System Acceptance Review
University Rover Challenge 2025

TEAM MOUNTAINEERS

West Virginia University
Team Mountaineers

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Introduction:

Team Mountaineers from West Virginia University is made up of 70 students from multiple engineering disciplines. The team is comprised of seven technical subteams: algorithms, communications, drivetrain, electronics, manipulation, programming, and science. These are supported by two non-technical subteams: management and the green team. Management focuses on team outreach, planning, procurement, and documentation, while the green team focuses on training new team members through introductory projects.

Using a systems engineering design process based on NASA's project lifecycle approach, Team Mountaineers has developed a new rover for the 2025 competition. The rover, Daedalus, shown in Figure 1, is supported by a commercial drone, Icarus, to assist in the Delivery Mission.

Core Rover Systems:

Following their strong performance in the 2024 URC competition, Team Mountaineers has adopted a design approach focused on greater modularity, improved user interfacing, and overall system robustness.

Drivetrain

Daedalus's drivetrain system builds off the success of the 2024 design, continuing the use of a split-body sheet metal chassis connected via a bearing mechanism. This design allows the two halves to rotate independently, maximizing contact with the ground as the rover drives. The front half of the chassis features swappable payloads to change the rover configuration for each mission. The first payload is used for the Delivery and Equipment Servicing (ES) missions, while the second payload is used for the Science mission. In addition to the two payloads, a secondary autonomy payload is installed into the ES configuration for the Autonomous Navigation (AN) mission. This allows rapid changes between missions and easy maintenance on the payloads.

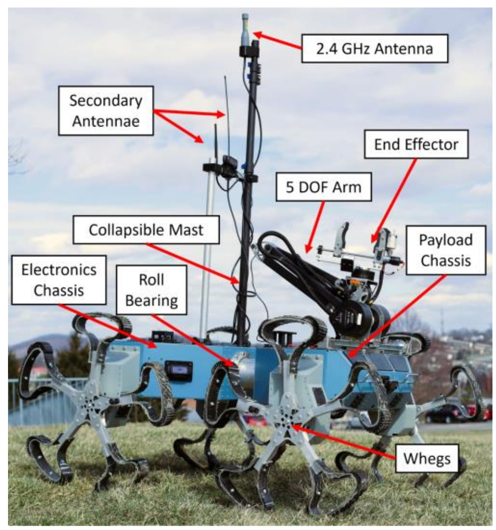

Figure 1. Annotated image of Daedalus.

The motor pods, which house the DC drive motors, extend below the main chassis, allowing the rover to achieve a ground clearance of 34 cm. Daedalus improves upon the use of wheel-legs, whegs, from its predecessor. The wheg assembly features a five-spoke aluminum hub with carbon-Kevlar composite feet. The radius of the whegs is increased compared to its predecessor, allowing for a maximum travel speed of 1.6 m/s. Additionally, redesigned wheg footers minimize vertical displacement, while custom TPU treads enhance traction—both working together to reduce ground impact. These improve the ability to traverse rocky terrain and loose soil while reducing vibrations during missions with delicate equipment, such as the Science mission. To fit within the 1.2-meter cubic sizing constraints, each wheg features a folding mechanism on one of the spokes.

Manipulation

Daedalus features a 9.4 kg manipulator, representing a 1 kg reduction from the team's 2024 design while maintaining an identical payload capacity and increasing the range of motion. This five-degree-of-freedom palletizer-style manipulator utilizes a composite four-bar linkage to minimize weight and torque requirements alongside a linear rail that enables precise horizontal translation. These components, in conjunction with the pitch and roll axis in the wrist, create a cylindrical workspace with a diameter of 100 cm and a horizontal length of 55 cm, allowing the rover to reach 8 cm below and 156 cm above the ground plane, respectively. At maximum extension, the manipulator is able to lift objects up to

10 kg in mass. To meet the updated requirements for the ES mission, the arm is equipped with an RGB-Depth camera, which provides data for autonomous typing. The end-effector, a lead screw driven clamping gripper, is embedded with force-feedback sensors, facilitating fine control of clamping force. Daedalus's manipulator also employs torque-based motor protection, allowing the rover to avoid destructive collisions during operation.

Electronics

Daedalus is powered through a custom-made power distribution board, which has built-in battery hot swap and emergency stop capabilities. This board steps down and regulates voltages to the levels needed for all rover subsystems shown in Figure 2. Daedalus is primarily controlled by a LattePanda Sigma onboard computer that communicates with a Raspberry Pi Pico, as well as an Nvidia Jetson Orin Nano during the autonomy mission. The Latte Panda communicates with brushless DC motors over a Controller Area Network (CAN) bus. The Raspberry Pi is housed on a custom payload printed circuit board (PCB) and interfaces with sensors and brushed DC motors.

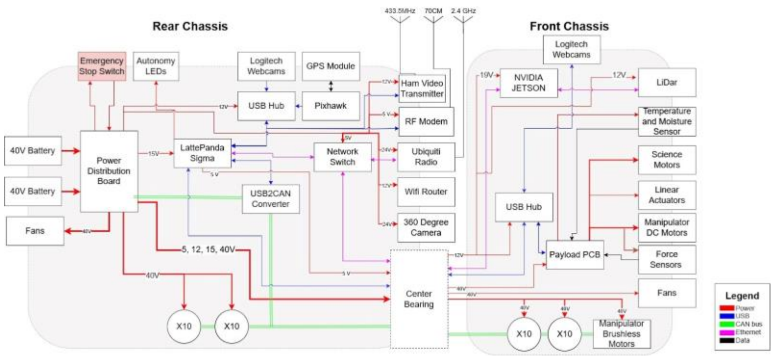

Figure 2. Electronics system block diagram.

Multiple radio systems facilitate rover-to-base-station communications. The primary communications system consists of a 2.4 GHz 90-degree sectorized base station antenna and a collinear omnidirectional antenna mounted atop the rover. The length of the rover's antenna mast extends to 3 meters, requiring a reduction in the weight of the primary antenna but improving the ability to maintain line-of-sight for communication. Auxiliary low data rate control signals are sent using 70 cm HAM band packet radios to ensure reliable long-range, non-line-of-sight transmission. Supplementary analog video is also broadcast to the base station over 433.25 MHz using amateur television transmission.

Programming

Daedalus utilizes Robot Operating System 2 (ROS 2) to take advantage of its distributed node framework and reliable management system. Figure 3 shows a block diagram of this software system. ROS 2 Discovery Servers reduce network congestion by organizing process communication. A health monitoring system presents users with critical system data, including motor status, communications signal strength, and computer resource usage. The LattePanda handles regular operations, while the NVIDIA Jetson handles demanding computer vision and point cloud processing during the AN mission.

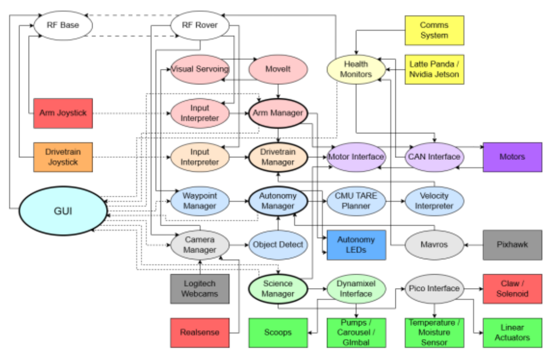

Figure 3. Daedalus's software structure diagram.

A new graphical user interface (GUI) was developed with the responsive web framework, React. This GUI presents operators with positional information, camera feeds, and other rover diagnostics while providing an interface for control during the science mission. A navigation page displays rover pose on user selectable backgrounds, including satellite imagery and elevation cost maps. Operators plan missions by placing markers on these backgrounds to represent points of interest, including GNSS coordinates and search areas. On the camera page, operators select specific views, adjusting their brightness, contrast, and rotation to give a comprehensive view of

Daedalus and its environment. To ensure the safety of the rover, operators can view telemetry and health data on any page. A separate science page gives operators access to a database of known spectrometer readings and displays instrument data while allowing for control of the pumps, scoops, and other instruments on the science payload.

Approach to Competition Missions:

Delivery

To complete the Delivery mission, the rover must demonstrate its ability to navigate varying terrain, maintain long-range communication, accurately locate designated items, and successfully manipulate and transport all required objects. Daedalus's use of whegs and a split body chassis offer advantages in traversing difficult terrain while maintaining four points of contact. Communication over the 2.4 GHz system is maintained for a tested range of 750 meters line-of-sight, with a seamless transition to the secondary system in non-line-of-sight areas. This ensures reliable connectivity throughout the mission under varied conditions.

To efficiently teleoperate and search for designated objects, Daedalus is equipped with multiple cameras that provide various perspectives of the rover and the surrounding terrain. The GUI navigation page assists operators in pathing to provided coordinates and visualizing item search radii. Upon detecting an item of interest, operators position the rover for collection. A clamping gripper applies up to 70 N of force, ensuring a secure grip for object retention on rough terrain. TPU-printed gripper plates allow the gripper to conform to irregularly shaped items, ensuring secure transportation.

Daedalus is supported by Icarus, a DJI Mavic 2 Pro drone that enhances missions with aerial reconnaissance. Icarus launches from the control station and scouts ahead to help Daedalus find objects and read signs.

Equipment Servicing

For the ES mission, the rover must perform precise manipulation as well as collect and transport a sample cache weighing up to 5 kg. During this mission, Daedalus uses the same manipulator as in the Delivery mission, with the addition of a solenoid for button and key pressing. The linear rail is especially useful for these tasks, allowing the manipulator to move in-plane with each lander face. Newly added force-feedback sensors allow operators to monitor clamping force when collecting objects.

To control the manipulator in the ES mission, operators are able to switch between joint and inverse kinematic control. Joint-based control allows operators to directly command each motor, allowing for quick and easily intuited motion. Inverse kinematic control allows the end-effector to move independently in cartesian space, facilitating planar tasks.

Visual servoing is used to complete the autonomous typing portion of the ES mission. Pre-defined manipulator joint states are programmed to allow for a camera view of the keyboard and to orient the solenoid to reach the intended key. Once a key command is received, a starting joint state and offset value are chosen relative to the position of the intended key. Image-space error is then calculated, normalized, and fed into a Jacobian matrix to translate it into joint velocities. Moveit 2 receives these joint velocities and plans the motion of the arm's motors to prevent self-collisions.

Autonomous Navigation

For the AN mission, Daedalus must navigate complex terrain and locate positions or objects of interest without human assistance. Daedalus performs autonomous navigation through the use of global and local path planning, object detection, and reflexive control. The global path planning system uses a simple A* planner that runs on low-resolution USGS digital elevation models of the competition area. The lowest-cost global paths are recommended to the operators, who then decide the most desirable course. A Livox Mid-360 LiDAR and the FAST-LIO algorithm generate a high-resolution map of the environment and rover odometry estimate. This information is processed by a local path planner, which runs collision avoidance and traversability modules to generate short, safe paths between global goals. During the traversal, a safety system checks for unsafe driving conditions by monitoring the rover's tilt and motor current. If unsafe conditions are detected, Daedalus returns to a known safe point and recomputes a safer path to the objective.

Once Daedalus has entered the vicinity of an object of interest, a search operation will begin. Gaussian probability distributions for each object are generated, and search points are selected by sampling the distributions. The distributions are updated as the rover moves between these search points and explores. AruCo markers are detected using the OpenCV ArucoDetector while other objects are located using a custom-trained YOLO model with a detection range of 15 meters. If an object is detected while searching, its relative position is determined and the rover travels to it. The rover signals arrival at a point by flashing its rear LEDs green.

Testing and Operations:

In preparation for URC 2025, Team Mountaineers underwent rigorous training and testing to build team-wide proficiency in all aspects of competitive rover design and operation. The manipulation, drivetrain, and science subteams completely remodeled the 2024 rover, Heimdall, using the newly selected CAD software, Onshape. The programming subteam completed a series of ROS 2 tutorials, while the electronics subteam constructed a replica of Heimdall's electrical system, dubbed flat Heimdall. In addition to these training efforts, members familiarized themselves with Heimdall, culminating in an internal mock competition to provide experience in a competitive environment. New members were assigned to teams and tasked with completing all four URC missions under the supervision of senior members serving as judges.

After documenting the strengths, limitations, and challenges discovered during the mock competition, a series of trade studies were conducted to make design decisions. Mechanical designs underwent finite element analysis in addition to physical testing of 3D printed prototypes to determine viability. All PCBs were stress tested using flat Heimdal, and the communications subsystems underwent range testing. Autonomous navigation capabilities were implemented on Heimdall to ensure base functionality. Following subsystem redesign, systems were tested in isolation before being integrated and retested as part of the complete system.

An on-campus rock garden was used for initial experiments before the rover was taken off-campus for further testing in a variety of environments. These efforts included deliberately pushing critical systems beyond competition requirements to identify the limits of the rover. This allowed the team to progress the NASA Technology Readiness Level (TRL) from TRL-1 to TRL-6 within a 7-month timeframe.

Further testing of the rover systems, as well as operator training, will continue. Each mission operator will log at least 100 hours of practice with particular emphasis on teleoperation and off-campus field testing. This will include mock missions with specific equipment, such as an arm motor, disabled to practice operation in suboptimal conditions. Additionally, a set of detailed operating procedures will be developed and refined for each mission to define success criteria and fallback modes in the event of unexpected challenges.

Team Development:

To assist in personal development and expand the range of projects team members work on, each team member is part of two subteams. All new non-senior members are also a part of the green subteam. This subteam focuses on smaller-scale introductory projects that provide members with lower-stake opportunities for learning. This year, the green subteam has developed a small rover named Loki which has a goal of being built using recycled components.

Team Mountaineers has conducted significant educational outreach in the greater Morgantown area since the last competition. The public was able to operate Heimdall at several on and off-campus events, including the Pittsburgh Robotics Discovery Day, the WVU Annual Pumpkin Drop, and engineering summer camps for local K-12 students. In total, the team has participated in 9 outreach events this year. Team Mountaineers also open-sourced their CAD and software designs after the last two competitions and has assisted several other URC teams with technical challenges during this competition cycle.

Budget and Gantt Chart:

The project budget, which features rover expenses, additional expenses, and travel allocations, is summarized in Table 1. As shown in this table, the team's funding is sufficient for travel if selected for URC 2025. Additionally, the Gantt Chart seen in Table 2 shows the planned and completed tasks to date.

Table 1. Project budget table.

INCOME			
Actual Income to Date			
	WVU MAE Department		$20,000
	WVU CSEE Department		$20,000
Total Income Recieved to Date			**$40,000**
Anticipated Income			
	NASA Space Grant Consortium		$5,000
Total Additional Income Anticipated			**$5,000**
		TOTAL INCOME	**$45,000**
EXPENSES TO DATE			
1 Electronics			
	1.1 Communications		$812.10
	1.2 LattePanda Computer		$579.00
	1.3 Nvidia Jetson Orin Nano		$250.00
	1.4 Livox Mid-360 Lidar		$838.00
	1.5 Pixhawk & GPS Module		$300.98
	1.6 Power Distribution Board		$424.06
	1.7 Payload PCB		$389.40
	1.8 Sensors		$666.59
	1.9 Wires & Connectors		$477.08
	1.10 Miscellaneous		$200.80
		Electronics	$4,938.01
2 Drivetrain			
	2.1 Chassis		$954.50
	2.2 Myactuator Motors		$2,516.00
	2.3 Composites		$465.84
	2.4 Machined Parts		$1,041.00
	2.5 Hardware		$519.42
		Drivetrain	$5,496.76
3 Manipulation			
	3.1 Myactuator Motors		$2,328.00
	3.2 Depth Camera		$280.40
	3.3 Hardware		$418.84
	3.4 Machined Parts		$1,794.00
	3.5 DC Actuators		$61.35
		Manipulation	$4,882.59
4 Science			
	4.1 Spectrometer		$1,650.00
	4.2 Motors and Actuators		$897.15
	4.3 Hardware		$117.54
	4.4 Machined Parts		$849.98
		Science	$3,514.67
5 Other			
	5.1 3D Printing Filament		$140.00
	5.2 Base Station Computers		$840.00
	5.3 Miscellaneous		$600.00
		Other	$1,580.00
		TOTAL ROVER EXPENSES TO DATE	**$20,412.03**
6 Additional Costs			
	6.1 PPE		$100.00
	6.2 Drone		$499.00
	6.3 Spare Motors		$2,152.00
	6.4 Miscellaneous		$800.00
		Additional	$3,551.00
		TOTAL EXPENSES TO DATE	$23,963.03
ANTICIPATED EXPENSES			
	Travel to Utah		$12,000.00
	Rover Shipping		$3,000.00
	Backup Parts		$5,000.00
		TOTAL ANTICIPATED EXPENSES	**$20,000.00**
FORECASTED BUDGET SURPLUS			**$1,037**

Table 2. Project Gantt chart.

Phases: Research and Planning Phase; Design Phase; Building, Testing and Integration Phase; Competition Preparation Phase. Months: September, October, November, December, January, February, March, April, May (Weeks 1 2 3 4).

Task #	Task Name	Percent Complete
1	Drivetrain	
1.1	Preliminary Research	100
1.2	Chassis Design	100
1.3	Refining Design	100
1.4	Manufacturing	100
1.5	Assembly	100
1.6	Testing and Integration	25
2	Manipulation	
2.1	CAD Training	100
2.2	Preliminary Research	100
2.3	Preliminary Design	100
2.4	Full Manipulator CAD	100
2.5	Subsystem Prototyping	100
2.6	Assembly and Integration	100
2.7	Testing and Training	25
3	Science	
3.1	Preliminary Research	100
3.2	Package Design	100
3.3	Experiment Design	100
3.4	Refining Design	100
3.5	Assembly	100
3.6	Testing and Integration	35
4	Programming & Algorithms	
4.1	ROS2 Tutorials	100
4.2	Preliminary Research	100
4.3	Architecture Design	100
4.4	Hardware Drivers	100
4.5	Driver Control	100
4.6	Preliminary Autonomy	100
4.7	Health Monitoring	100
4.8	Obstacle Avoidance	100
4.9	Manipulator Autonomy	100
4.10	Testing and Integration	40
5	Electronics	
5.1	Preliminary Research	100
5.2	Circuit Board Designs	100
5.3	Simulations	100
5.4	Component Interfacing	100
5.5	Testing and Integration	45
6	Competition	
6.1	Operator Training	15

Science Plan:

To assess the life support capability and habitability of the mission site, surveys of sediment depositions, hydraulic erosion, and soil desiccation are analyzed to determine sampling locations. Known information on the lithology of the Mars Desert Research Station (MDRS) from *The Regolith Geology of the MDRS Area* [1] is compared to panoramic photographs compiled from wide-angle cameras placed around the rover. From these, a stratigraphic profile can be produced at each sampling location. Detailed location shots taken by onboard cameras indicate the cardinal directions, elevation, and sedimentary structures.

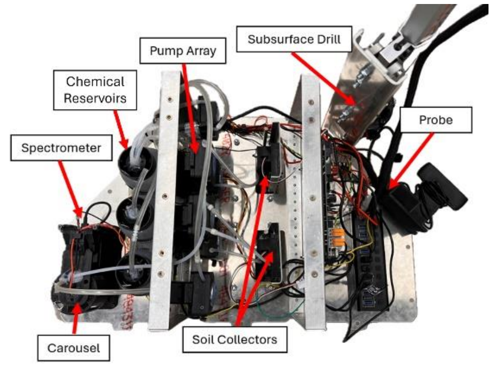

Figure 4. Annotated image of science payload.

To facilitate the detection of life at the selected sites, a science payload containing a spectrometer, chemical assay, and three soil collectors was developed. This payload, separate from Daedalus, is shown in Figure 4.

Spectroscopy analysis reveals information about soil composition, including life's macromolecules. Naturally occurring pigmented molecules, such as photosynthetic chlorophyll and antioxidative carotenoids, are examples of such compounds [2]. Distinct spectral patterns from photon absorption indicate the presence of organic substances within the color wavelength range. The solvent for all experiments is 70% isopropyl alcohol (IPA), which has appropriate solubility for hydrophobic substances and ideal suspension of soil.

Two new life detection tests are added this year. Baeyer's test, the first new test, detects several unsaturated compounds including lipids, nucleic acids, and primary/accessory pigments [3]. Baeyer's reagent contains potassium permanganate and anhydrous sodium carbonate. In the presence of unsaturated compounds, oxidation of the carbon backbone and reduction of permanganate occurs, leading to dissipation of the original purple color and formation of a dark precipitate [4]. Spectral results can be cross-referenced to confirm extant or extinct life forms. A wide range of positive results from samples can occur within a five second period, including indication of many biopigments and flavonoids. The second new test, the fizzing carbonates test, uses 1M hydrochloric acid (HCl) to detect the presence of common byproducts within extinct life forms [5]. When HCl is added to the solution, any organic carbonate ions available decompose into weak acid and carbon dioxide, with the escaping gas being observable through bubbling [6]. Both the Baeyer's test color shift and carbonates test bubbling are observable through a camera within the science payload. The IPA, Baeyer's reagent, and HCl represent environmental hazards and will be handled and disposed of appropriately.

To obtain surface samples for testing, a surface collection package with two scoops and six peristaltic pumps is used. Each scoop has a linear actuator and a digital servo, offering control of depth and rotational speed when collecting samples. A pump connected to the IPA reservoir then transports the IPA to a drum where a solution is formed. After this solution is mixed, another pump is then used to move the solution to cuvettes stored in an eight-slot rotating carousel. The visible light spectrometer captures the spectra of the solution with a halogen bulb to provide backlight for analysis. Two pumps transport Baeyer's reagent and HCl separately to samples contained in the cuvettes.

Subsurface collection is performed with a custom-manufactured drill bit attached to a high-torque motor and a 30 cm stroke linear actuator. At the desired depth, rotation of the drill is reversed to open an internal 3D printed soil cache and collect samples greater than 5 grams. Once the sample has been collected, rotation is reversed again to seal the cache. A sensor then extends into the drilled hole to collect soil moisture and subsurface temperature data.

[1] J. Clarke, "The Regolith Geology of the MDRS Study Area", January 2003. [2] H. Hashimoto, C. Uragami, and R. J. Cogdell, "Carotenoids and Photosynthesis," in Carotenoids in Nature: Biosynthesis, Regulation and Function, C. Stange, Ed., Cham: Springer International Publishing, 2016, pp. 111–139. doi: 10.1007/978-3-319-39126-7_4. [3] P. Flowers et al., "20.1 Hydrocarbons - Chemistry 2e | OpenStax." Accessed: Feb. 13, 2025. [Online]. [4] Francisco Sánchez Viesca and Reina Gómez Gómez, "A complete and sustained organic/inorganic reaction mechanism of Baeyer's test," World J. Chem. Pharm. Sci., vol. 4, no. 2, pp. 001–005, May 2024, doi: 10.53346/wjcps.2024.4.2.0023. [5] S. Ronca et al., "Biogenic calcium carbonate as evidence for life," Biogeosciences, vol. 20, no. 19, pp. 4135–4145, Oct. 2023, doi: 10.5194/bg-20-4135-2023. [6] E. Vitz et al. "3.3.7: Geology- Using the Acid Test to Distinguish the Minerals in "Calomine," Chemistry LibreTexts. Accessed: Feb. 17, 2025. [Online].