

Artemis Rovers

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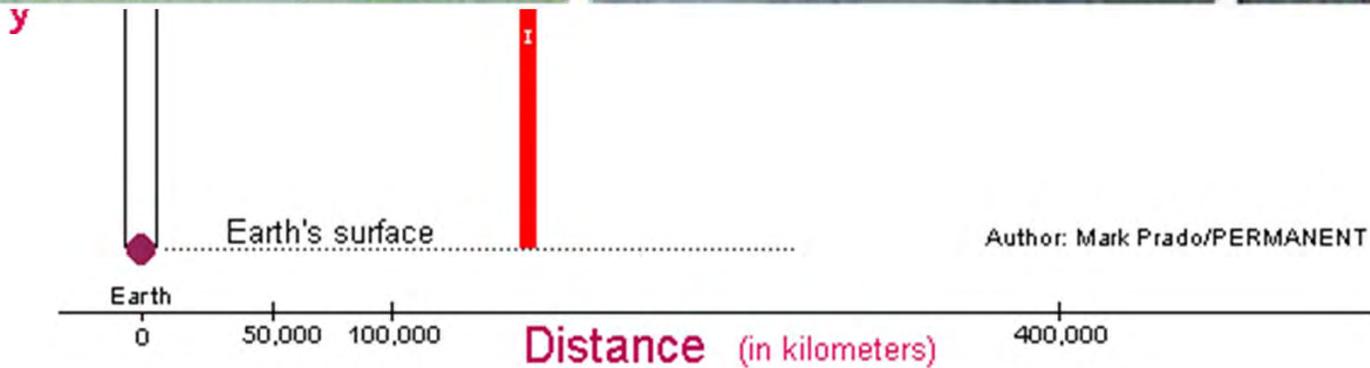
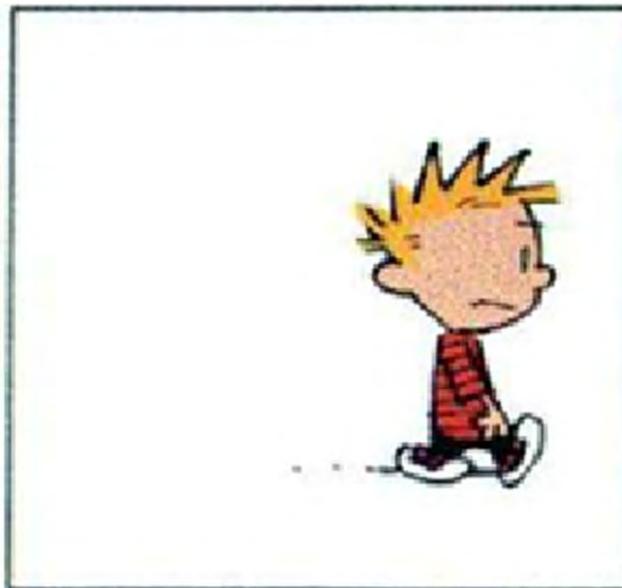
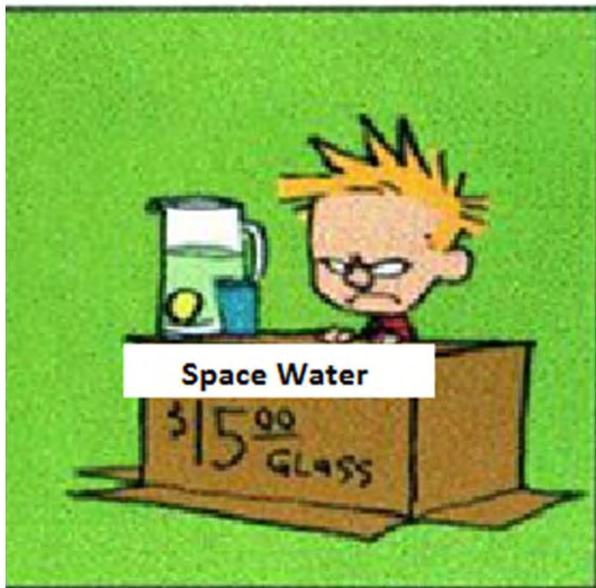
The Moon: It has been so lo



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Recently...

- Recent scientific discoveries indicate a great deal of water on the moon
 - Chandrayaan, Casini, LCROSS
- Water production on the moon will ultimately lower the cost of space exploration. Ultimately, this will be an industrial or even commercial activity.



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50 YEARS
1962 - 2012

Future of lunar activity

Exploration – driving further, looking for resources

Groundworking – drilling, blading, shoveling

Logistics – moving equipment around

Commercial activity – Shorter development cycles, lower cost.

- Several phases of commercial lunar surface activity
 - **Precursor – Find the water and “characterize the ore body” - RESOLVE**
 - Intermediate – several generations of pilot production, increasing volume
 - Long term – increasing production to meet demand
- As the nature of lunar robotic activity changes, so too will the nature of the equipment used.
- Mobility platforms will need to change to accommodate shift in activities and the shift towards commercially driven enterprise.

1. Cost/complexity

2. Durability and ruggedness

3. Payloadcentricity

4. Traction

5. Modularity

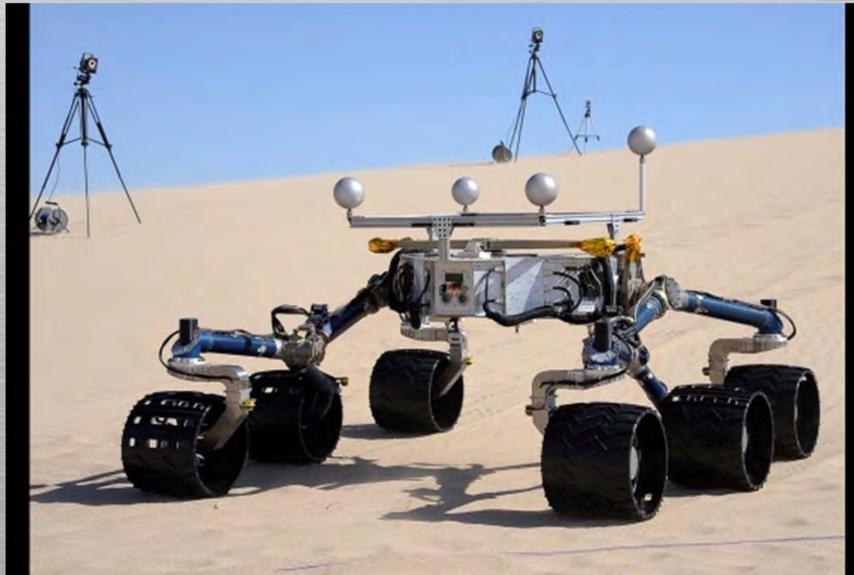
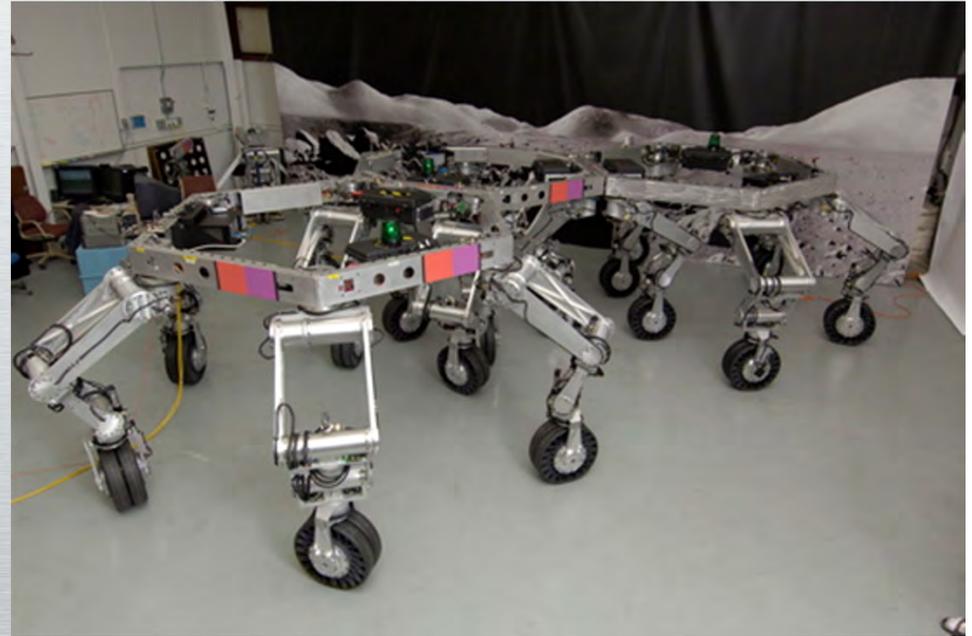


1. Lower Cost

- Lower design cost
- Lower production cost
- Lower repair and maintenance cost

By using:

- Few components
- Stronger components
- Interchangeable components



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2. Increase Durability

- Ground-working tasks involve unexpected loads – fewer and stronger components
- Reduced complexity (pivots, joints, motors)

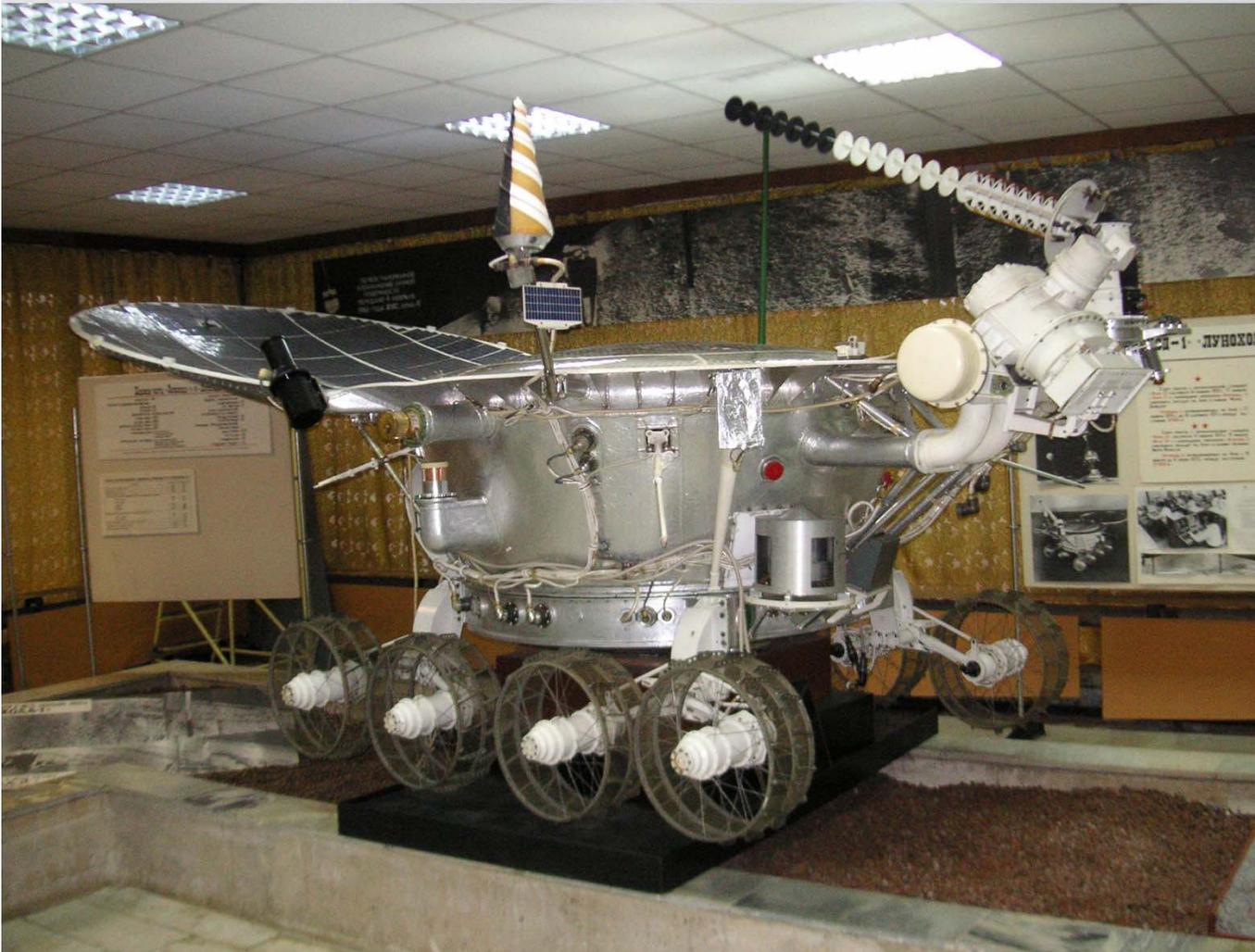


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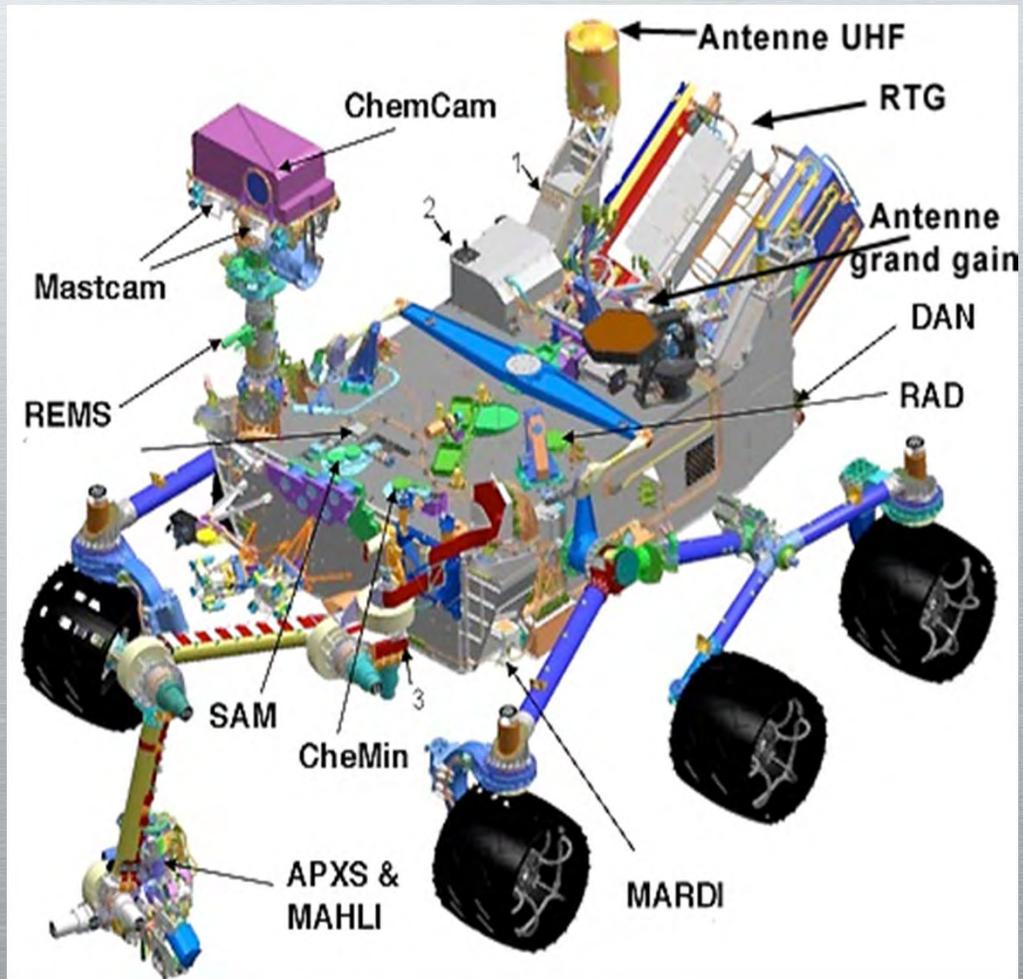
Skid steering

- Typical for terrestrial vehicles operating with low ground pressure
 - Below 5 psi.
- Reduces envelope of vehicle
- Reduces complexity of vehicle



3. Payloadcentricity

- Suite of instruments vs. integrated payload
- Larger, heavier, power hungry
- Reaction loads from ground working (blading, drilling)



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4. Improved Traction

- Groundworking tasks increase required tractive forces by almost an order of magnitude
- Current rovers use small diameter, rigid wheels
- Terrestrial solutions
 - Large diameter rubber pneumatic tires
 - Tracks – steel or rubber



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5. Increased Modularity

- Multi-mission capability
 - Use the same mobility platform for multiple missions.
- Long-term fleet activity will benefit from modularity on the component level.
 - May be able to fly payloads and/or component rather than entire systems



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Mauna Kea Hawaii, 2008







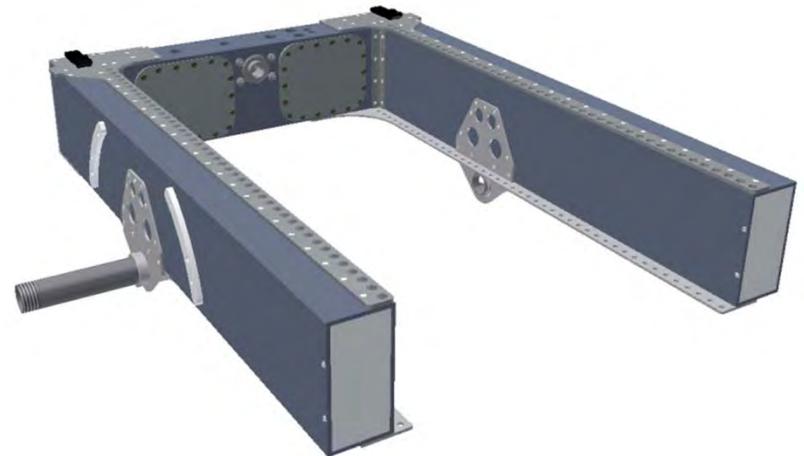
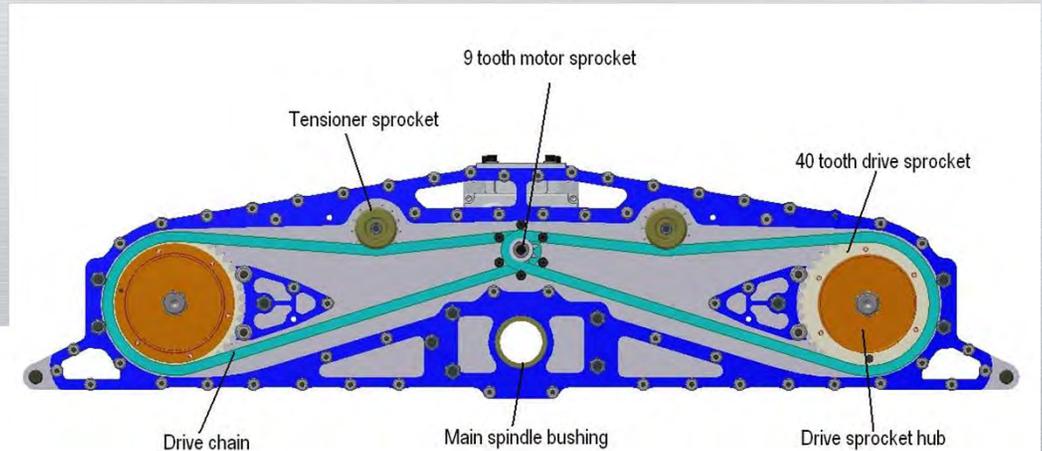
Local Fauna

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Artemis Rover Background

Juno I Rover (2008)

- Skid steer – two motors
- Simple, lightweight, rugged
- High payload/mass ratio
- Modular design
- Large battery volume (replaceable)



Juno Tandem rover (2009)

- Improved efficiency
- More traction
- Better redundancy





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2010 Hawaii Field Deployment

RESOLVE payload and associated GSE (500kg) was mounted to a tandem of Juno Rover



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2010 Hawaii Field Deployment



Extreme



Juno II Rover Upgrades – New Features



- Motors
- Transmissions
- Suspension
- Traction
- Control
- Battery
- Mast

Traction – Titanium Tracks



Artemis Jr. Development



RESOLVE 3rd Generation (Precursor to Flight)



Two-Phase Development

- Develop miniaturized unit for field test in July 2012
- Develop lunar vacuum compatible unit for testing in 2014

Subsurface Sample Collection – Core Drill [CSA]

- Complete core down to 1 m
- Minimal/no volatile loss
- Low mass/power (<25 kg)
- Wide variation in regolith/rock/ice characteristics for penetration and sample collection
- Wide temperature variation from surface to depth (300K to <100K)

Sample Evaluation – Near Infrared Spectrometer (NIR)

- Low mass/low power for flight
- Mineral characterization and ice/water detection before volatile processing
- Controlled illumination source

Resource Localization – Neutron Spectrometer (NS)

- Low mass/low power for flight
- Water-equivalent hydrogen ≥ 0.5 wt% down to 1 meter depth at 0.1 m/s roving speed

Volatile Content Extraction – Oxygen & Volatile Extraction Node (OVEN)

- Temperature range of <100K to 900K
- 50 operations nominal
- Fast operations for short duration missions
- Process 30 to 60 gm of sample per operation (Order of magnitude greater than TEGA & SAM)

Volatile Content Evaluation – Lunar Advanced Volatile Analysis (LAVA)

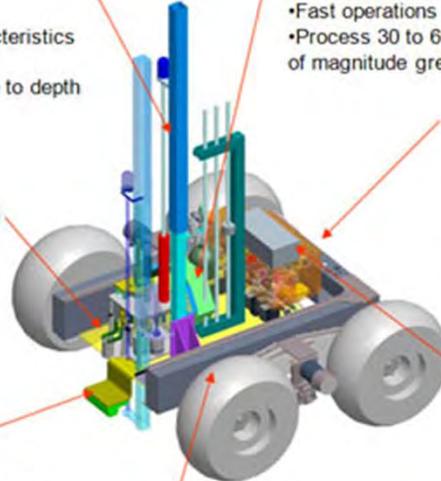
- Fast analysis, complete GC-MS analysis in under 2 minutes
- Measure water content of regolith at 0.5% (weight) or greater
- Characterize volatiles of interest below 70 AMU

Operation Control – Flight Avionics [CSA/NASA]

- Space-rated microprocessor

Surface Mobility/Operation [NASA/CSA]

- Low mass/large payload capability
- Driving and situation awareness, stereo-cameras
- Autonomous navigation using stereo-cameras and sensors



- Integrated RESOLVE payload led to redesigned rover.
- Sketches began in January, 2011.
- Program officially began in May, 2011

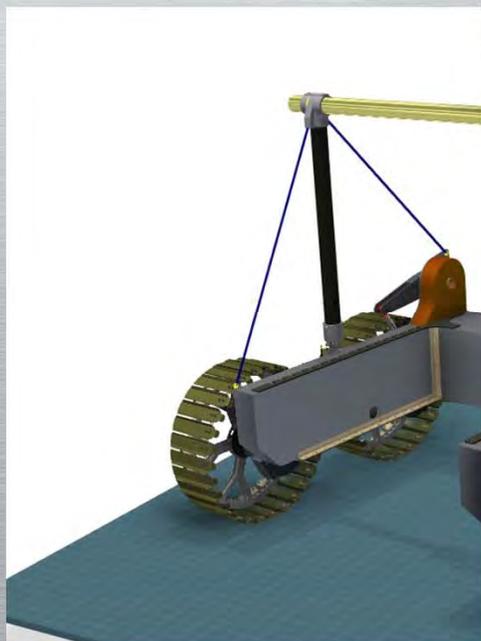
Artemis Jr. Development

Objectives:

- Provide mobility
- Maintain mobility
- Maintain / Advance

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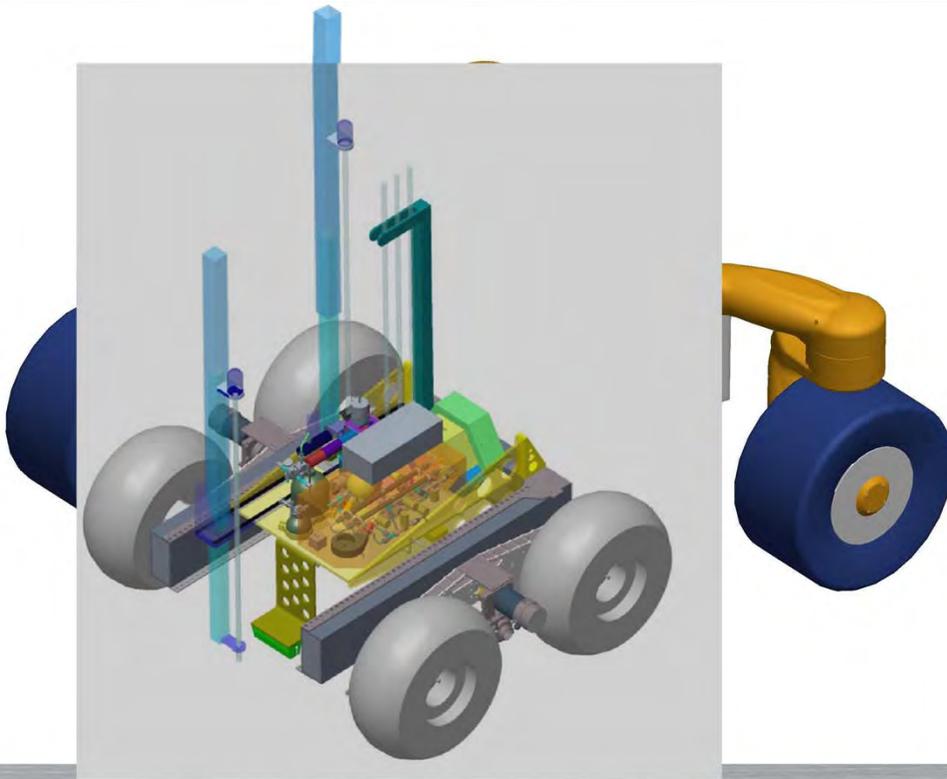
ARtemis JUnior Design 2 = AR-JU-D2

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Payload-centric chassis

Payload volume and mass vs.
vehicle volume and mass



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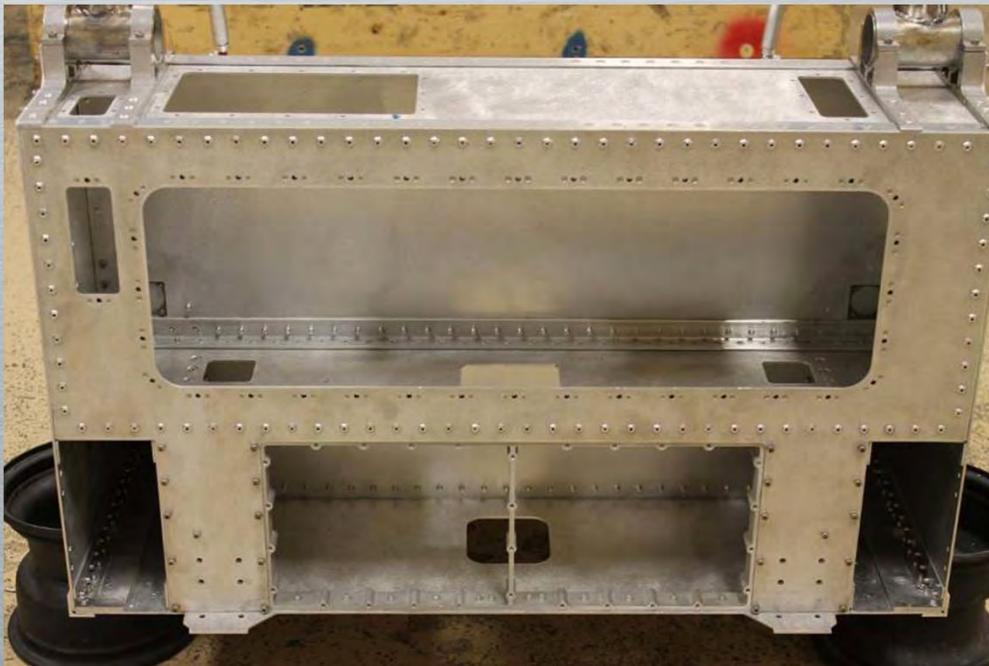
Chassis

- Features
 - Lightweight, rigid structure; less than 45 kg (about half the mass of previous generation)
 - Payload mounted quickly to lower flange
 - Solar panel easy to adjust or remove
 - Mast provided rigid structure for cameras



Chassis

- Large, centralized payload bay
- Batteries, electronics, and suspension housed within single volume – protected from dust and thermal extremes.



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Drive System

- Features
 - Custom designed gearbox doubles as a suspension element
 - Reduced mass
 - Multiple operational modes (two-speed gearbox, neutral, brake)
 - 10 cm/s and 100 cm/s

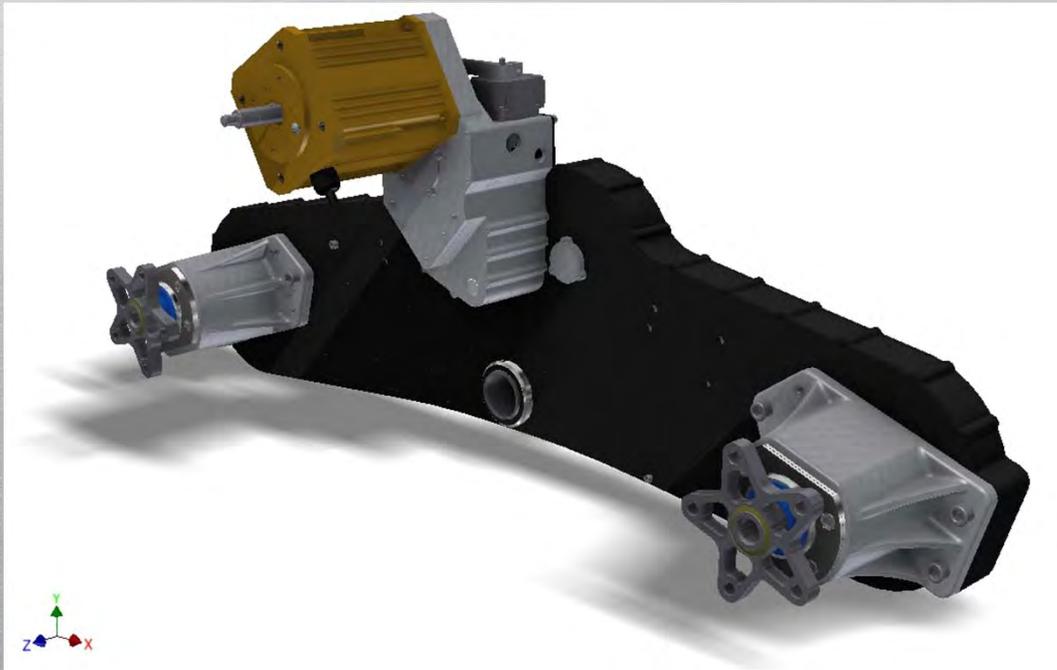


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Drive System

- Single stage chain reduction
- High-Neutral-Low gearbox

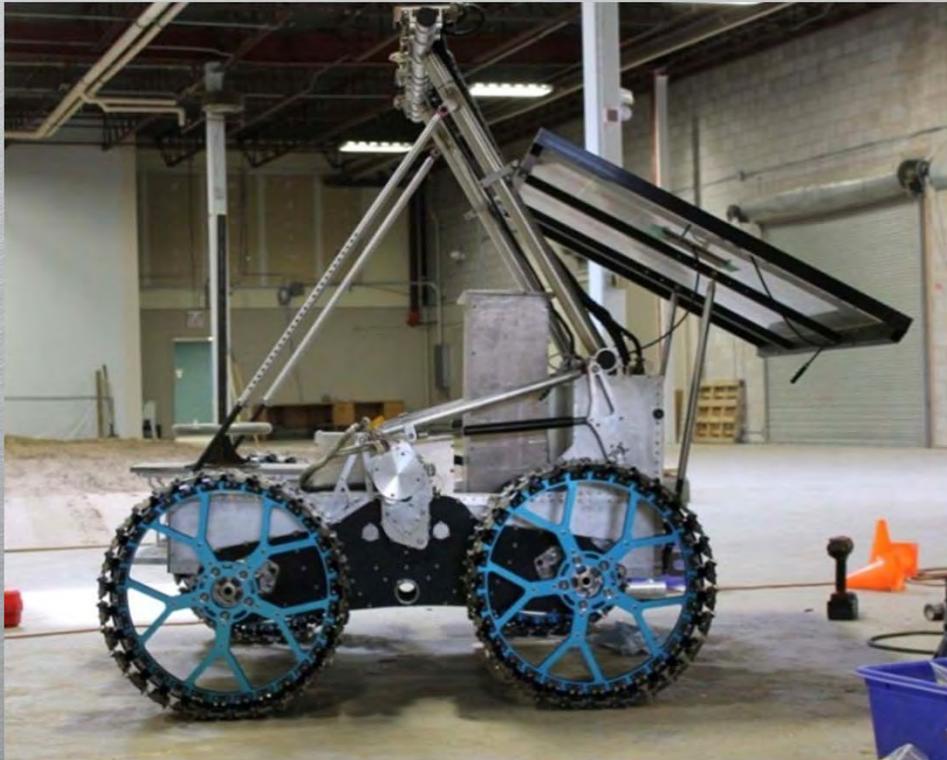


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Suspension

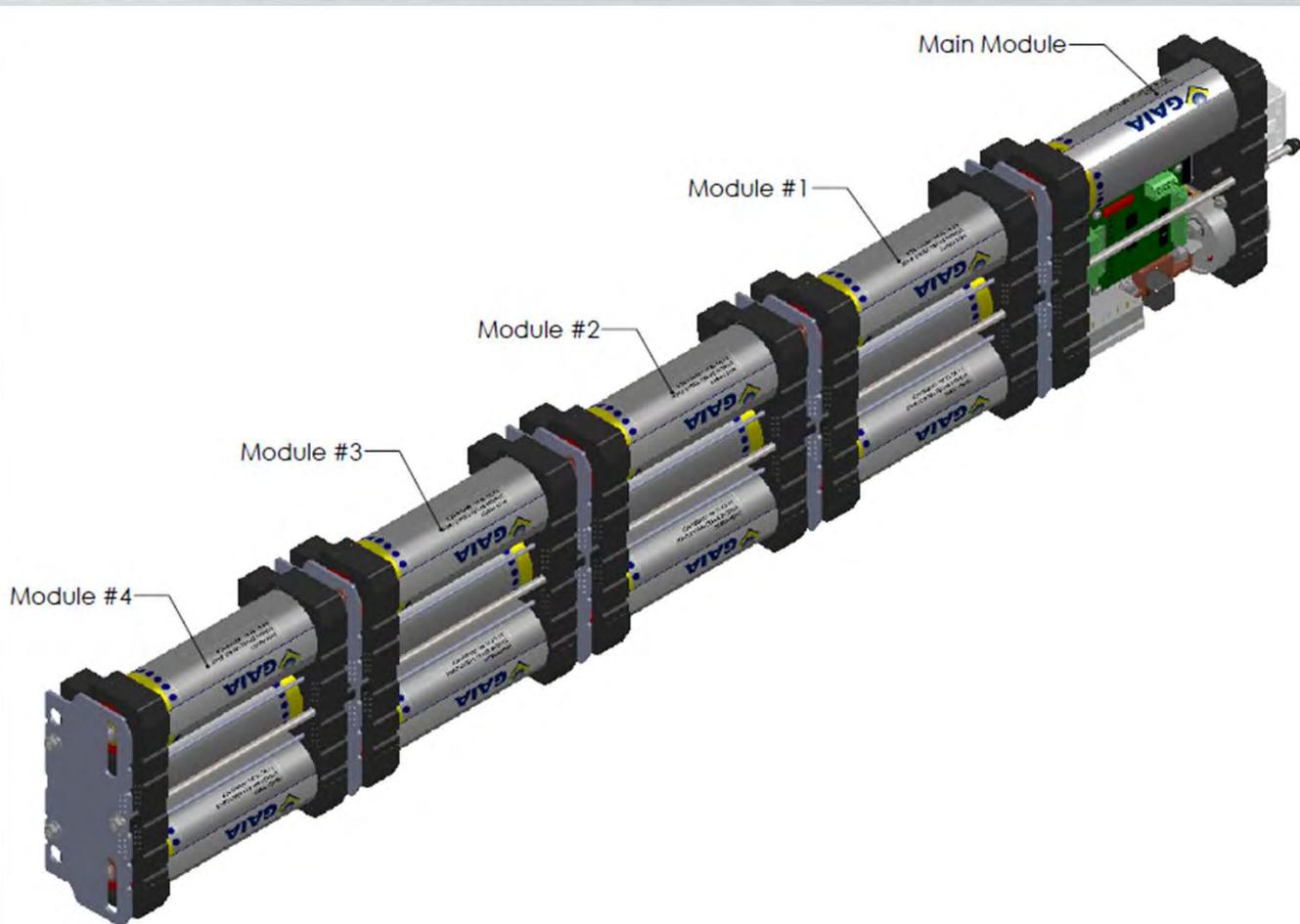
- Features
 - Geometric suspension
 - Actuator allows rover to pitch fore and aft.
 - Protected from contamination and thermal extremes



Power

Lithium-Ion battery packs:

- Built by Lithium Technology Corporation
- 2.57 kWhr per pack
- 5.14 kWhr total
- 110 Amp continuous current
- 30% reduction in mass



Traction Elements

Work completed during Juno Upgrade led to development of lightweight wheels.



TWACS

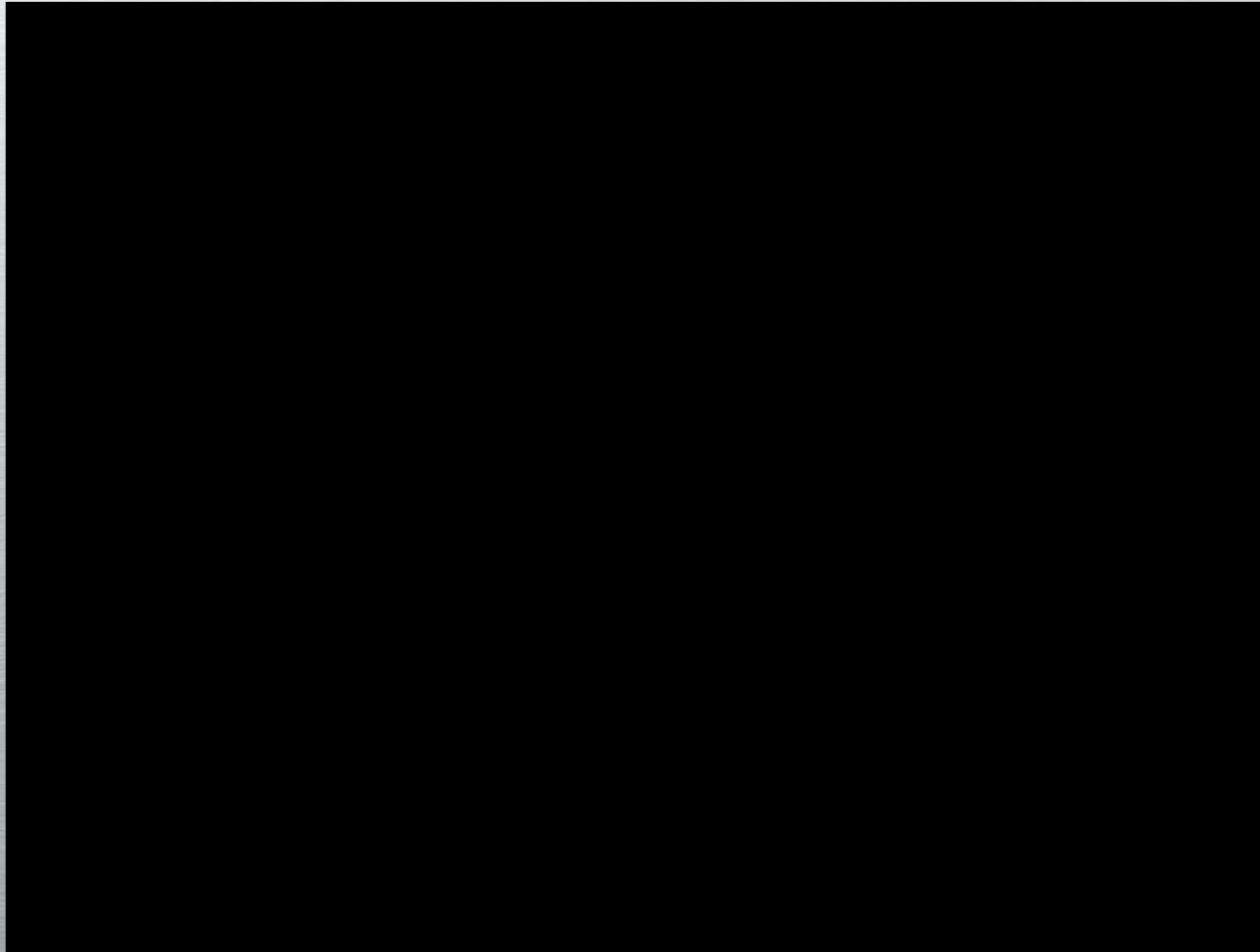


TIRELESS

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Wheel testing at CSA



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RESOLVE / Destin Drill

RESOLVE (Regolith & Environment Science, and Oxygen & Lunar Volatile Extraction)



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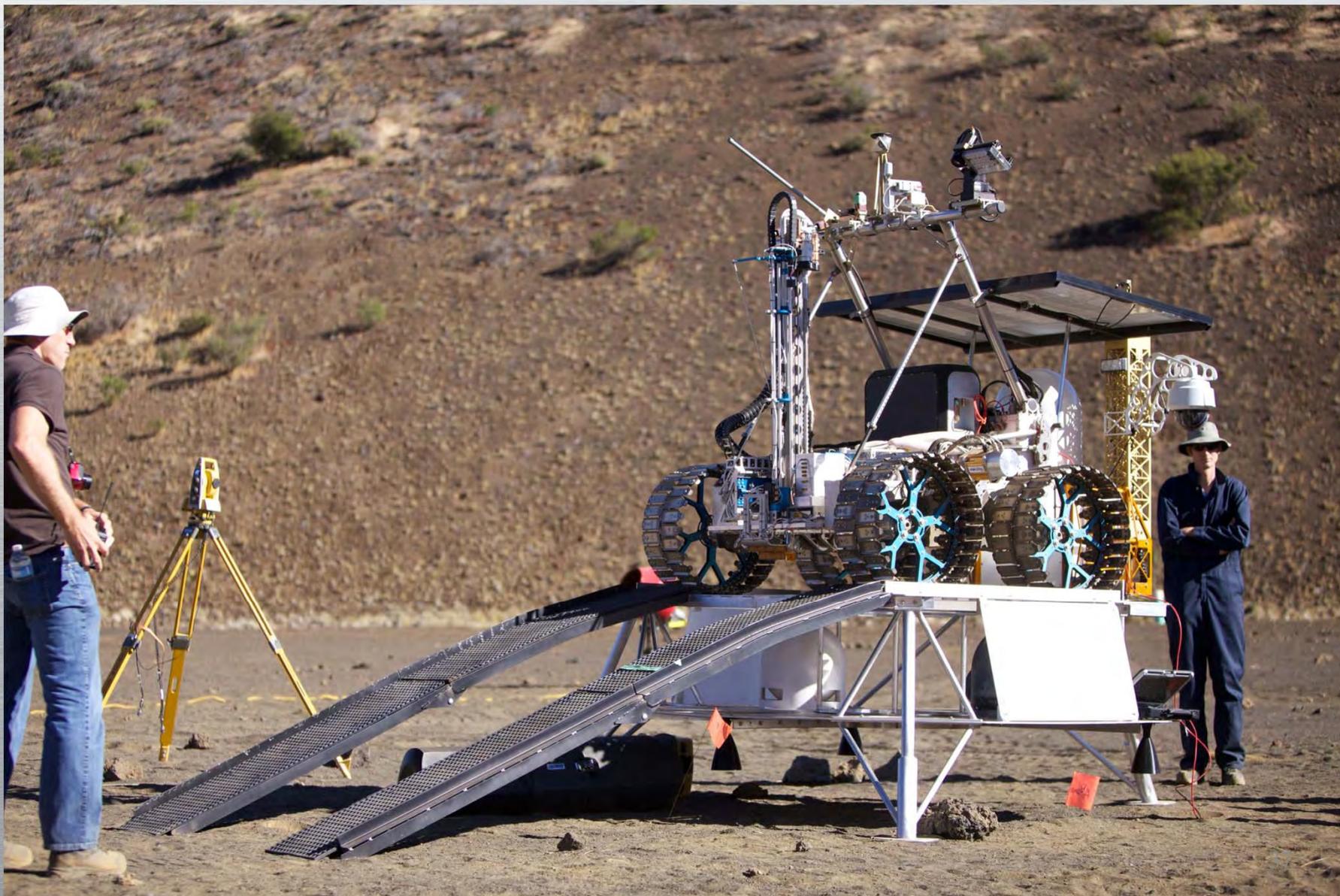
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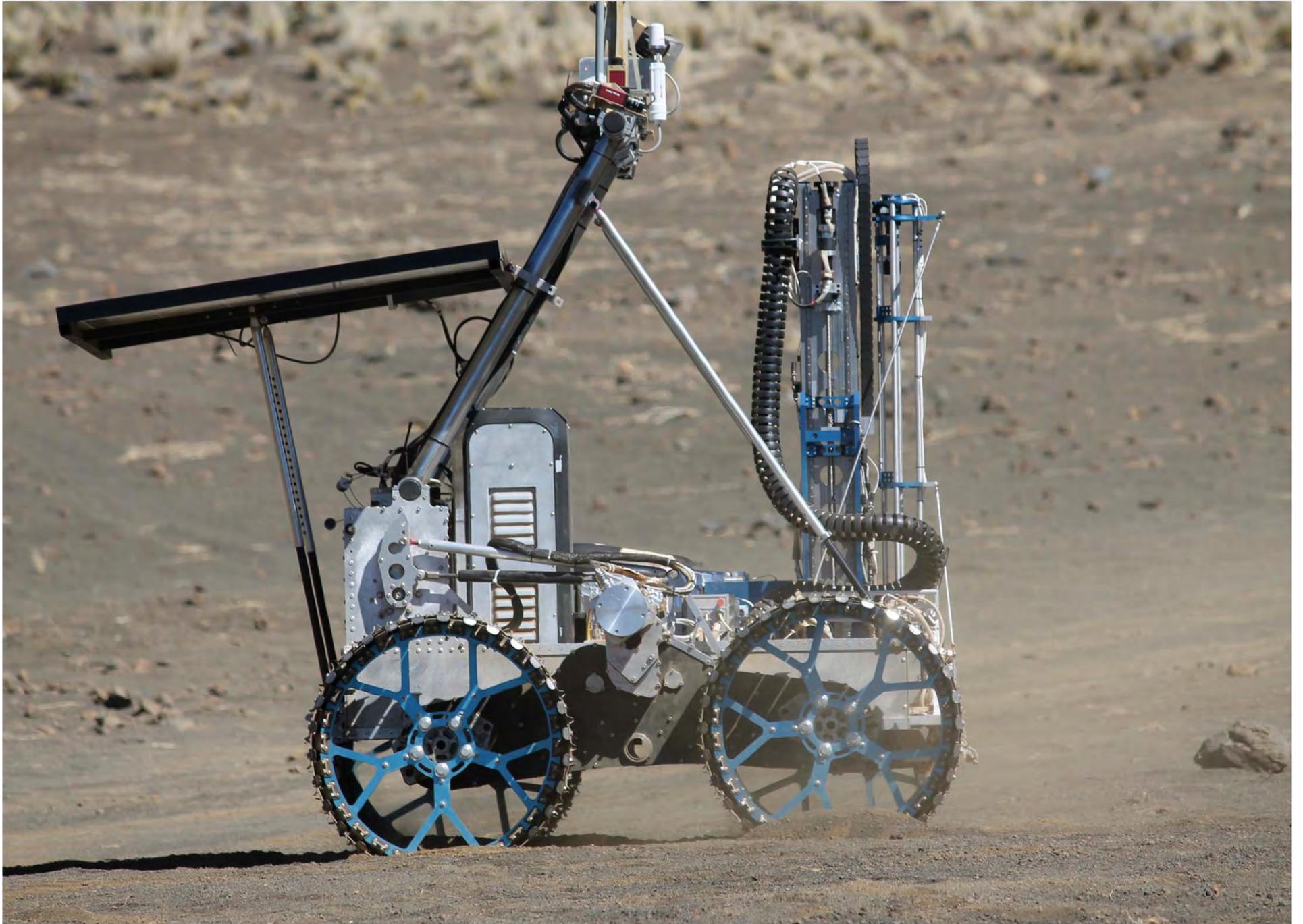


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RESOLVE, July 2012, Mauna Kea Hawaii





Hawaii, 2012: RESOLVE

- 1.1 km total traverse, both tele-operated and autonomous.
- Multiple sample capture with NORCAT's DESTIN drill.
- Multiple sample processing (RESOLVE).



Hawaii, 2012: RESOLVE

- Tilting feature allowed for a steeper ramp.
- Steeper ramp is a shorter ramp.
- Shorter ramp is a lighter ramp.

MMAMA – 2012 – Apollo Valley





Hawaii, 2012: Apollo Valley

- 23 km total traverse in Hawaii.
- Multiple mobility tests with various wheels.

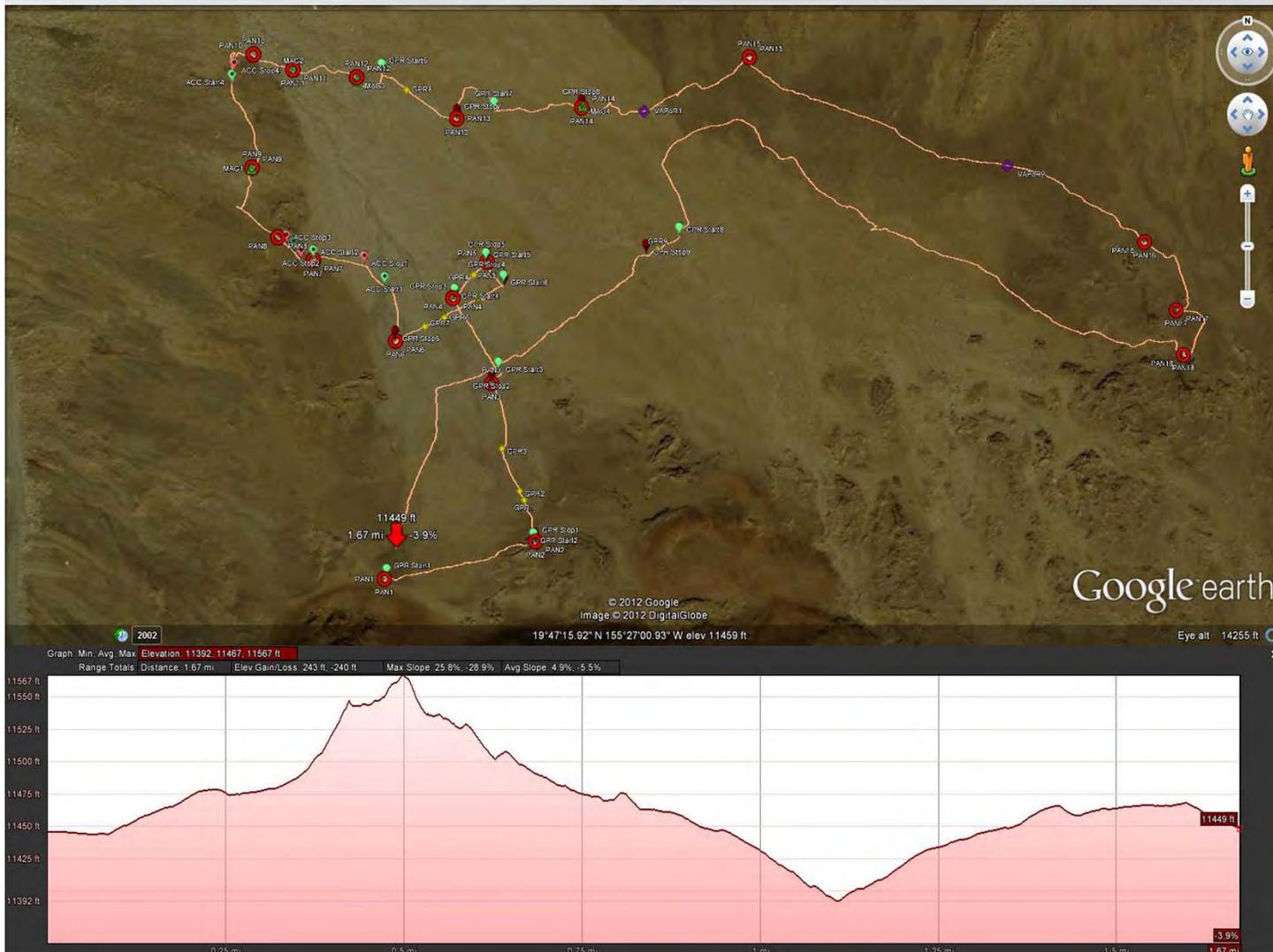
Hawaii, 2012: Apollo Valley



- Soft sand is the other extreme.
- This has proven to be a problem on Mars and may be an issue at the edges of lunar craters.

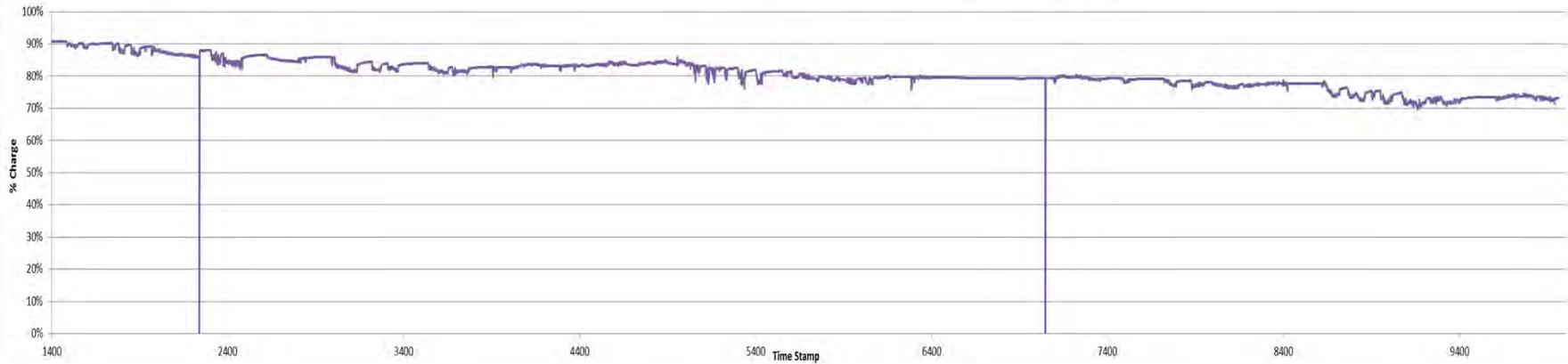
Rover Traverses – Apollo Valley

- GPS equipped, routes mapped.
- Enabled us to construct a traverse profile with respect to power consumption.

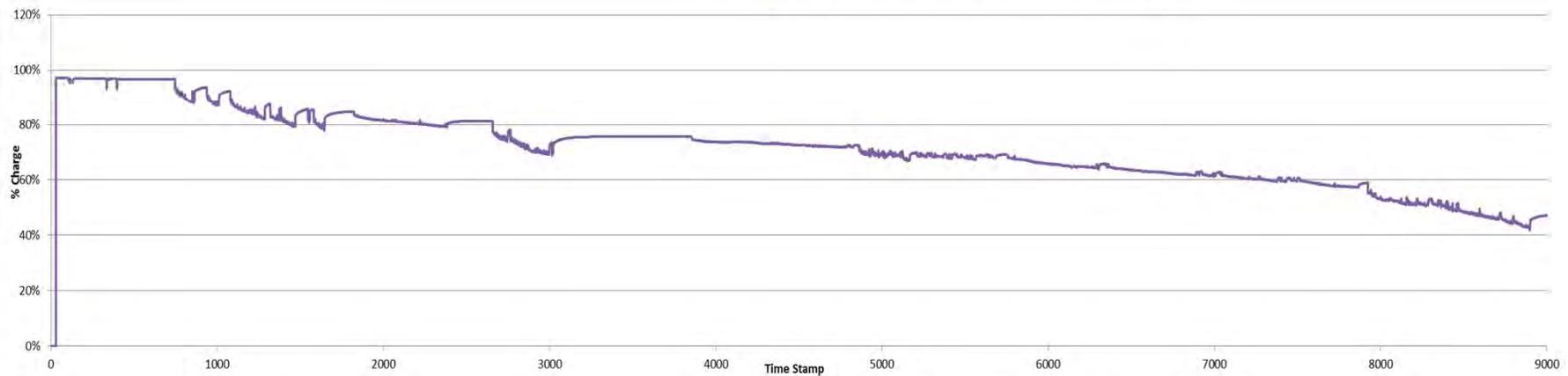


Power Consumption – Wheel Test

Metal Wheels - Average Battery State of Charge (SOC)



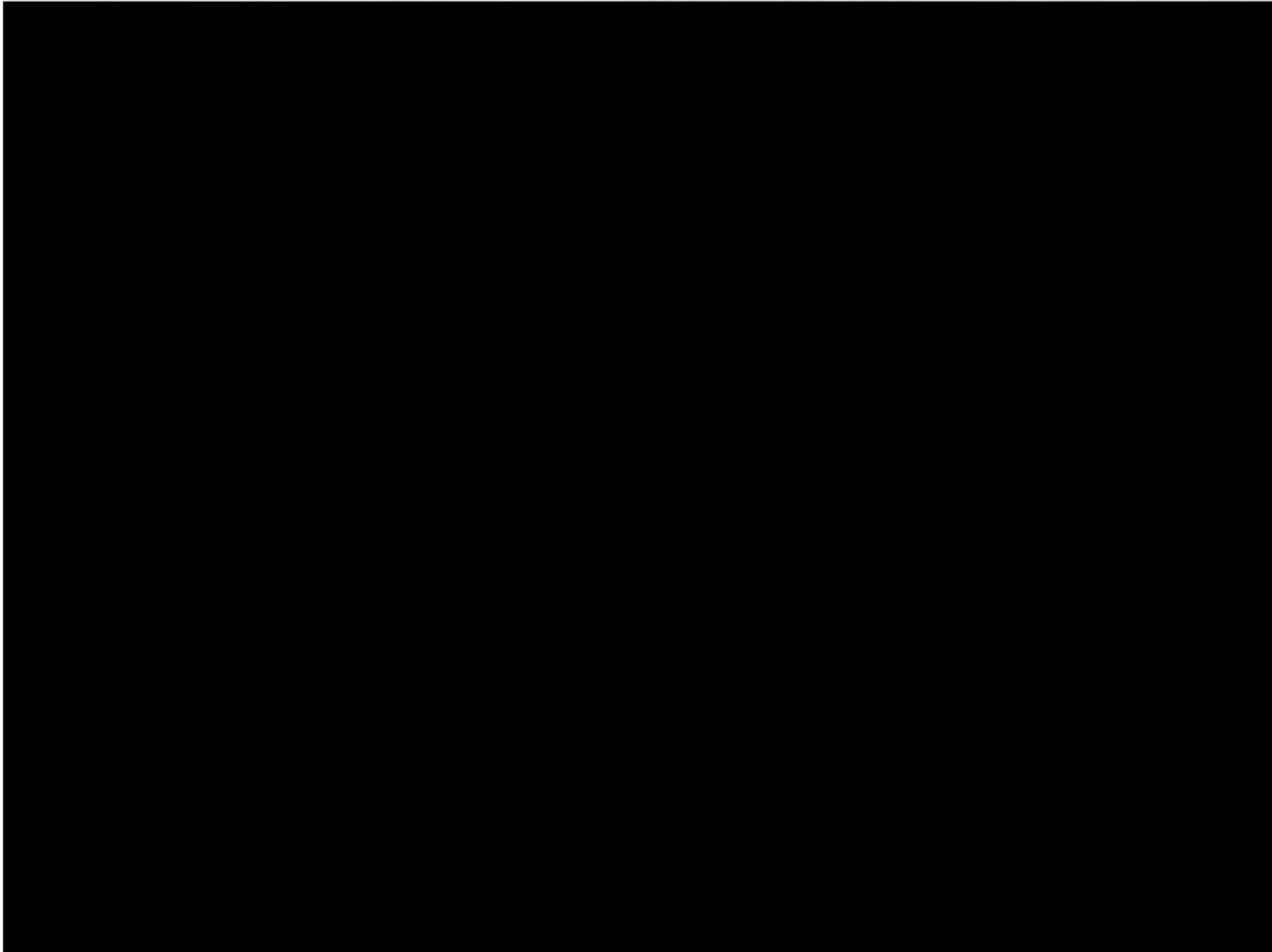
iRings - AVERAGE BATTERY STATE OF CHARGE (SOC)



Wheel Efficiency Results

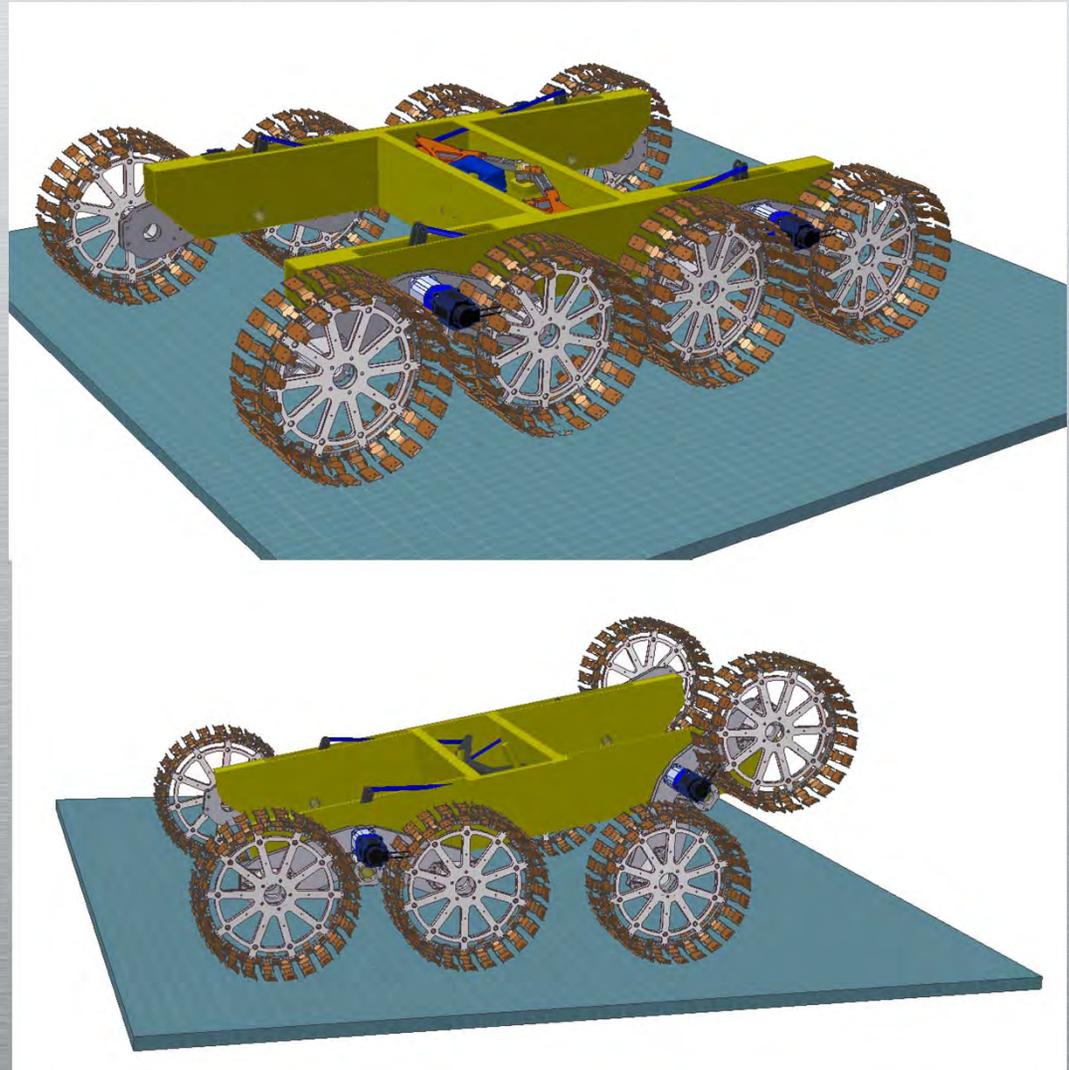
Data	Metal Wheels	iRings
-----Total Traverse-----		
Motor Temperature, Peak (deg C)	48	75
Motor Temperature, AVG (deg C)	34	40
Ambient Temperature (deg C)		
Starting Voltage (%)	92	97
Ending Voltage (%)	77	41
Distance Traversed, Total (km)	4.2	4.4
Energy Consumed (kWh)	0.382	1.01
-----Common Traverse (Staging Area to near peak on Upper Access Road)-----		
Motor Temperature, Peak (deg C)	35	75
Motor Temperature AVG (deg C)	24	50
Starting Voltage (%)	92	97
Ending Voltage (%)	82	76
Distance Travelled (km)	1.2	
Energy Consumed (kWh)	0.086	0.239

Other Payloads



Artemis Rover Concept

- 500 kg empty
- 15 km/h
- 300 kg payload
- Modular design enabled interchangeability between Artemis Jr. and Artemis Sr.





Conclusion

- Successfully demonstrated various Artemis rover technology in various analogue settings.
- Showed the advantage of modular architecture in terms of design and fabrication schedule.
- Designed and tested viable alternative to rubber tires.



Acknowledgments:

ComDev

Neptec Design Group

NORCAT

NGC

Provectus Robotics

Canadian Space Agency

NASA

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Questions?



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