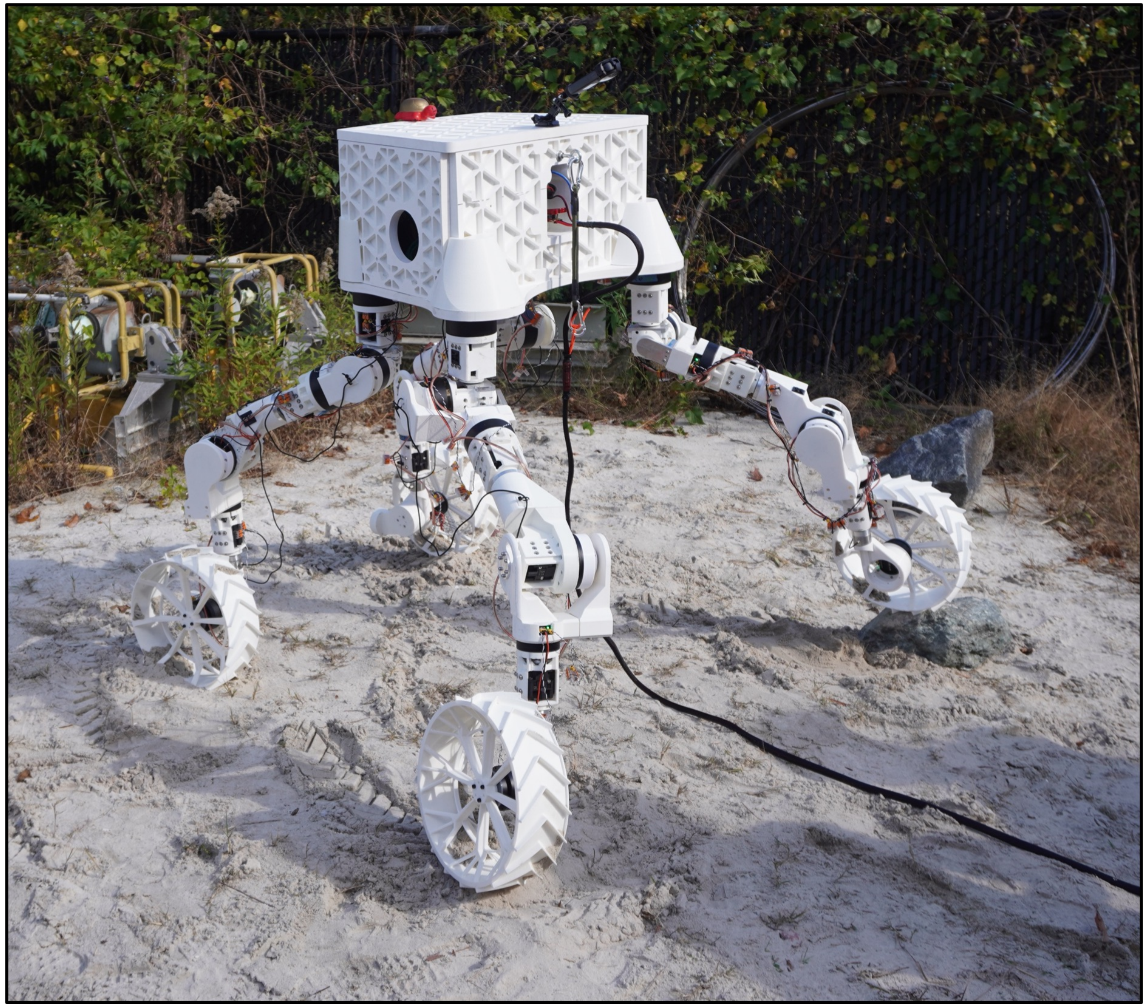
  - Fletcher Smith
  - Dominic Manzella
- Maryland Space Grant interns – Wheel Test Rig Design
  - Ali Arnaout (UMBC)
  - Evan Lewis (Harford Community College)

Thank You!

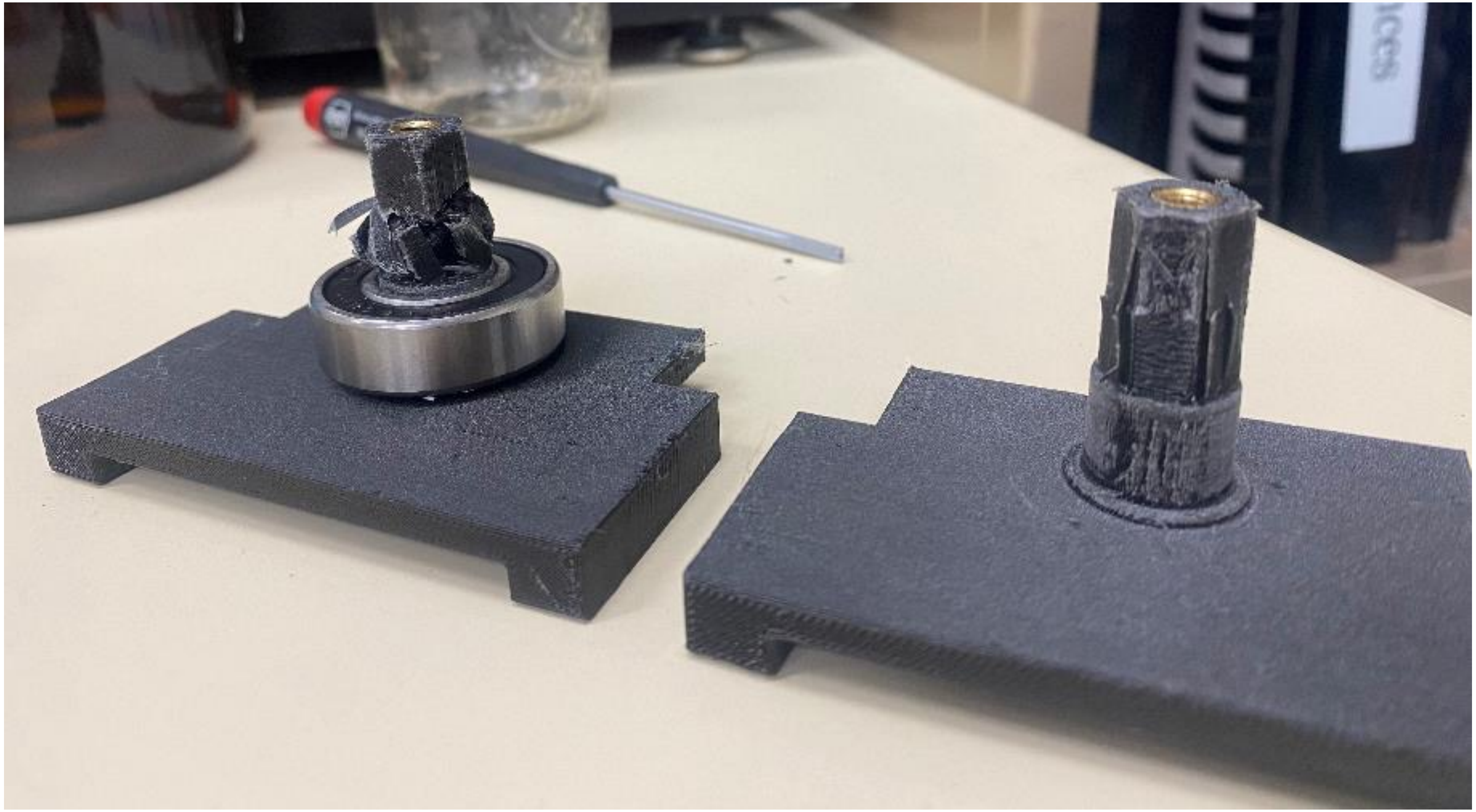




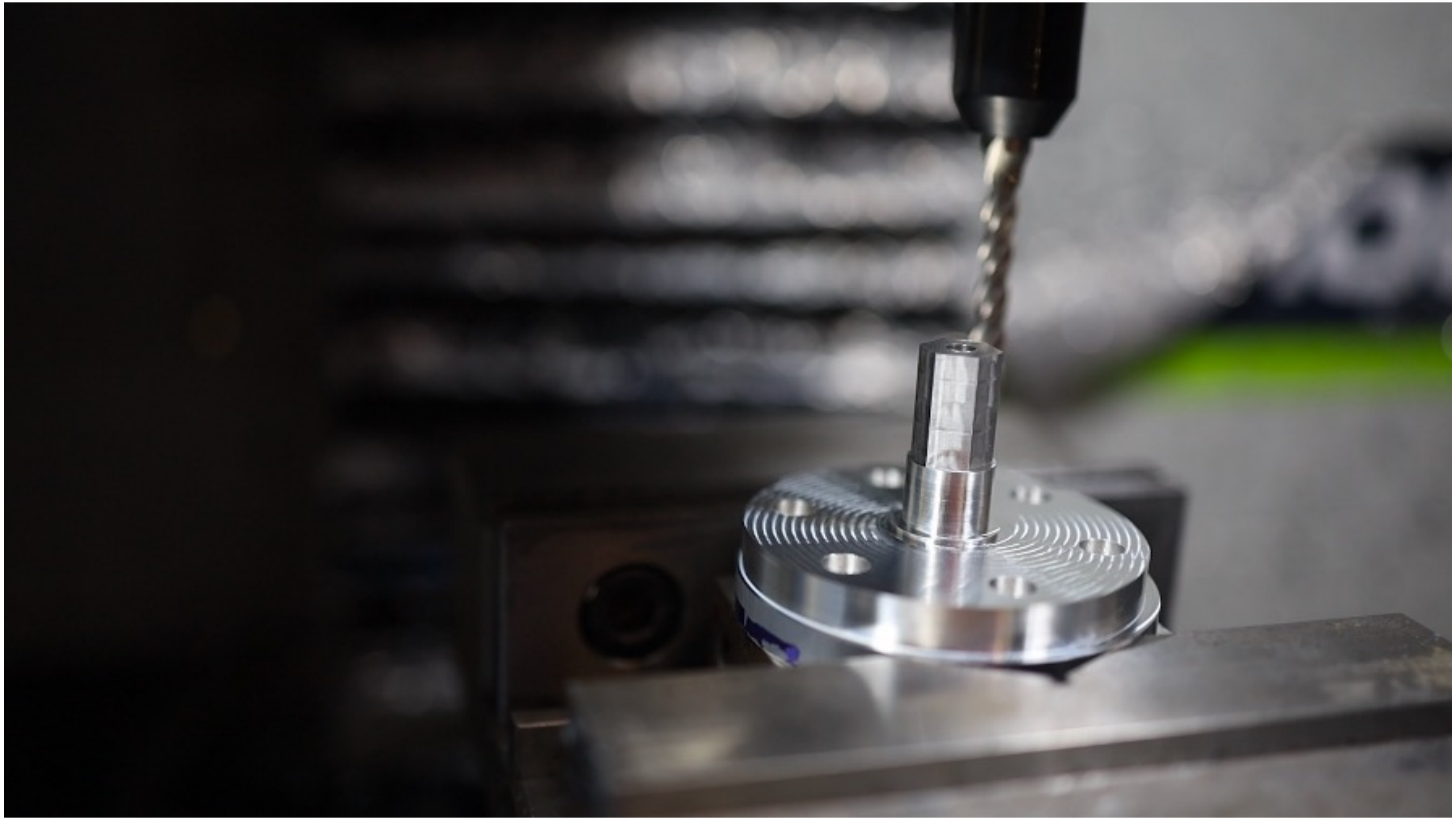
Supplemental Slides

Driveshaft Failures – Input to Gearbox

Driveshaft Failures – Output from Gearbox



Aluminum Driveshafts



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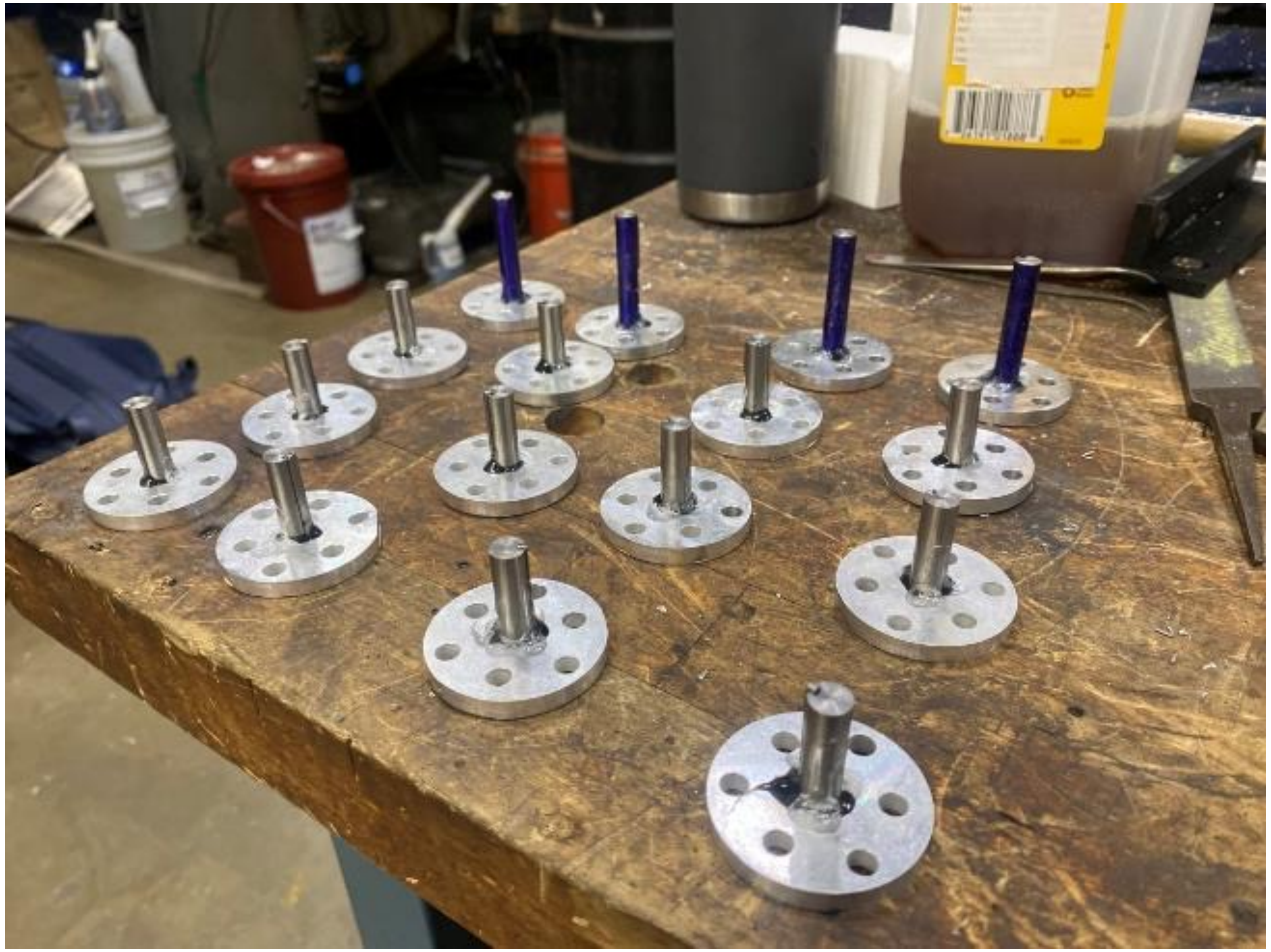
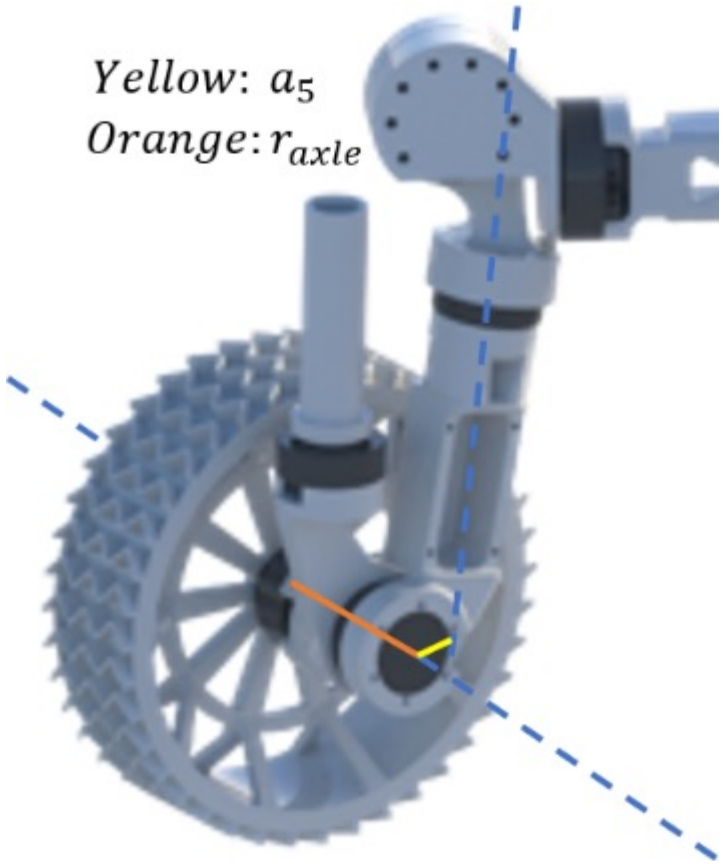
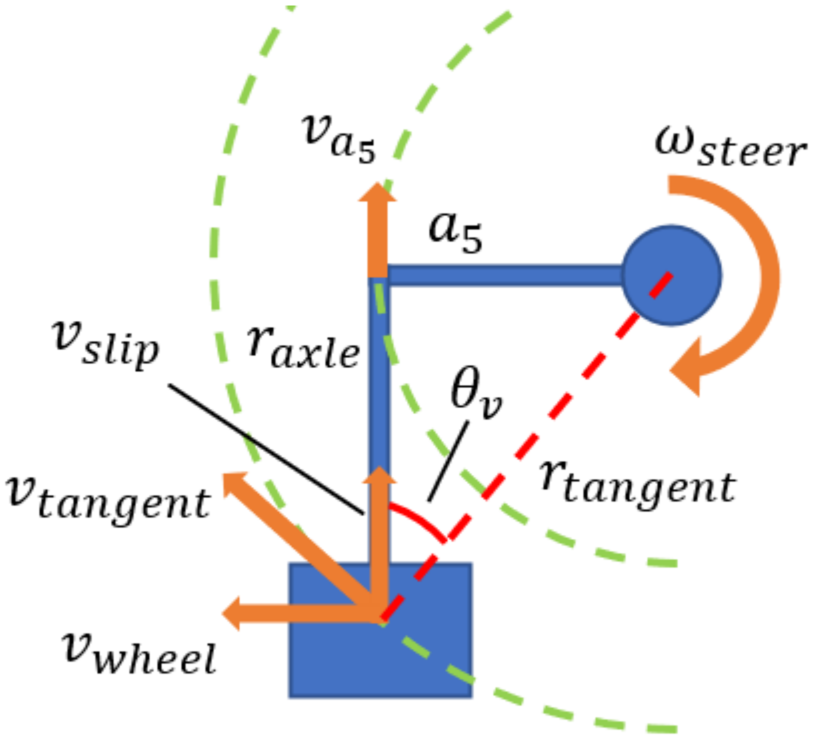


Kinematics – Wheel Offsets





Kinematics – Driving