SHREWs : Strategic Highly-compliant Roving Explorers of other Worlds

DARTMOUTH ENGINEERING

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Introduction

SHREWs are modular, collaborative rovers for exploring the Permanently Shadowed Regions (PSRs) of the Lunar South Pole. These four-wheel drive vehicles are highly-mobile units that affect their own extrication from immobilizing terrain via locomotion mode switching. Caravans of SHREWs provide collaborative deployment and extrication as a system redundancy. SHREWs allow multiple passages into the depths of PSRs through energy efficient design and access of solar power along the lit edges of craters. Concept innovations enable geophysical data acquisition required to scout for in-situ resource utilization (ISRU) in PSRs.

Concept-of-Operations

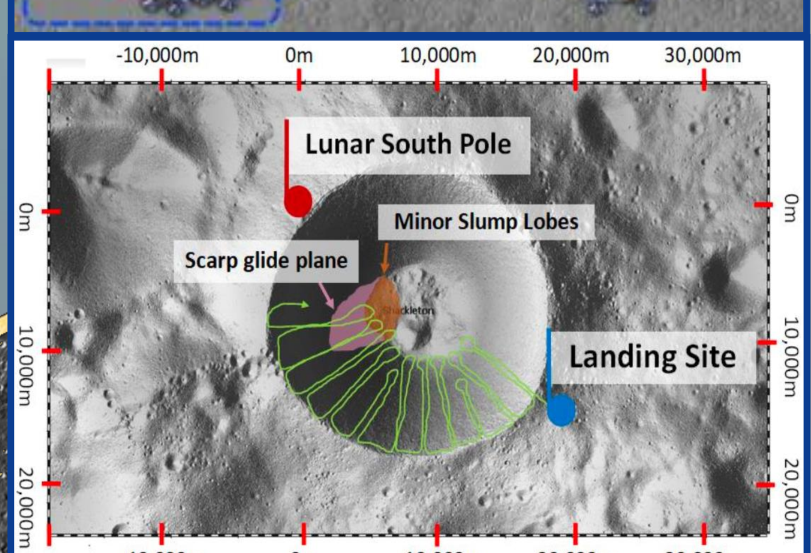
1. CLPS delivers modules in transport configuration to PSR edge, 100 m from rim of Shackleton Crater.

2. Modules exit lander, expand to driving configurations, and link to form a caravan. Solar module stays at rim edge for power generation.

3. Vehicles unspool via winches to deliver exploration SHREW(s) to PSR floor.

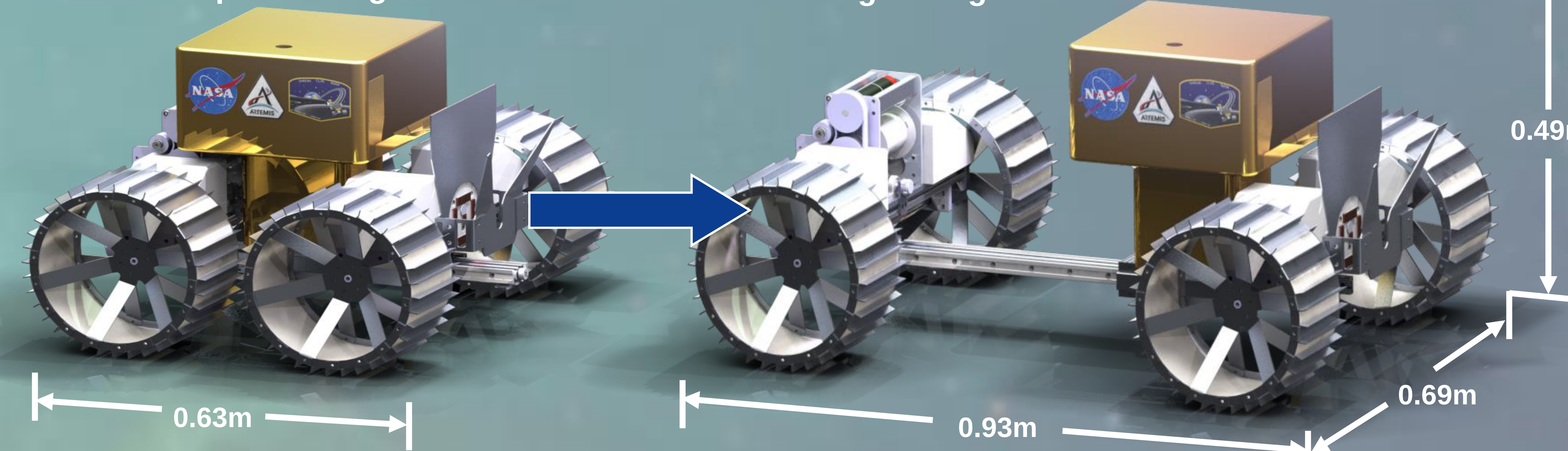
4. Exploration SHREW detaches from winch train to explore PSR floor.

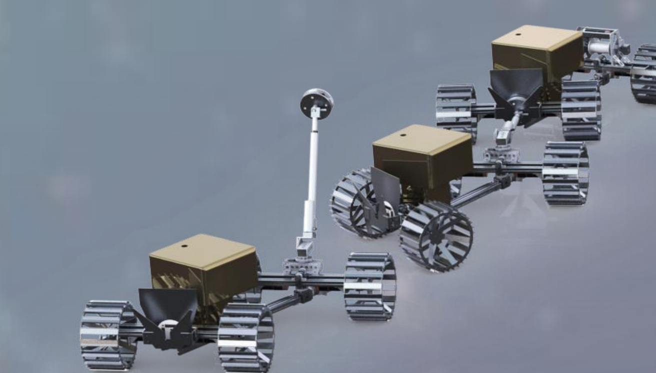
5. Exploration SHREW completes research and returns to winch train for rim return and redeployment.



Innovations

- Novel mobility concept suited for partially tethered traverses in PSRs.
- Novel driving modes & poses via independent axle yaw control. Front and rear axle roll degrees-of-freedom retain 4-wheel contact with uneven terrain.
- Winch, latching mechanism & end effector enable multi-vehicle coordination and power transfer between units
- Expandable mid-frame for push-pull and inchworm locomotion with one additional actuator aids in avoiding immobilization.



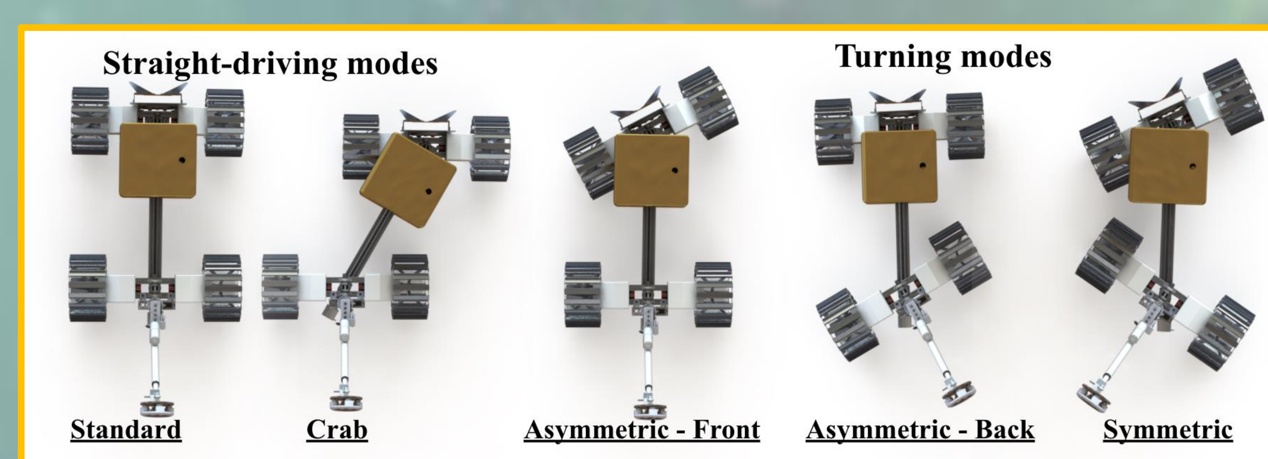


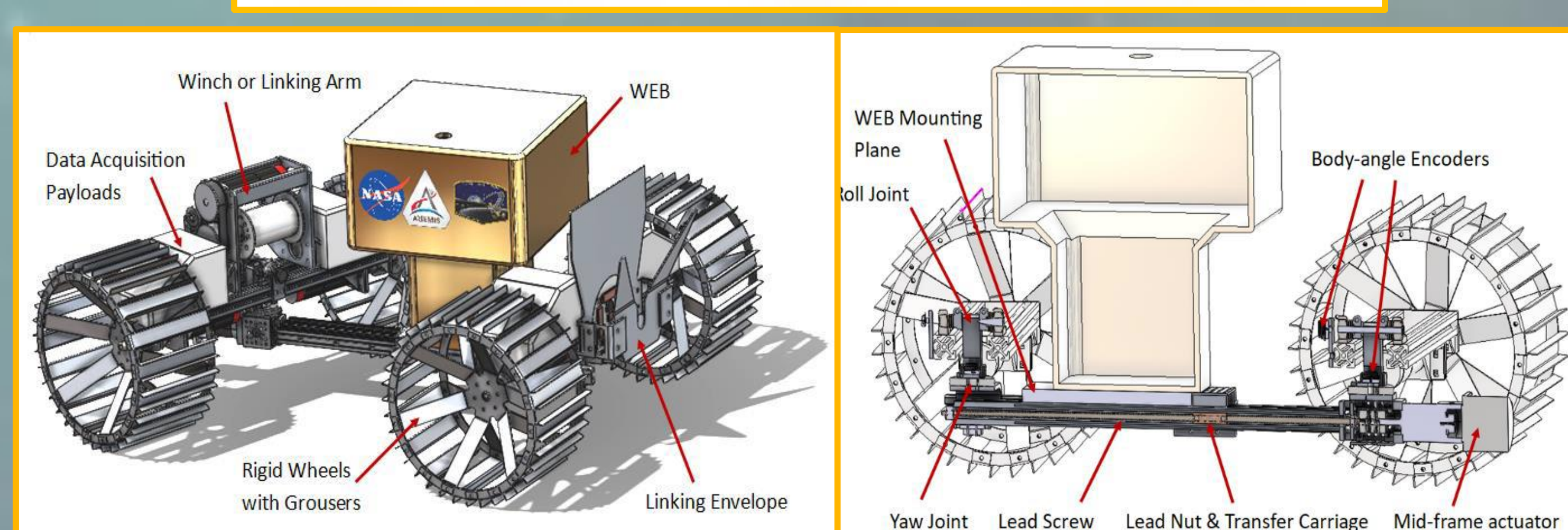
Locomotion Test Results

- Heading drift < 1° / 10 m.; Min. turn radius = 75 cm
- Driving configurations behaved as expected
- Traverses 25° slopes on grass
- Sinkage in sand < 3 cm; Trafficable sand mound: 25.5 cm (91% of wheel diameter)

Mechanical Design

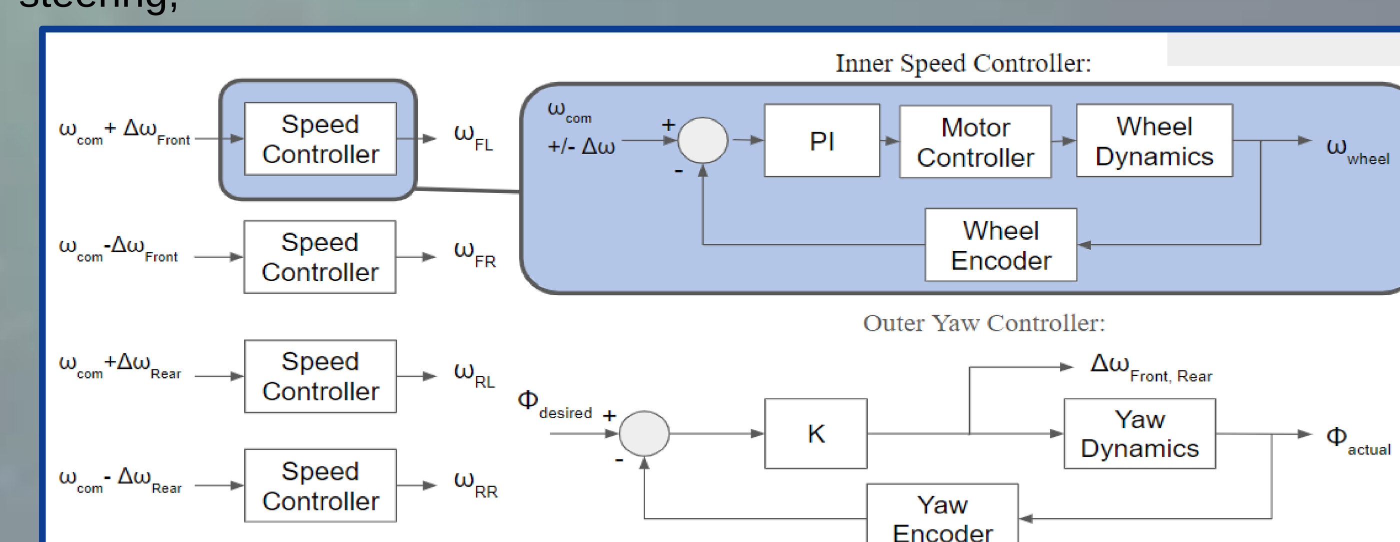
- Design requirements derived from BIG Idea specifications, lunar environment, ROS/ Gazebo simulation.
- Multiple locations for instrumentation (Ground Penetrating Radar, Spectrometer, Cameras) along axles or suspended from midframe.
- Autonomous linking arm for physical, electrical connection via copper busbars. Includes winch for higher slope angle traverses.
- Terrestrial motors sized for 15 ° slopes, winch supports slopes up to 25 °.

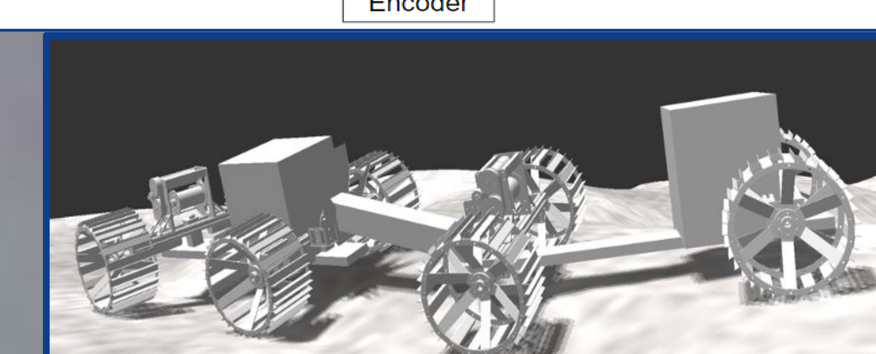




SHREW Control System

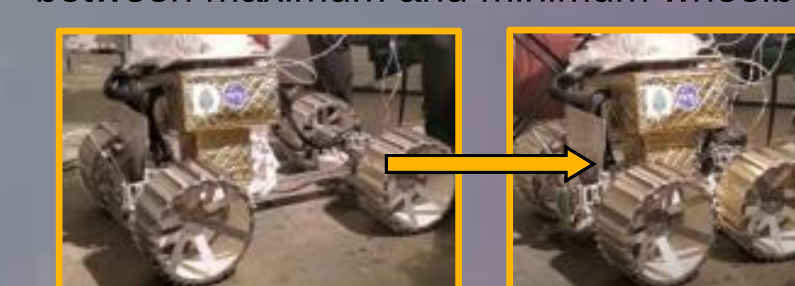
- Four wheel speed control loops (Zero Steady state error, 2 s. settling time)
- Two outer control loops command yaw angle between mid-frame & axle and increment/ decrement wheel speeds to repoint each axle
- Yaw angle response acts as proprioceptive sensor of terrain heterogeneity
- Controllers prototyped in ROS/Gazebo for complex modes (push-pull, caravans)
- Caravan control: First front axle dictates heading; front axle angle controlled to be perpendicular to connector arm; rear axle controlled for symmetric steering;





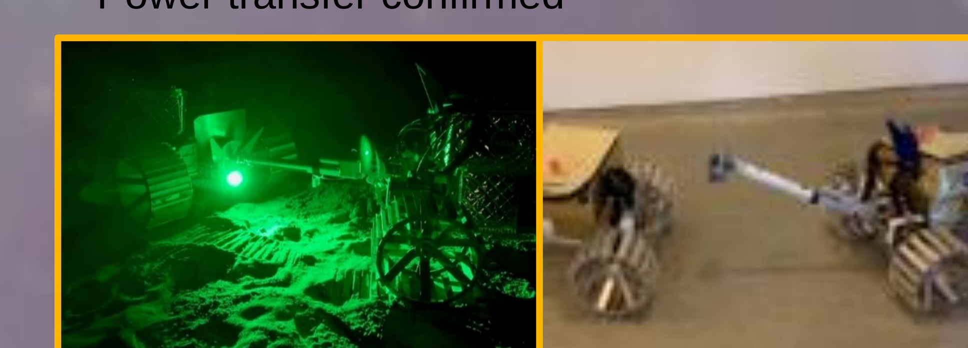
Mid-Frame Testing Results

- Benchtop testing verifies viable actuation between maximum and minimum wheelbase



Linking Tests

- Linking Tests performed at a variety of distances, alignments, and in simulated PSR lighting conditions
- Connection distance: 50-80 cm, Connection arc: $\pm$ 45°, Max height difference: 30 cm
- Power transfer confirmed

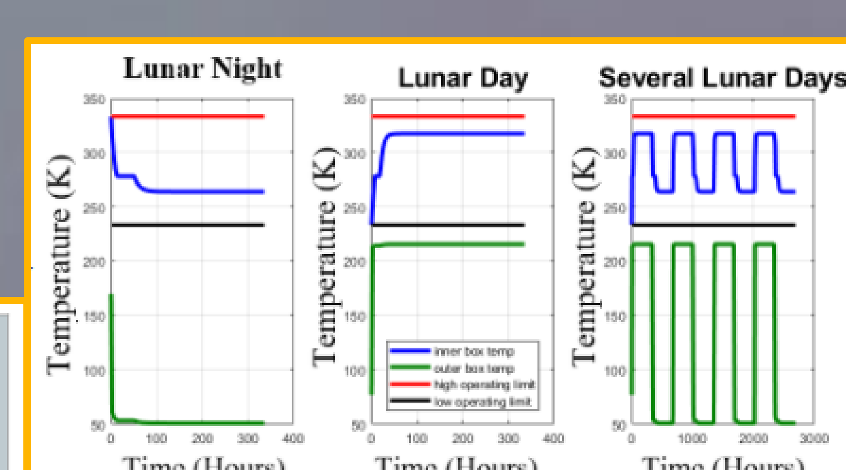


Lunar System

- Dust mitigation: Regolith is abrasive and exposed elements must be protected.
  - Beta cloth on mid-frame for full coverage
  - Passive dust brush on winch line
  - Electrical connection plate on linking arms charged to remove dust
- Materials: 12.5 – 15.5 kg lunar design using Nomex composite, aluminum, carbon fiber.
- Electronics: custom, radiation hardened microcontrollers, motor controllers, and batteries. 500 Wh for 18-19 h, 8 km. traverses.
- PFPE/PTFE motor lubricant rated -80° to 250° C
- Thermal protection: Paraffin wax passive heat exchange in Warm Electronics Box; Casing layers reflect heat and insulate.

Beta Cloth Sleeve Layers	Teflon T-164	Beta 4484	Teflon T-164	Beta 4484	Aluminized Kapton Film

Dust Mitigation Beta Cloth Layering



Thermal Model over ConOps Cycle

Data Transmission

- Lander provides 70 kbps/kg of bandwidth (1050 kbps for one 15-kg SHREW). Caravan provides data relay from PSR to lander
- Sufficient for low frame rate video, high-definition stills, and near real-time transmission of GPR data.
- Semi-autonomous operation: 1.3s lag time to Earth

Summary of SHREW Parameters on Earth and Moon

Parameter	Terrestrial Vehicle	Lunar Vehicle
Nominal Mass	18.9 kg	12.5 kg
Mass with Winch & Linking Arm	21.6 kg	15.3 kg
Mass with Payload	22.6 kg (Simulated Load)	13.5 kg(Micro GPR) 15.5 kg (Spectrometer)
Energy Capacity	576 Wh	Minimum 500 Wh
Operating Voltage	24-32V DC	28V DC (set by Challenge)
Drive Motors	Brushless DC 3-Stage w/ 63:1 gr	Custom Brushless DC
Electronics Thermal Operating Range	N/a	-40°C to 60°C
Dust Mitigation	Cotton Canvas Cover	Teflon/Beta Cloth Sleeve; Nylon and Zephyr Fiberglass Brushes

Testing of Lunar Frame

- Flexural tests of beams constructed from Nomex verified that lunar frame can withstand worst-case loading as weakest member supported 1630 N.

Present Technological Readiness

- As of Jan. 2020, concept at NASA TRL 4
- Next steps include design iteration, increased specificity of ConOps, implementation of caravan locomotion, testing of push-push locomotion, drawbar pull testing in lunar regolith simulant.

Acknowledgments

The Dartmouth team thanks Dr. Laura Ray, Scott Ramsay, Eva Klein, and the BIG Idea organizers and judges for their incredible support to this project.