INCOSE URC 2026

Team Mountaineers

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West Virginia University

Presentation Agenda

1. Systems Thinking Demonstration
2. Team Collaboration & Roles
3. Requirements Traceability & Validation
4. Architecture & Design Rationale
5. V&V Execution & Results
6. Risk Management
7. Lifecycle & Sustainability

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Section #1:

Systems Thinking Demonstration

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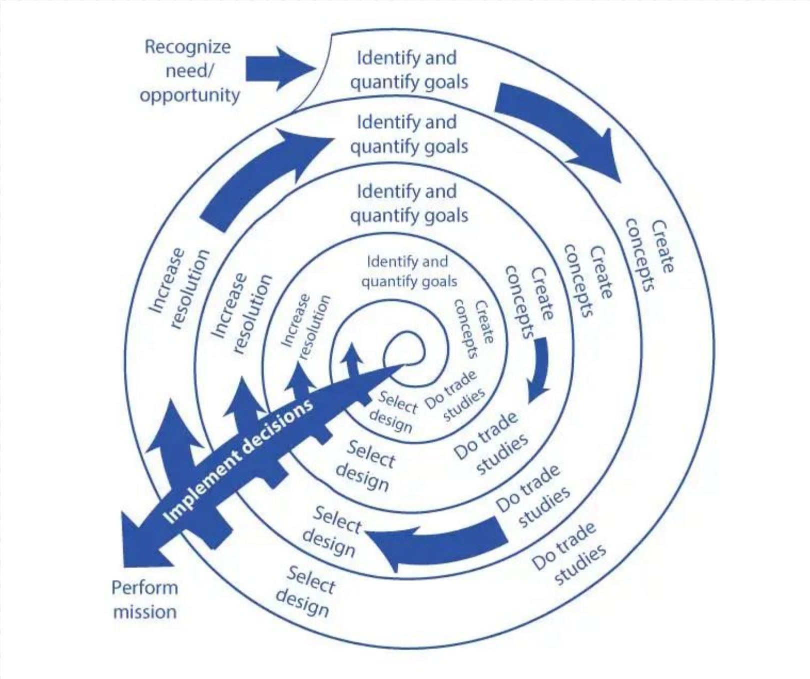
Systems Thinking Demonstration

- Approach to systems engineering (SE) is based on the NASA Systems Engineering Handbook.
- Iterative design cycles between competition years provide insight into rover goals, challenges, and potential solutions.



[1] From NASA Systems Engineering Handbook

Systems Thinking Demonstration

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Guiding Questions & Principles:

- Competitions rules & parameters.
- What are the goals of this system?
- What does success look like?
- Who will use the system?
- What happens if the system fails?
- How can we simplify the system?
- Analytics, Aesthetics, and Algorithms (AAA)

Section #2:

Team Collaboration & Roles

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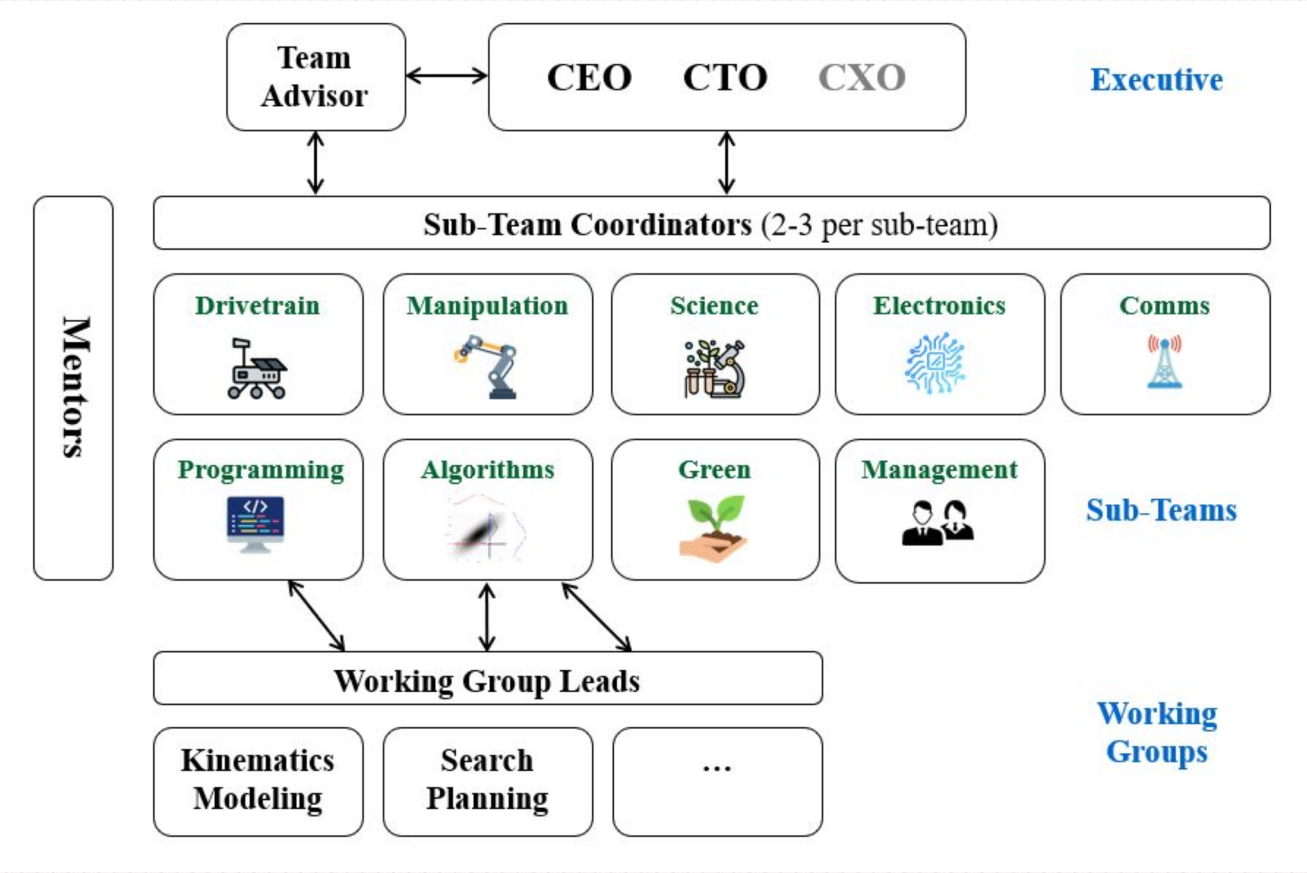
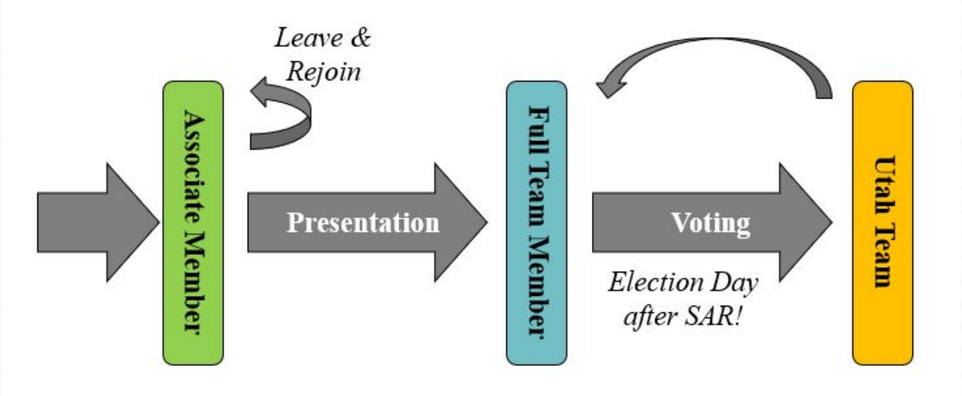
Team Structure





Section #3:

Requirements Traceability & Validation

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Requirements Traceability & Validation

Stakeholder Expectations → Technical Requirements → Logical Decomposition → Design Solutions

Stakeholder Expectations

- Mission Summaries from Previous Year
- Updated Competition Rules
- Recommended Improvements
- Innovative Designs

What was done right in 2025

- Most focused development targets reached: e.g., lighter robot, wheg geometry and socks, long antenna mast, folding methods, etc.
- Flat Heimdall and mini Heimdall for training
- Brought back the Comms sub-team
- Refined manipulator with improved workspace and protection
- Improved data display (e.g., joint angles, signal quality)
- Well trained ES and delivery missions
- System has matured to a level that appears not need major changes
- Drone practice
- Figured out chemical transportation and disposal
- Science training pre-Utah
- Team bonding dinners before Utah, Spooky Spot the Difference is Goated

Technical Requirements

- Overall Design Goals
- Subsystem-Level Technical Requirements

WVU URC 2026 Technical Requirements
Author: Team Due: Oct 10

Objective: Define the constraints and technical requirements for each URC sub-teams. Technical requirements transform the stakeholder expectations into a set of *unique*, *quantitative*, and *measurable* "*shall*" statements that can be used for defining the design solutions.

Each sub-team please define *functional requirements* (what functions need to be performed), *performance requirements* (how well these functions should be performed), and *interface requirements* (how different components are connected).

For example:
- The obstacle detection algorithm shall detect and identify obstacles while the rover is traversing the planetary surface (*functional*)
- Obstacles taller than 20 cm above the ground within 360º field of view and within a distance range of 0.5-5m from the rover center shall be identified over 99% of the time with the rover moving at 2m/s (*performance*)
- The obstacle detection algorithm shall report the types, locations, and sizes of the obstacles along with the detection confidences at a rate of 10 Hz and a latency no greater than 100ms (*interface*)

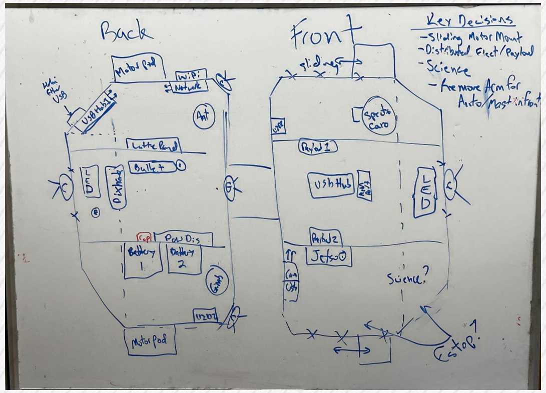
Read Chapter 2, and 4.2 of the NASA Systems Engineering Handbook: https://www.nasa.gov/wp-content/uploads/2018/09/nasa_systems_engineering_handbook_0.pdf

Feel free to look at previous years' design documents. However, a better approach is to try to come up with your own requirement definition for this year and then read the previous year versions to catch anything missing.

After completing a draft, please go through this ***checklist***:
- Are the requirements written correctly (i.e., in the right format with a "shall")?
- Are the requirements technically correct?
- Do the requirements satisfy stakeholders (i.e., the URC rules)?
- Are the requirements potentially feasible? (maybe hard to fully gauge at this point)
- Are the requirements redundant or over specified?
- Are the requirements verifiable? (e.g., with enough information to be accountable?)
- Is the rationale for the requirement properly documented? (e.g., reason for the requirement, assumptions)

Logical Decomposition

- Rover System Organization
- Operational Methods (Base Station Design, GUI Layout, Basic Mission Procedures)



Design Solutions

- Brainstorming
- Trade Studies
- Prototyping

Section #4:

Architecture & Design Rationale

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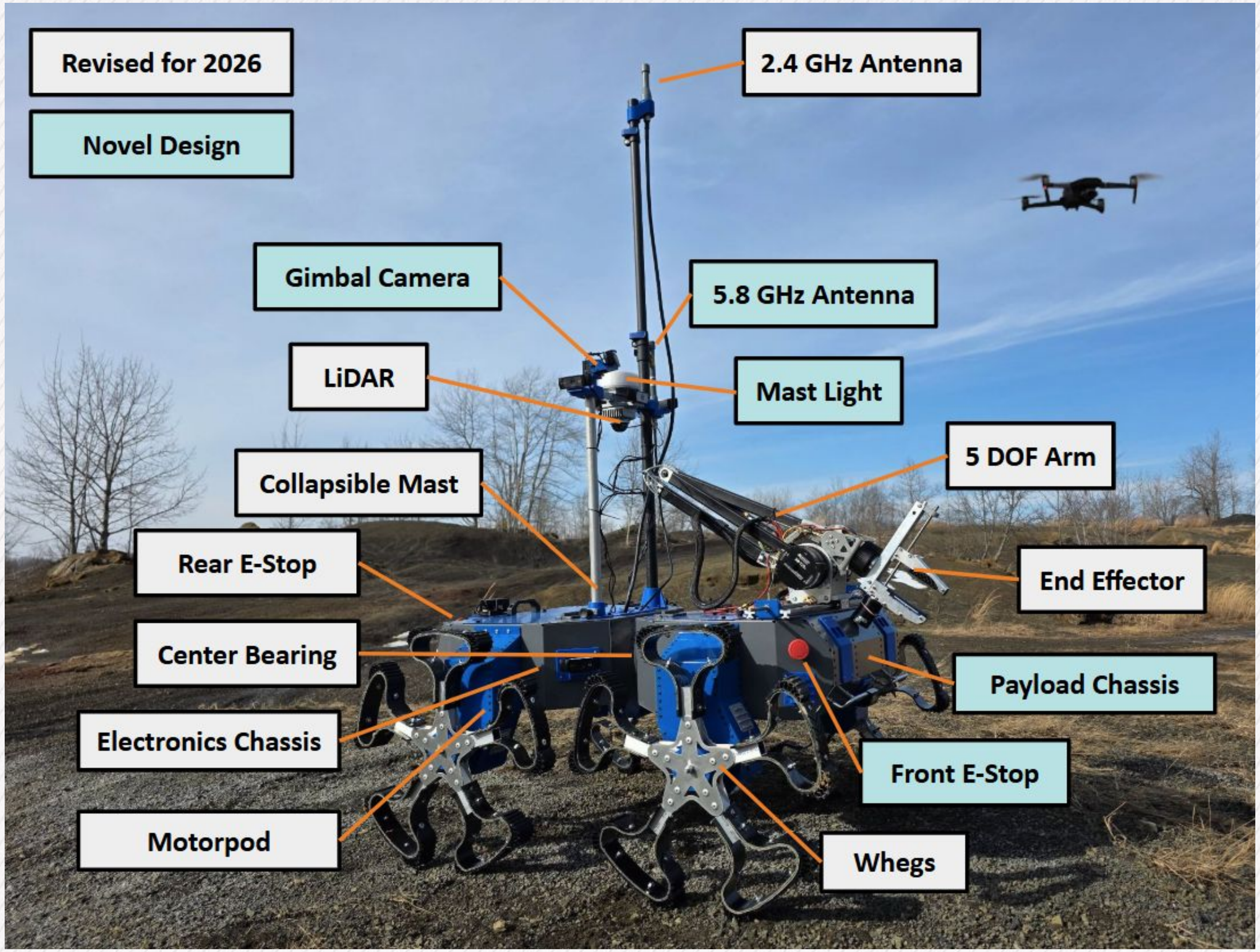
Architecture & Design Rationale (Mechanical)

What was designed and why?

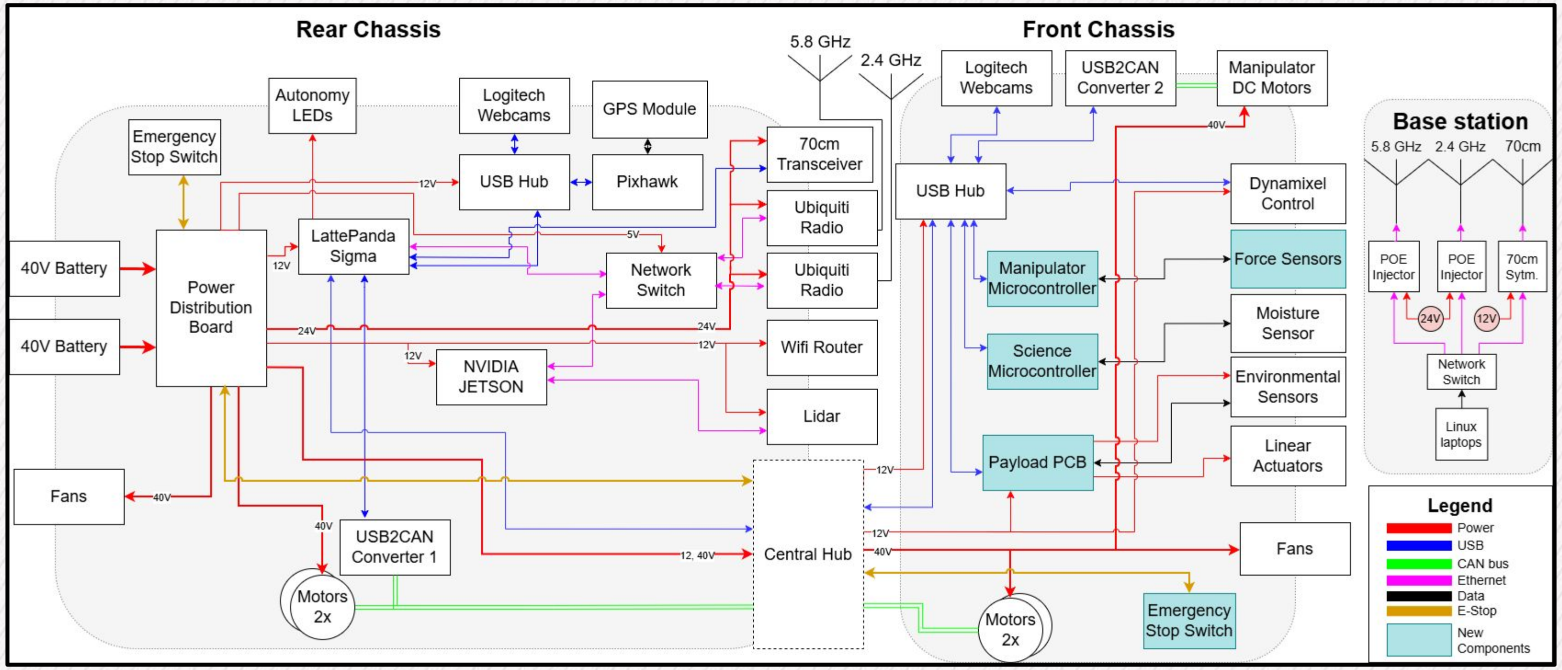
- Split-body chassis with a rotating center bearing for stability.
- Wheel-leg (wheg) design.
- 5 degree-of-freedom (DOF) manipulator arm.
- Gripper end effector.
- Bi-directional rotary digging (BiRD) system end effector.
- Collapsible mast for antennas.



Architecture & Design Rationale (Electronics)

What was designed and why?

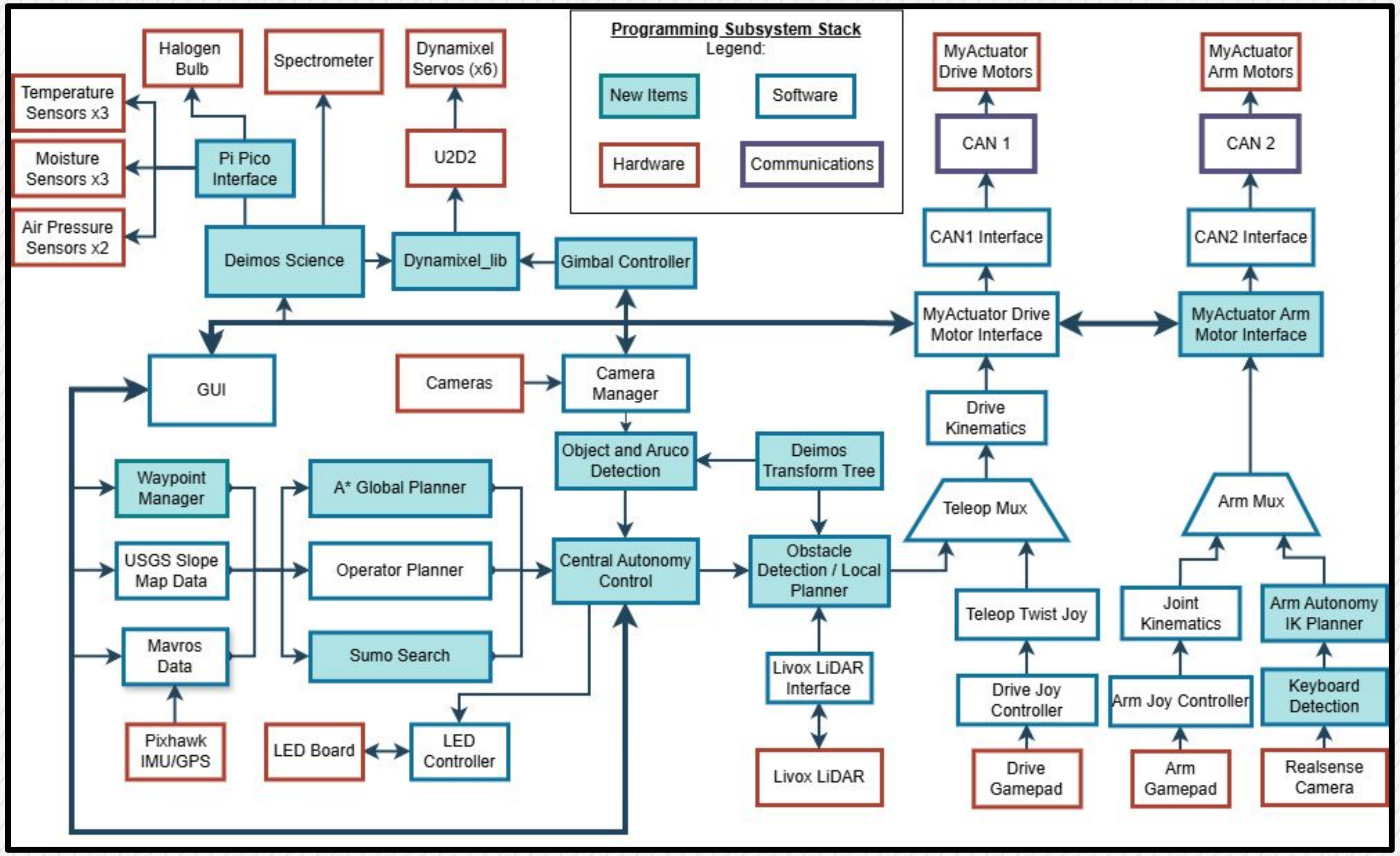
- Dual onboard computers for autonomous detection and data storage.
- Quick Swappable 40V, 4Ah batteries
- Custom PCBs for power distribution and sensor integration.
- Dual 5.8GHz and 2.4GHz comms system for



Architecture & Design Rationale (Software)

What was designed and why?

- Web-Based Graphical User Interface (GUI) for operator usability and adaptability
- Robot Operating System 2 (ROS2) for subsystem modularity
- Sensors redundancy to ensure graceful degradation
- LiDAR-Inertial Simultaneous Localization and Mapping (SLAM)
- YOLOv12 Visual Perception Model



Architecture & Design Rationale

Iteration of Wheel-Leg (Wheg) Designs

<u>Heimdall Whegs (2024)</u>

- Initial 20” diameter wheg design.
- Carbon fiber composite footers joined to an aluminum spoke hub.

<u>Daedalus Whegs (2025)</u>

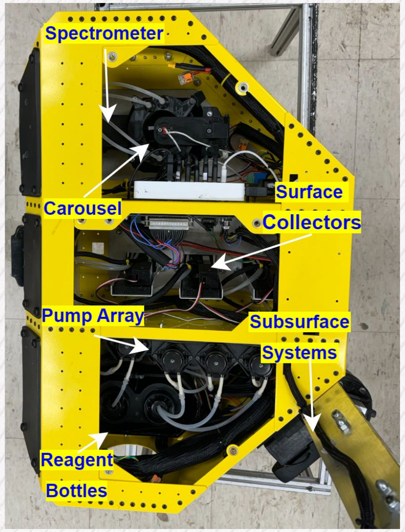
- New 24” diameter composite wheg design.
- Folding wheg design to fit within space constraints.

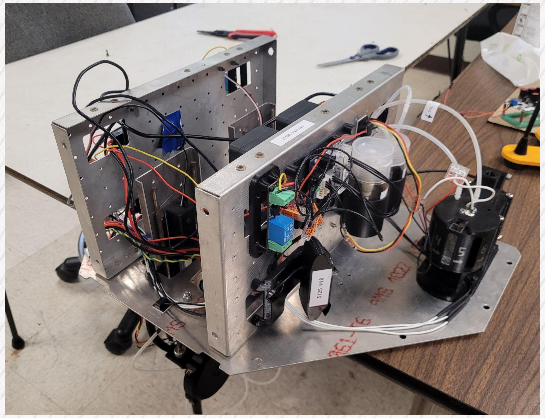
<u>Deimos Whegs (2026)</u>

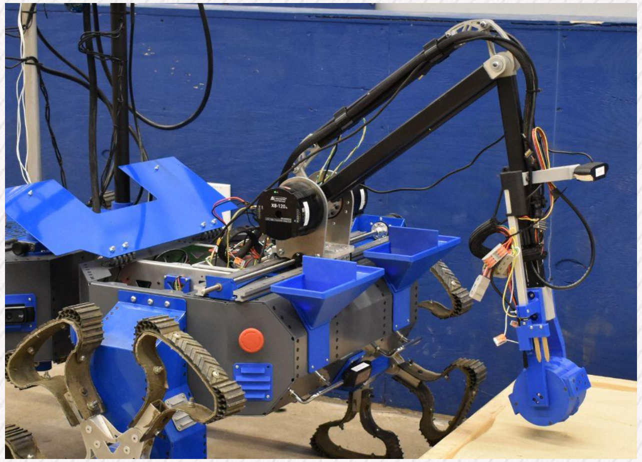
- New 20” diameter metal and 3D-printed wheg.
- Quick-swap F1 bolt design.

Architecture & Design Rationale

Iteration of Manipulation & Science Payload Chassis







<u>Heimdall (2024)</u>

- Separate manipulation and science chassis.
- Entire chassis swapped between mission days.

<u>Daedalus (2025)</u>

- Separate payload inserts for manipulation and science.
- Swapped through bottom of chassis frame.

<u>Deimos (2026)</u>

- Integrated manipulation and science payloads in one chassis.
- Only requires a 2-bolt end-effector swap.

Section #5:

V&V Execution & Results

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Verification of System

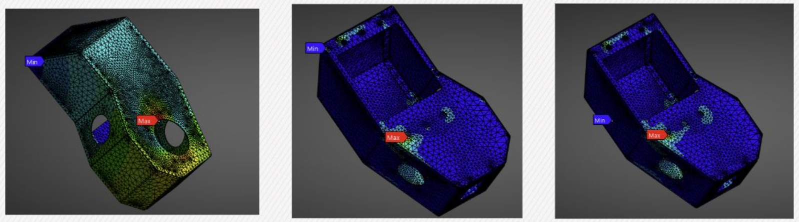
Verification: “Did we build the system correctly?”

- Finite Element Analysis on hardware components prior to manufacturing.
- Software components tested miniature rover testbeds using data collected from previous competition years
- Testing functionality of cross-component communication between subsystems prior to integration.
- Root Cause Analysis (RCA) when components malfunction or break.

Motor Pods

Maximum points in deformation (1.3883 mm), strain (0.0037879 m/m) and stress (222 MPa). Yield Stress of 5052 Aluminum is 193 MPa.

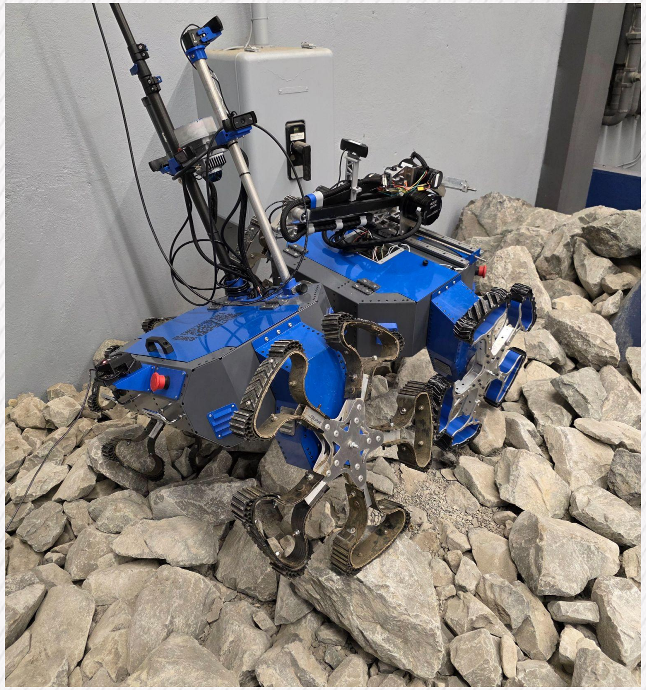
Deformation | Strain | Stress

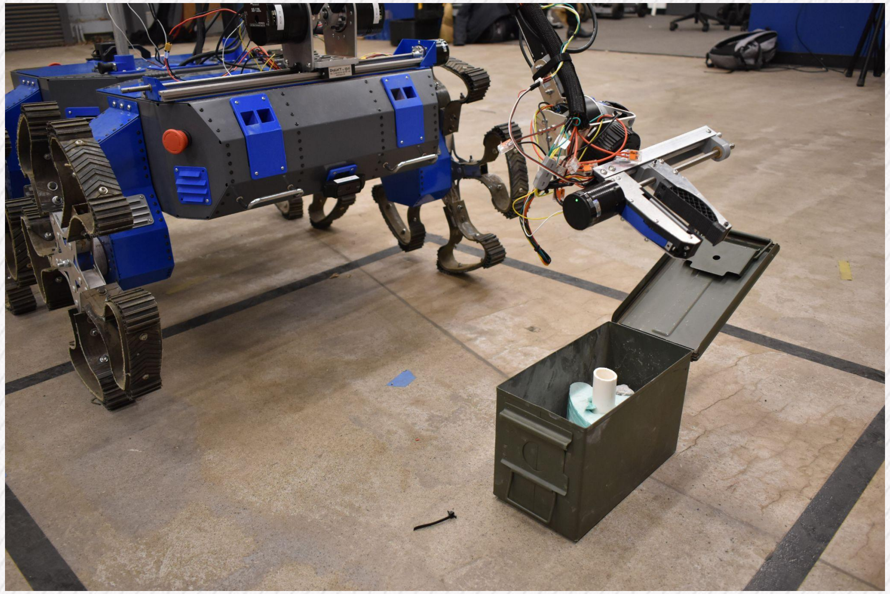


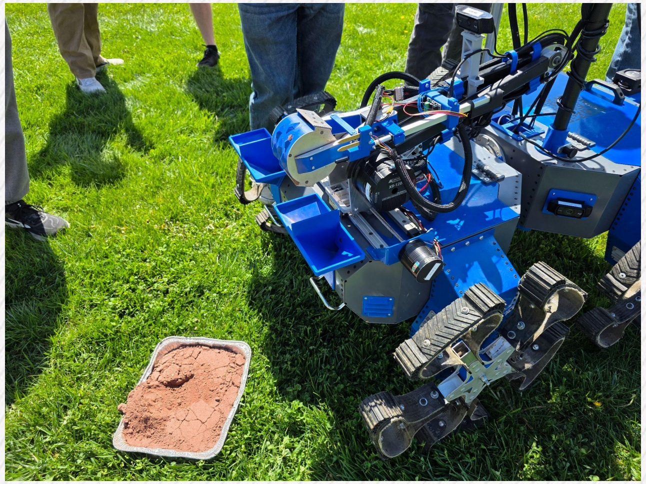
Validation of System

Validation: "Did we build the correct system?"

- Mock competitions for each mission.
- Replica lander built to practice equipment servicing mission.
- Mobility and durability testing in the rock garden at West Virginia University.



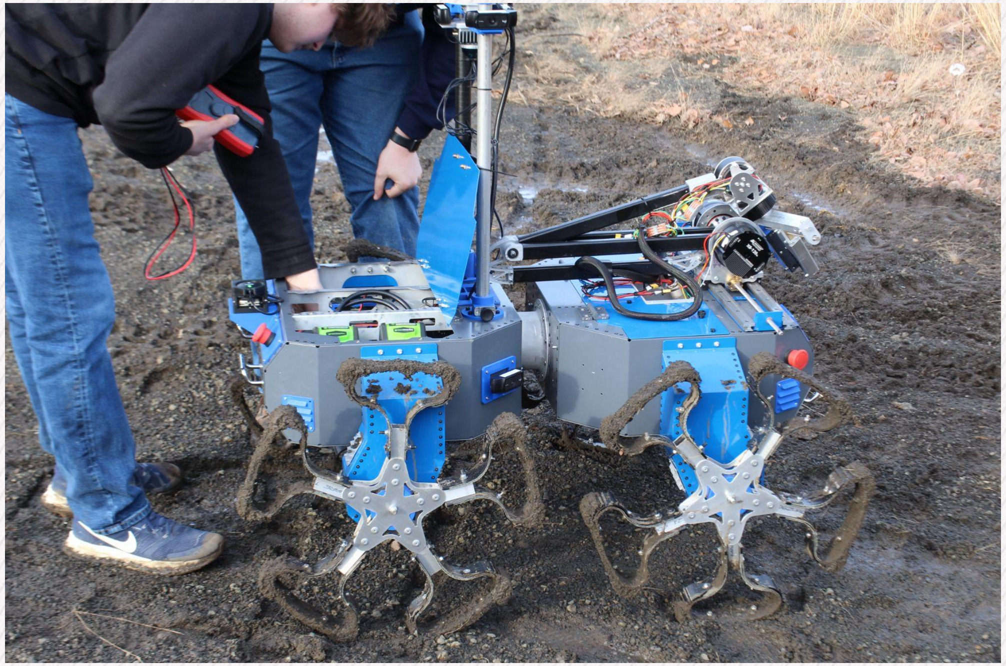




V&V Results

Results: “Did our V&V methods help achieve the system’s intended purpose?”

- 50+ hours of operator training on systems allowed us to:
    - Find many mechanical, electrical, and software issues.
    - Become familiar with how to best operate the system.
    - Demonstrate system validation for competition rules and environment.



    - Realize the difficulty of building a simple, reliable, and robust system.
    - Develop good problem solving skills and design backup plans to ensure mission success.

Section #6:

Risk Management

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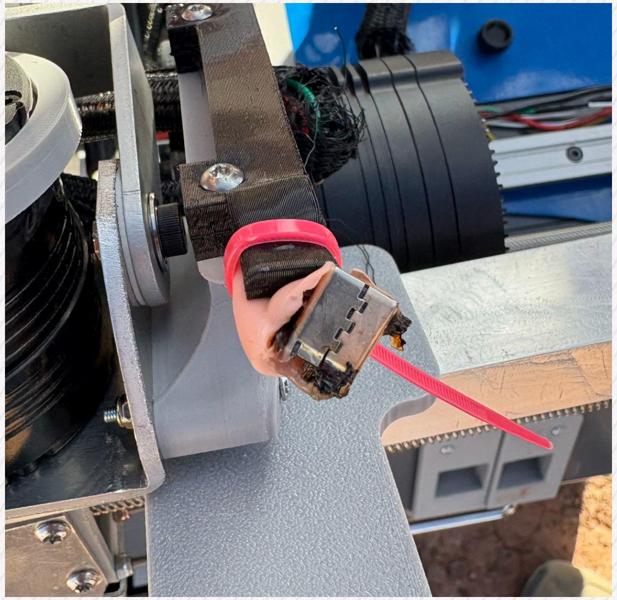
Risk Management

Task Assessment:
- Evaluating payoff associated with a specific risk
- Prevent risk to future mission performance
- Mitigate risk / mitigate damage if something goes wrong



Safety Nets:
- Manual and software emergency stops
- Hardware component back-ups
- Analytics including communications and battery monitoring

Reassessment:
- What to do when nothing goes to plan?
- *Graceful degradation* - given sub-system failure, system continues operating at reduced or simplified capacity.
- Pivoting plans to fit reduced capacity mission constraints.

Section #7:

Lifecycle & Sustainability

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Lifecycle & Sustainability

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Fall 2025

Pre-Phase A: Concept Studies
Sept 2025
Orientation & Requirements Development

Phase A: Concept & Technology Development
Oct 2025
Mock Competition & Trade Studies

Phase B: Preliminary Design and Technology Completion
Nov 2025
Preliminary Design & FEA Analysis

Phase C: Final Design & Fabrication
Dec 2025
Final Design & Procurement

Jan 2026
Assembly of Deimos

Summer 2026

Phase D: System Assembly, Integration and Test, Launch
Feb 2026
SAR Preparation & Initial Testing

Mar & Apr 2026
Rigorous System Testing & Refinement

Phase E: Operations & Sustainment
May 2026
Competition Preparation & Competition

Phase F: Closeout
June 2026
Develop mission summaries & open source all competition documents

Let's Go!

THE MARS SOCIETY
University Rover Challenge
ROVER
CHALLENGE
SERIES
PROTOCASE

Citations

[1] “Systems engineering handbook,” NASA, https://www.nasa.gov/reference/systems-engineering-handbook/ (accessed May 28, 2026).