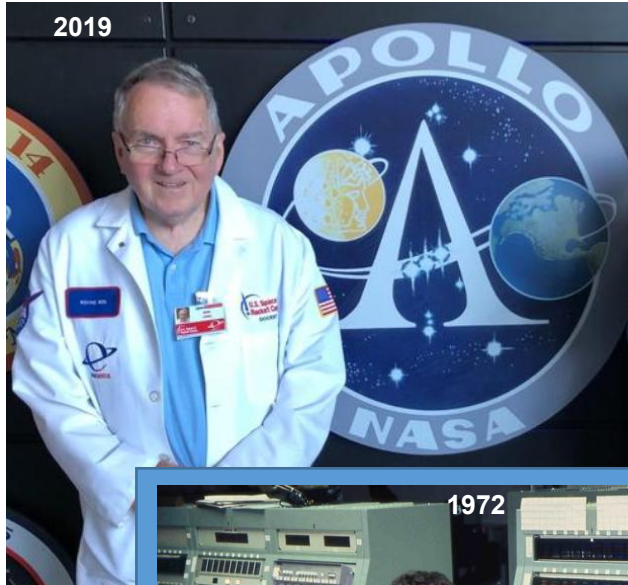
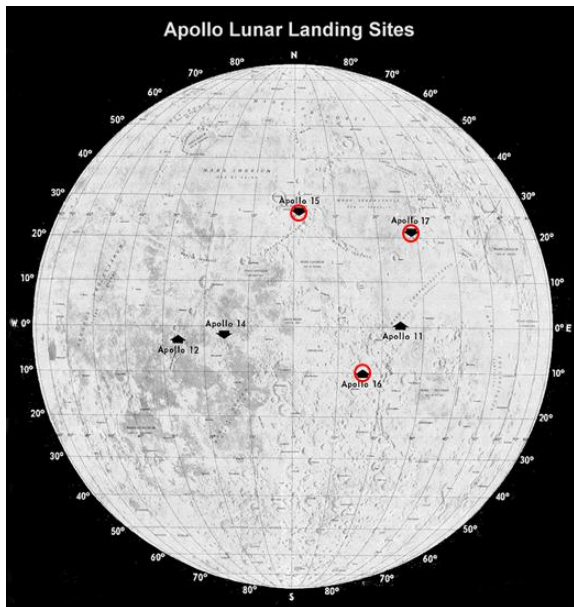


Challenges for Potential Reuse of Apollo Lunar Rovers



**Ron Creel - Retired Space and Thermal Systems Engineer
Member of the Apollo Lunar Roving Vehicle (LRV) Team**

Three Apollo Lunar Rovers Are Now Located on the Moon



Apollo Lunar Rover

With the amazing successes and ever increasing skills learned from the first 3 Apollo landings on the Moon, NASA decided to make the next flights, Apollo 15, 16, and 17, more ambitious. Landing sites were no longer smooth and relatively safe. The J Series Lunar Modules (LM) allowed a much longer stay on the lunar surface. To extend the astronauts' exploration area on the moon, the first Lunar Roving Vehicle (LRV) was designed, tested, and completed in just 17 months by a team of several hundred dedicated workers. Three light rovers, plus 7 test and training units along with spare parts for a fourth flight unit, were built by the Boeing Company, Aerospace Group at their Kent Space Center, outside Seattle, Washington under contract to the NASA-Marshall Space Flight Center. AC Delco Electronics Division Laboratories of General Motors in Santa Barbara, California, was the primary mobility system subcontractor.

The battery powered rover proved to be an extremely dependable vehicle allowing the astronauts to explore many square miles away from their landing sites with ease and safety. The onboard television camera, remotely controlled from the ground, allowed viewers on Earth to become a "third astronaut" and join in the excitement of each Extra-Vehicular Activity (EVA).



LRV Wheels
Each of the Rover's four wheels was comprised of a spun aluminum hub that contained a titanium bump stop inside the tire. The tire was a woven mesh of zinc-coated piano wire. For initial ground tests, wheels were tested to the tire's outer circumference. Each wheel weighed 2 lunar lbs and was designed for a driving distance of 150 kilometers.

Radiators
Thermal control of the LRV was accomplished by semi-passive means to ensure that component operating temperature limits were not exceeded. While driving, heat dissipated in the electronics located in the forward chassis area was stored in the 80 lb batteries and fusible metal heat tanks contained within insulation protected by dust covers. As shown in these images at the end of each EVA traverse, the astronauts opened the dust covers and stored heat was allowed to be radiated away using fused silica mirrors. When the batteries reached a lower limit, the dust covers would close automatically preventing additional cooling from taking place, and protecting the radiators from dust collection during the next driving period.

Television Camera
At science station stops, the crew aligned the high gain antenna on the LRV towards Earth to allow color television signals to be transmitted. The television camera was then remotely controlled from Mission Control on the Earth. To track and observe the LM during ascent from the Moon at the end of the exploration mission, lift-off events had to be anticipated and assessed 3 seconds ahead of time because of the signal delay between the Earth and Moon.

Navigation System
With rougher terrain to traverse, the Rover needed a navigation system that would allow the astronauts to venture beyond sight of their LM home base. In the event of a Rover breakdown, the astronauts were not to drive any further than they could safely walk back to the LM. Navigation was achieved from three sources - the directional gyroscope for heading, odometer data from the wheels, and the signal processing unit provided bearing and velocity. All readings were displayed on the control and display console situated in front of the T-hand controller.

Communications
The range from which the astronauts could operate from the Lunar Module during EVA traverses was extended by the suitcase sized device called the Lunar Communications Relay Unit (LCRU). The LCRU could be carried or mounted on the front of the LRV. It acted as a portable relay station for voice, TV and telemetry directly between the crew and Mission Control.

ROVER 1
Signal Processing Unit Electronics Radiators & Batteries
High Gain Antenna
15mm movie camera
S-Band Antenna
Core Tube Vise
Map Holder
Scoop
Tongs
Lunar Rake
Soil Penetrometer
Gnomon
CDR's Seat
Seatbelts
Seat Storage Bags

*"This rover is remarkable"
CDR Dave Scott, Apollo 15*

*"Truly an amazing vehicle"
CDR John Young, Apollo 16*

*"...it handles just the way as advertised, maybe even better"
CDR Gene Cernan, Apollo 17*

Non-Polar Latitudes

- Apollo 15 = 26.10 deg. N
- Apollo 16 = 8.99 deg. S
- Apollo 17 = 20.16 deg. N

STOWAGE & DEPLOYMENT

With space on the LM at a premium it was necessary to design a method to fit the LRV into the only space left available - the pie-shaped Quadrant 1 of the LM's descent stage. To squeeze the rover into this space, the engineers at Boeing decided to hold the Rover into 3 parts. Utilizing a series of jacks, hinges and lanyards, the LRV was designed to be semi-automatically unfolded by the astronauts and could be deployed from its stowed configuration onto the lunar surface and be operational in approximately 10 minutes (as shown in images 1 through 6). Once on the surface, the astronauts then outfit the rover with all of its necessary exploration equipment. This loading took less than an hour to complete before each EVA traverse was begun.

GENERAL DESCRIPTION

When deployed on the lunar surface, the Rover carried a payload of 1,000 lbs., more than twice its own weight. This cargo included two astronauts and their Portable Life Support Systems, PLSS (about 800 lbs.), 100 pounds of communication equipment, 100 pounds of scientific equipment and photographic gear, and 60-80 pounds of lunar samples.

The LRV had separate forward and rear steering systems, which could be used separately or together. If one steering system failed, it could be disconnected and the vehicle could operate with the other system. Each of the vehicle's harmonic traction drives had an odometer that provided distance information. The rover's forward motion was accomplished using a T-bar hand controller situated between both astronauts allowing either one to drive the rover, although only the three mission commanders actually drove the LRV's.

Two 105 amp hour, 36 volt, silver zinc batteries provided the vehicle's power, although either battery could power all the vehicle's systems, if required. Each wheel had an independent suspension and was individually powered by a 1/4 horsepower electric motor (providing a total of one horsepower). The vehicle's top speed was about 8 miles per hour on a relatively smooth surface. The LRV was stable on slopes up to 25 degrees.

The LRV had separate forward and rear steering systems, which could be used separately or together. If one steering system failed, it could be disconnected and the vehicle could operate with the other system. Each of the vehicle's harmonic traction drives had an odometer that provided distance information. The rover's forward motion was accomplished using a T-bar hand controller situated between both astronauts allowing either one to drive the rover, although only the three mission commanders actually drove the LRV's.

Length: 10 feet 2 inches
Height: 44 inches
Wheelbase: 7.5 feet
Tread width: 6 feet
Earth Weight: approx. 460 pounds
Moon Weight: approx. 77 pounds

Folded Rover ready for storage into Quad 1
Fully Loaded Rover

MOON LRV 001

When deployed on the lunar surface, the Rover carried a payload of 1,000 lbs., more than twice its own weight. This cargo included two astronauts and their Portable Life Support Systems, PLSS (about 800 lbs.), 100 pounds of communication equipment, 100 pounds of scientific equipment and photographic gear, and 60-80 pounds of lunar samples.

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LUNAR ROVER MISSIONS

J-SERIES

The J Series Lunar Modules (LM) allowed a much longer 70 hour stay on the lunar surface. This meant the astronauts could explore the area around their landing site with 3 separate EVAs lasting approximately 7 hours each. Additional consumables were required for the longer stay as well as additional equipment to land with the increased payload which included the Lunar Roving Vehicle (LRV).

Apollo 15 - July 26 - August 7, 1971
CDR Dave Scott, LRV in use, CDR Al Worden
Landed in the moon's Sea of Descent in the Hadley-Apennine region at Latitude -26.10 deg. N and Longitude -33.83 deg. E.
The astronaut stayed a total of 660 hours on the lunar surface and traveled a distance of 17.2 miles on the rover during 3.0 hours of driving. They traveled back to the LM on the rover during 1.4 hours of driving. They collected 27.1 lbs. of lunar regolith material.

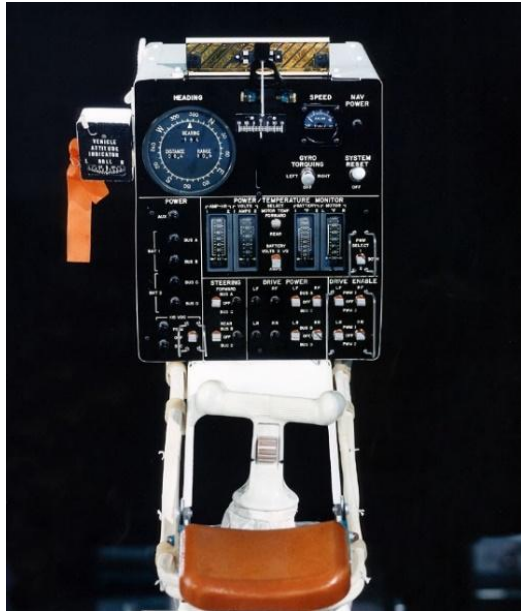
Apollo 16 - April 16 - 27, 1972
CDR John Young, LMP Charles Duke, CIP Ken Mattingly
Landed in the moon's Descartes Highlands region at Latitude -8.89 deg. S and Longitude = 15.51 deg. E.
The astronaut stayed a total of 71 hours on the lunar surface and traveled a distance of 16.5 miles on the rover during 3.4 hours of driving. They traveled back to the LM on the rover during 1.4 hours of driving. They collected 27.1 lbs. of lunar regolith material.

Apollo 17 - December 7 - 17, 1972
CDR Gene Cernan, LMP Harrison Schmitt, CIP Ron Evans
Landed in the moon's Taurus-Littrow region at Latitude -20.16 deg. N and Longitude -30.83 deg. E.
The rover was driven approximately 22.2 miles in 4.5 hours around the entire valley. In the 7 hours the astronauts explored the site, they collected 29.2 lbs. of lunar regolith material. The mission marked the first time the LM "You can see the repairs in the image on the right."

Special thanks go to Karl Diederich and Ron Coker for their support and assistance in the construction of this model. Design figure 30-10390-001 Don H. McMillan. Unless otherwise noted, action by Don H. McMillan and Ron Coker. All other images courtesy of NASA. See the computer model at: www.k12usa.com The poster is dedicated to the ground handling system who designed, built and tested the operational rover to the astronauts who delivered and drove the rovers on the moon and to my parents, Ruth and Bill who showed me Apollo Earthland in July of 1971. For further information about the Rover and the Apollo program visit four websites: Karl Diederich's web site: www.k12usa.com; Don H. McMillan's: www.donhmc.com; Ron Coker's: www.roncoker.com; and Don Jones' Apollo Lunar surface panel: www.apollo15.com

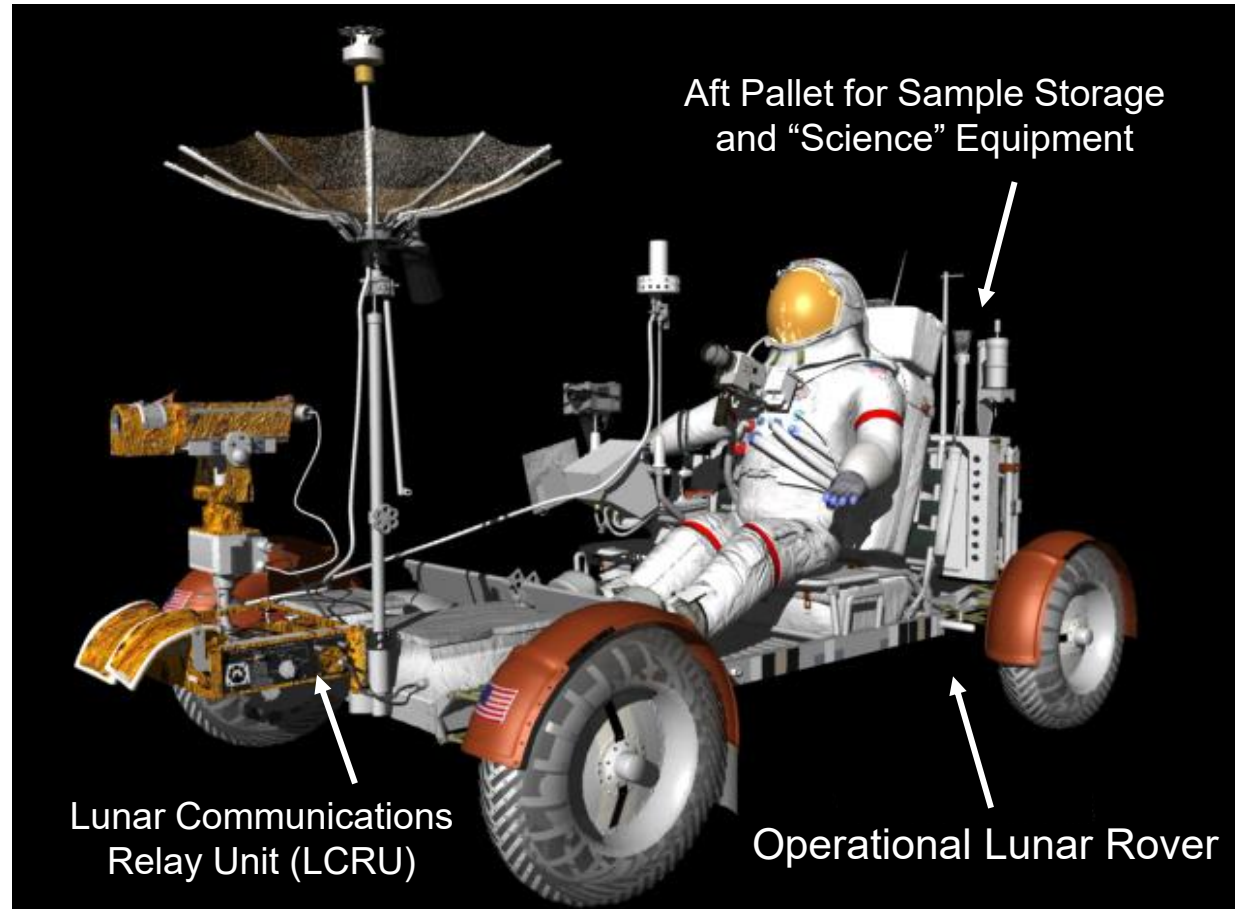
Apollo Rovers Contribute 6 Component, Power, and Mobility Challenges for Reuse

Display and Control Console and Hand Controller for Drive Power, Braking, Steering, and Navigation



Insulated Front Panel for Power and Navigation Initialization/Review
Dust Degraded Exterior Surfaces

Apollo 16 and 17 Switch to Provide Power for LCRU

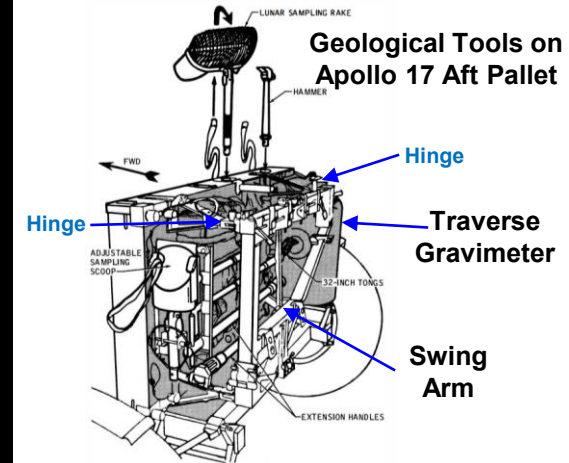


Lunar Communications Relay Unit (LCRU)

Operational Lunar Rover

Forward Chassis Electronics
 Insulate / **Isolate** from **Dust**
 Store Generated Heat in **Batteries** and Wax Boxes
 Radiator Dust Covers
 Opened Back at the LM

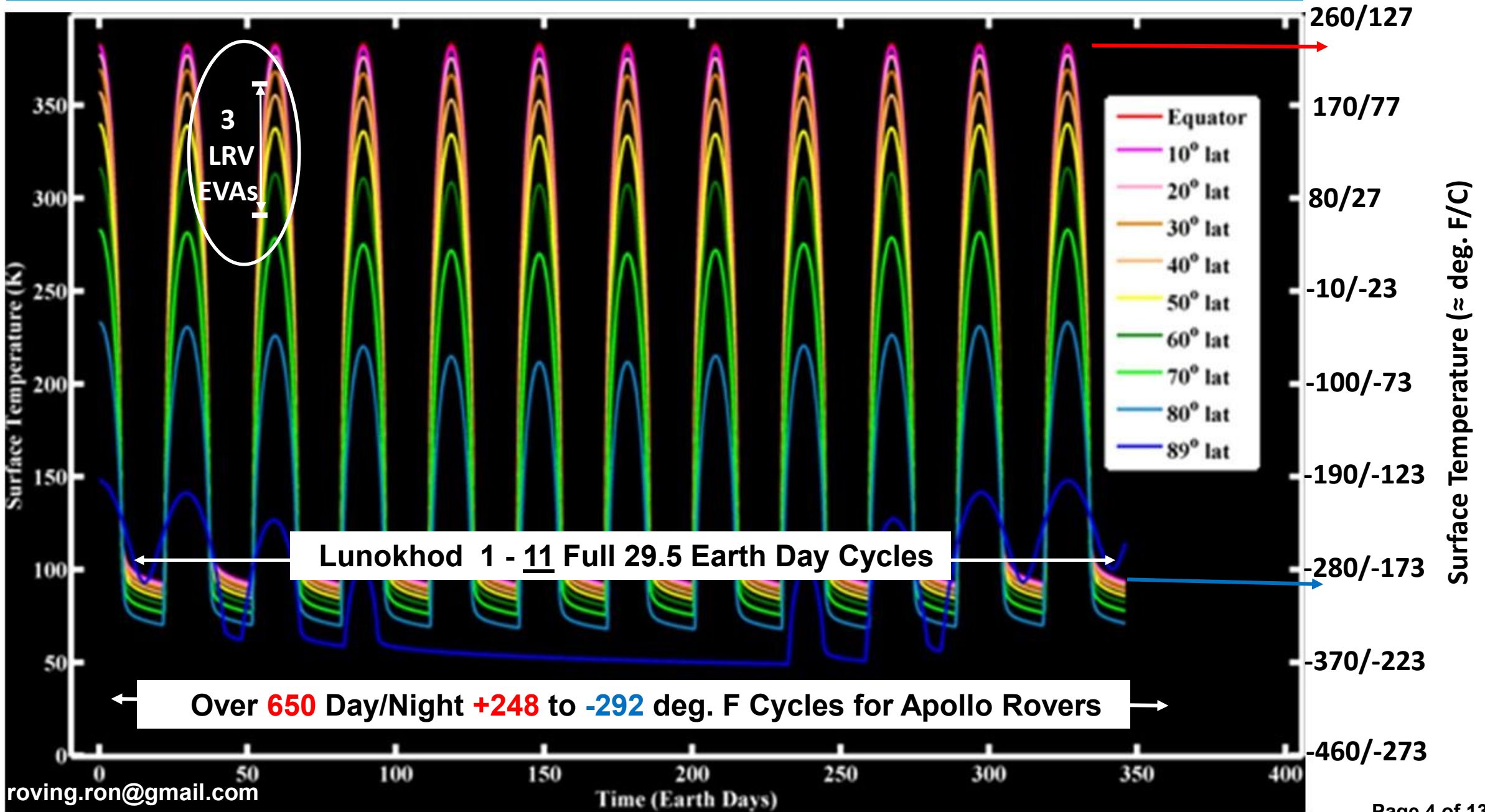
Mobility
 Exterior **Traction Drive**, Fluid Damper, and Steering Components
 Have **Dust** Degraded Surfaces
 Internal Conduction Maximized
Vital Fenders and Extensions



Three Different Aft Pallet Configurations

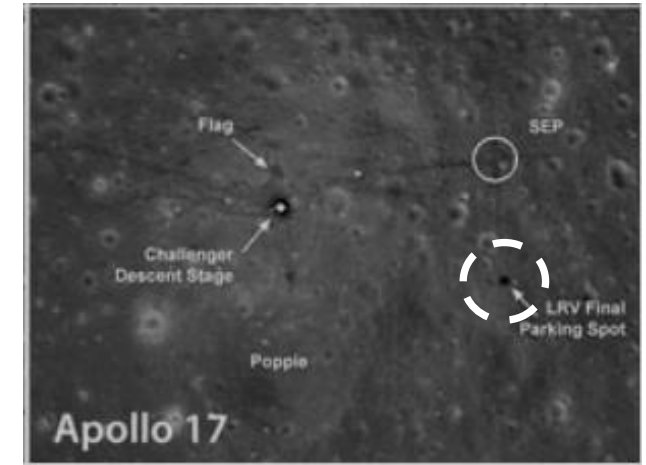
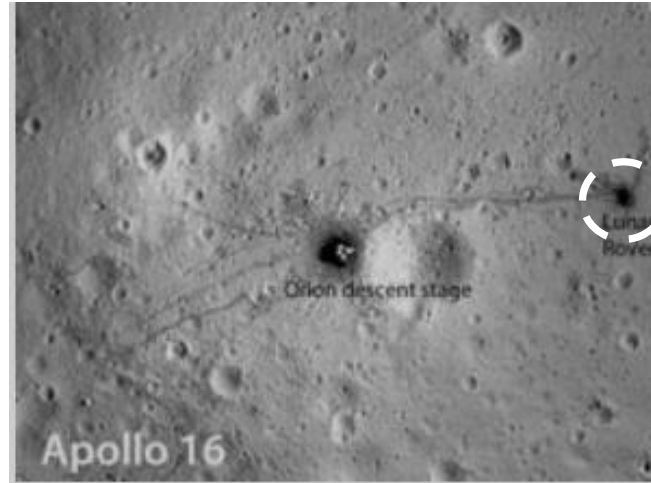
Maintain All Surfaces Within Astronaut Touch Constraints as Replacements are Made

Challenge 1 - 54+ Year Rover Components' Exposure to Temperature Extremes

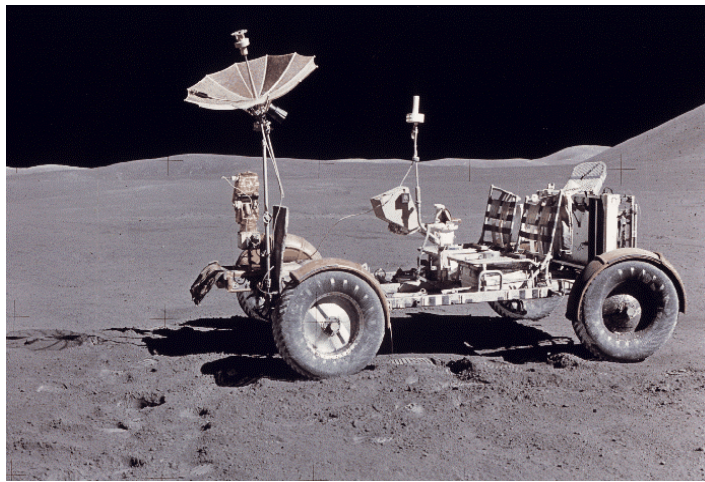


Challenge 2 - Preparation for Unknown Rover Condition and Fenders and Extensions Status

Mysterious "Black" Areas at Present Parked Rover Locations in LRO* Photos!



Required Rover Fenders and Extensions Status Before Multi-year Extreme Temperature Exposure



Left Front Fender Extension Missing on Apollo 15 Rover



Right Rear Fender Extensions Lost on Apollo 16 and 17 Rovers

Temperature Extremes May Have Warped Fenders and/or Removed Fender Extensions

Apollo 17 Right Rear Fender Extension Crew Repair

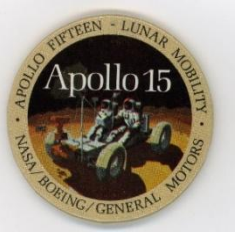


Apollo 17 Fender Repair and other Extensions Now in Museums



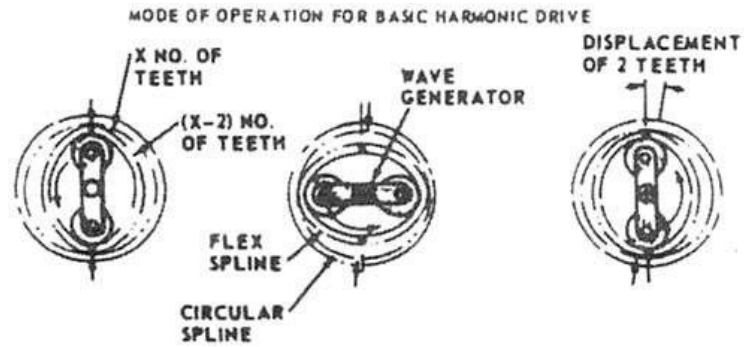
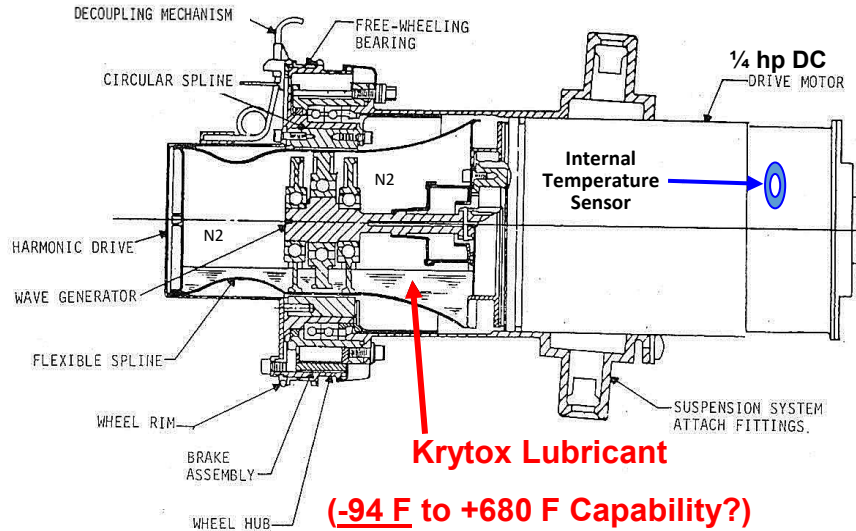
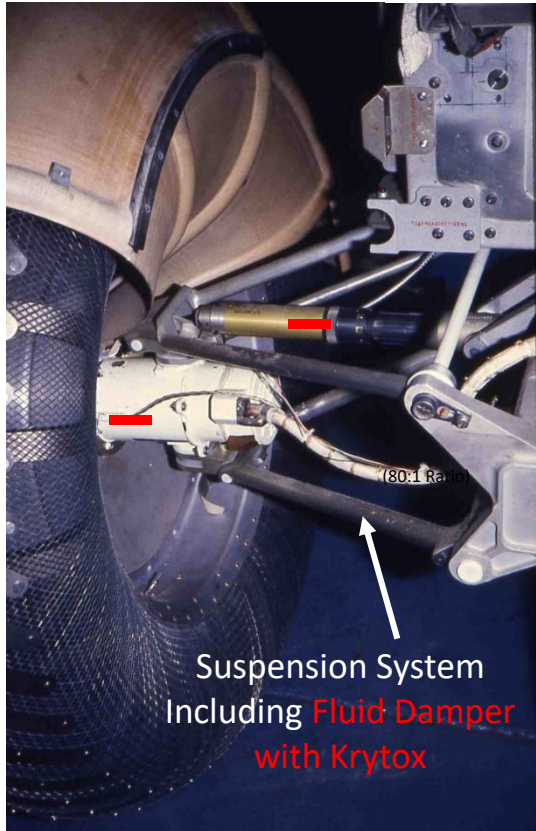
All 3 Apollo 17 Fender Extensions and Repair Removed

* LRO = Lunar Reconnaisance Orbiter

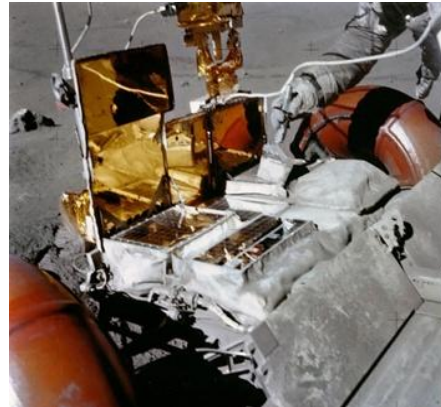


LRV Mobility and Forward Chassis Subsystems Present Reuse Challenges

Mobility Subsystem



Forward Chassis Subsystem



- Multi-Layer Blanket for Insulation, with Dust Covers for Thermal Radiators
- Thermal Straps Conduct Electronics Heat Into 59 Pound Non-Rechargeable Silver-Zinc Batteries
- Electronics Heat Also Stored in Wax Boxes (Fusible Mass Tanks) During Extra-Vehicular and Driving Activities (EVAs)
- Low Solar Absorptance ($\alpha_s = 0.07$) Space Radiators to Reject Heat When Dust Covers Are Opened at the End of EVAs

4 **Sealed** DC Motor and Harmonic Drive Units Used for Traction Power on the LRVs

Challenge 3 - Maintaining LRV Components Within Temperature Limits - deg. F

Batteries and noted Electronics are protected for **Hot** exposure, if the integrity of the Forward Chassis insulation blanket can be maintained, but long-term **Cold** temperature exposure is a challenge

External Mobility components should be all right for **Hot** temperature exposure, but there is also concern for **Cold** temperature exposure

Forward Chassis Electronics

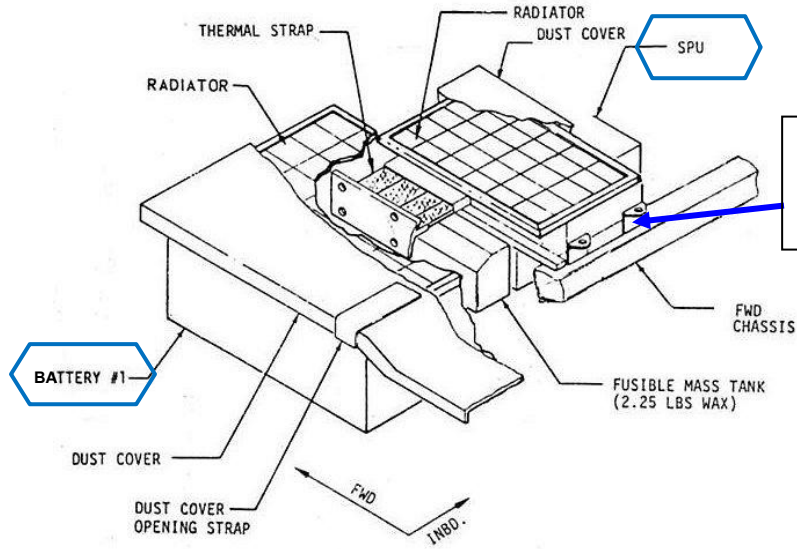
Mobility

Component	Minimum Survival	Minimum Operating	Maximum Operating	Maximum Survival
Batteries*	-15	40	125	140
Signal Processing Unit (SPU)	-65	30	130	185
Directional Gyro Unit (DGU)	-80	-65	160	200
Indicating Meters	-22	-22	160	160
Position Indicator	-65	-22	185	185
Drive Controller Electronics (DCE)	-20	0	159	180
Traction Drive	-50	-25	400	450
Suspension Damper	-70	-65	400	450
Steering Motor	-50	-25	360	400
Wheel	-250	-200	250	250

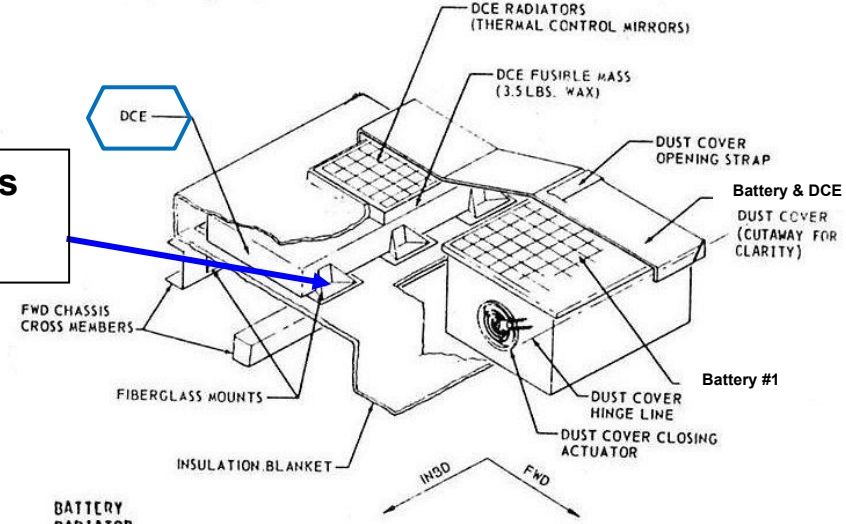
* 163 wt-hr/kg Stored Power per Battery

Challenge 4 – Detaching and Reattaching Fiberglass Rail Mounts & Electronics Component Connectors for Battery Replacement

Signal Processing Unit (SPU) Thermal Control

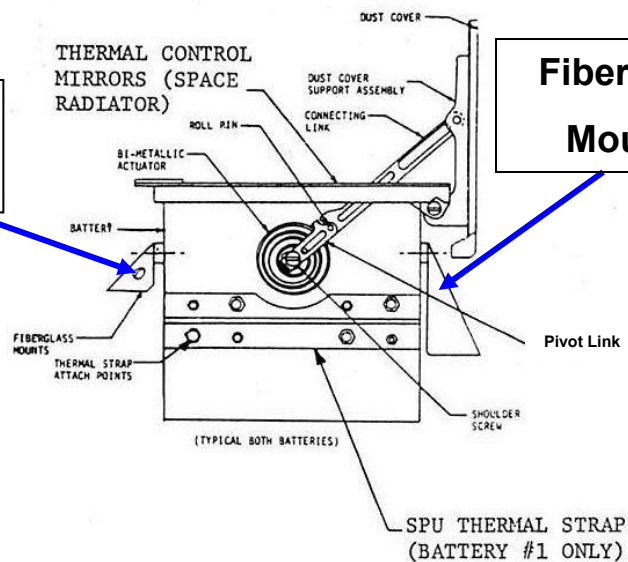


Fiberglass Mounts

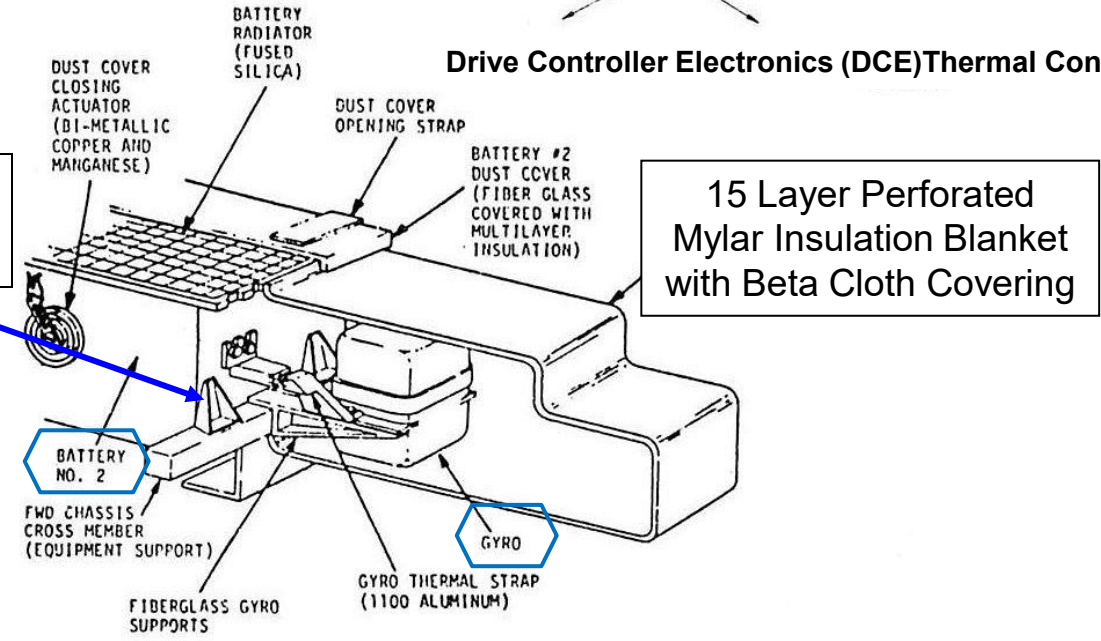


Drive Controller Electronics (DCE) Thermal Control

Numerous Screws



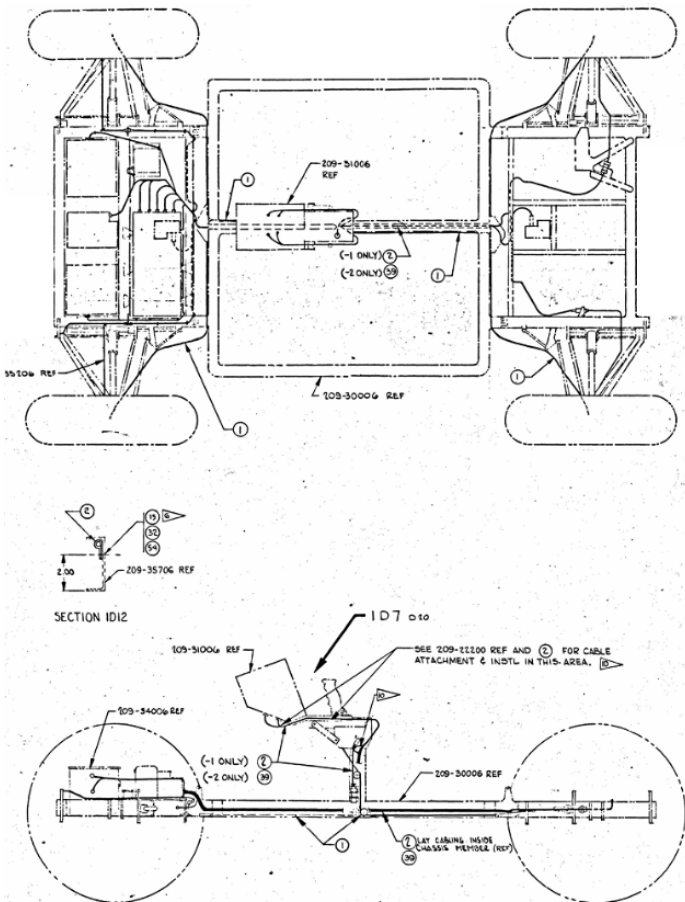
Fiberglass Mounts



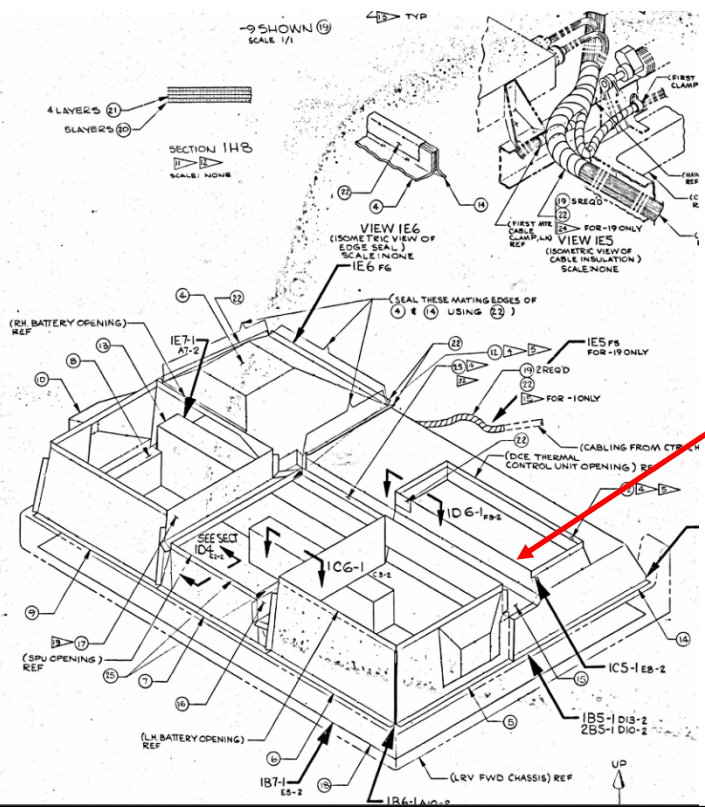
Directional Gyro Unit (DGU) Thermal Control

Challenge 5 - Disconnecting Cables and Reconnecting Them Later

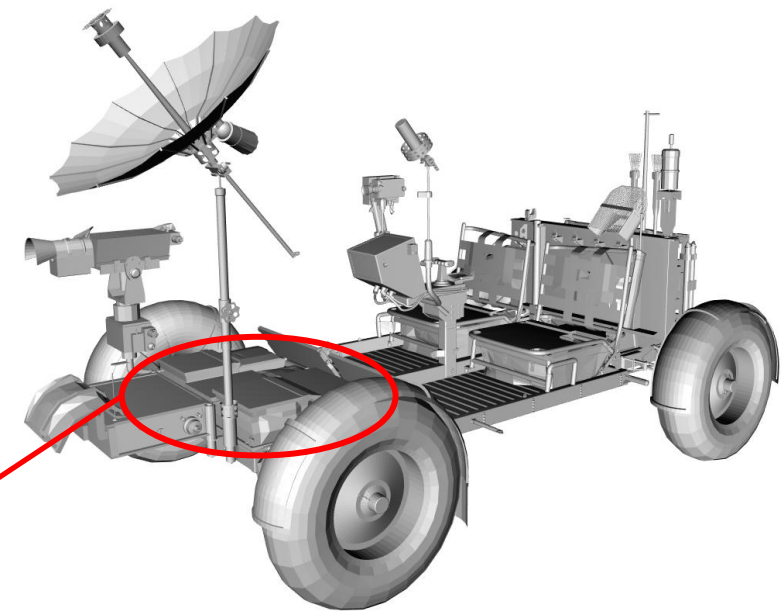
LRV Cable Runs



LRV Forward Chassis Cables



181 Node LRV SINDA* Thermal Model



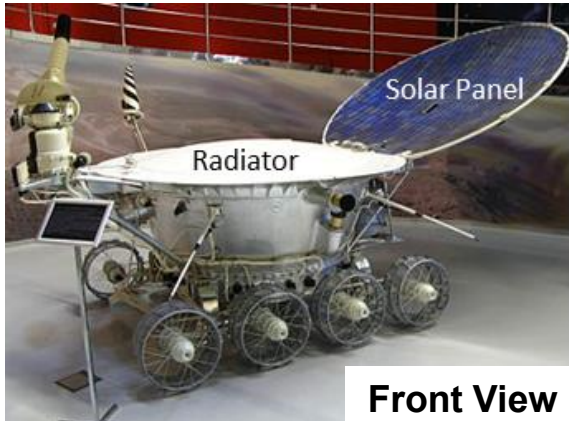
LRV Qualification Unit is now at Smithsonian Air and Space Museum - and 4th Rover is on display at NASA Kennedy Space Center to help with Reuse testing

Qualification Unit at Marshall Space Flight Center after Apollo 15

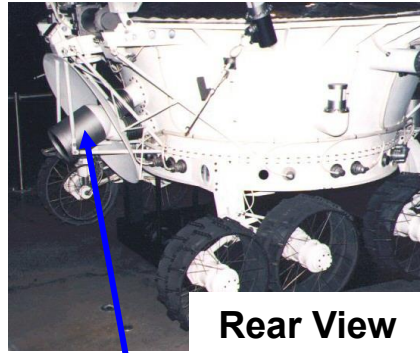
* SINDA = Systems Improved Numerical Differencing Analyzer

Challenge 6 - Supplying Power for LRV Electronics Nighttime Survival and Operation on the Moon

Russians Successfully Used Nuclear Isotope Heat Sources for Several Lunar Cycles on Their Two Lunokhod (Moonwalker) Robotic Rovers (1970 to 1973)



Front View



Rear View

LUNOKHOD

Isotope Heater

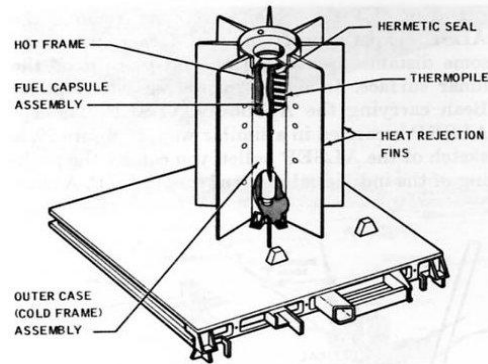
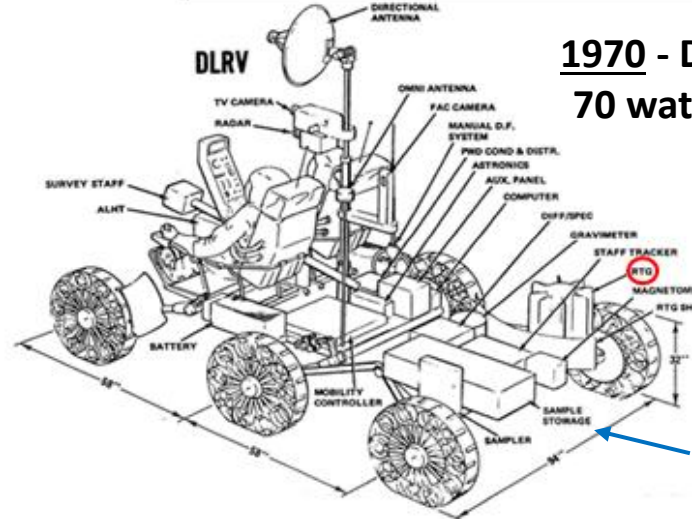
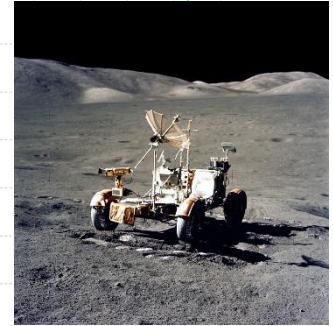
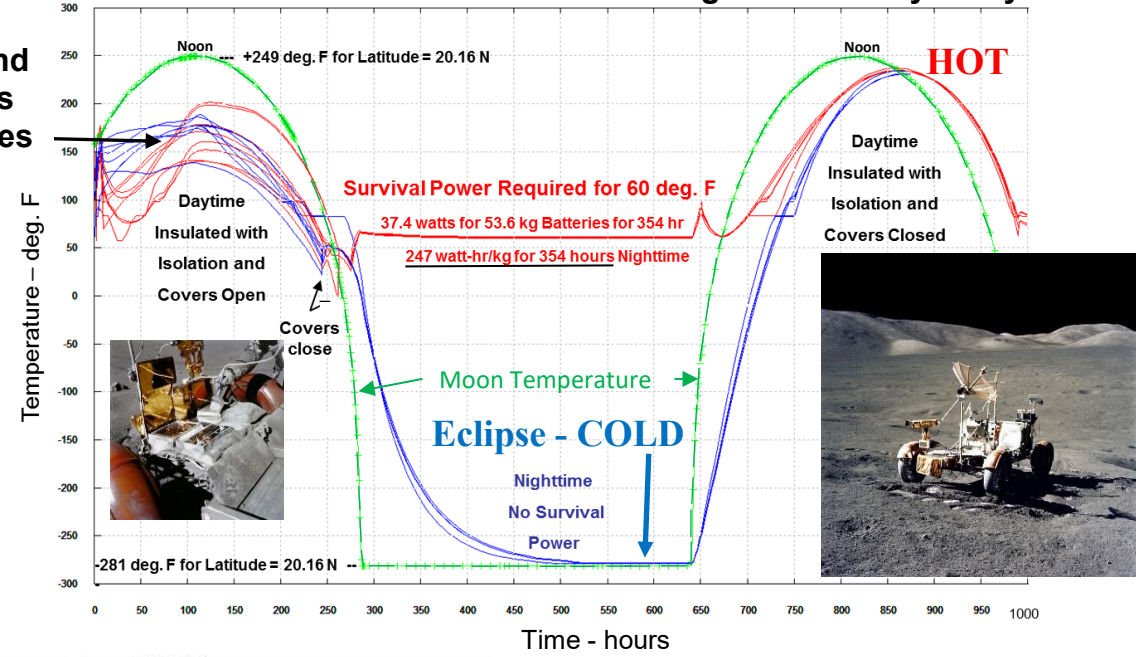


FIGURE 25.—Radioisotope Thermal Generator. This element provides all of the power used by the ALSEP furnishes continuously about 70 watts.

Five Apollo Lunar Surface Experiment Packages (ALSEPs) Survived for Several Years (1969 - 1977) Using RTGs

LUROVA™ Simulation Used for 2012 Nightrover Study Analysis

Batteries and Electronics Temperatures

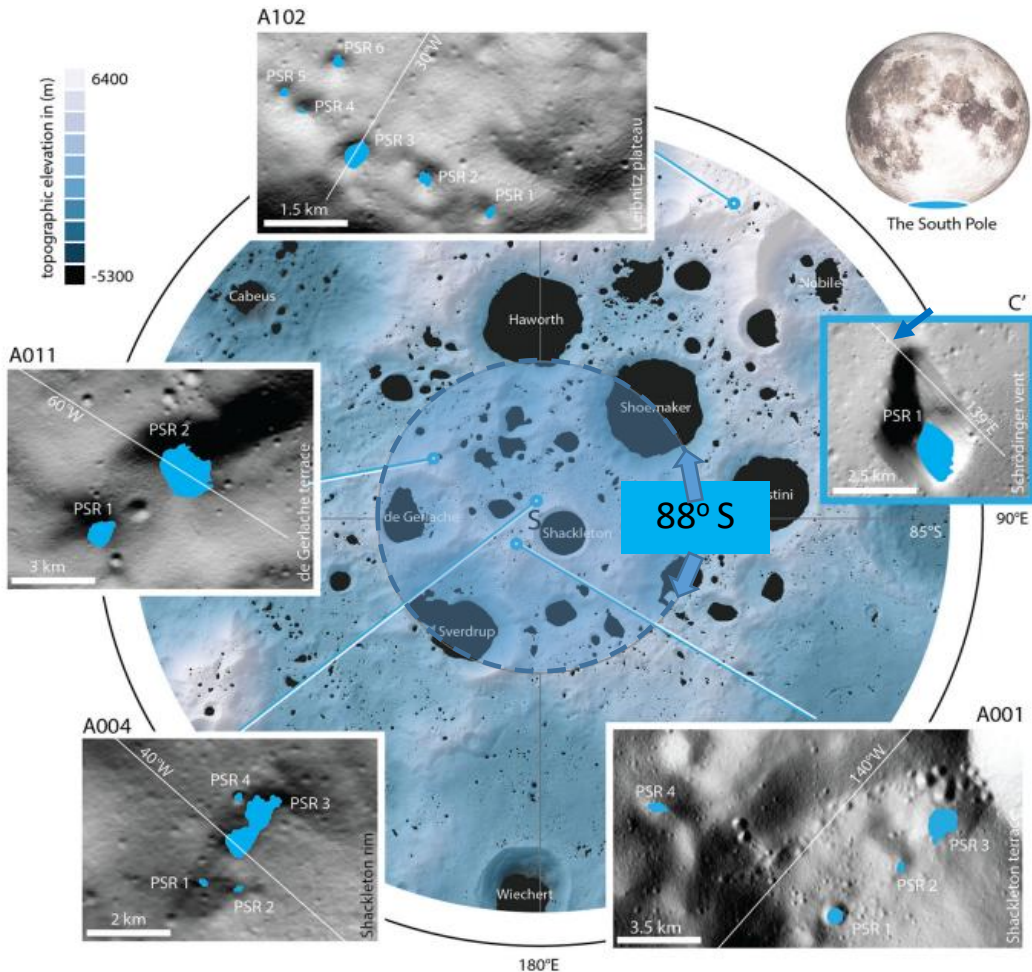


1970 - DLRV Dual Mode Rover Concept with a 70 watt Nuclear RTG for Cancelled Apollo 18

RTG = Radioisotope Thermoelectric Generator

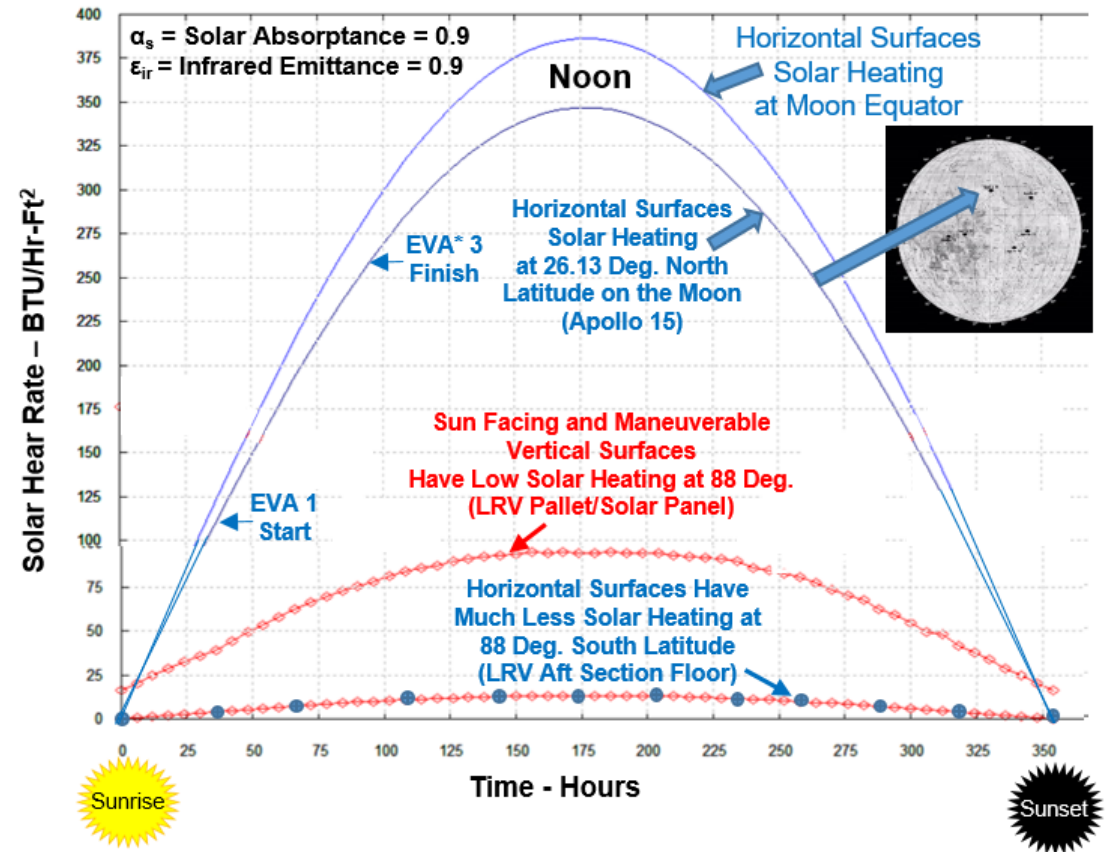
Trailer Installed for Robotic Operation

NASA Is Preparing for Candidate Lunar South Pole Permanently Shadowed Regions (PSRs)



2021 Source: "Peering into Lunar Permanently Shadowed Regions with Deep Learning" (<https://www.nature.com/articles/s41467-021-25882-z>)

Much Lower Solar Heating in South Pole Region with Difficult and Risky "Chasing the Sunlight" Traverses for Providing Dependable Solar Power



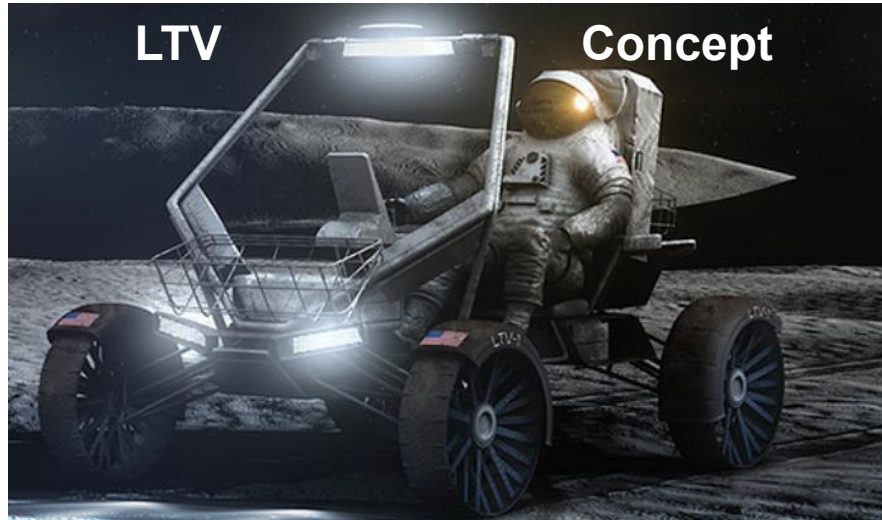
* EVA = Extra-Vehicular Activity

NASA Lunar Terrain Vehicle and JPL Endurance Rover Share Nighttime Exploration Objectives

Alternate Power Recommendation Presented at 2023 JPL Endurance Rover Science Workshop

LUNAR TERRAIN VEHICLE (LTV)

Single Spacecraft for Ten Year Crewed and Robotic Moon Exploration



LTV “**Chasing the Sunlight**” Traverses Will Be **Difficult** and **Risky**, and Could be **Dangerous**, Especially for Emergency Need for Dependable and Immediate Energy for Transit Back to the Lunar Home Base

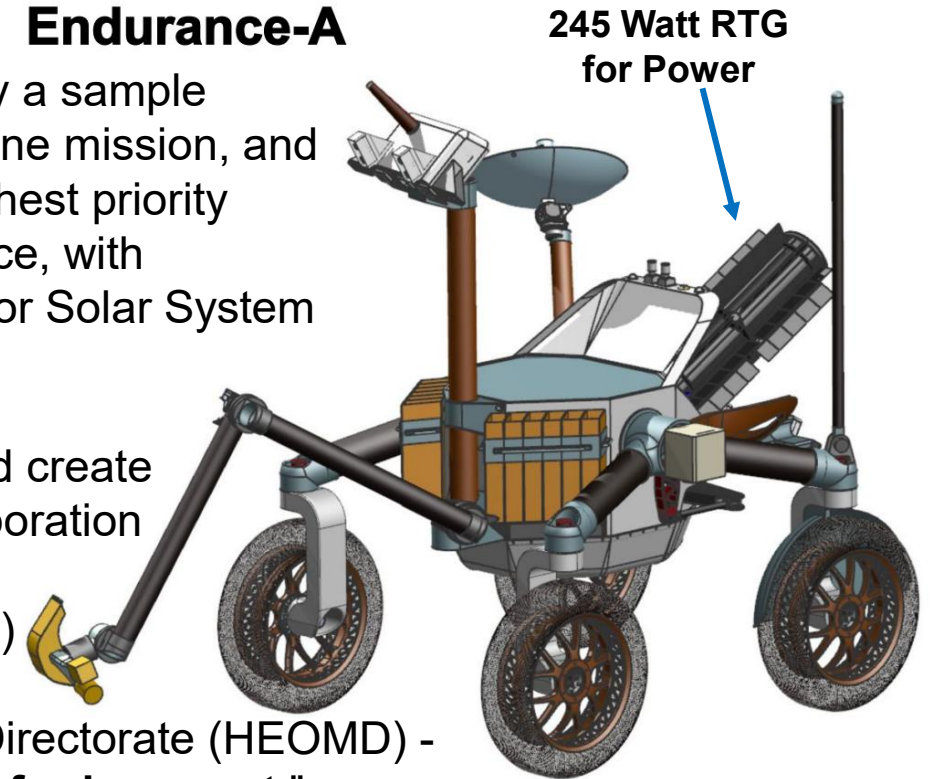
Requires Heavy and Maneuverable Panels for Solar Energy Collection

roving.ron@gmail.com

Endurance-A

“Endurance is effectively a sample collection campaign in one mission, and it would address the highest priority questions in lunar science, with enormous implications for Solar System science.”

Endurance-A option would create a new paradigm for collaboration between NASA’s Science Mission Directorate (SMD) and Human Exploration and Operations Mission Directorate (HEOMD) - **achieving more science for less cost.**”



Recommendation - Combine These Rovers to Provide Dependable Exploration Power and Gain Significant Cost Savings

Additional Benefit: Reduces Size/Mass of Batteries and Solar Panels

Summary

- Apollo Rovers Contribute **6** Component, Power, and Mobility **Challenges** for Reuse:
 - **1** - 54+ Year Rover Components' Exposure to Temperature Extremes
 - **2** - Preparation for Unknown Rover Condition and Fenders and Extensions Status
 - **3** - Maintaining LRV Components Within Temperature Limits
 - **4** - Detaching and Reattaching Fiberglass Rail Mounts & Connectors for Battery Replacement
 - **5** - Disconnecting Cables and Reconnecting Them Later
 - **6** - Supplying Power for Apollo LRV Electronics Nighttime Survival and Operation on the Moon
- Alternate **RTG** Power Recommended for Rover Nighttime and Pole Thermal Survival on the Moon

Remember Murphy's Law - "If Something Bad Can Happen, It Will"

So Always Have Backups!

We Certainly Don't Want Another "Houston We Have A Problem"

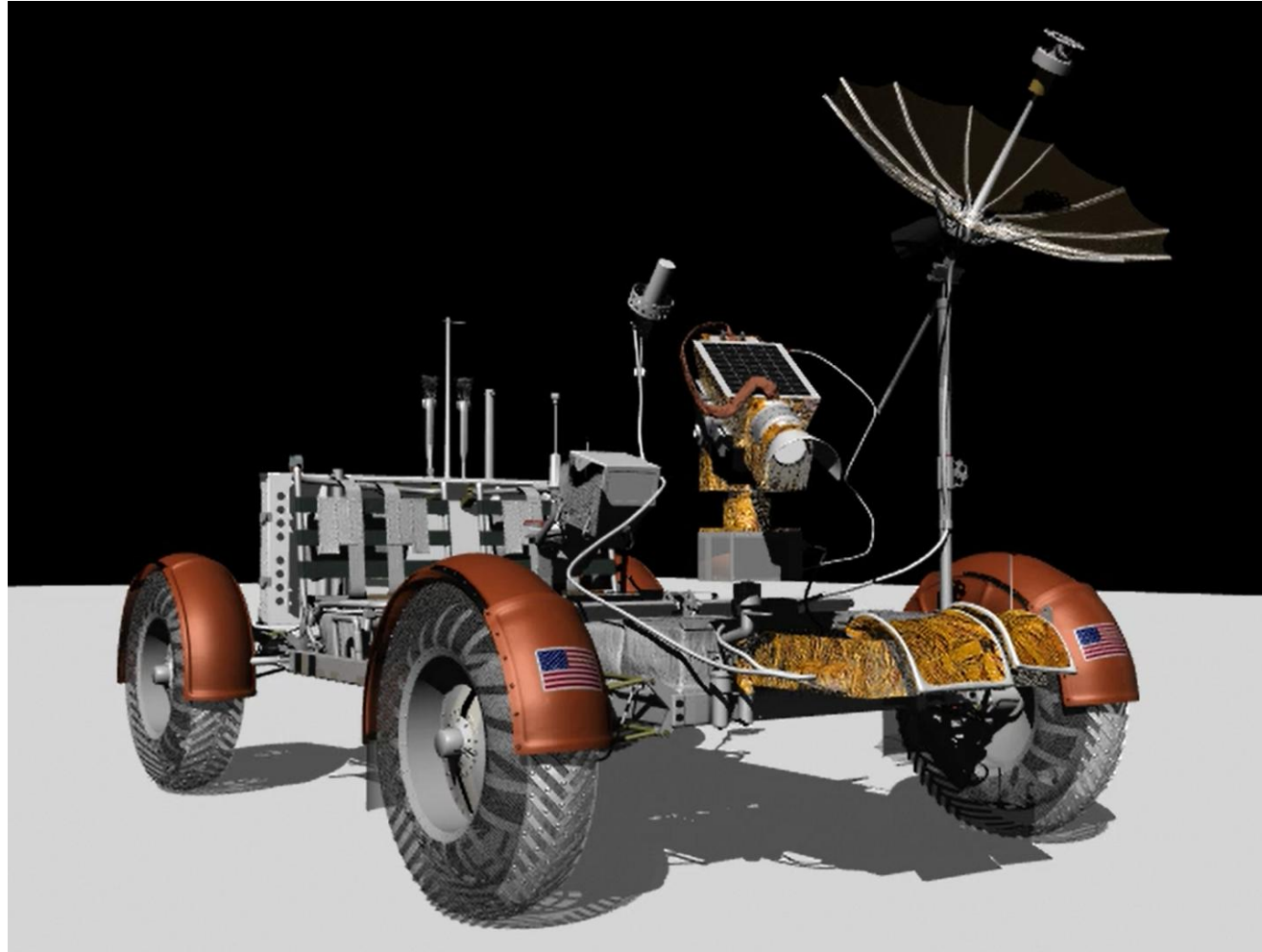
Call from a Rover Crew on the Moon!

And Please Remember to Always Capitalize "Moon"

Murphy's Laws

1. In any field of endeavor, anything that can go wrong, will go wrong.
2. Left to themselves, things always go from bad to worse.
3. If there is a possibility of several things going wrong, the one that will go wrong, is the one that will cause the most damage.
4. Nature always sides with the hidden flaw.
5. If everything seems to be going well, you have obviously overlooked something.

Backup



Apollo Astronauts Provided Valuable Assistance for LRV Crew Station Configuration and Component Testing



NASA Astronauts Had a Vested Interest in Development of the LRV - Shown Here are Left to Right Young, Cernan, Haise, Duke, England, Fullerton, Peterson



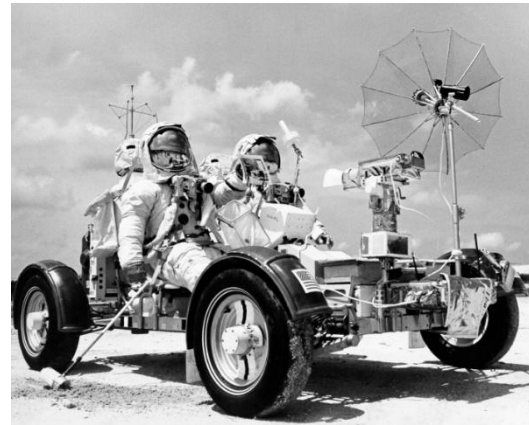
After Apollo 15, the Crew Signed Autographs for NASA Employees

roving.ron@gmail.com

Protective "Gold" Display Console Front Cover Plate for Earth Handling



"T" Shaped Hand Controller to Fit Astronaut Glove



Practicing Driving Sample Collection



"One-G" Trainer Provided Simulation of All LRV Interfaces



Folded LRV Stowed in Lunar Module with Floor Panels Removed for On-pad Battery Installation



Apollo 15 Crew Checking Out Their Installed LRV

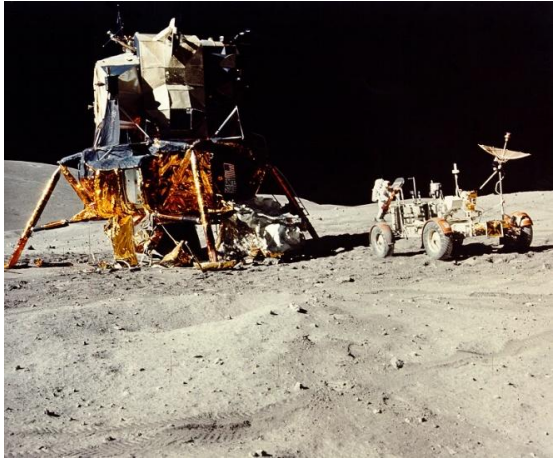


Astronaut "Silver Snoopy" Awarded for Thermal Modelling after Apollo 16 in July, 1972

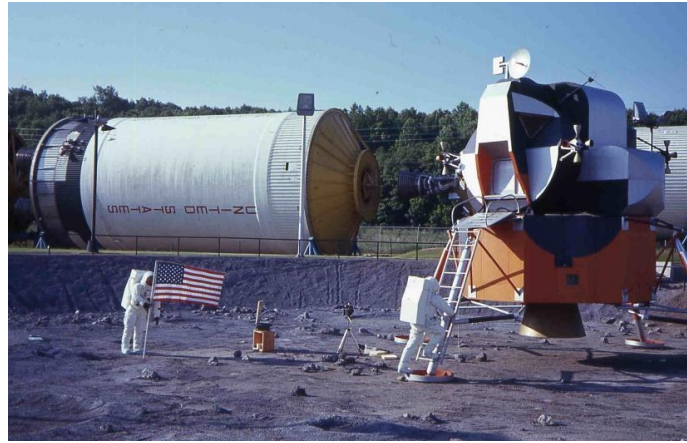
Astronauts Appreciated Timely and Accurate LRV Thermal Modeling



Post Apollo 16 - LM Parking Proximity Constraint Changed, and TVAC Fender Testing



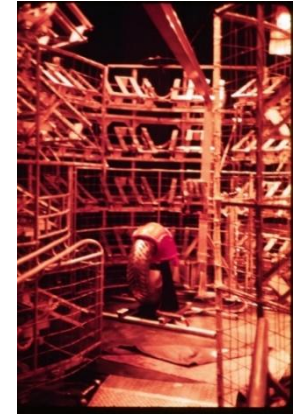
LRV Parked Too Close to LM



Battery Proximity Test at U.S. Space and Rocket Center



Re-designed Fender Extension TVAC Deployment Test at MSC

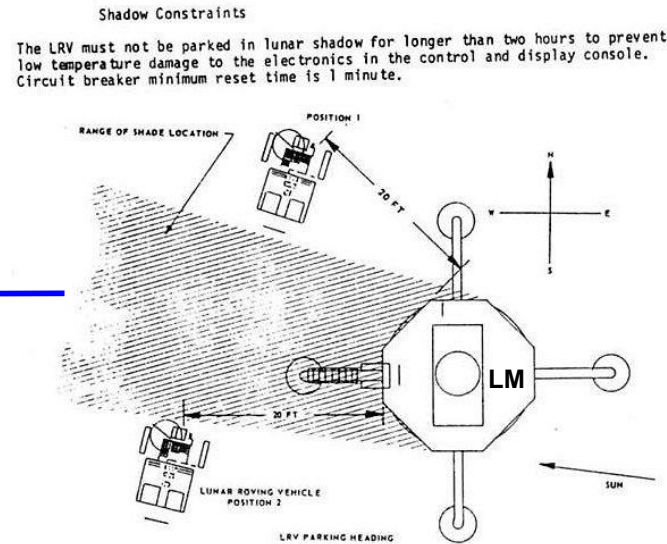


Additional "Switch and Meter Failures" were Not Repeated in Thermal Testing in Redstone Arsenal Army Thermal Test Chamber using the LRV Qualification Unit, so no fix was made for Apollo 17, which had non-critical repeats.



Form Factor Meter Photographed to Validate Model "View Factors" to LM

FWDCHA Computer Model

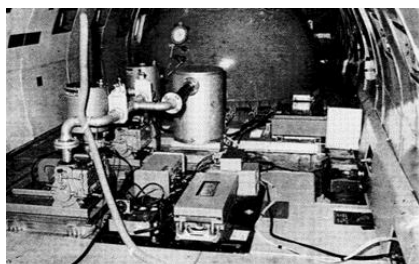
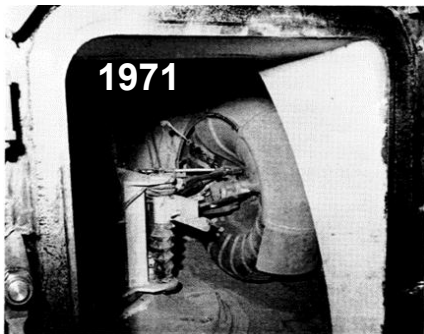


Parking Constraint Changed for Apollo 17



Ron With LM and LRV Vibration Test Unit at U.S. Space and Rocket Center

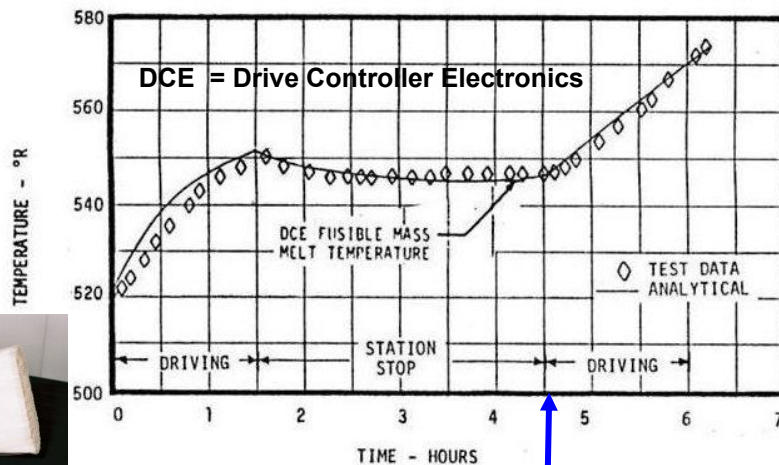
Rover Thermal Models Were Correlated with Extensive Thermal Vacuum (TVAC) Testing Data



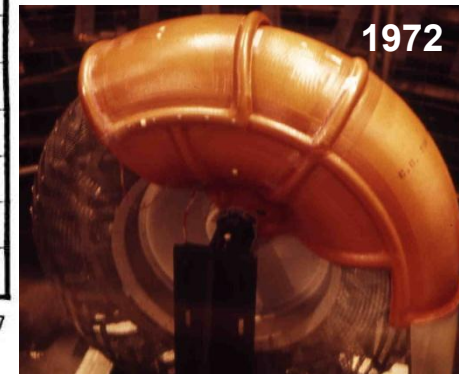
KC-135 Vacuum / Reduced Gravity Tests Verified the Need for Fenders Radiator **Dust Brush** Cleaning Also Tested at MSC* Using Apollo 12 Soil, but Did **NOT** Work on the Moon



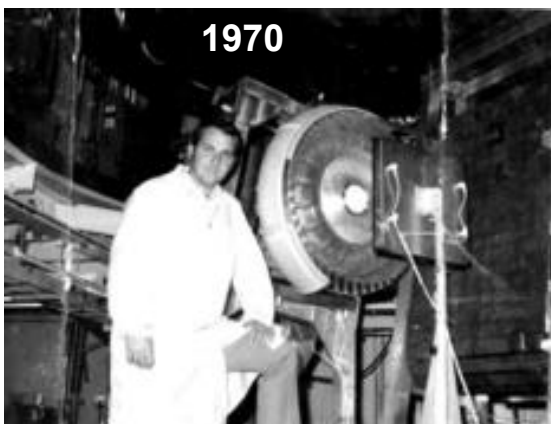
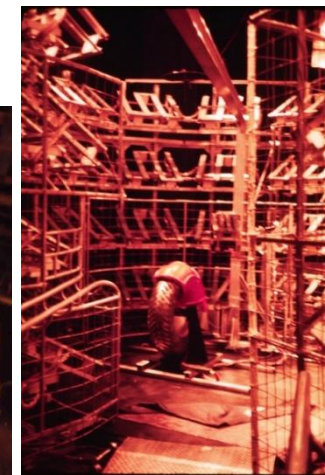
Lunar **Dust Brush**



DCE TEST DATA CORRELATION

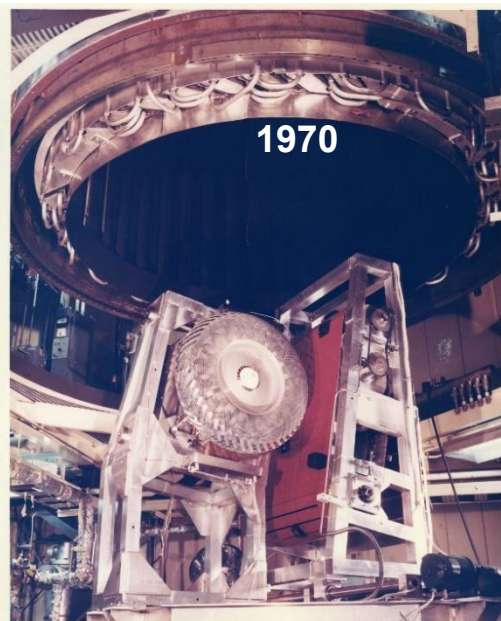


Fender Extension Deployment TVAC

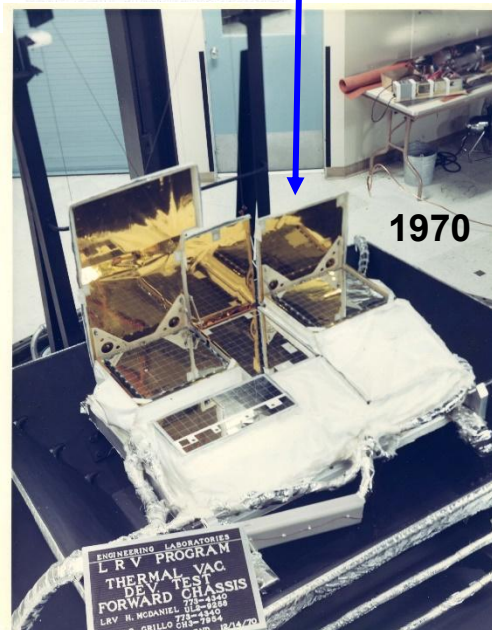


Ron Creel with Rover Mobility "M/4" Thermal Test Unit

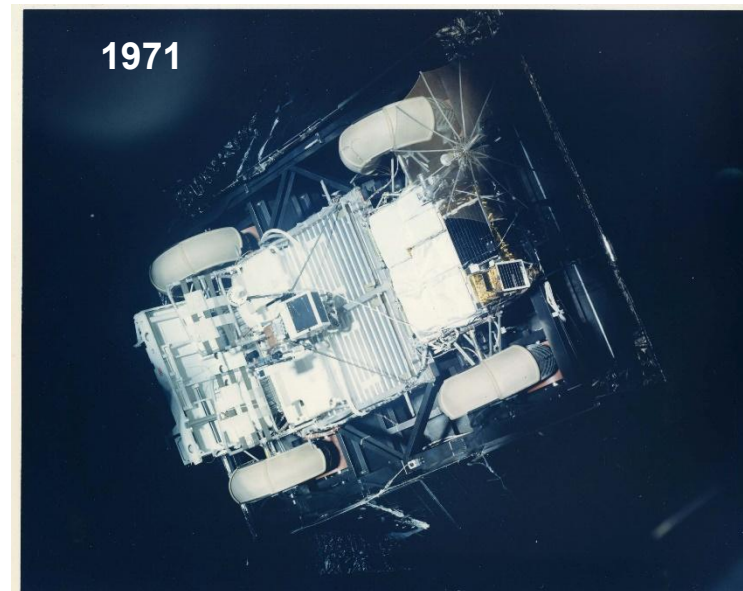
* MSC = Manned Spacecraft Center
 roving.ron@gmail.com



Mobility Subsystem TVAC

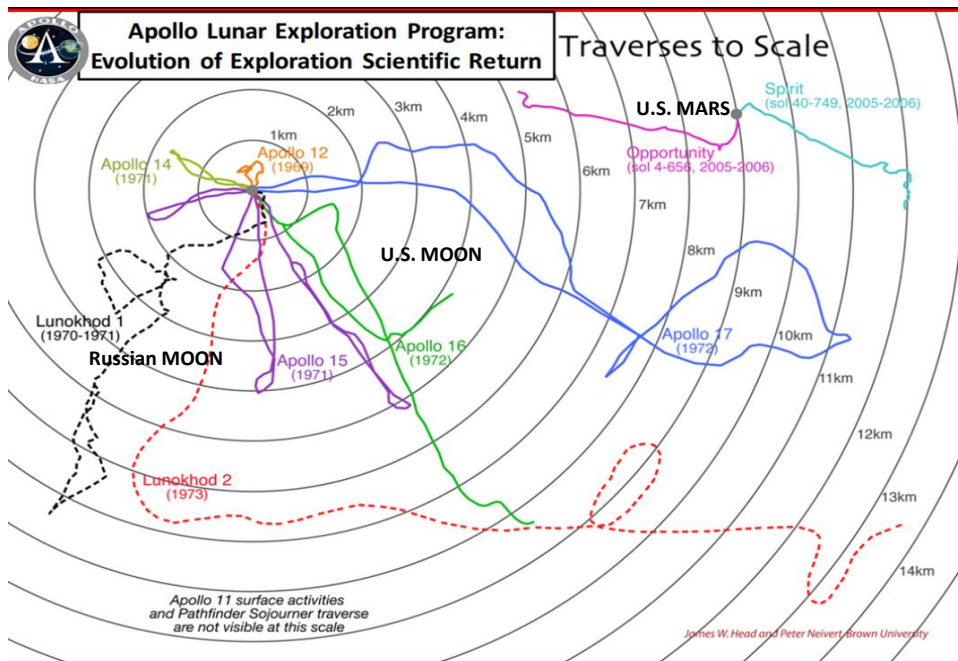


Forward Chassis Thermal Development "Tub" TVAC



Qualification and Flight Units TVAC

Apollo LRV Performance Comparison and Apollo 17 Wheel Condition after Driving 35.7 km (22.2 mi) on the Moon



	Pre - LRV	Apollo 15	Apollo 16	Apollo 17
EVA Duration (hrs:min)	19:16	18:33	21:00	22:06
Driving Time (hrs:min)	-	3:02	3:26	4:29
Surface Distance Traversed (km)	3.55	27.9	26.9	35.7
Average Speed (km/hr)	0.18	9.20	7.83	7.96
Longest Traverse (km)	-	12.5	11.6	20.3
Maximum Range From LM (km)	-	5.4	4.5	7.6
Regolith Samples Collected (kg)	97.6	77.6	96.7	116.7

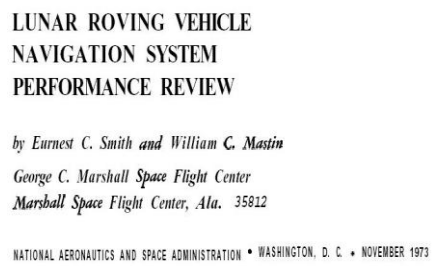
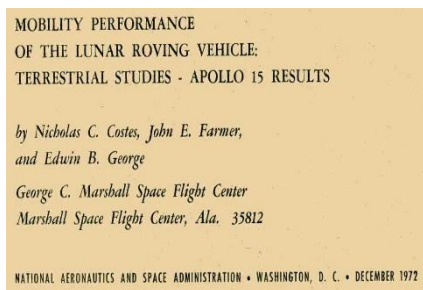
LRV Performance Comparison on the Moon

Range - The LRV will be capable of performing four 30 km traverses in a 78 hour period for a total of 120 km.

Test and Flight Correlated
19 Node LUROVA™
Thermal Model
Provided Excellent
Thermal Monitoring
and Predictions

All LRV components remained within operational temperature limits throughout the surface EVAs on all 3 Missions. As Predicted, Drive Motor Temperatures were "Off Scale Low" (below 200 deg. F) throughout most of the EVAs. The Maximum Motor Temperature of 270 deg. F occurred during the longest driving period in EVA 3 on Apollo 17

Mobility and Navigation Performance Documents



Apollo Lunar Surface Journal (ALSJ) is Another Good LRV Reference

Final Close-Up View of Apollo 17 Left Rear Wheel with Fender Extension Removed



Backup Page 4

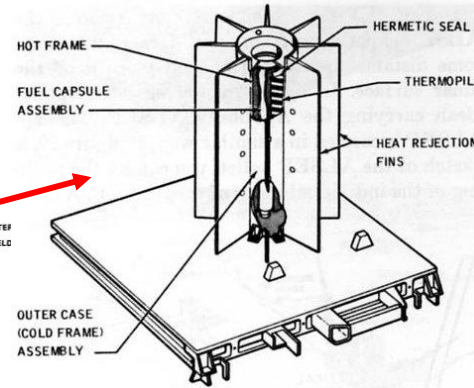
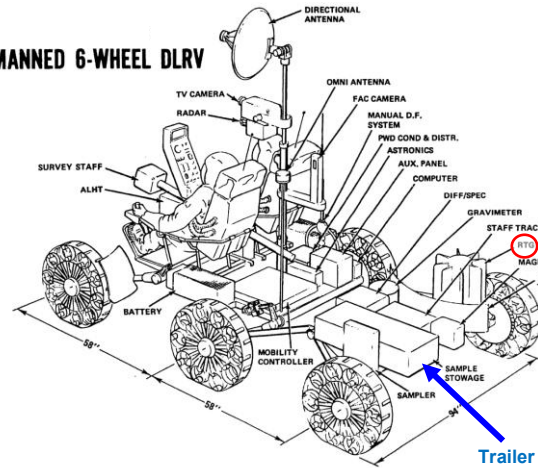
Nuclear Energy Provided Dependable/Efficient Moon Survival Power/Heat

- Nuclear Sources Used on ALSEPs and Studied for U.S. Apollo 18 Dual Mode Rover (DLRV)

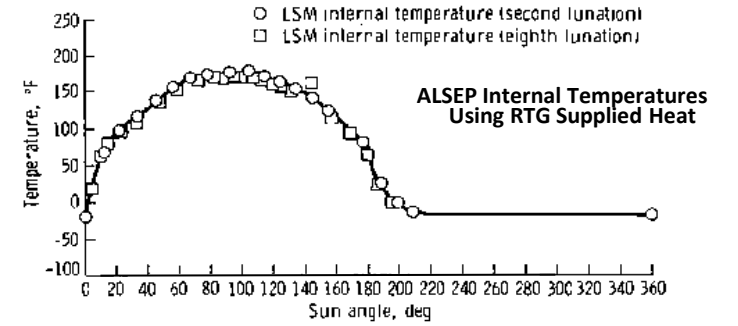
Lunokhod Wheel Gears



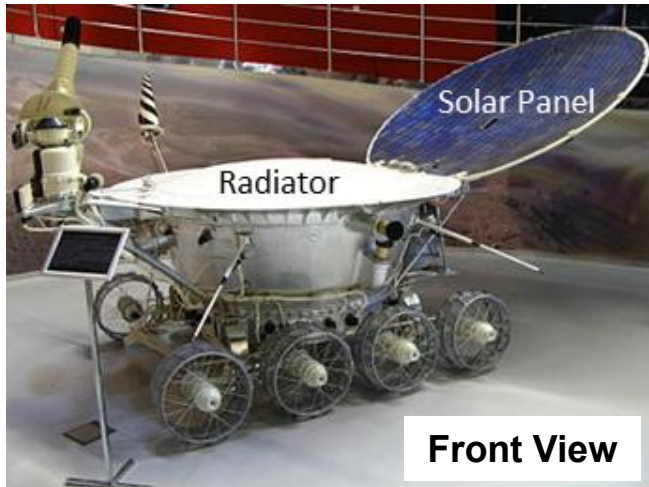
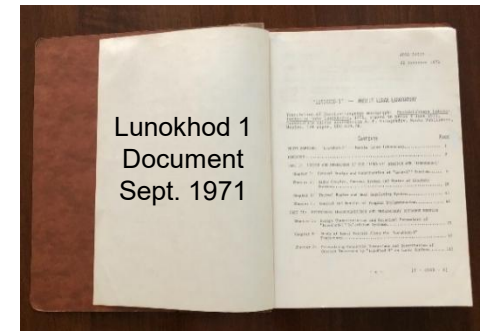
MANNED 6-WHEEL DLRV



SNAP-27 -Radioisotope Thermal Generator. This equipment provides all of the power used by the ALSEP. It furnishes continuously about 70 watts.

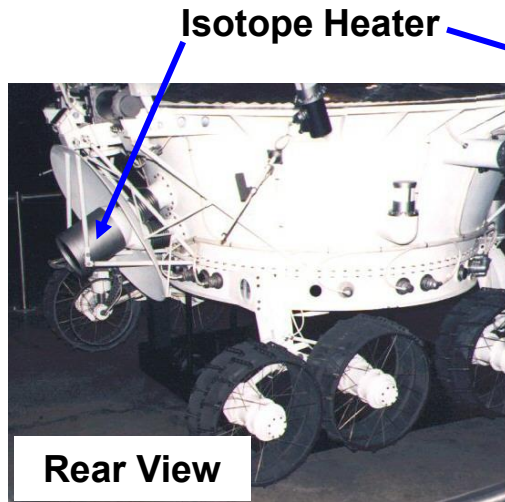


Russians Successfully Used Nuclear Isotope Heat Sources for Several Lunar Cycles on Their Two Lunokhod (Moonwalker) Robotic Rovers (1970 to 1973)



Front View

LUNOKHOD



Rear View

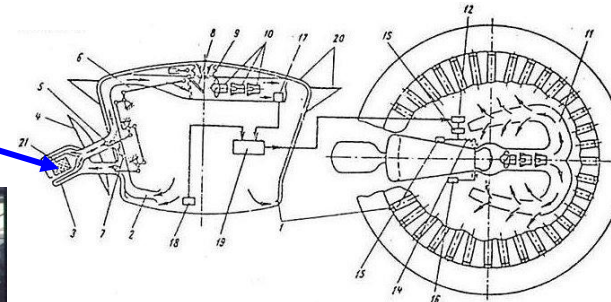


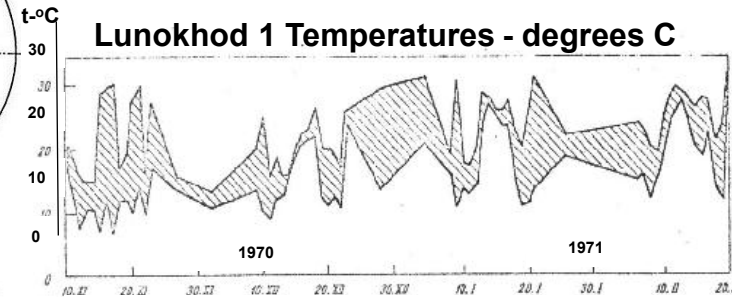
Diagram of lunokhod heat regulating system. 1) air passages of cold channel; 2) air passage of hot channel; 3) heating unit (HU); 4) HU shield; 5) HU "blinds"; 6) control of HU blinds; 7) baffle plate; 8) baffle; 9) connecting sheath; 10) three-step fan; 11) collector; 12) baffle drive; 13) step mechanism; 14) spring traction; 15) cam mechanism; 16) angular movements sensor; 17) SE1 sensing element; 18) SE2 sensing element; 19) radiator-cooler; 20) collector of HU blow-off system; 21) fuel cell.

For monitoring the thermal regime aboard the lunokhod there are thermetric temperature sensors which make it possible to obtain routine information on the temperatures of all lunokhod systems during any communication session.

Lunokhod 1- Mobile Lunar Laboratory

* ALSEP = Apollo Lunar Surface Experiment Package

Lunokhod 1 Temperatures - degrees C



Gas temperature in "Lunokhod 1" instrument compartment plotted data. The shading corresponds to the temperature range based on several measurements.

The results of Lunokhod operation on the Moon confirmed the high reliability of the vehicle's chassis. Over a five month period, the undercarriage did not experience a single mechanical failure, thereby demonstrating the probability of establishing a highly reliable chassis for lunar conditions.