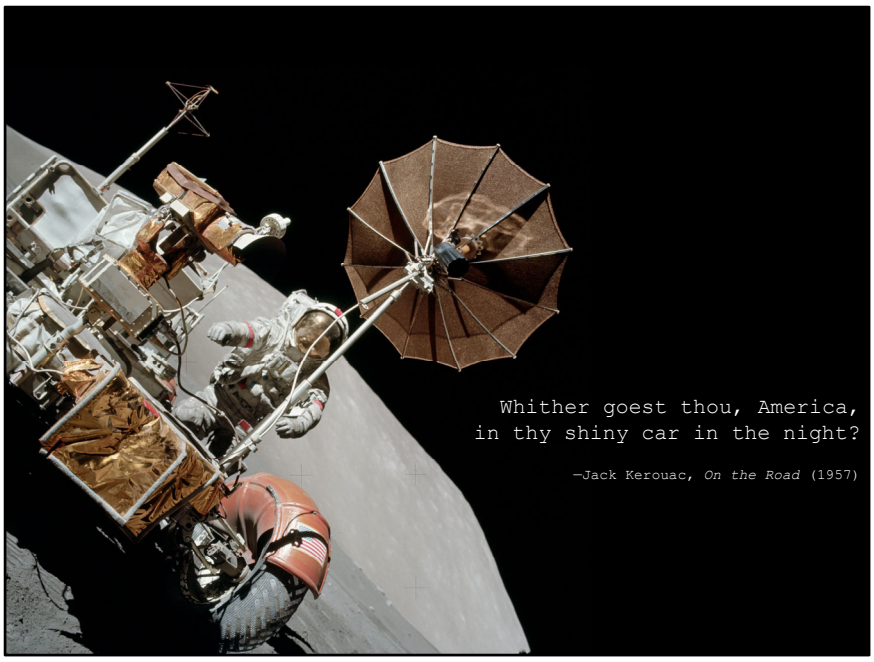

Whither goest thou, America,
in thy shiny car in the night?
—Jack Kerouac, *On the Road* (1957)

# The Apollo Lunar Roving Vehicle

# The Apollo Lunar Roving Vehicle

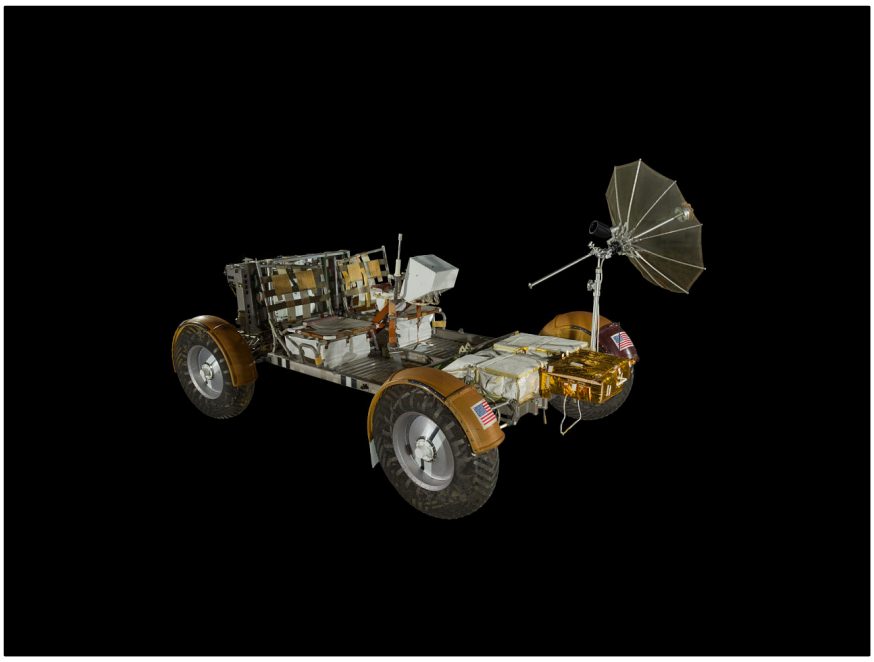
*a Boeing joint*


Act I

Act I

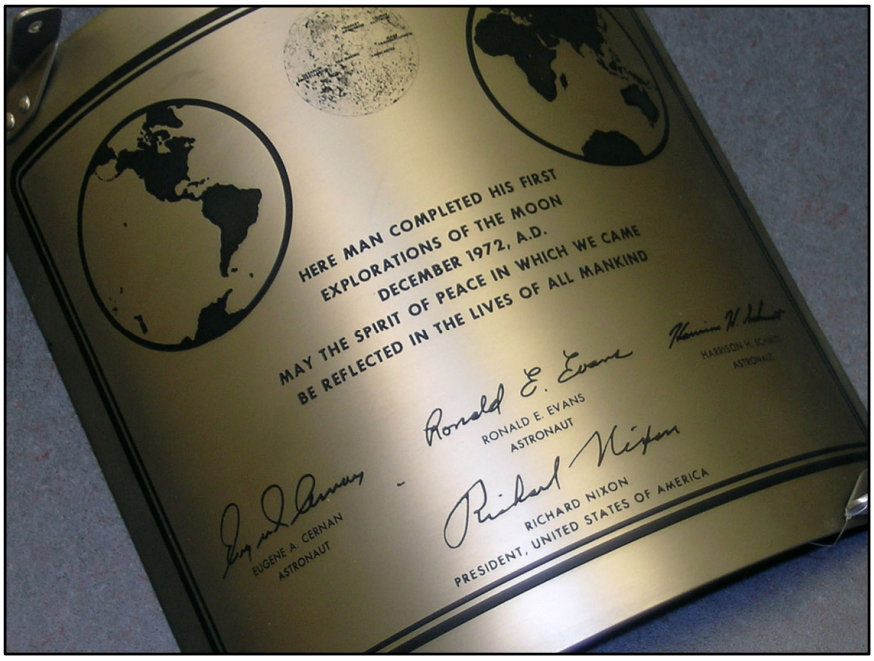
# Welcome to the moon

https://svs.gsfc.nasa.gov/4302



https://airandspace.si.edu/collection-objects/lunar-roving-vehicle-qualification-test-unit/nasm_A19760746000


APOLLO * XVII
CERNAN * EVANS * SCHMITT



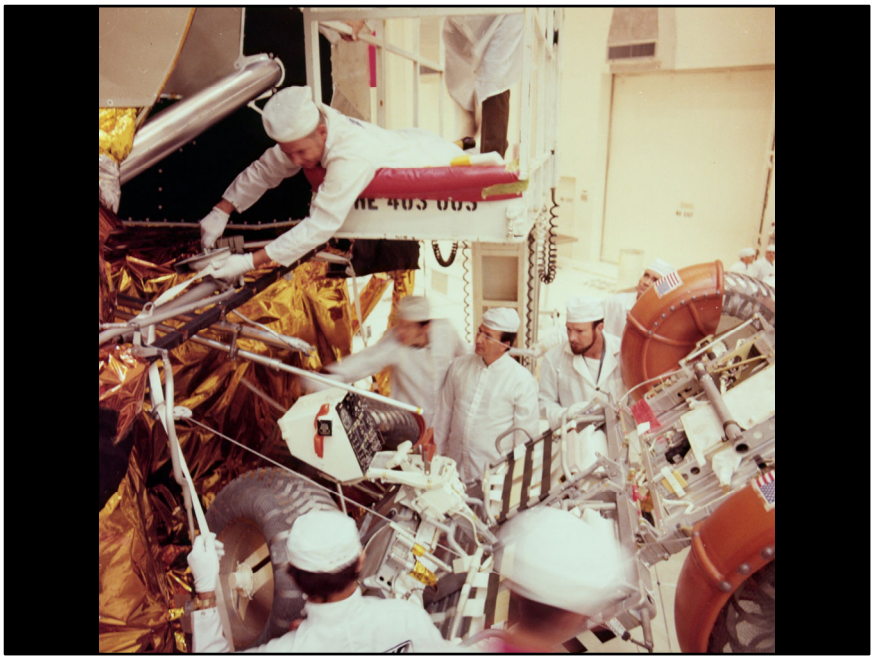

https://airandspace.si.edu/collection-objects/plaque-lunar-module-apollo-17/nasm_A19751405000


https://www.hq.nasa.gov/alsj/a17/AS17-134-20480HR.jpg

https://www.hq.nasa.gov/alsj/a17/ap17-S72-55830.jpg


https://www.hq.nasa.gov/alsj/a17/ap17-72-H-1561HR.jpg

Explorer’s Club Annual Dinner, 16 March 2019
L-R: Charles Duke (Apollo 16), Buzz Aldrin (Apollo 11), Walter Cunningham (Apollo 7), Al Worden (Apollo 15), Rusty Schweickart (Apollo 9), Harrison Schmitt (Apollo 17), Michael Collins (Apollo 11), Fred Haise (Apollo 13)

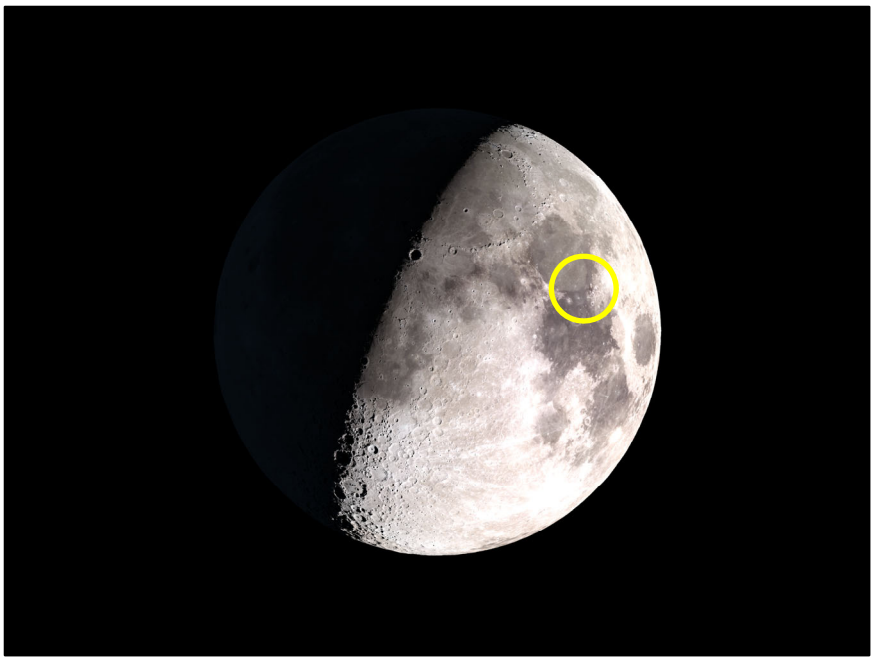


https://www.hq.nasa.gov/alsj/a16/ap16-71-HC-1452HR.jpg

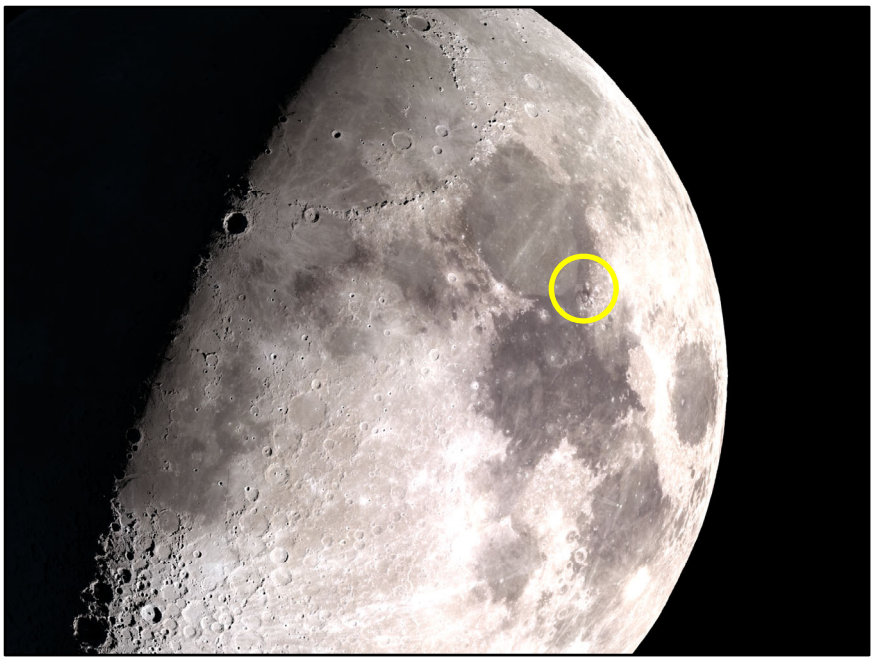

Building 18-24
https://www.kentwa.gov/home/showpublisheddocument/14146/637178776659230000

**¡DISCLAIMER OF SORTS!**

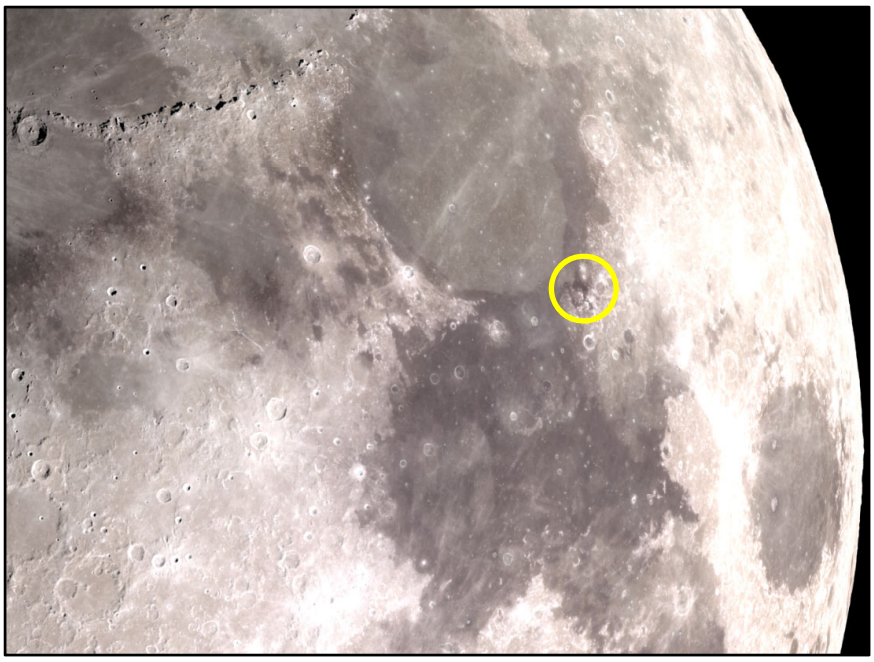
Not a Boeing presentation



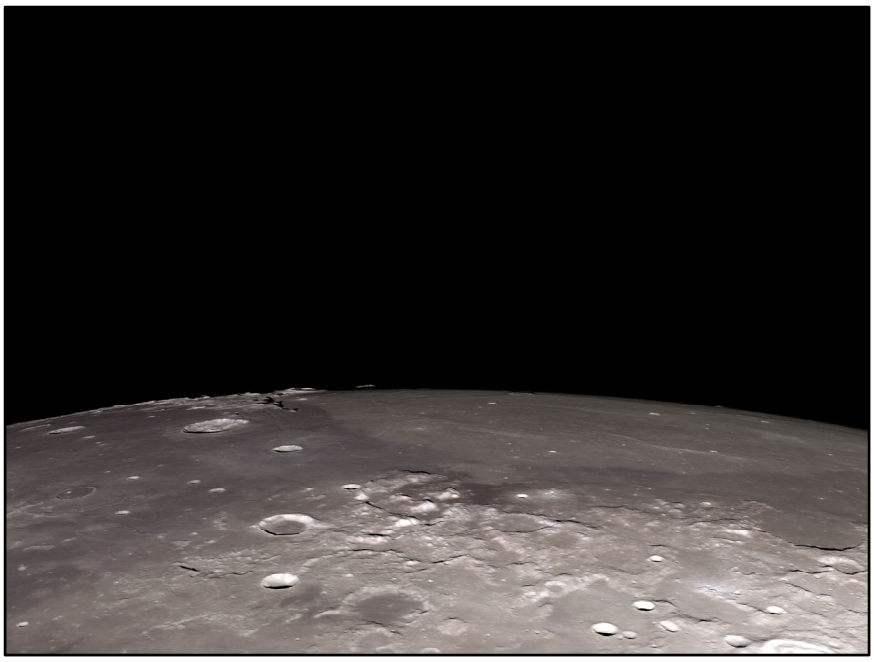
https://svs.gsfc.nasa.gov/4302
Mare Serenitatis and Mare Tranquillitatis



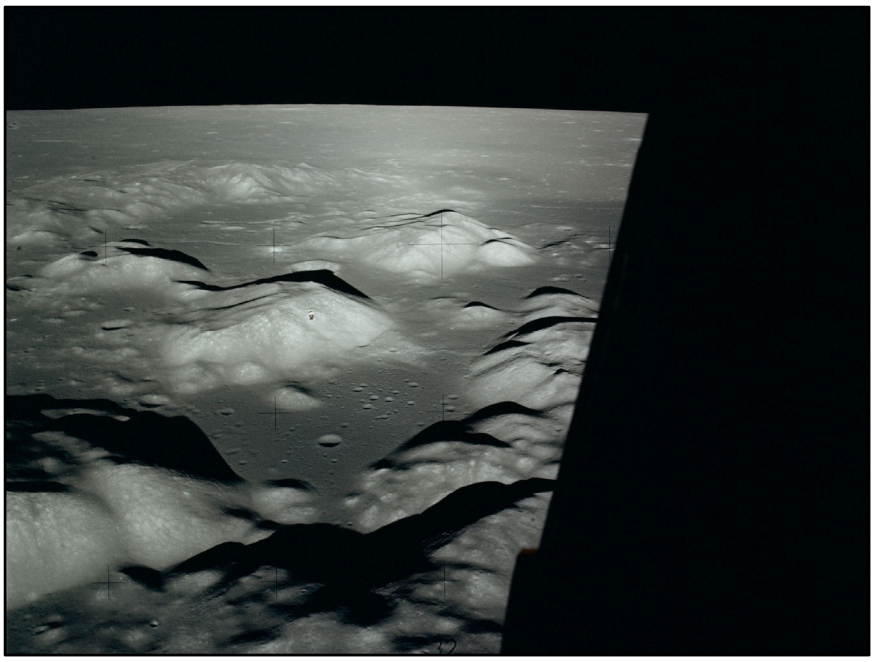
https://svs.gsfc.nasa.gov/4302
Montes Taurus



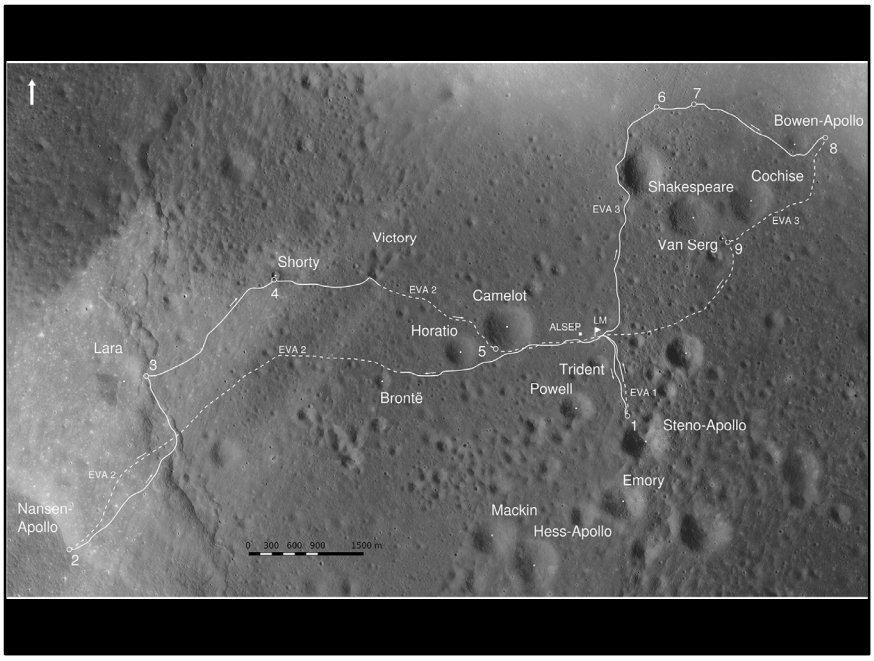
https://svs.gsfc.nasa.gov/4302
Littrow Crater



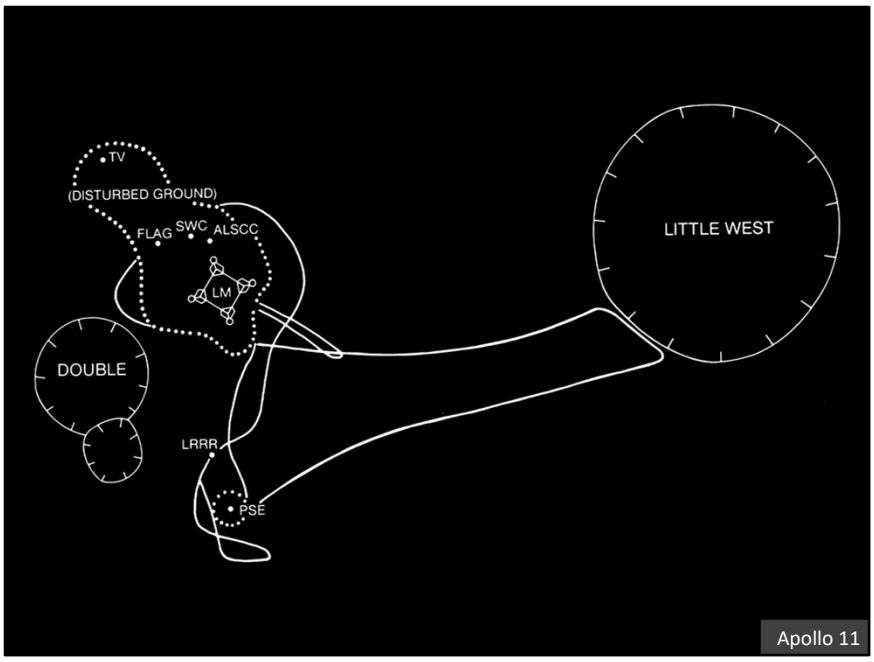
https://svs.gsfc.nasa.gov/4302
Plinius, Dawes, Vitruvius



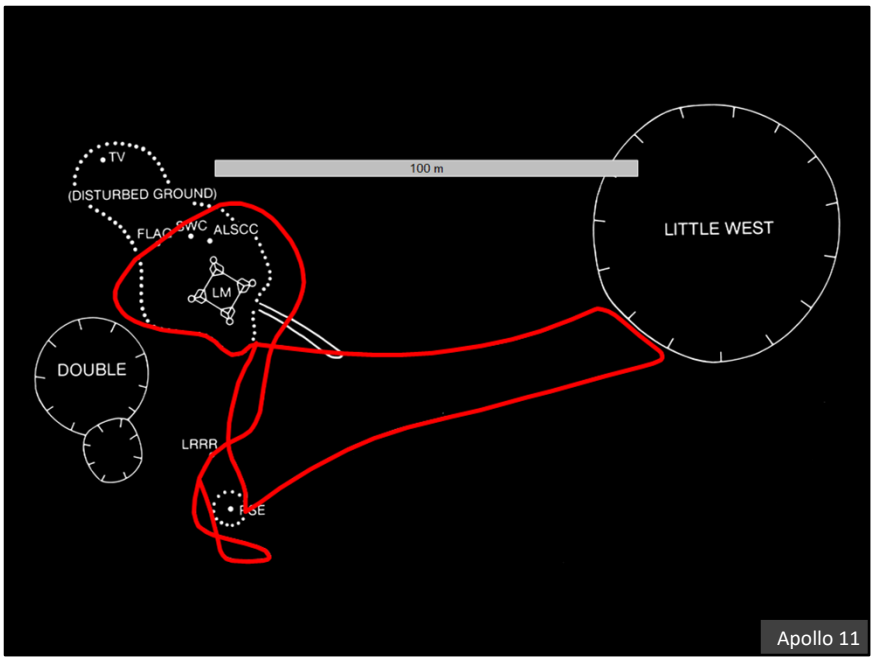
https://www.hq.nasa.gov/alsj/a17/AS17-147-22466HR.jpg

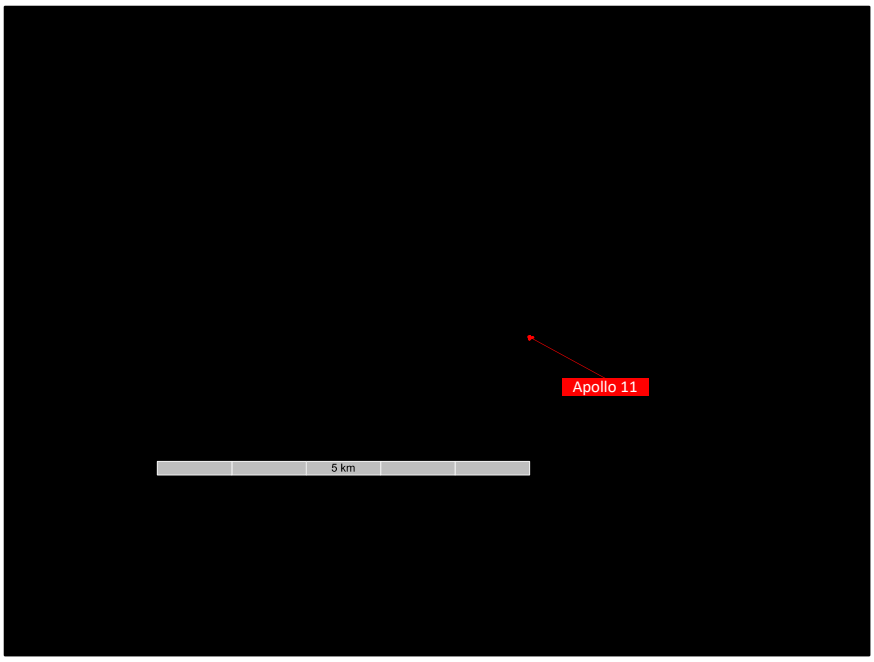



https://doi.org/10.1029/2018EA000408
Haase, Isabel, et al. "Coordinates and maps of the Apollo 17 landing site." *Earth and Space Science* 6.1 (2019): 59-95.

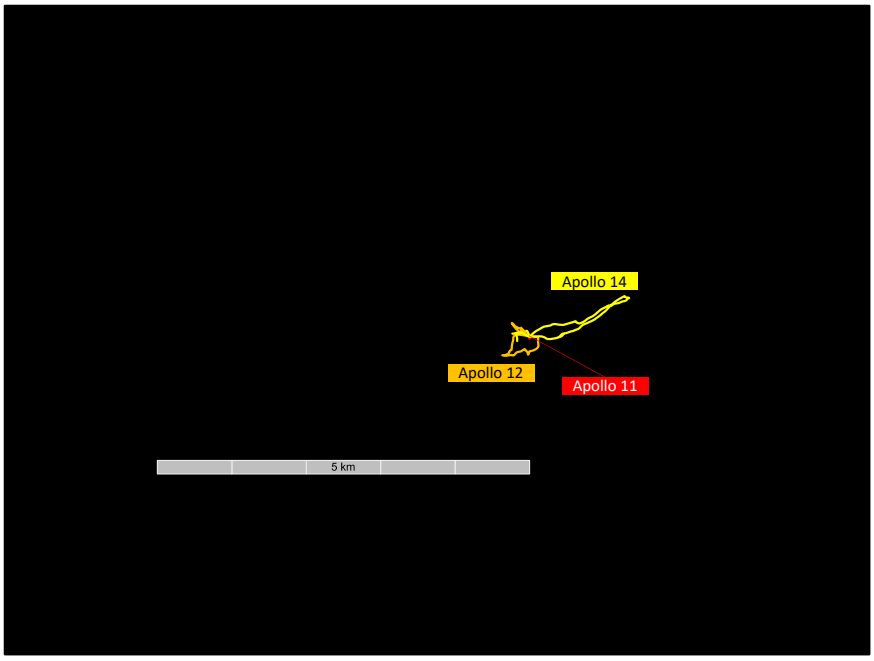


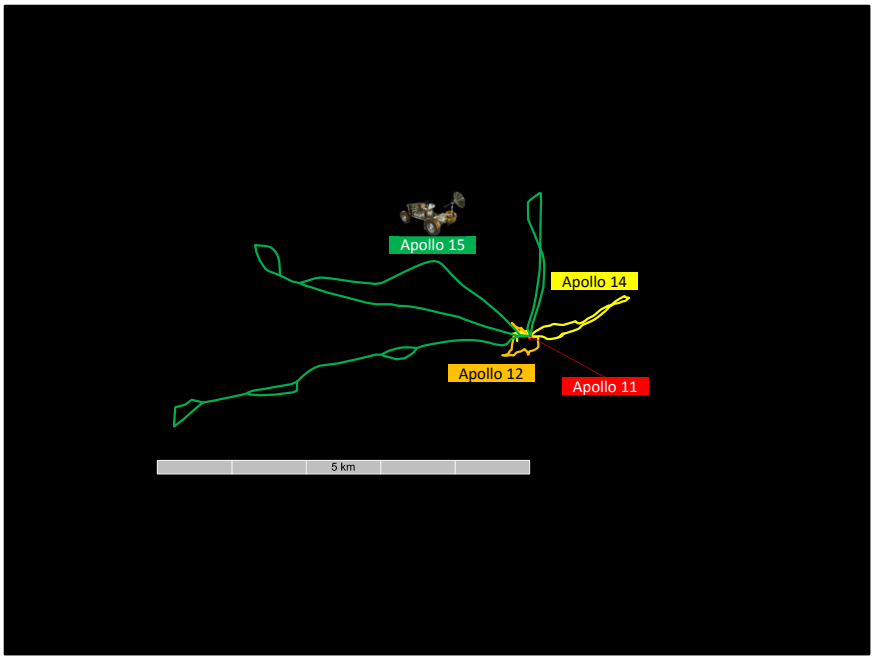

https://www.lpi.usra.edu/publications/slidesets/apollolanding/ApolloLanding/apollolanding_index.shtml

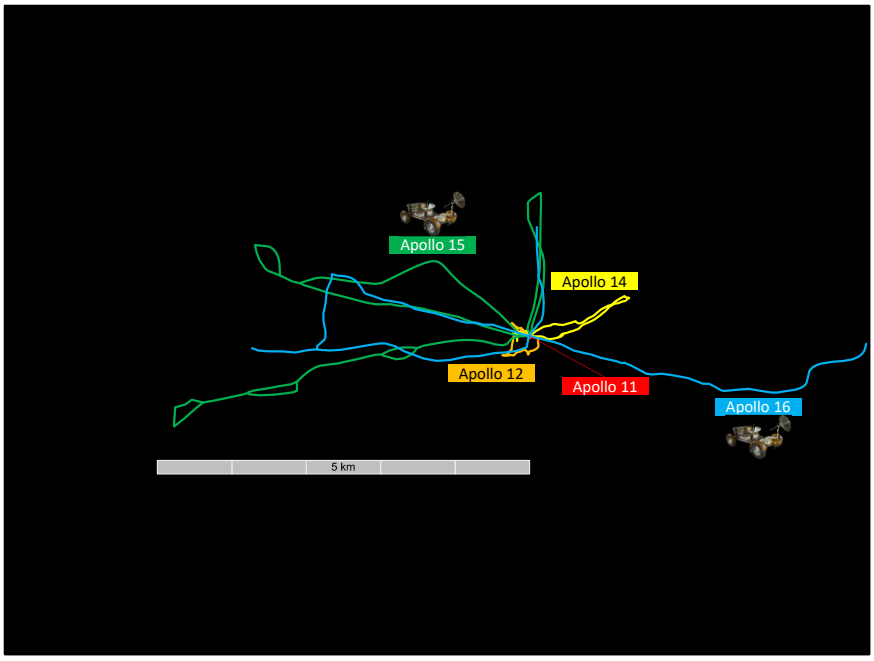

TV
(DISTURBED GROUND)
100 m
FLAG
SWC
ALSCC
LM
LITTLE WEST
DOUBLE
LRRR
FSE
Apollo 11


Apollo 11
5 km

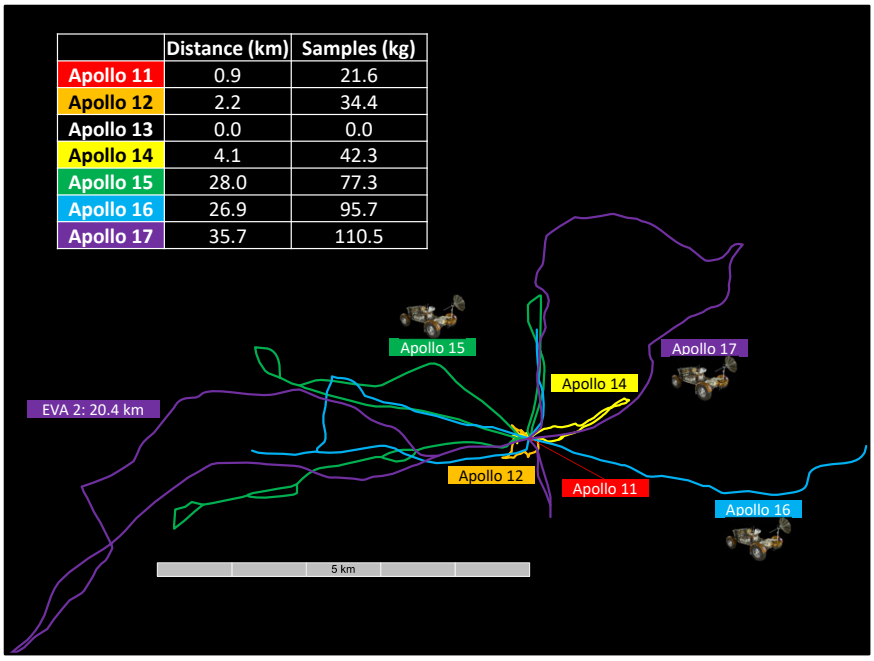

Apollo 12
Apollo 11
5 km


Apollo 14
Apollo 12
Apollo 11
5 km


Apollo 15
Apollo 14
Apollo 12
Apollo 11
5 km


Apollo 15
Apollo 14
Apollo 12
Apollo 11
Apollo 16
5 km


Apollo 15
Apollo 17
Apollo 14
Apollo 12
Apollo 11
Apollo 16
5 km

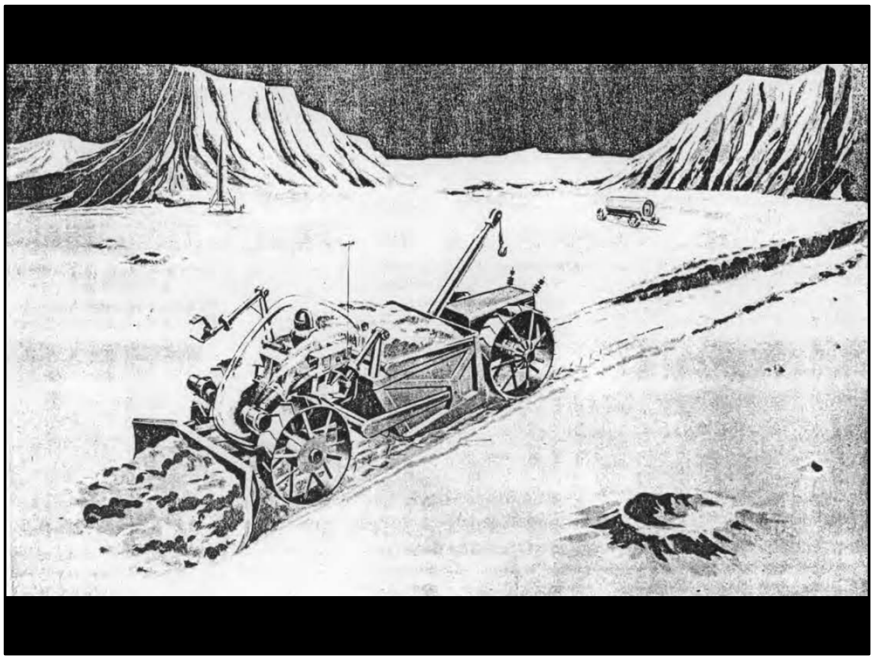



NASA SP-2000-4029
Apollo by the Numbers: A Statistical Reference

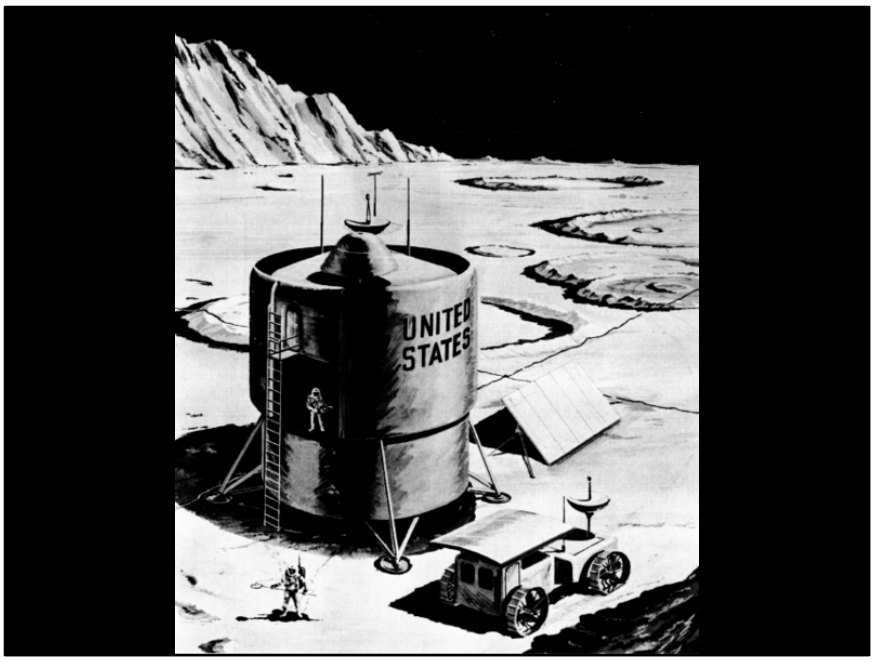
Act II

Act II

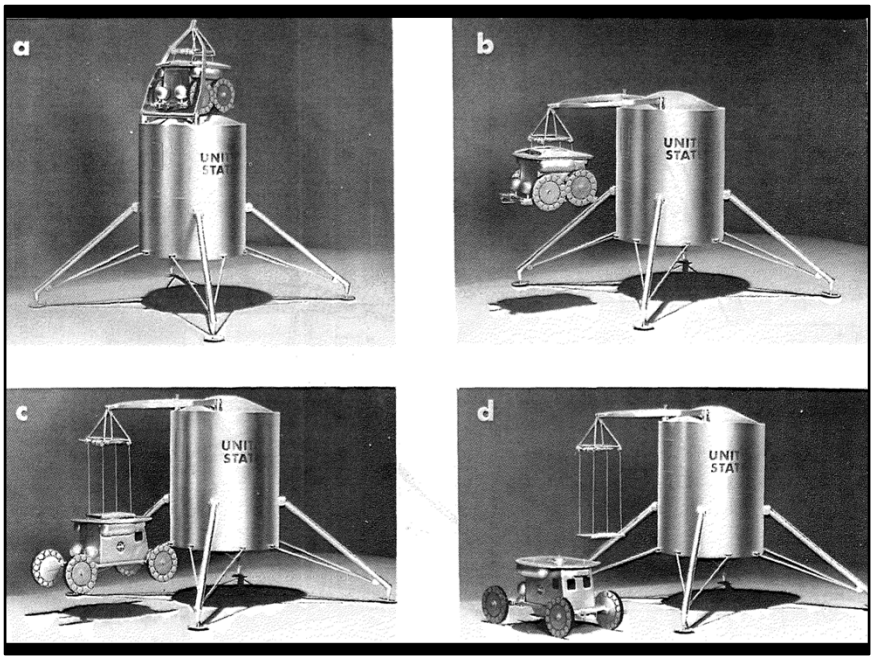
# Competitors and precursors



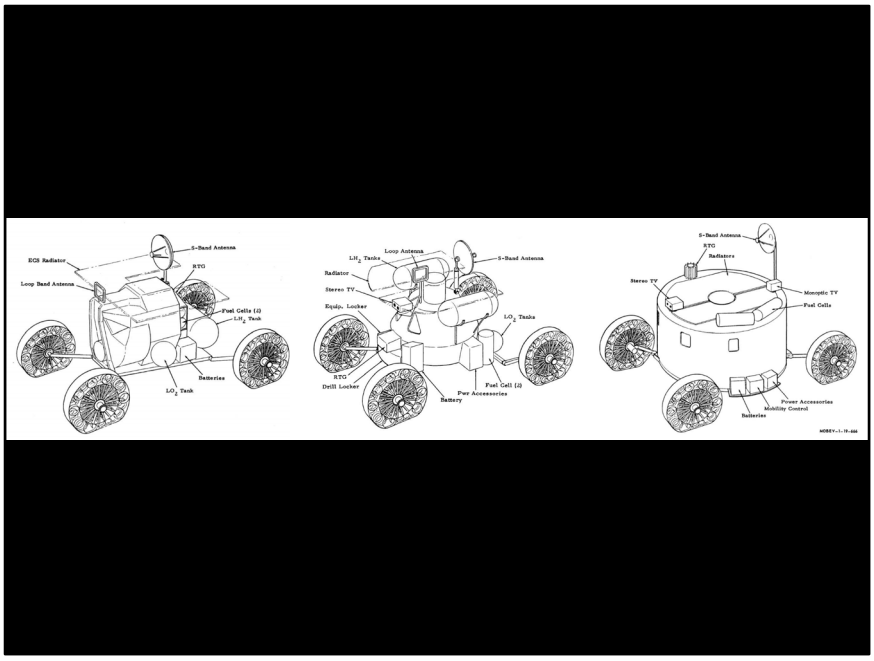
https://nsarchive2.gwu.edu/NSAEBB/NSAEBB479/
https://nsarchive2.gwu.edu/NSAEBB/NSAEBB479/docs/EBB-Moon01A_sm.pdf
https://www.smithsonianmag.com/air-space-magazine/forgotten-plans-reach-moon-apollo-180972695/



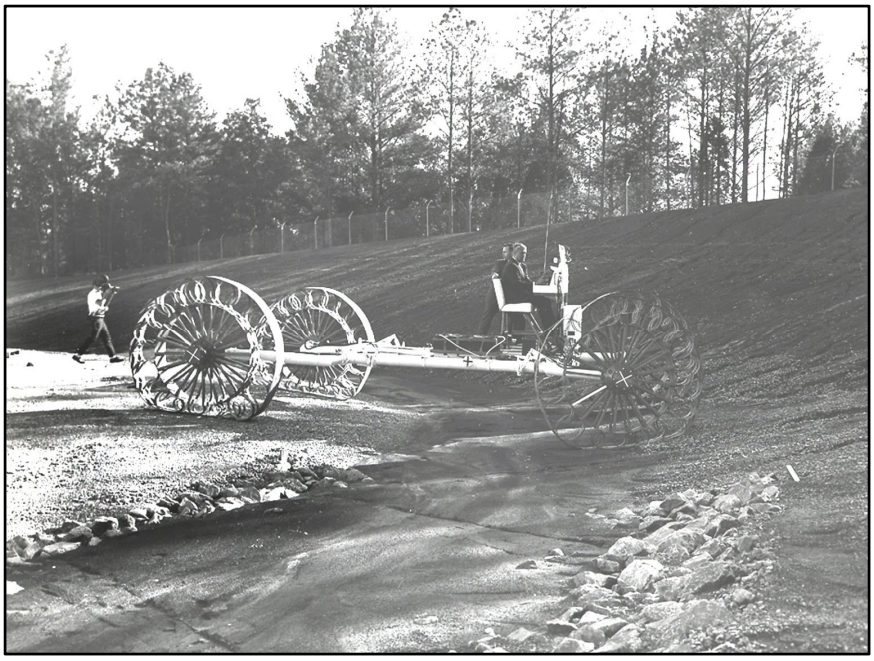

Boeing, Lunar Exploration Systems for Apollo



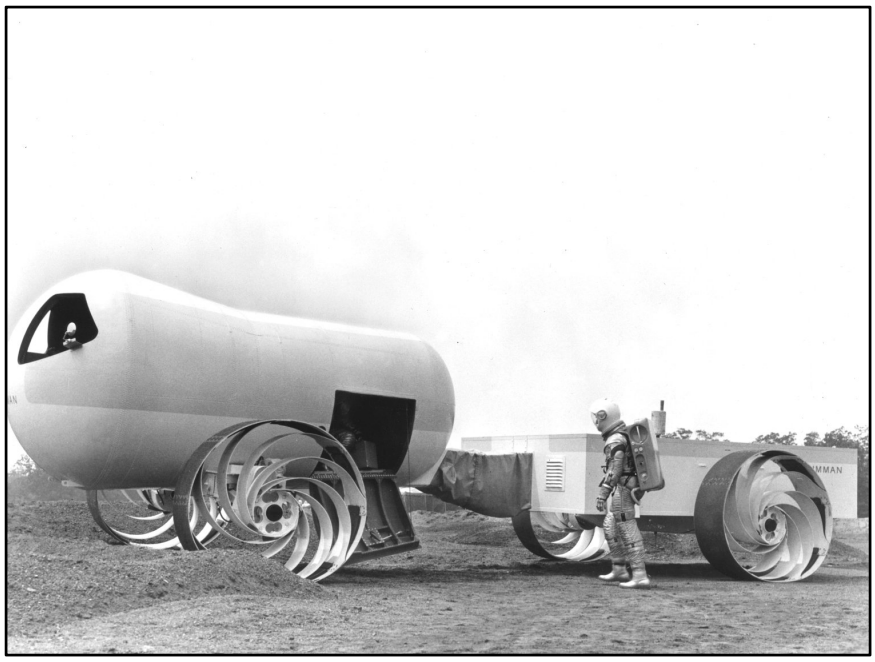

Lockheed, Lunar Exploration Systems for Apollo
https://www.lpi.usra.edu/lunar/documents/LMSC-665606.pdf




Bendix
Lunar surface mobility systems comparison and evolution study /MOBEV/ Final report
https://ntrs.nasa.gov/citations/19680006032

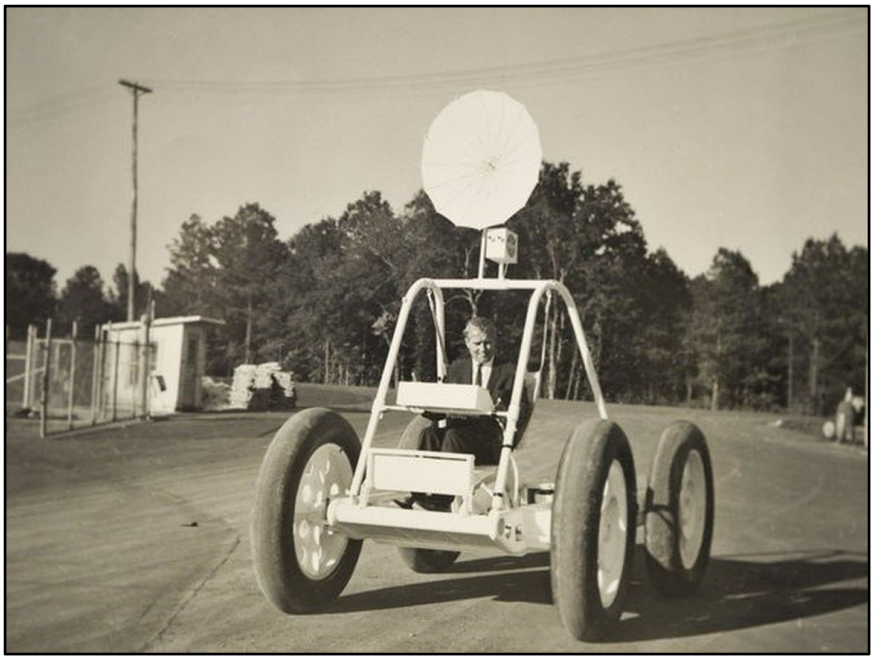


Bendix
https://archive.org/details/MSFC-6640863

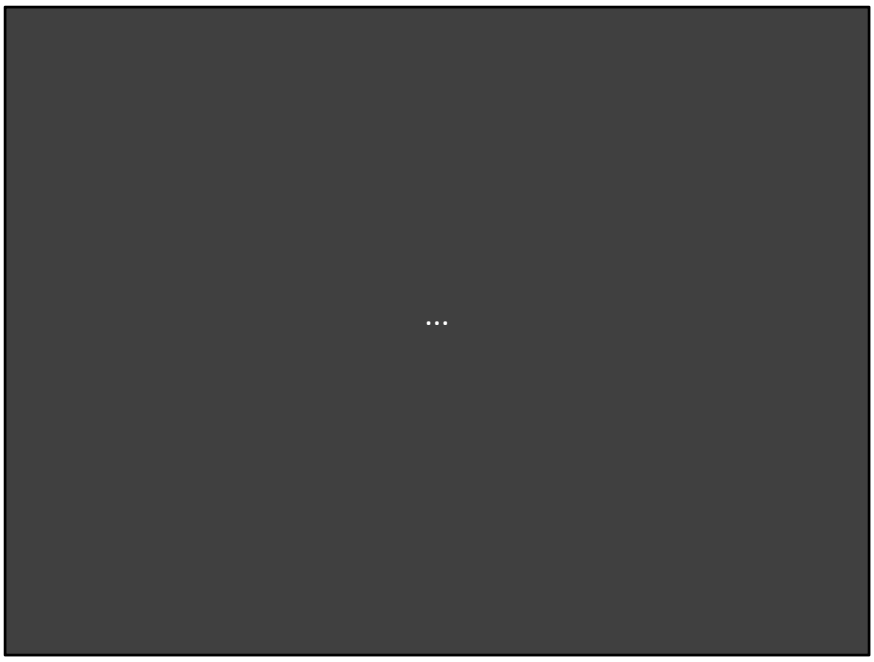


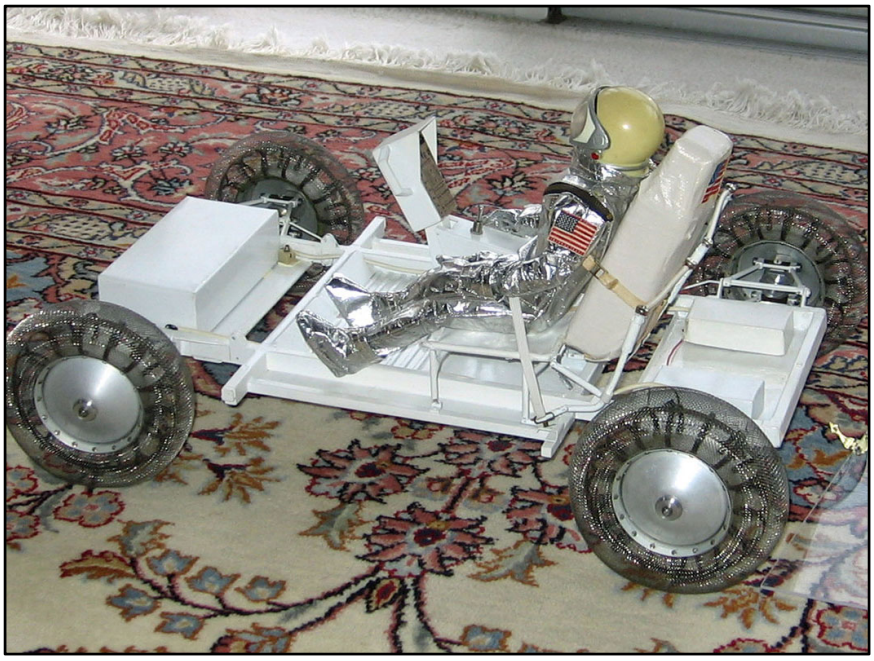
Lunar Logistics System, Grumman (Project 344)
https://archive.org/details/MSFC-0401768


https://www.hemmings.com/stories/article/a-corvair-the-moon-and-mars

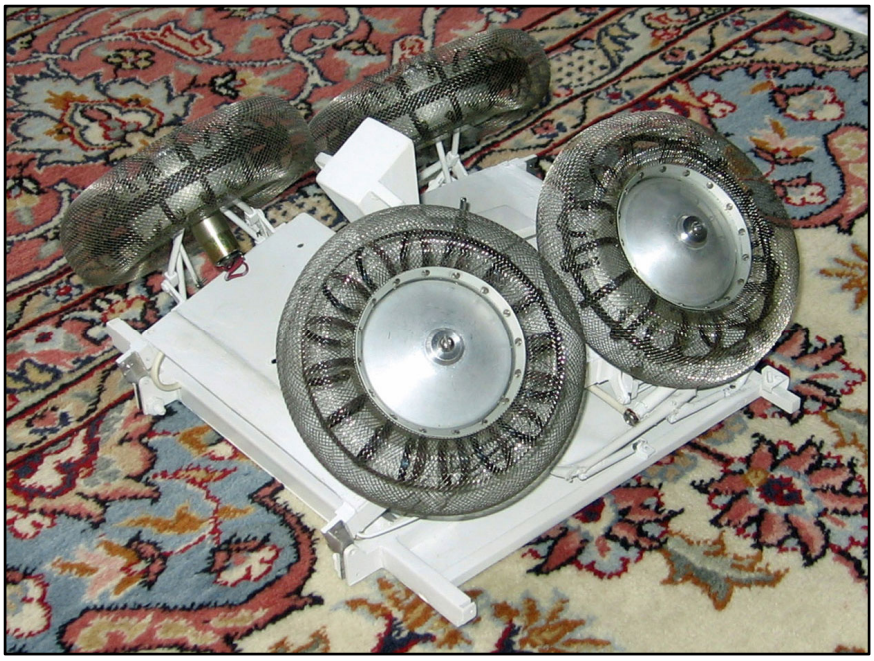


https://www.al.com/news/huntsville/2015/10/a_member_of_werner_brauns_rock.html

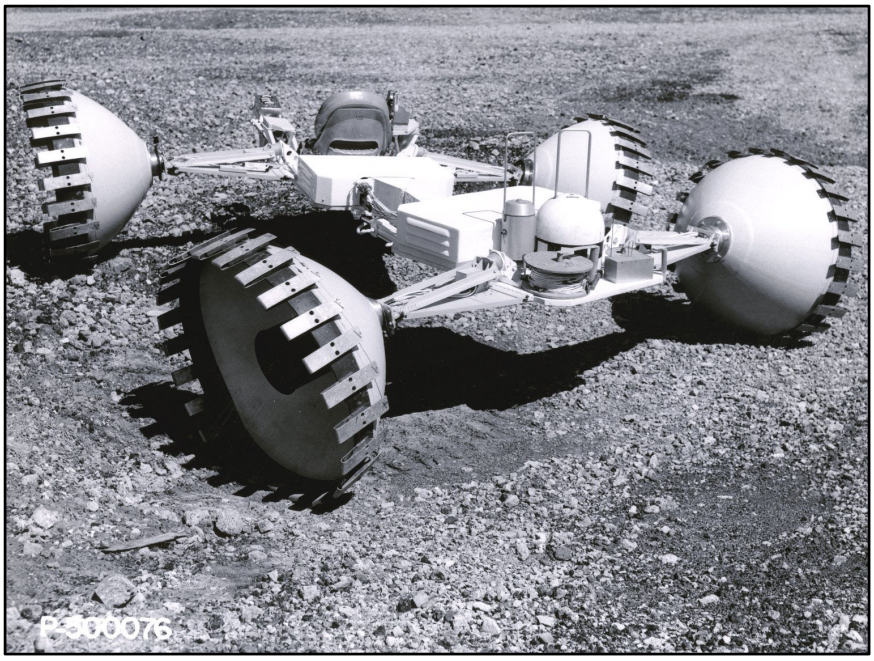




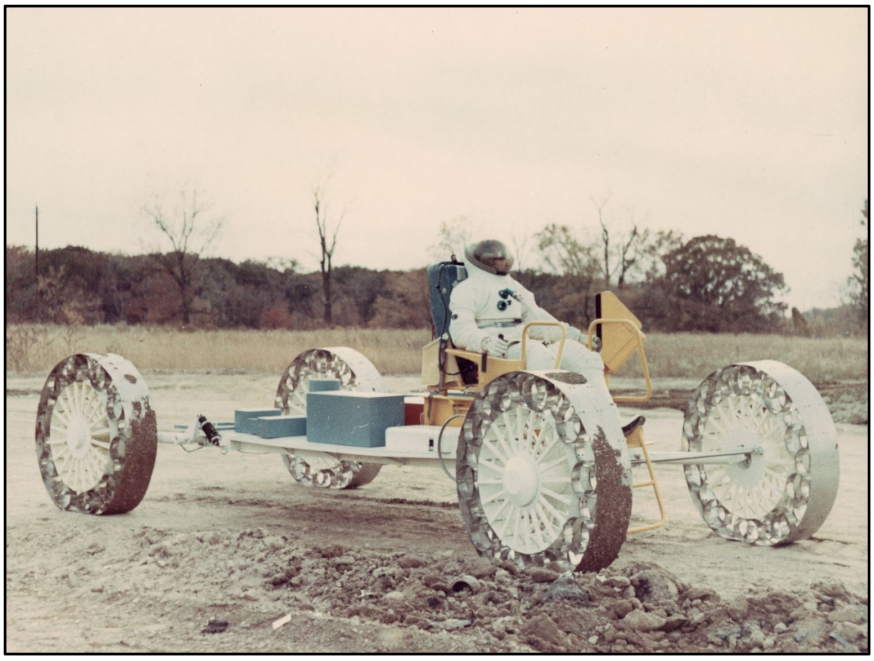
https://www.rocketstem.org/2015/07/06/construction-of-the-lunar-rover-changed-exploration-of-the-moon/



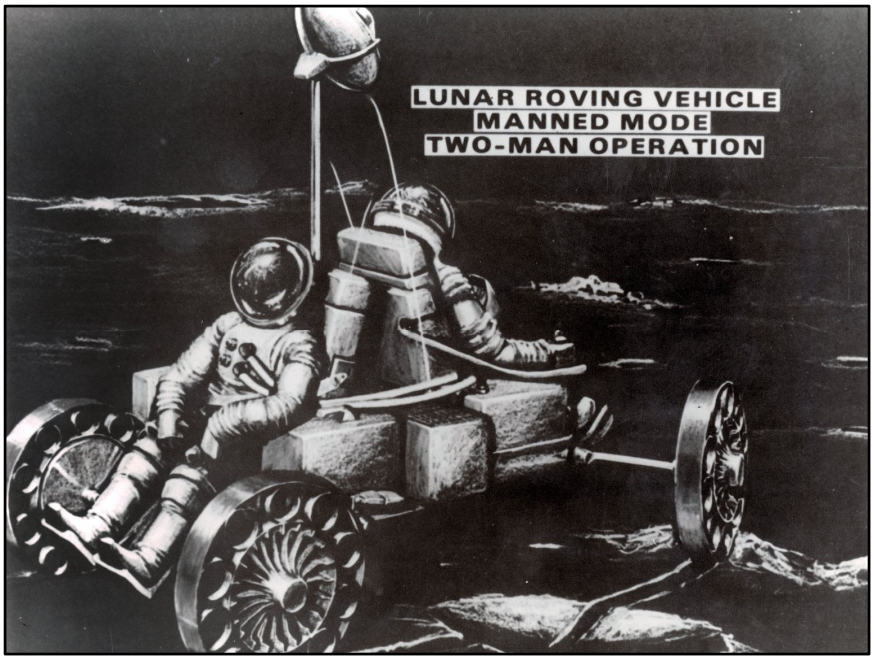
https://www.rocketstem.org/2015/07/06/construction-of-the-lunar-rover-changed-exploration-of-the-moon/



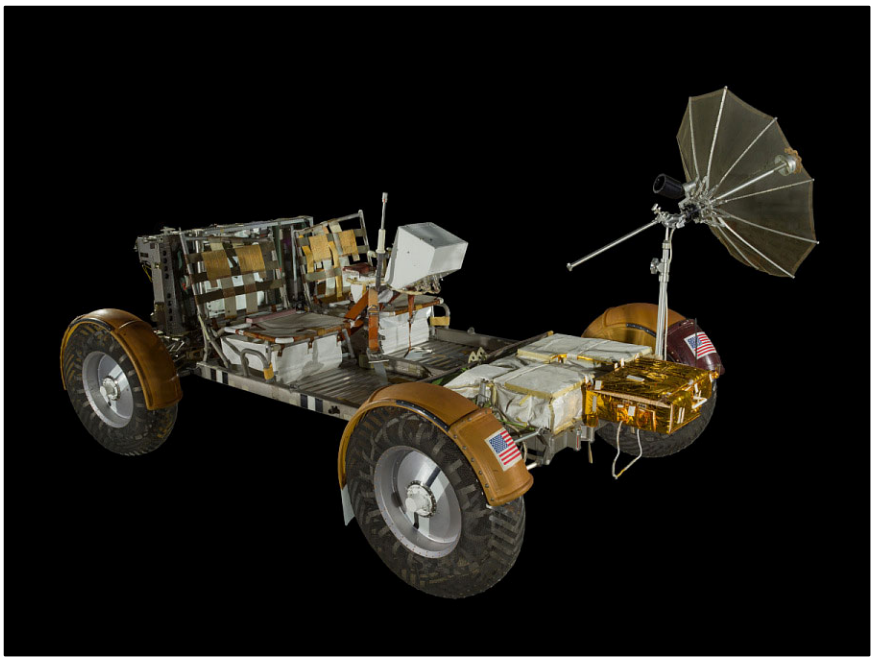

Grumman
https://archive.org/details/MSFC-0401754



Bendix
https://archive.org/details/MSFC-0401758




Chrysler
https://archive.org/details/MSFC-0401761



https://airandspace.si.edu/collection-objects/lunar-roving-vehicle-qualification-test-unit/nasm_A19760746000

Congratulations on winning the contract.

You have 17 months to deliver LRV-1 for Apollo 15.

You bid $19M cost-plus.

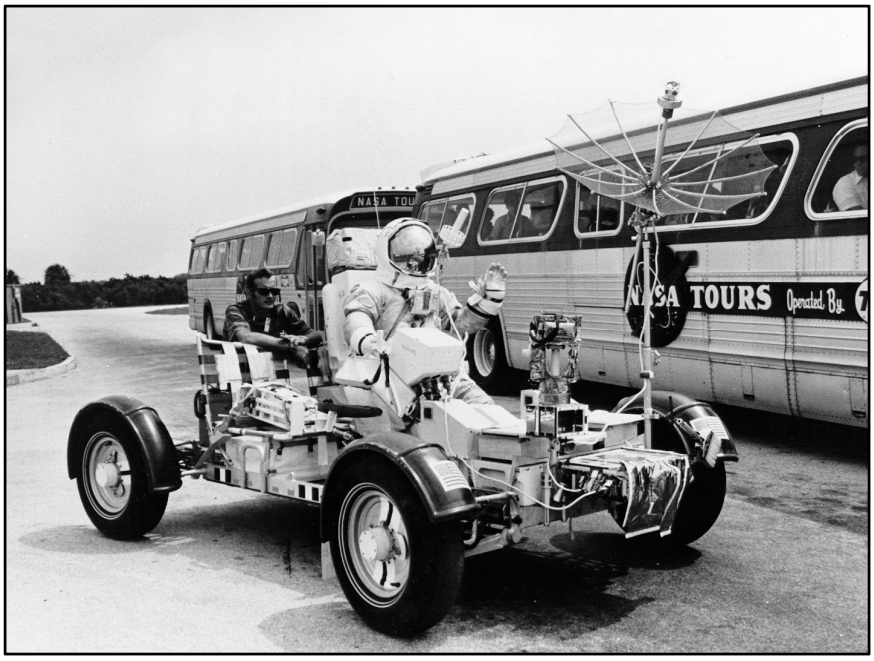
Good luck.


A FEW
MOMENTS LATER

You are behind schedule and over budget.

¯_(ツ)_/¯

1-G Trainer
https://archive.org/details/S71-23843




https://www.hq.nasa.gov/alsj/a17/ap17-72-H-1190HR.jpg

Grover
https://astrogeology.usgs.gov/rpif/photos/grover-photo-collection
https://astrogeology.usgs.gov/rpif/videos/grover

Act III

Act III

# A spacecraft on wheels

## Requirements

**Configuration:** four wheels, batteries, electric motor

**Weight:** max 400 lbm (including stowage)

**Cargo:** 100 lbm experiments + two astronauts (370 lbm each)

**Range:** four 30 km traverses

**Life:** 78 hours

**Stowage:** stowed in one LM bay

**Speed:** max 16 km/hr fully loaded

**Deployment:** by one astronaut

## Requirements

**Obstacles:** 30 cm high, crevasse 70 cm wide at zero velocity

**Slope:** climb and descend 25 deg fully loaded

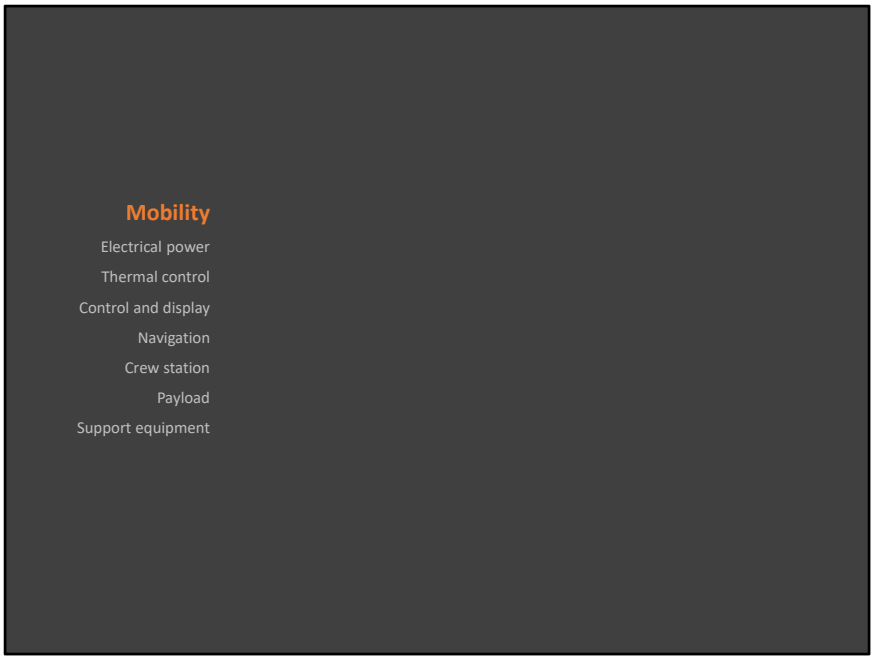
**Failures:** no single-point failure aborts the mission; no second failure endangers crew

**Reverse:** yes

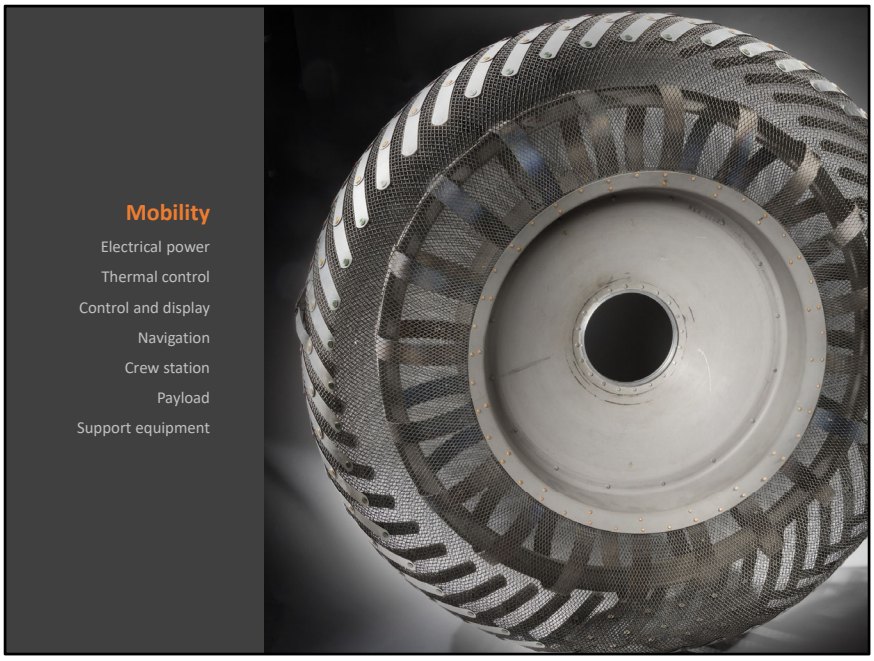
**Clearance:** 35 cm on flat surface

**Static stability:** 45 deg pitch and roll fully loaded

**Turn radius:** one vehicle length



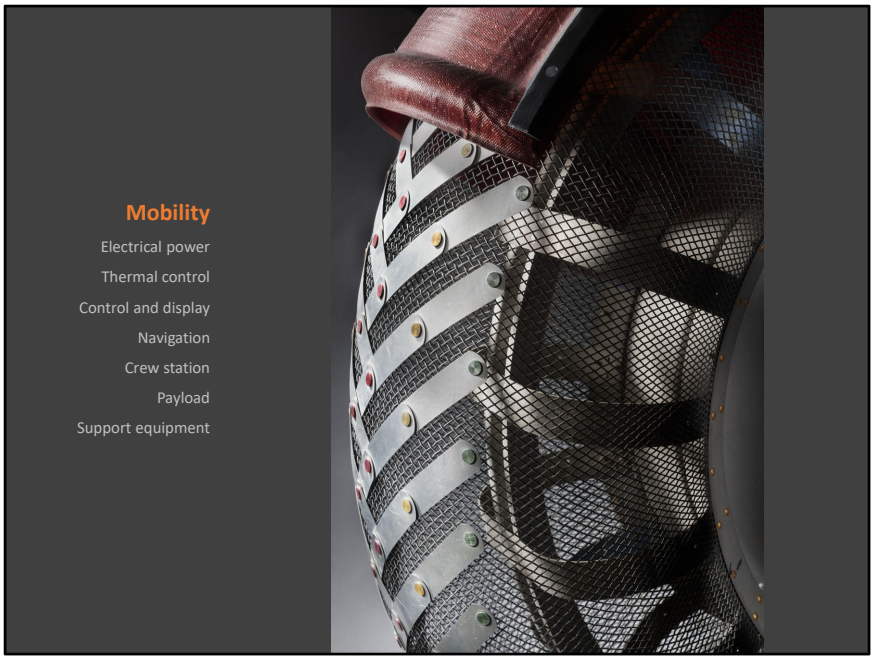

Wheels
Traction drive
Suspension
Steering
Hand controller
Drive control electronics (DCE)
Chassis




https://airandspace.si.edu/collection-objects/wheel-lunar-rover/nasm_A19750830000

Zinc-coated piano wire, 0.84 mm (0.033 in) diameter
81.8 cm (32 in) diameter
22.9 cm (9 in) wide
5.48 kg

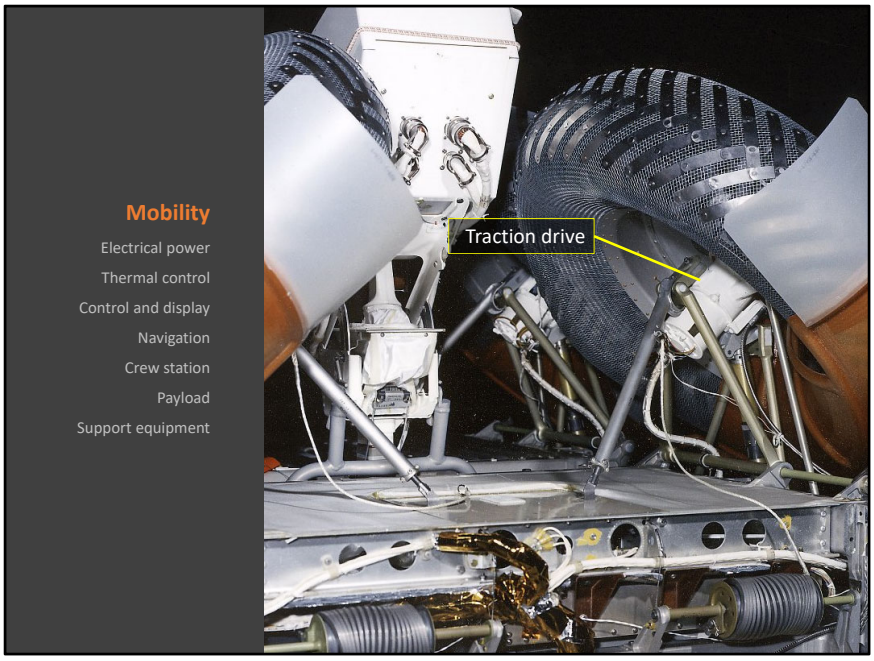
Titanium cleats, 50%
50% via testing, low power number, high pull coefficient



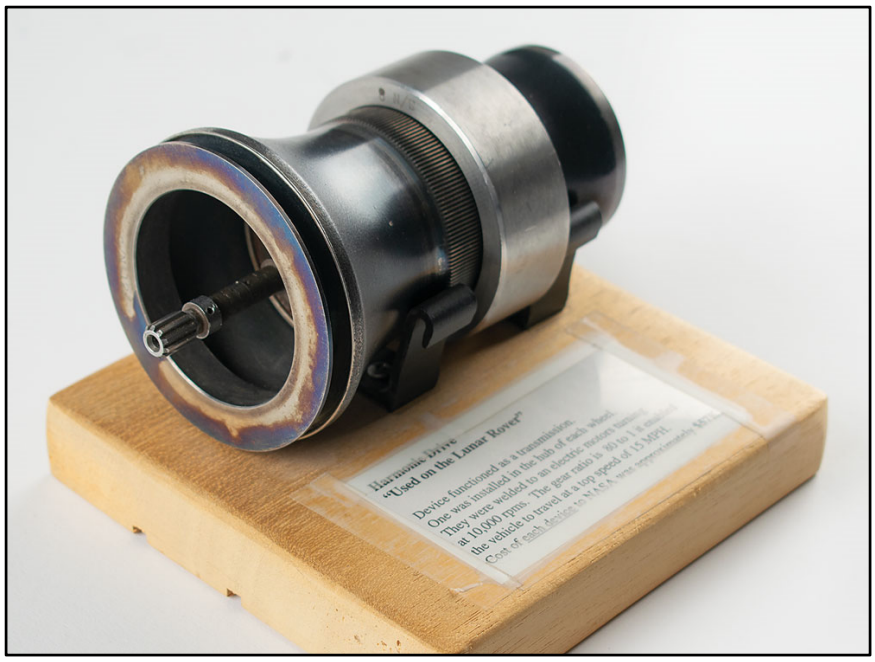

https://airandspace.si.edu/collection-objects/wheel-lunar-rover/nasm_A19750830000

Zinc-coated piano wire, 0.84 mm (0.033 in) diameter
81.8 cm (32 in) diameter
22.9 cm (9 in) wide
5.48 kg

Titanium cleats, 50%
50% via testing, low power number, high pull coefficient

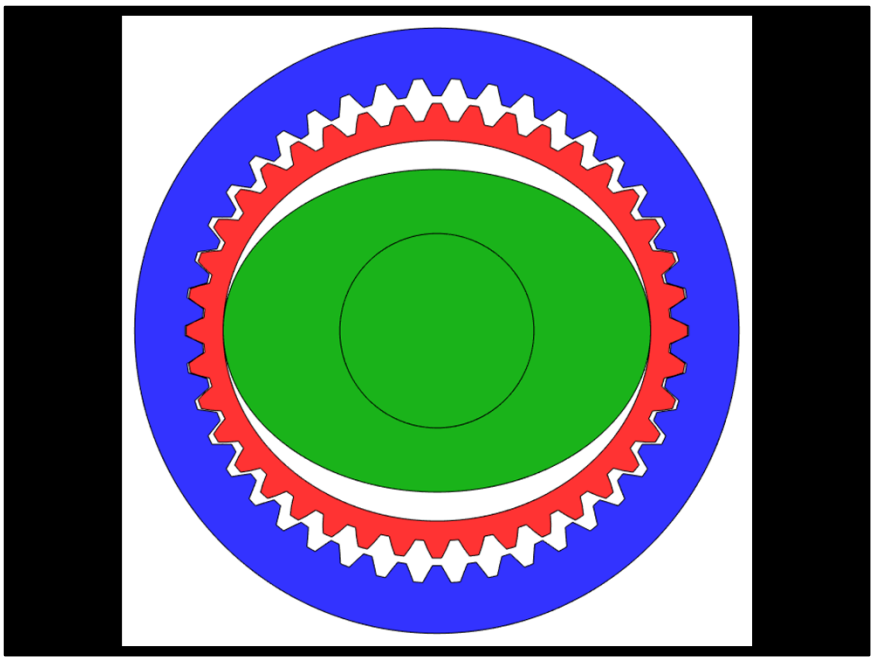



190W (0.25 hp)
10,000 rpm
Brushed DC
Two pins attaching motor to wheel




https://www.rrauction.com/auctions/lot-detail/343028305882201--lunar-rover-harmonic-drive-unit/?cat=0
https://www.bostonglobe.com/business/2019/01/13/this-company-gears-went-moon-and-they-still-going-places/VUlxXuKbIpcb68NDxFeD3O/story.html

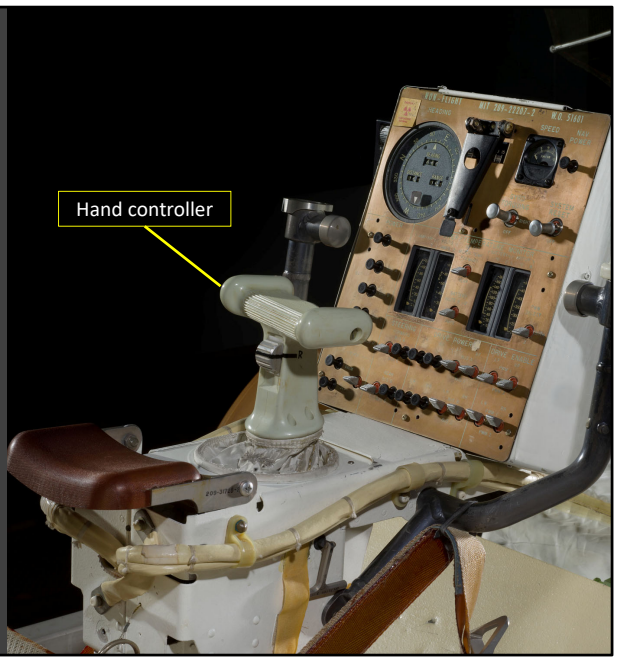

https://www.rrauction.com/auctions/lot-detail/343028305882201--lunar-rover-harmonic-drive-unit/?cat=0



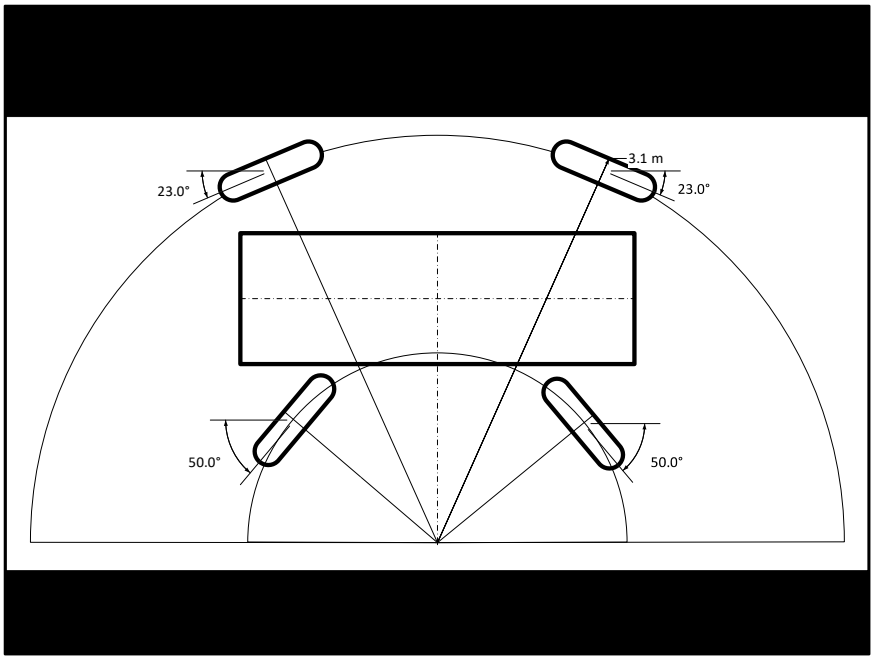
https://en.wikipedia.org/wiki/Strain_wave_gearing
Example: 42:40 (20:1)
LRV: 160:158 (80:1)

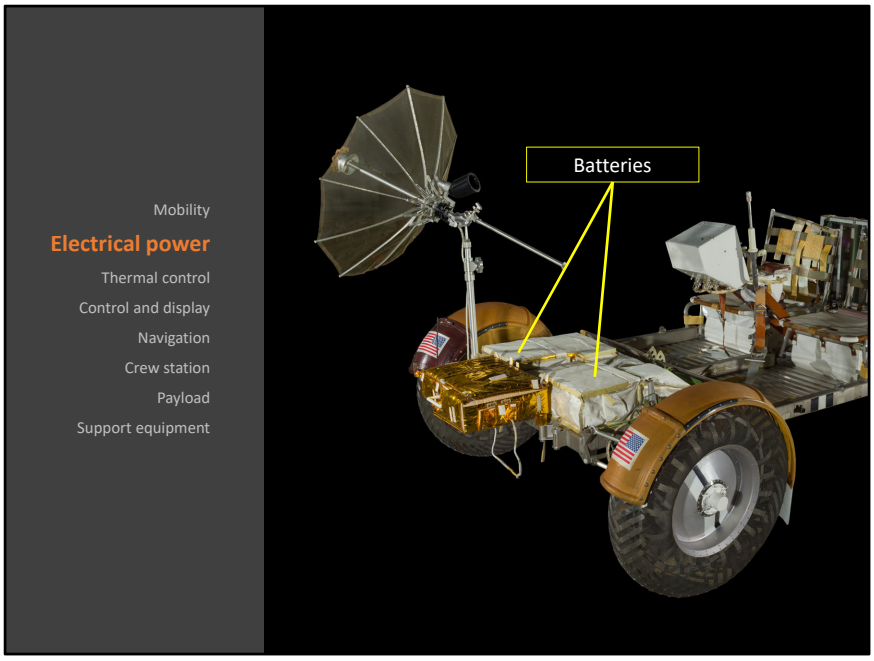
**Mobility**

Electrical power
Thermal control
Control and display
Navigation
Crew station
Payload
Support equipment



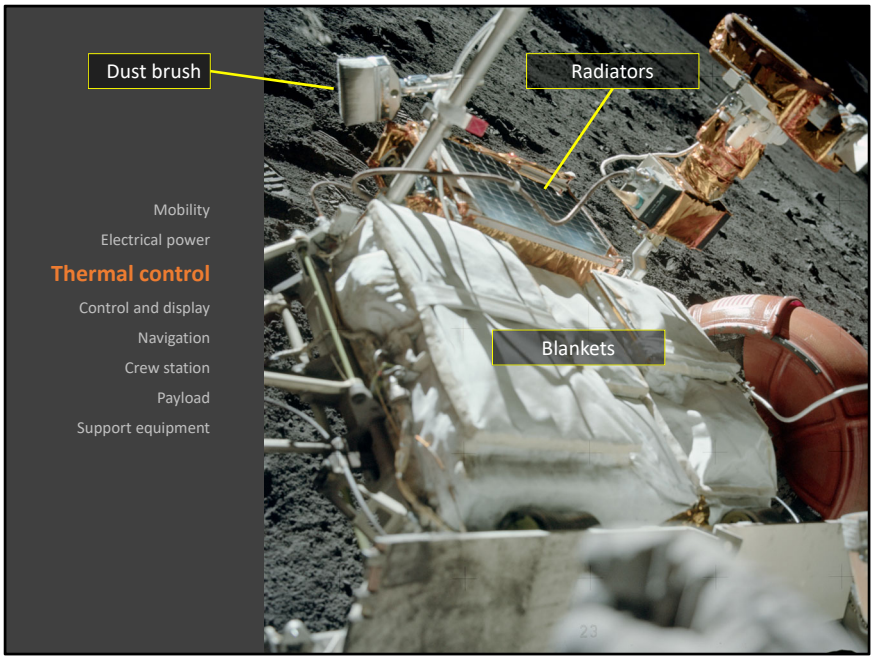

https://airandspace.si.edu/collection-objects/lunar-roving-vehicle-qualification-test-unit/nasm_A19760746000
https://www.smithsonianmag.com/air-space-magazine/the-spacecraft-on-wheels-180963200/
Promethium-147


3.1 m
23.0°
23.0°
50.0°
50.0°



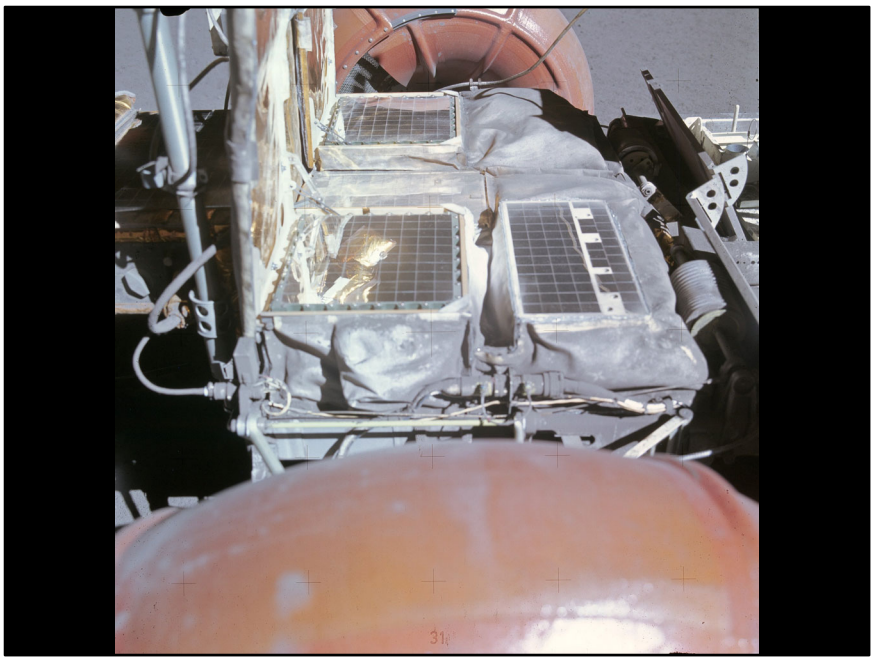

Batteries
Distribution and monitoring system
Caution and warning system

Silver-zinc plates in potassium hydroxide electrolyte
23 cells
115 amp-hours
Installed in LRV on launch pad ~2 days before launch
Temp/voltage monitored until T-18 hours



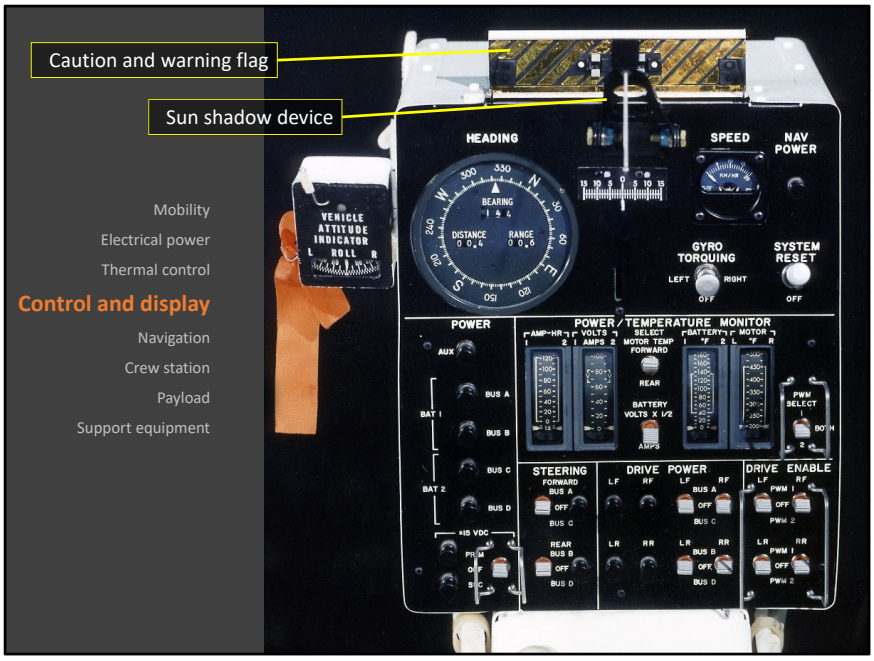

Temp (A17): 111degC to -71degC
Atmosphere:

Heat sinks
Radiators
Insulation blankets
Surface coatings



https://www.hq.nasa.gov/alsj/a15/AS15-88-11891HR.jpg

https://www.hq.nasa.gov/alsj/a17/a17.sta2.html#1424834

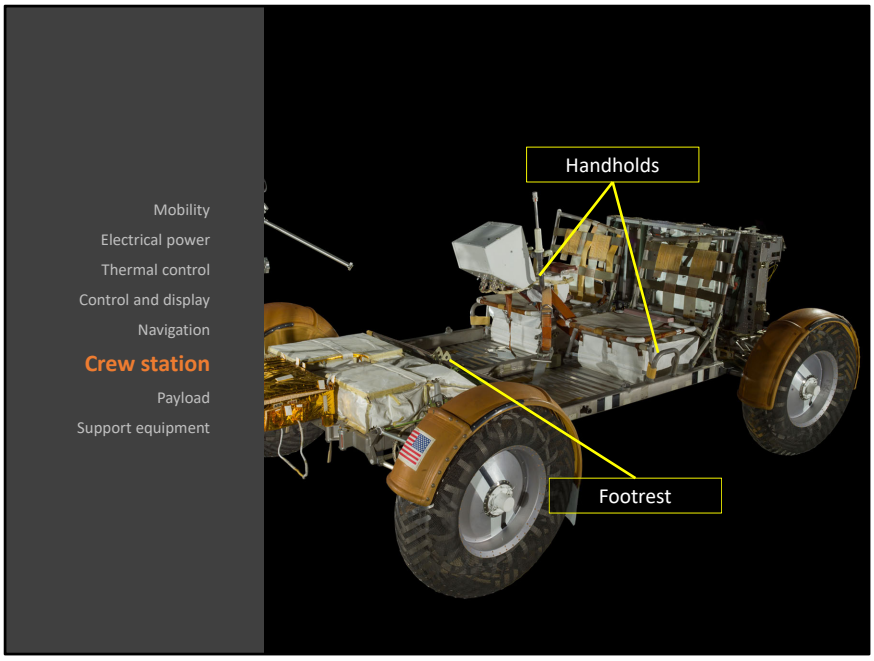



Integrated position indicator (IPI): heading, bearing, range, distance
Speed indicator
Attitude indicator: pitch, roll
Sun shadow device

https://archive.org/details/MSFC-7021041


Signal processing unit (SPU)
Directional gyro unit (DGU)

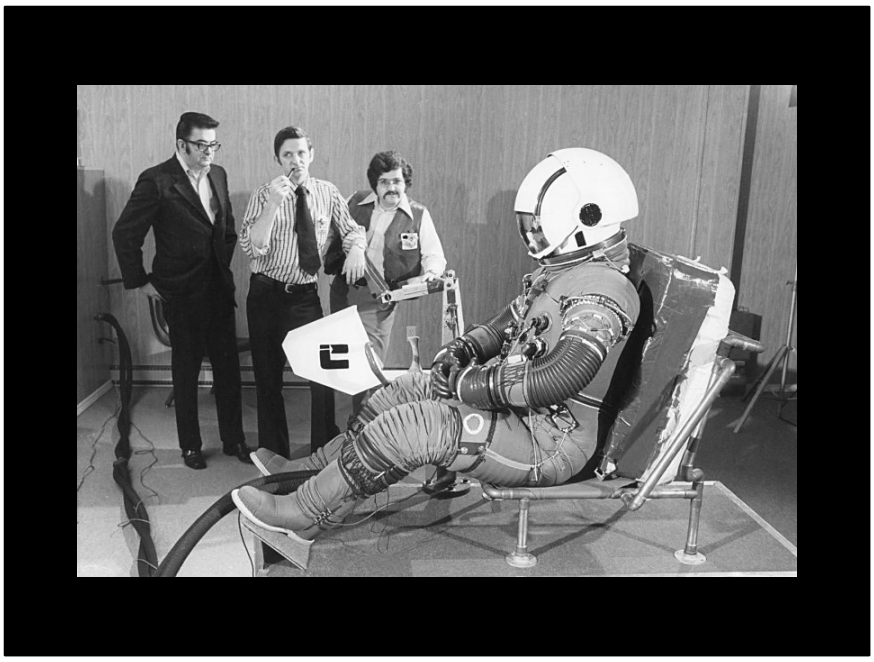
http://www.glenswanson.space/uploads/1/2/5/7/125738648/on_course_to_tomorrow.pdf




Surface Gravity: 1.62 m/s2

Seats and seatbelts
Footrests
Inboard and outboard handholds
Armrest
Floor panels
Fenders
Toeholds

https://www.hq.nasa.gov/alsj/a17/ap17-KSC-72PC-415BW.jpg



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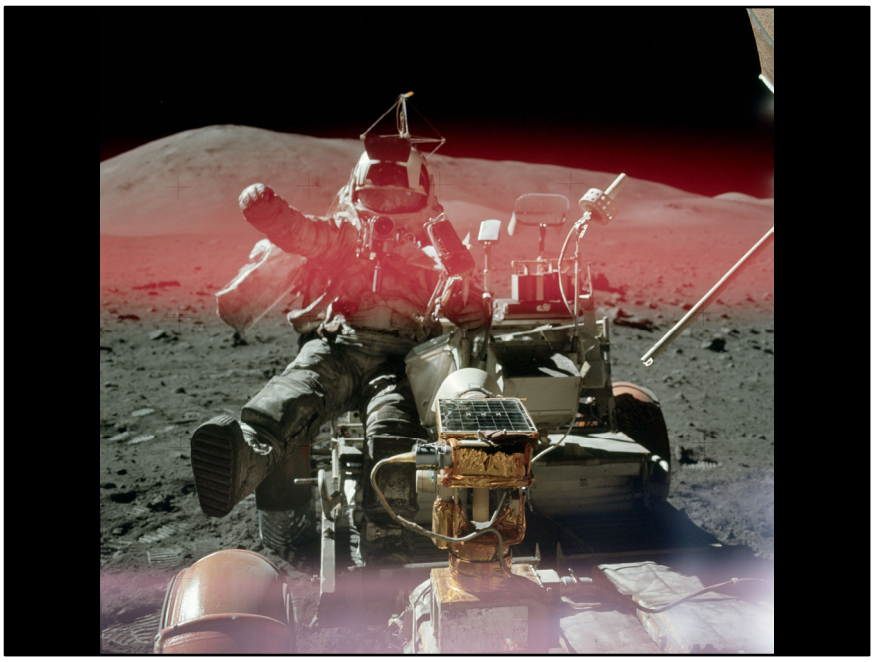
https://www.hq.nasa.gov/alsj/a17/ap17-KSC-72P-363.jpg



https://www.hq.nasa.gov/alsj/a17/AS17-134-20452HR.jpg

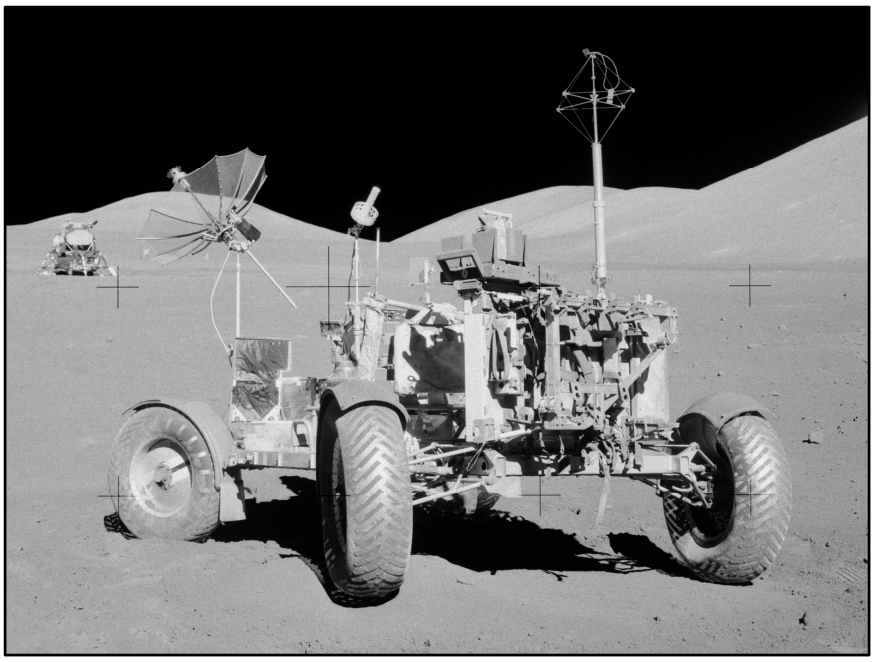

https://youtu.be/Bnku-Ed_38k?t=447

Intermission

Intermission

# Rover repair

https://airandspace.si.edu/collection-objects/extension-fender-lunar-roving-vehicle-apollo17/nasm_A19760009000



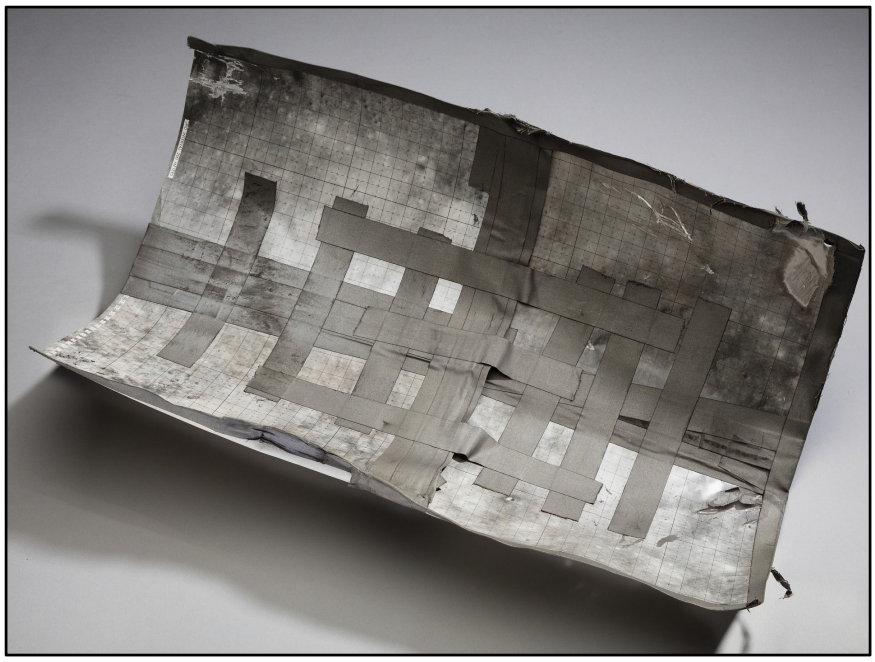
https://www.hq.nasa.gov/alsj/a17/AS17-143-21933HR.jpg

https://www.hq.nasa.gov/alsj/a17/ap17-S72-55170HR.jpg

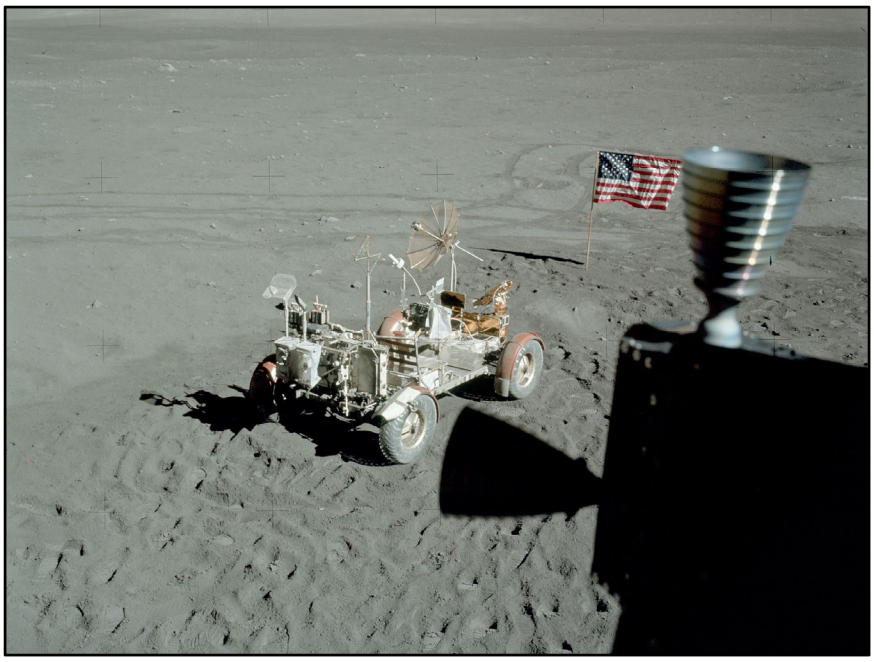
https://www.hq.nasa.gov/alsj/a17/a17.outcam.html#1411056

https://www.hq.nasa.gov/alsj/a17/AS17-137-20979HR.jpg

https://airandspace.si.edu/collection-objects/maps-fender-extension-lunar-roving-vehicle-apollo-17/nasm_A19760010000



https://airandspace.si.edu/collection-objects/maps-fender-extension-lunar-roving-vehicle-apollo-17/nasm_A19760010000



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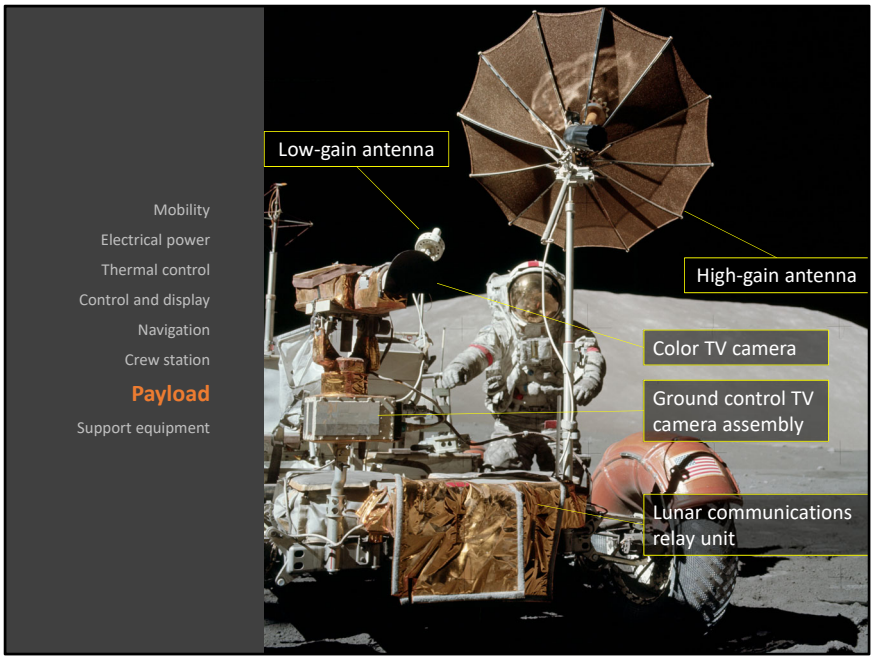
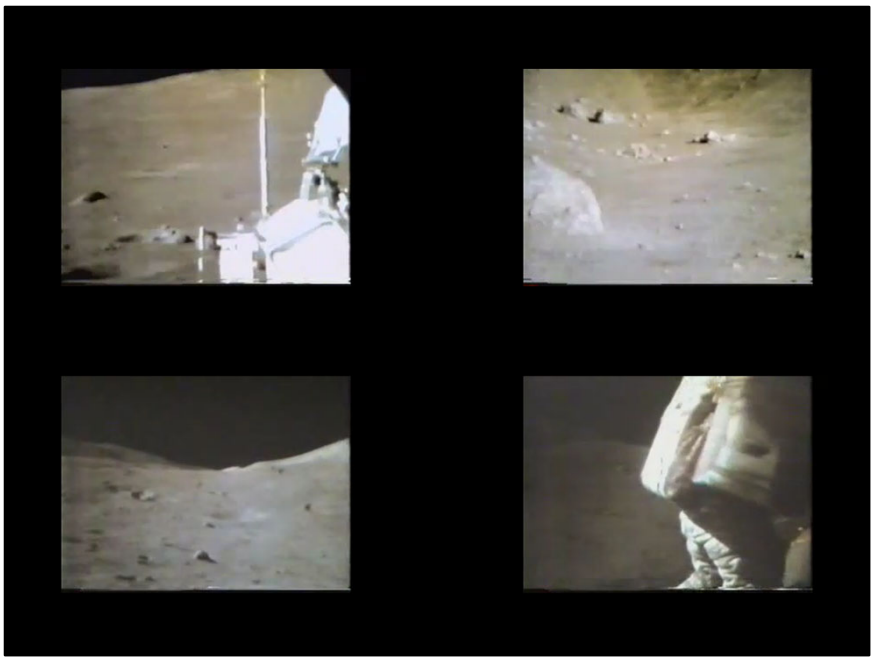
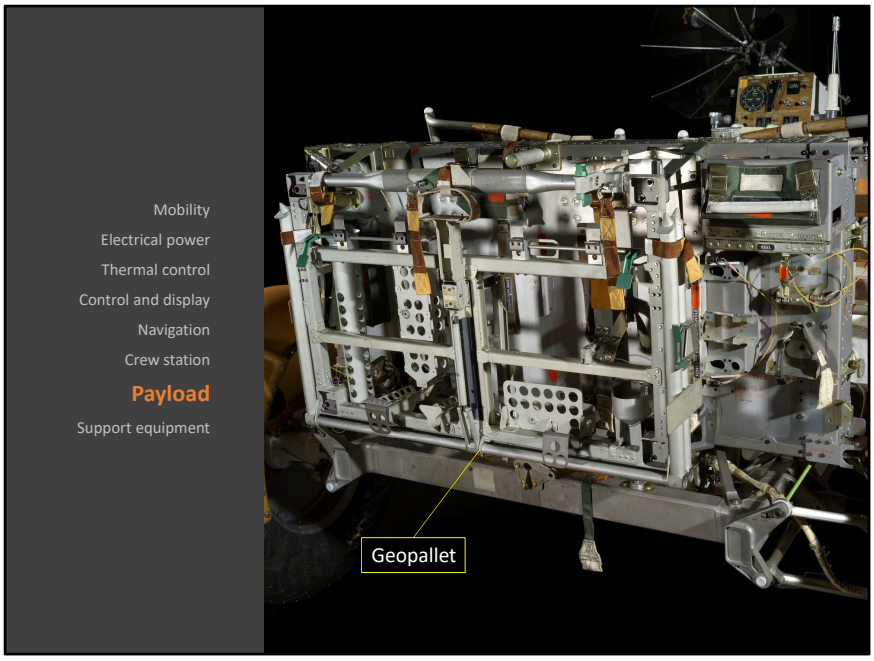



Lunar Communications Relay Unit (LCRU)
Ground Control TV Camera Assembly (GCTA)
High-gain antenna
Low-gain antenna
Under-seat stowage
Pallet



https://www.hq.nasa.gov/alsj/a17/video17.html
https://content.time.com/time/subscriber/article/0,33009,903039,00.html




Lunar Communications Relay Unit (LCRU)
Ground Control TV Camera Assembly (GCTA)
High-gain antenna
Low-gain antenna
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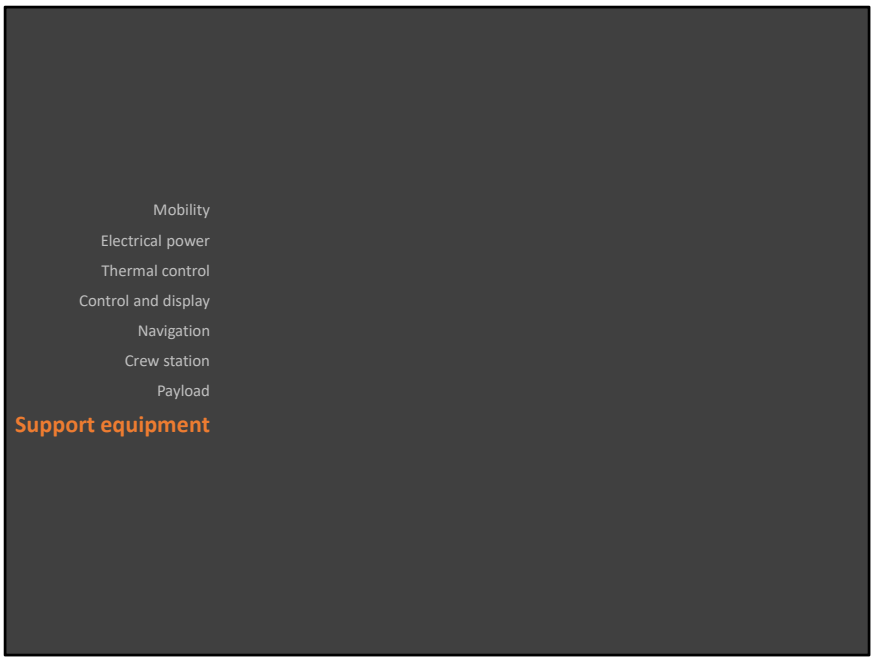
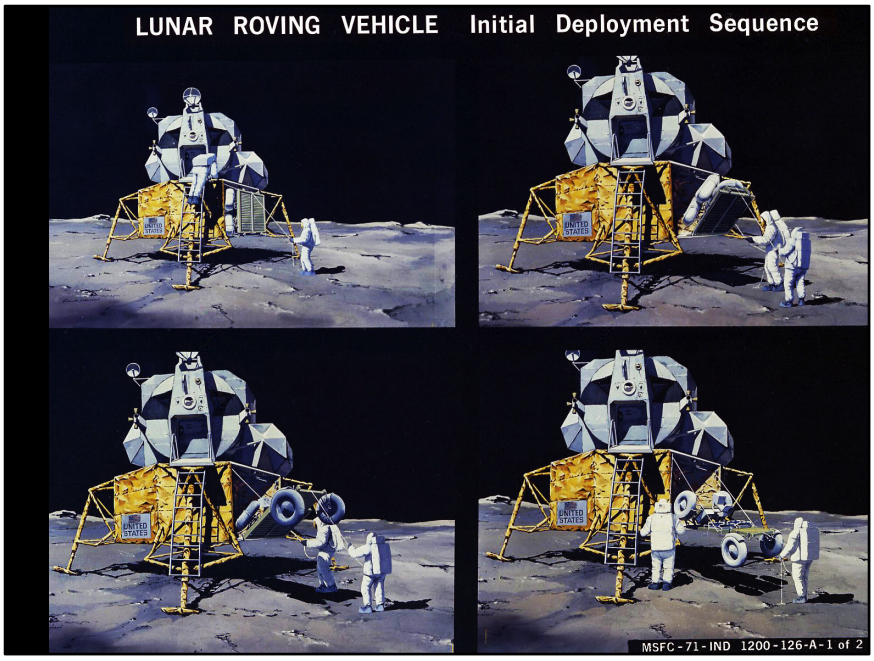


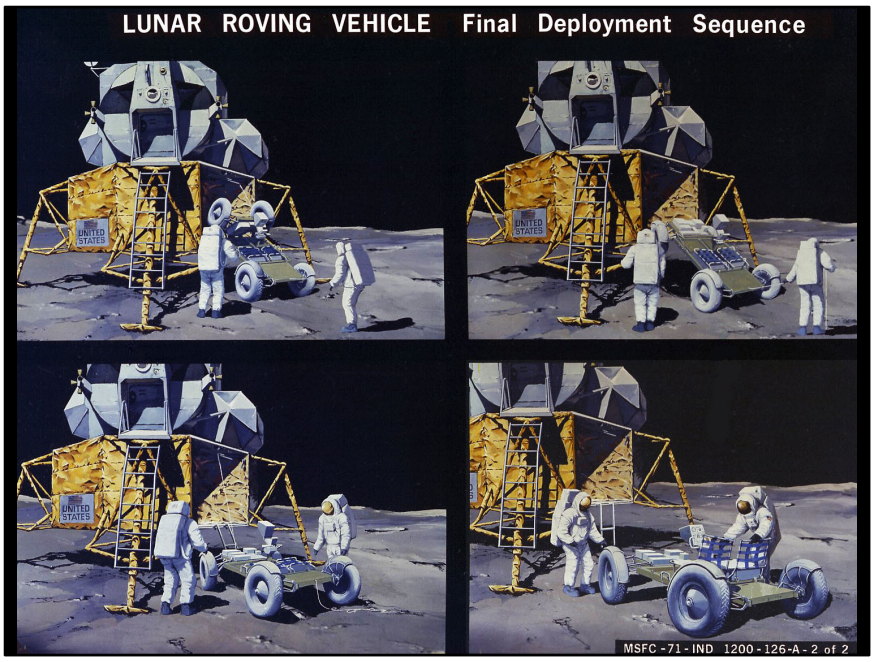

Structural support
Deployment hardware

Act IV

Act IV

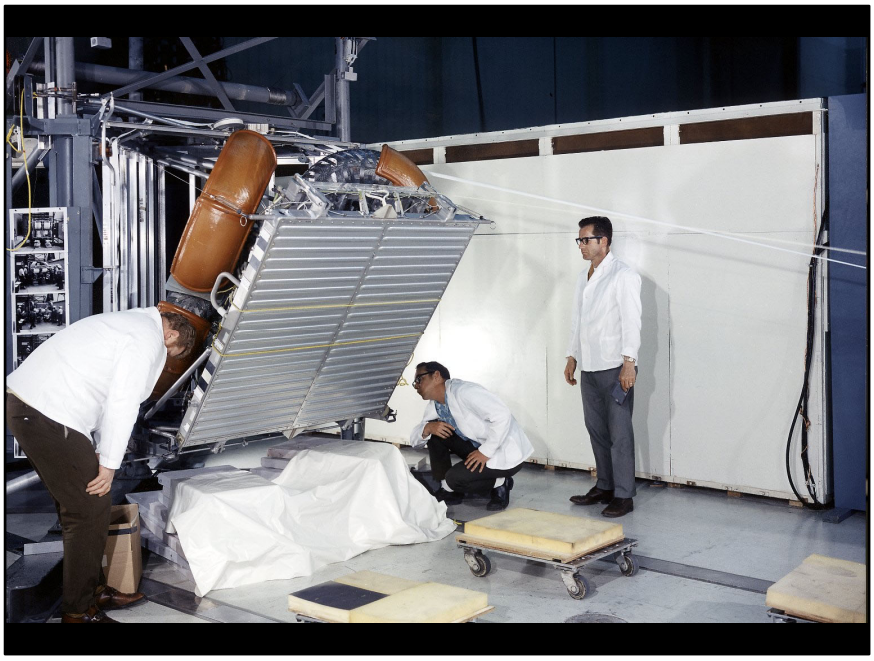
# Deployment


LUNAR ROVING VEHICLE Initial Deployment Sequence
MSFC-71-IND 1200-126-A-1 of 2




https://www.wired.com/2013/07/unpacking-a-moon-car/
https://www.wired.com/images_blogs/wiredscience/2013/07/LRV-deployment-MSFC-1.jpg
https://www.wired.com/images_blogs/wiredscience/2013/07/LRV-deployment-MSFC-2.jpg

https://archive.org/details/MSFC-7021099



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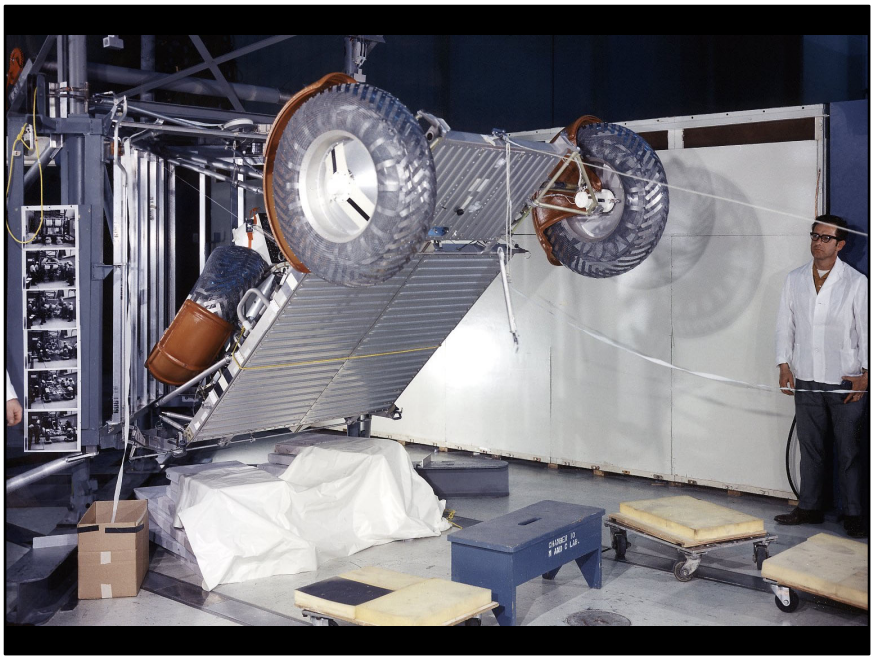

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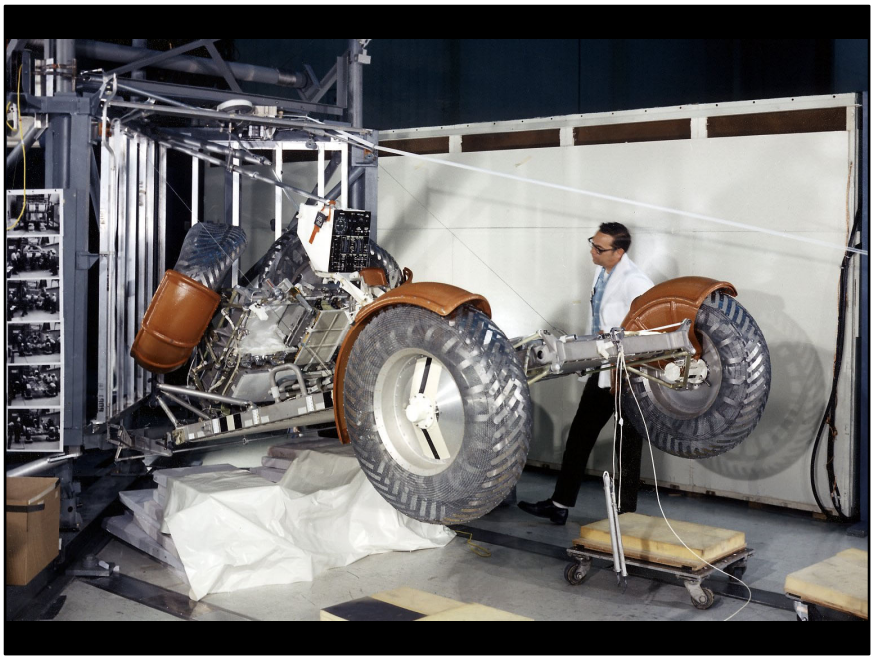

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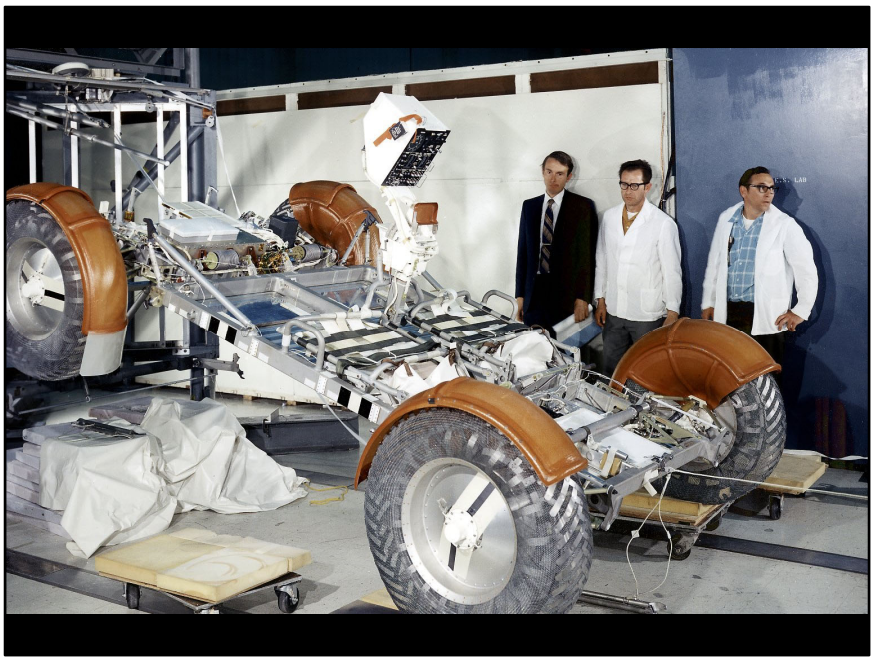

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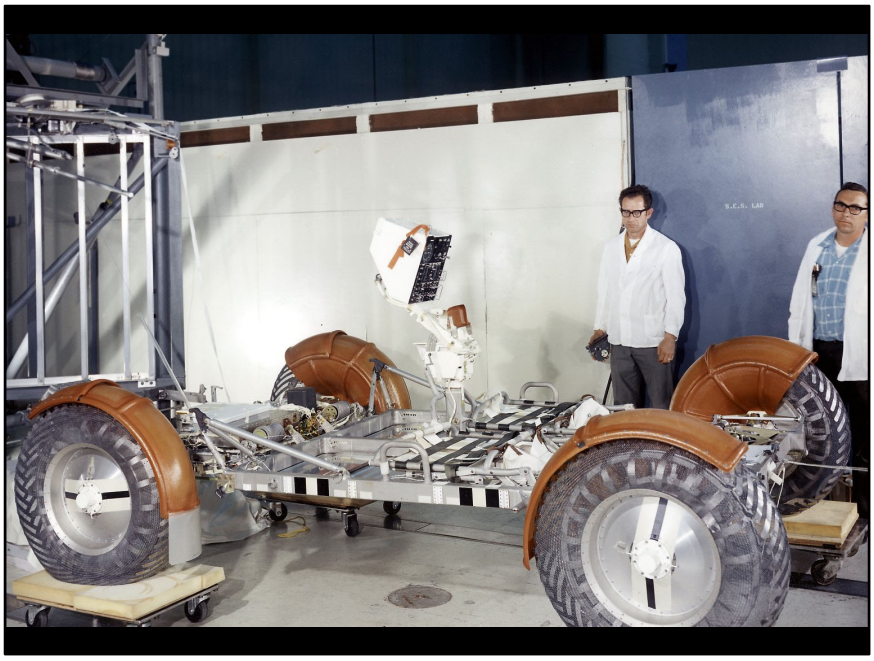
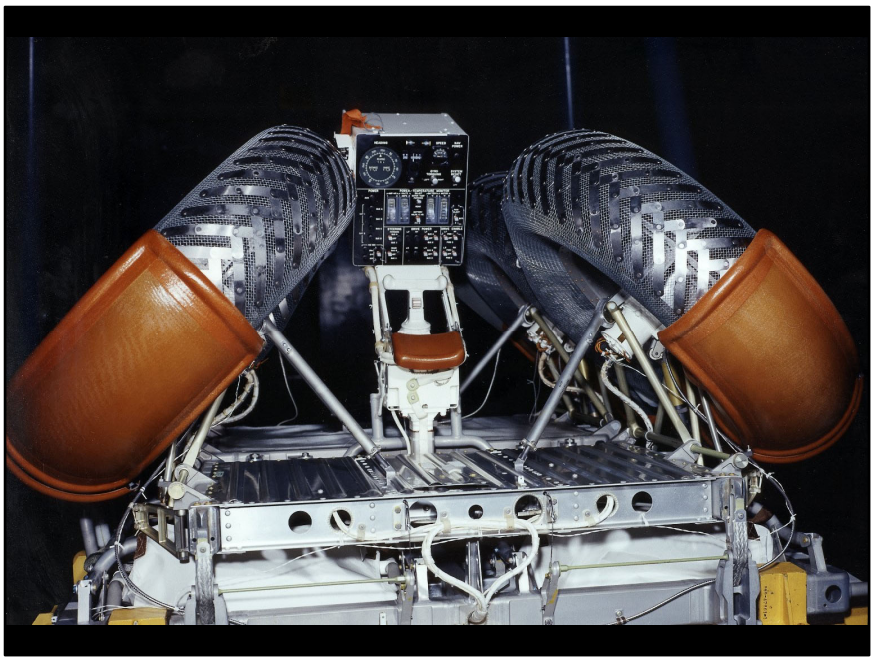


https://archive.org/details/MSFC-7021104



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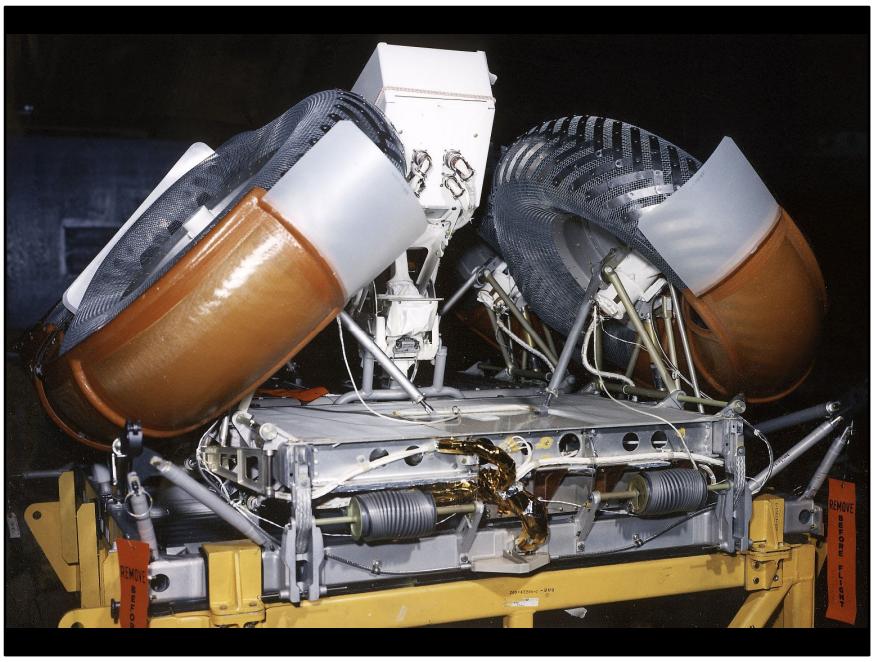


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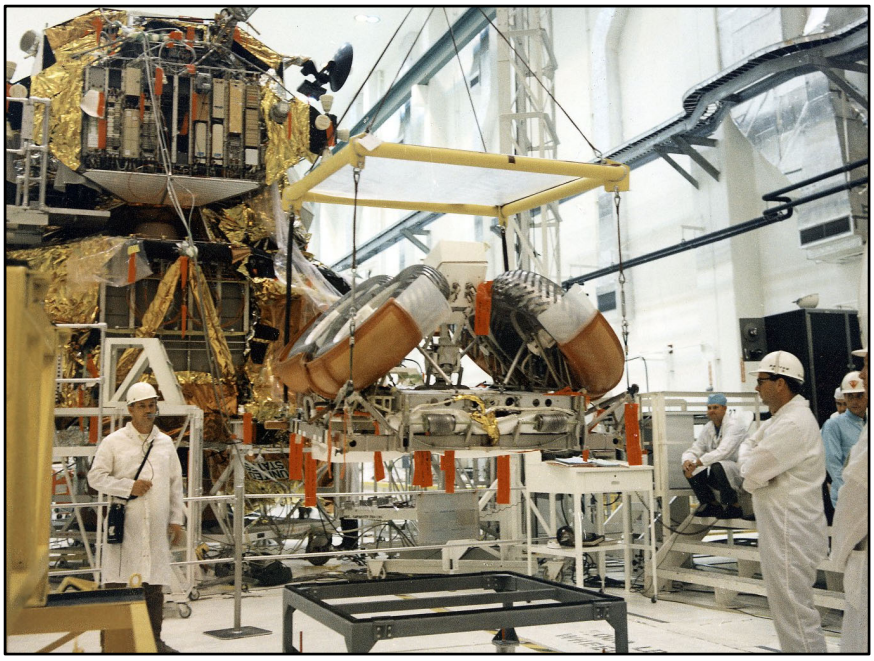
https://www.hq.nasa.gov/alsj/a17/ap17-KSC-72P-202.jpg



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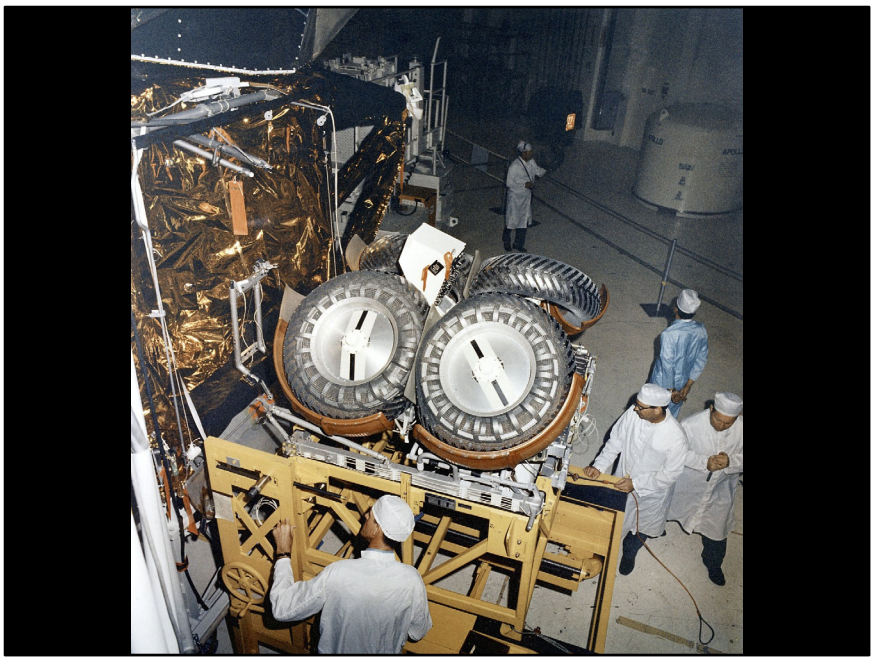

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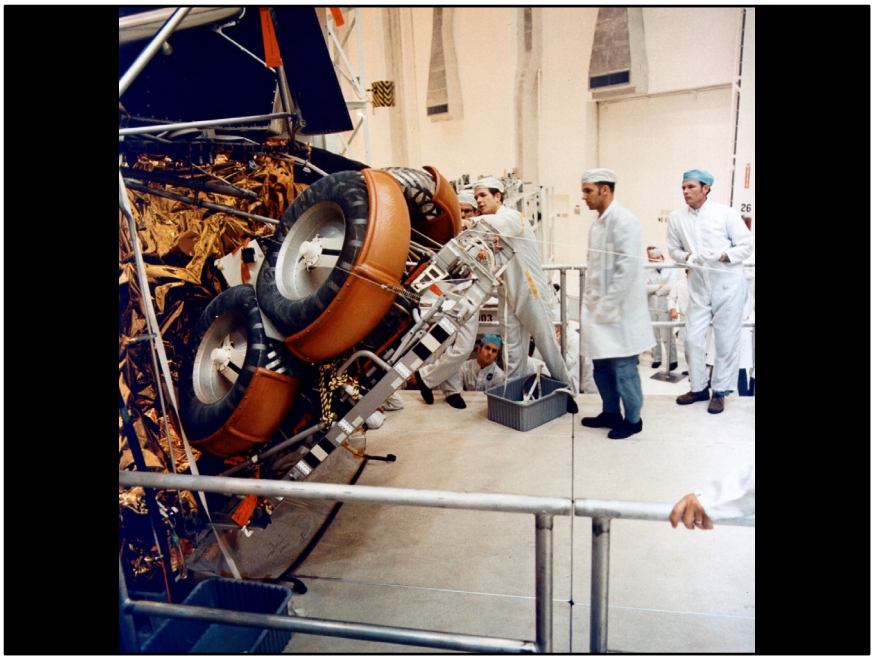
https://archive.org/details/MSFC-7020222



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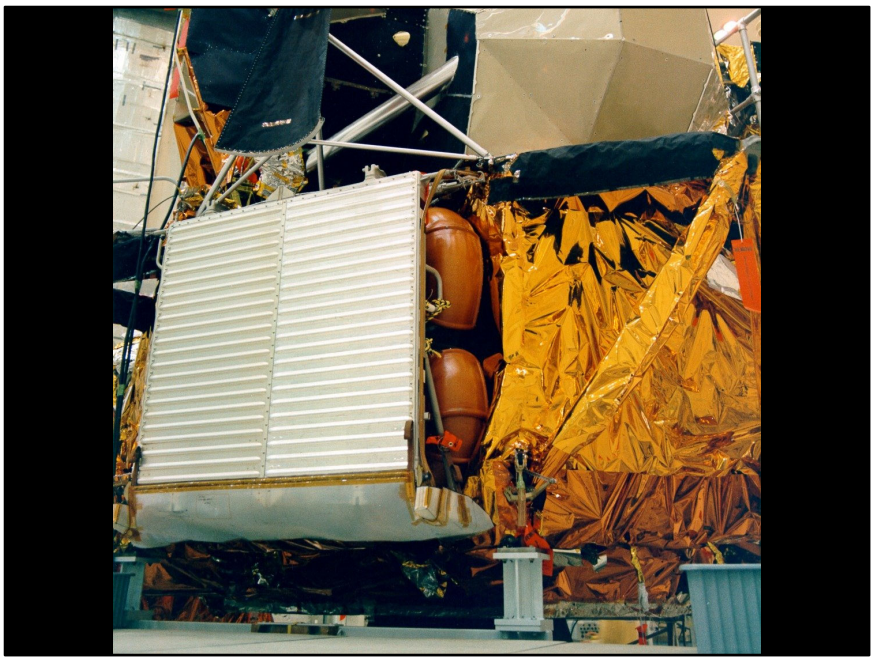
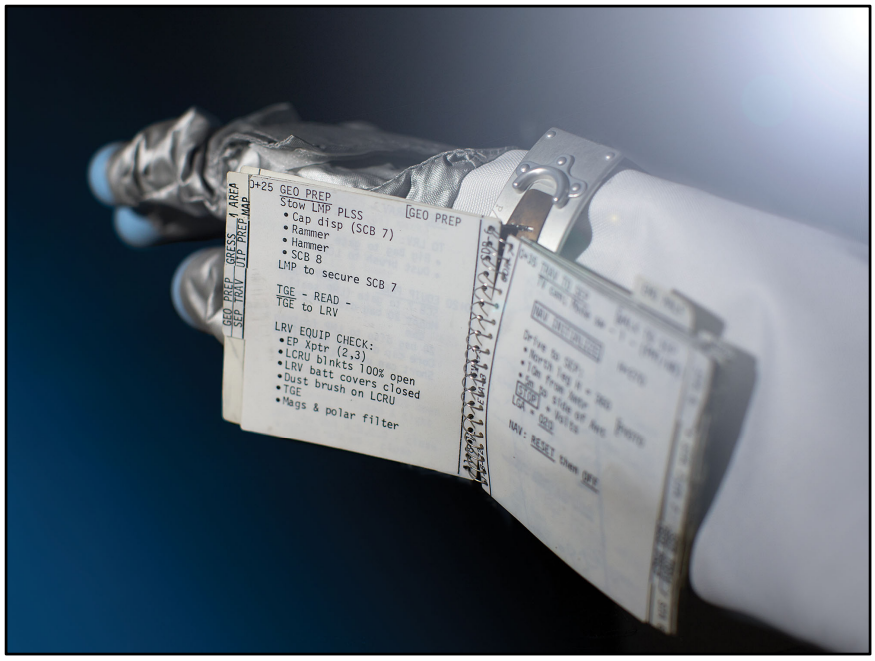


https://www.hq.nasa.gov/alsj/a15/ap15-KSC-71PC-415HR.jpg

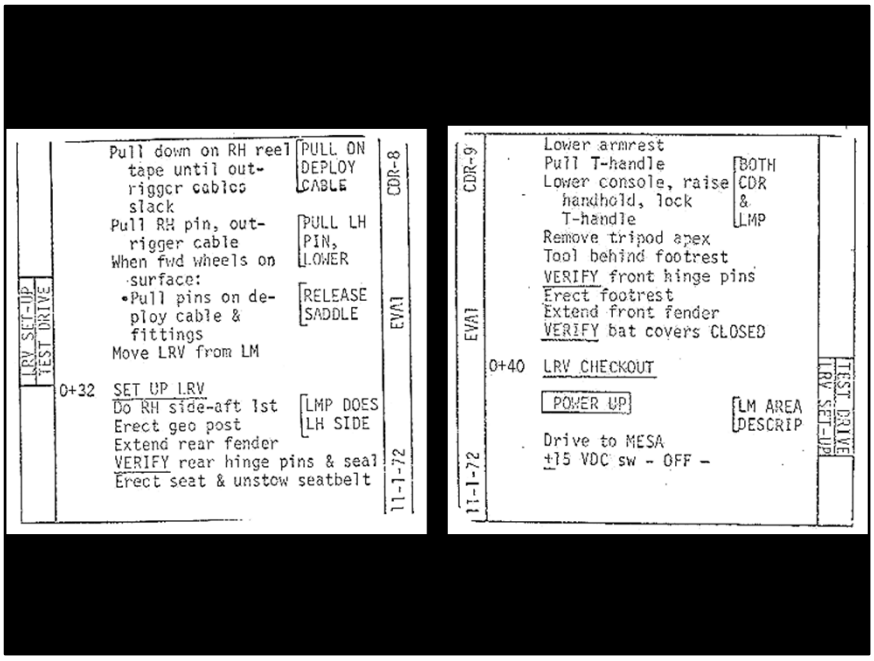
Act V

Act V

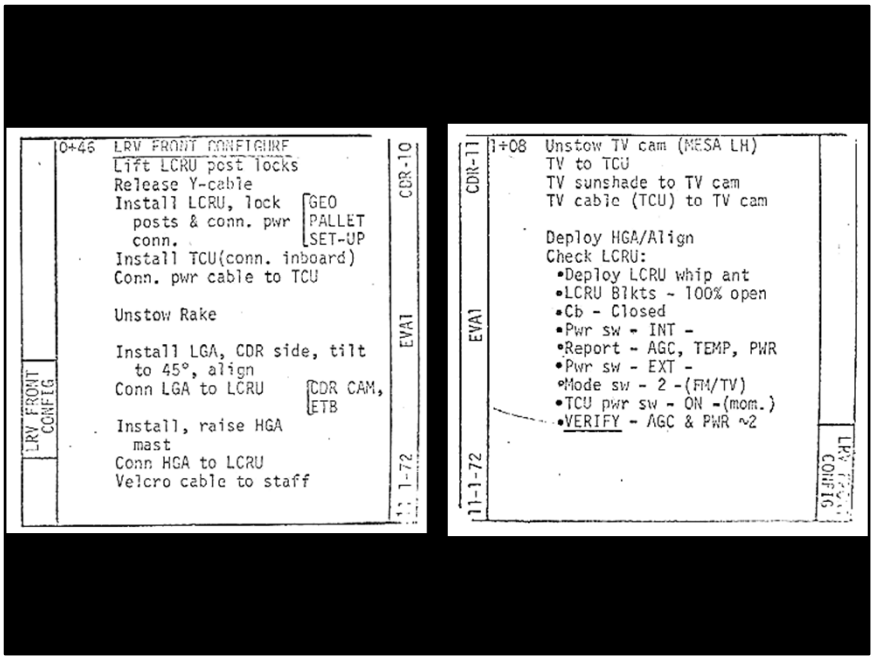
# On your mark




https://www.rrauction.com/auctions/lot-detail/li/343459706193433/
https://www.smithsonianmag.com/air-space-magazine/the-fourth-crewmember-37046329/




https://www.hq.nasa.gov/alsj/a17/cuff17.html
CDR-8, CDR-9



0+46 LRV FRONT CONFIGURE
Lift LCRU post locks
Release Y-cable
Install LCRU, lock posts & conn. pwr conn. [GEO / PALLET / SET-UP]
Install TCU(conn. inboard)
Conn. pwr cable to TCU

Unstow Rake

Install LGA, CDR side, tilt to 45°, align
Conn LGA to LCRU [CDR CAM, ETB]

Install, raise HGA mast
Conn HGA to LCRU
Velcro cable to staff

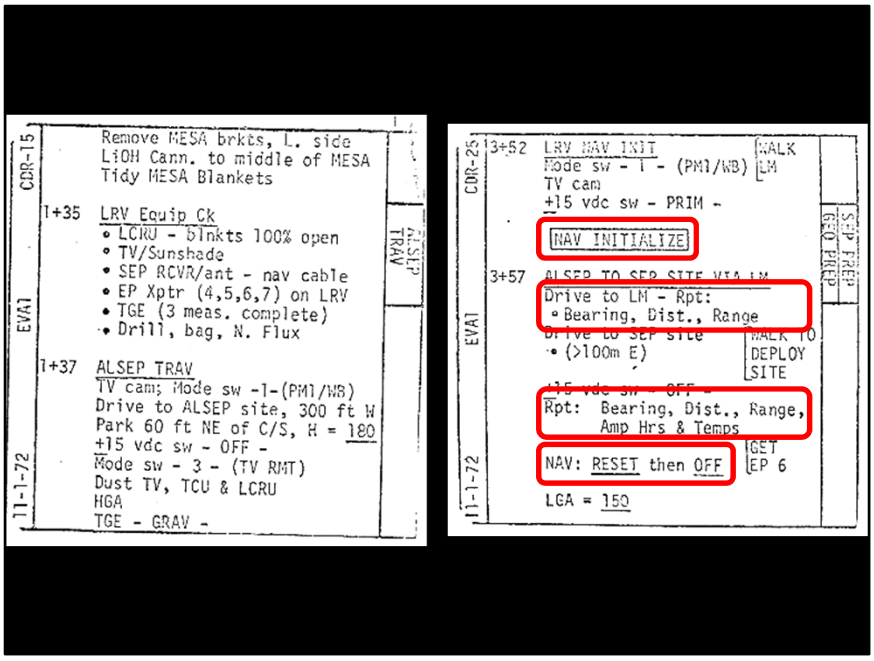
LRV FRONT CONFIG
EVA1
CDR-10
11-1-72

1+08 Unstow TV cam (MESA LH)
TV to TCU
TV sunshade to TV cam
TV cable (TCU) to TV cam

Deploy HGA/Align
Check LCRU:
•Deploy LCRU whip ant
•LCRU Blkts - 100% open
•Cb - Closed
•Pwr sw - INT -
•Report - AGC, TEMP, PWR
•Pwr sw - EXT -
•Mode sw - 2 -(FM/TV)
•TCU pwr sw - ON -(mom.)
•VERIFY - AGC & PWR ~2

CDR-11
EVA1
11-1-72

https://www.hq.nasa.gov/alsj/a17/cuff17.html
CDR-10, CDR-11



Remove MESA brkts, L. side
LiOH Cann. to middle of MESA
Tidy MESA Blankets

1+35 LRV Equip Ck
- LCRU - Blnkts 100% open
- TV/Sunshade
- SEP RCVR/ant - nav cable
- EP Xptr (4,5,6,7) on LRV
- TGE (3 meas. complete)
- Drill, bag, N. Flux

1+37 ALSEP TRAV
TV cam; Mode sw -1-(PM1/WB)
Drive to ALSEP site, 300 ft W
Park 60 ft NE of C/S, H = 180
+15 vdc sw - OFF -
Mode sw - 3 - (TV RMT)
Dust TV, TCU & LCRU
HGA
TGE - GRAV -

CDR-15 EVA1 11-1-72 ALSEP TRAV

3+52 LRV NAV INIT
Mode sw - 1 - (PM1/WB)
TV cam
+15 vdc sw - PRIM -
NAV INITIALIZE

3+57 ALSEP TO SEP SITE VIA LM
Drive to LM - Rpt:
- Bearing, Dist., Range

Drive to SEP site
- (>100m E)

WALK TO DEPLOY SITE

+15 vdc sw - OFF -
Rpt: Bearing, Dist., Range, Amp Hrs & Temps

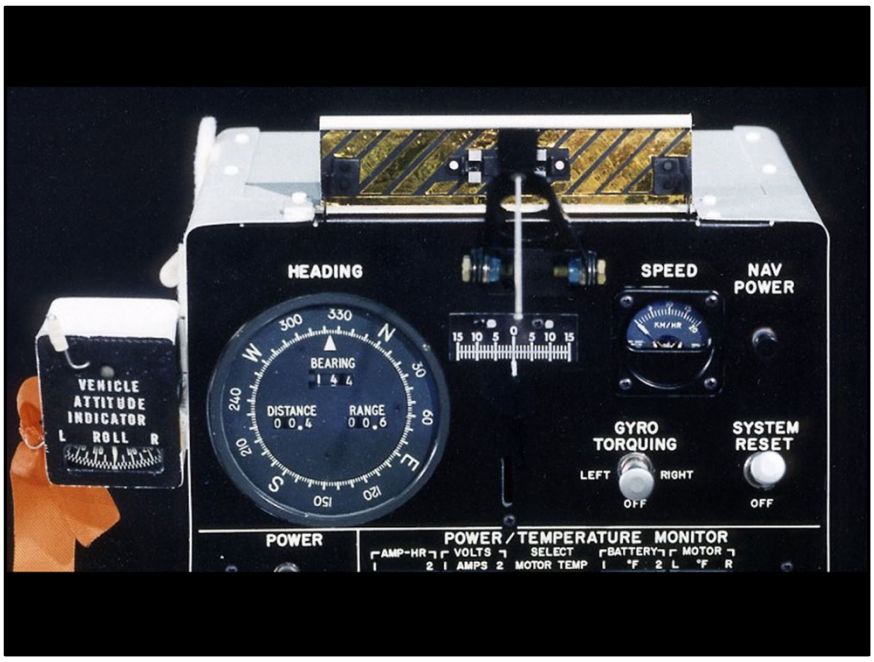
NAV: RESET then OFF

GET EP 6

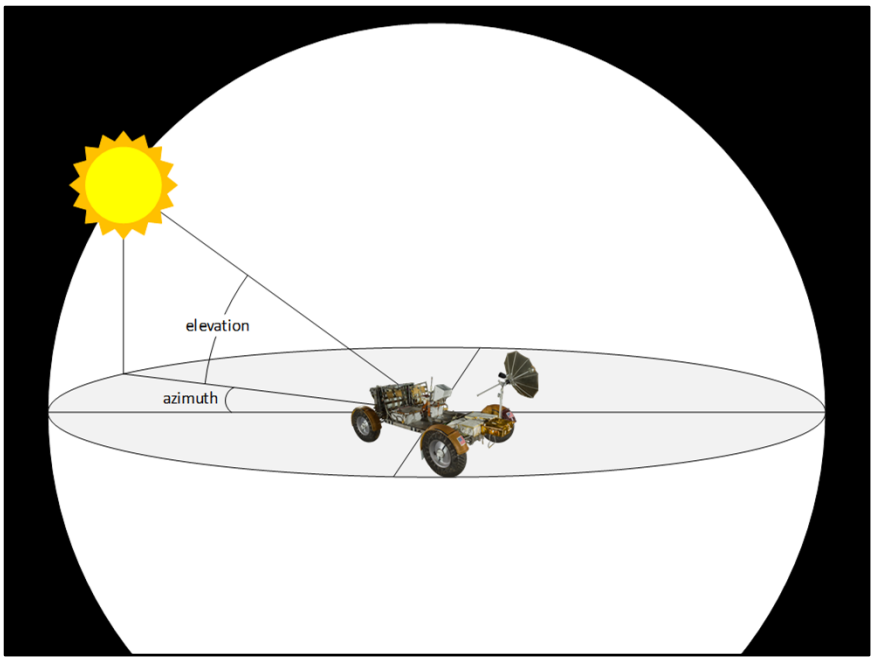
LGA = 150

CDR-25 EVA1 11-1-72 WALK LM GEO PREP SEP PREP

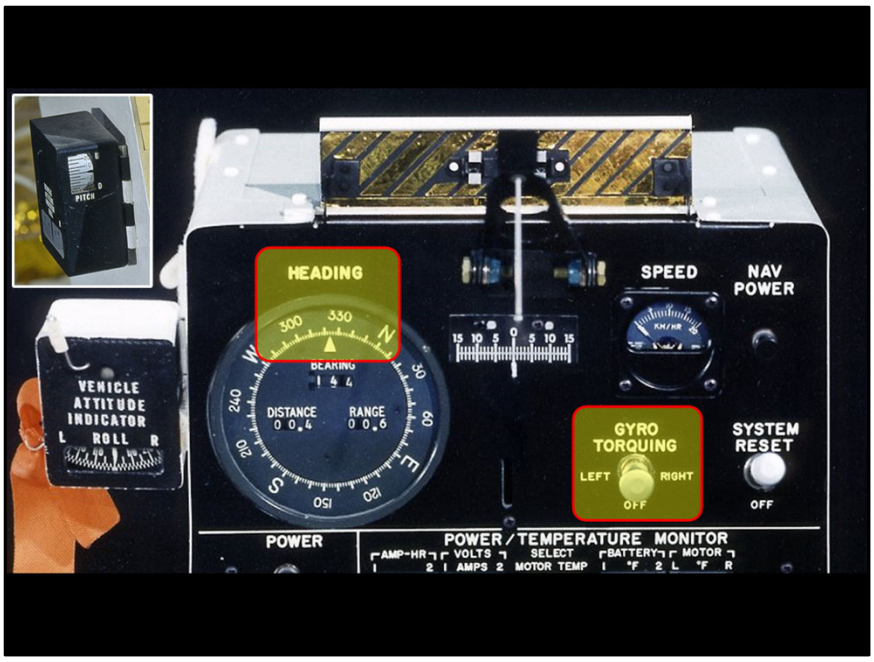
https://www.hq.nasa.gov/alsj/a17/cuff17.html
CDR-15, CDR-25

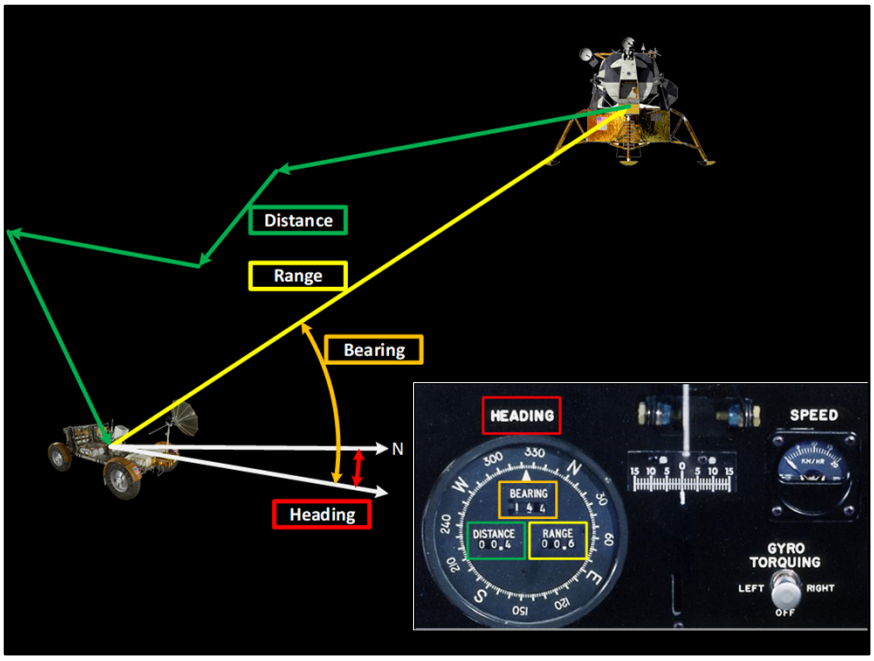



https://archive.org/details/MSFC-7021041
Operations Handbook pages 1-39 and 1-40 explain all switches
Init starts at page 2-22


elevation
azimuth


HEADING
SPEED
NAV POWER
BEARING
144
DISTANCE
00.4
RANGE
00.6
GYRO TORQUING
LEFT
RIGHT
OFF
SYSTEM RESET
OFF
POWER
POWER / TEMPERATURE MONITOR
AMP-HR
VOLTS
SELECT
BATTERY
MOTOR
AMPS
MOTOR TEMP
VENICLE ATTITUDE INDICATOR
L ROLL R
PITCH

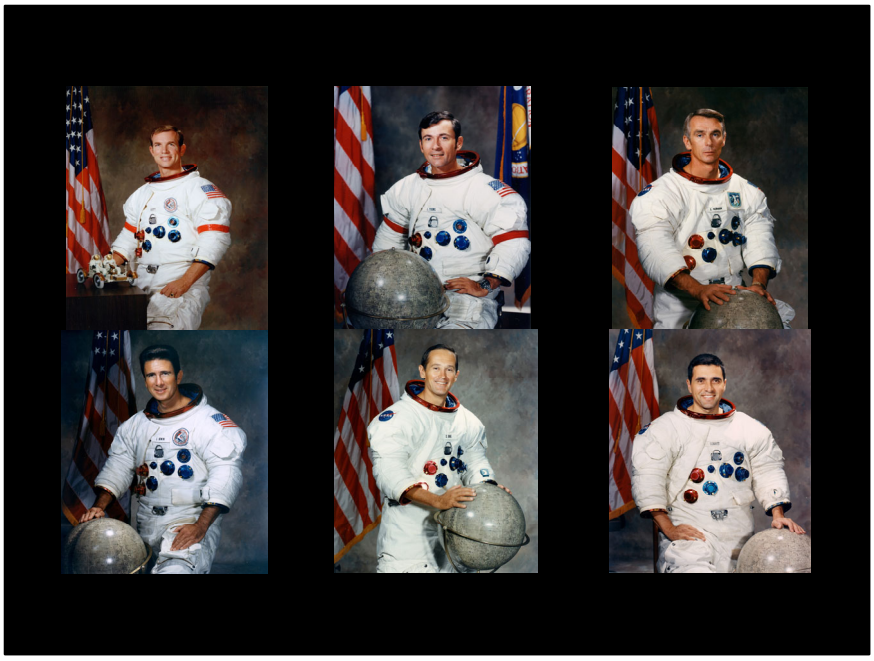

HEADING
SPEED
NAV POWER
VEHICLE ATTITUDE INDICATOR
L ROLL R
BEARING
DISTANCE
RANGE
GYRO TORQUING
LEFT
RIGHT
OFF
SYSTEM RESET
OFF
POWER
POWER / TEMPERATURE MONITOR
AMP-HR
VOLTS
SELECT
BATTERY
MOTOR
AMPS
MOTOR TEMP

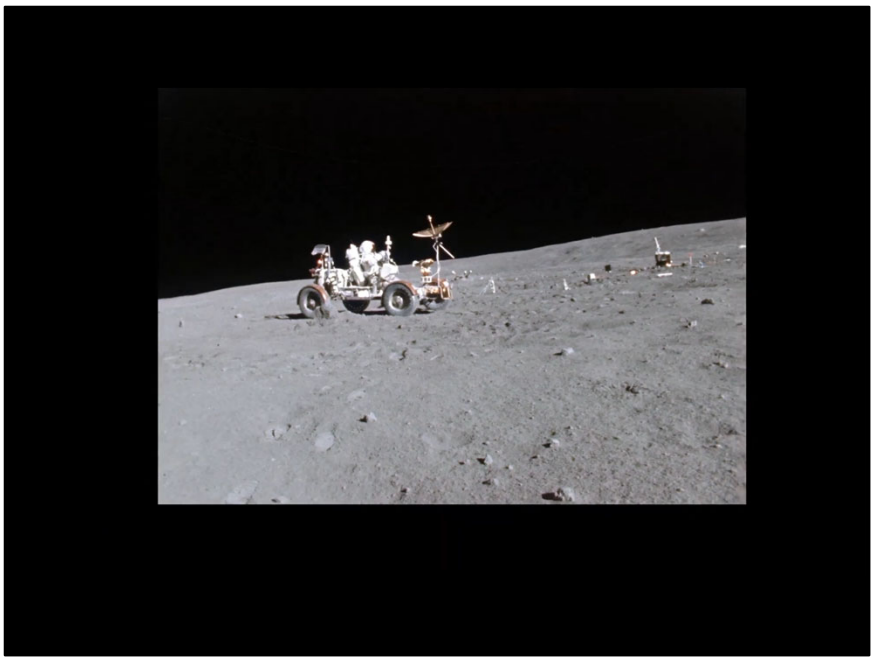

Distance
Range
Bearing
N
Heading
HEADING
SPEED
BEARING
DISTANCE
RANGE
GYRO
TORQUING
LEFT
RIGHT
OFF

Act VI

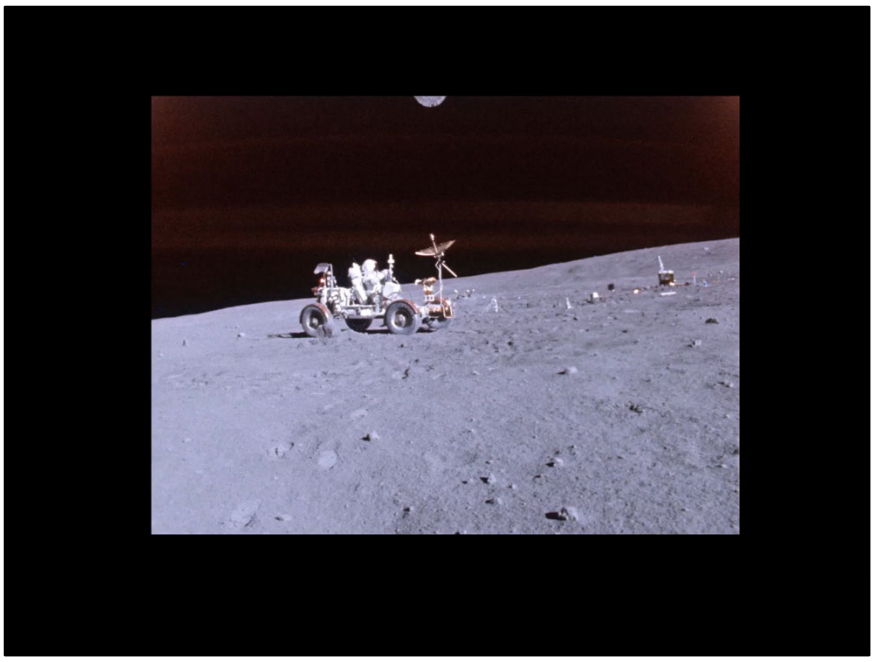
Act VI

# Hit it

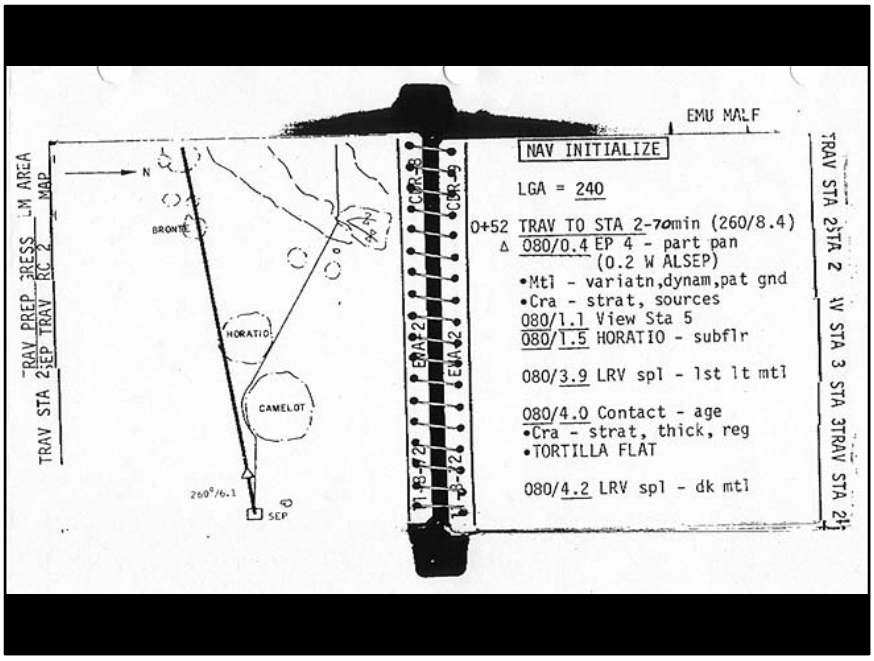




https://www.youtube.com/watch?v=X30z82aeSHw

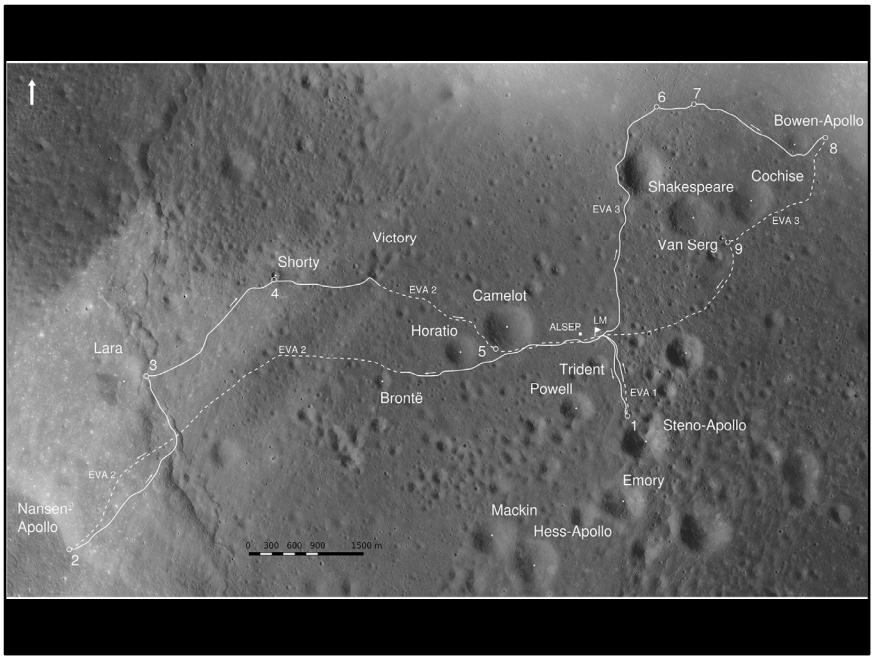


https://www.youtube.com/watch?v=X30z82aeSHw

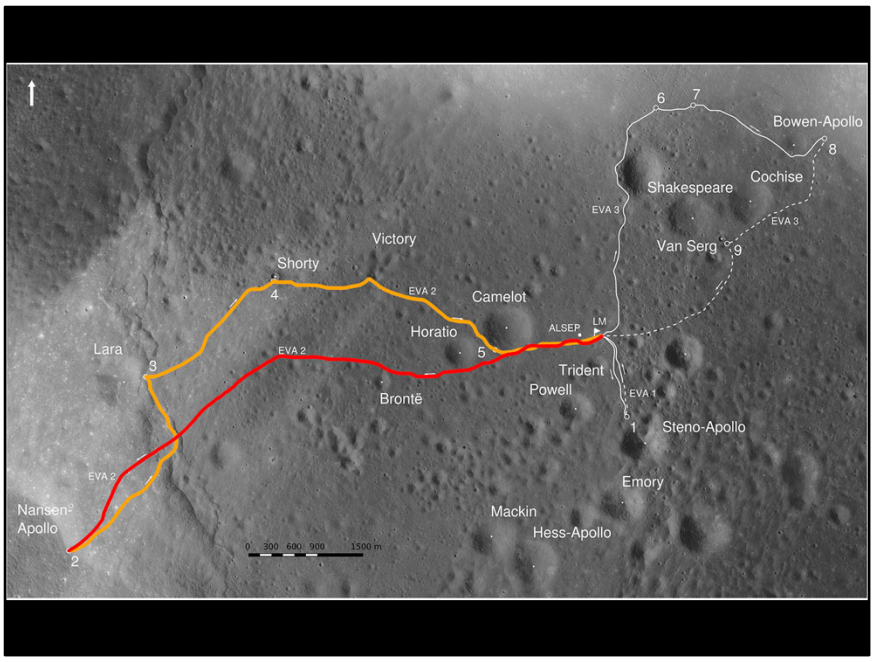



https://www.hq.nasa.gov/alsj/a17/A17A1411600.mp3
11:30/141:27:42
12:16/141:28:34
12:56/141:29:16

https://www.hq.nasa.gov/alsj/a17/A17A1412909.mp3
0:28/141:29:30
1:21/141:30:25



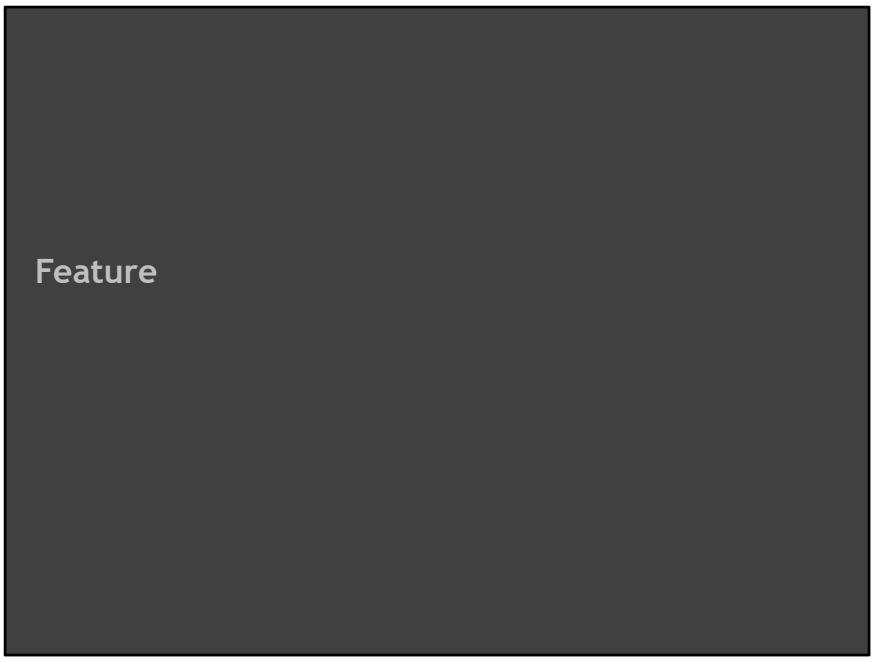

https://doi.org/10.1029/2018EA000408
Haase, Isabel, et al. "Coordinates and maps of the Apollo 17 landing site." *Earth and Space Science* 6.1 (2019): 59-95.


6
7
Bowen-Apollo
8
Cochise
Shakespeare
EVA 3
EVA 3
Van Serg
9
Victory
Shorty
4
EVA 2
Camelot
Horatio
ALSEP
LM
Lara
3
EVA 2
5
Trident
Powell
Brontë
EVA 1
1
Steno-Apollo
EVA 2
Emory
Nansen-Apollo
2
Mackin
Hess-Apollo
0 300 600 900 1500 m

https://www.hq.nasa.gov/alsj/a15/AS15-86-11659HR.jpg

https://www.hq.nasa.gov/alsj/a17/a17pan22493-19w_ej.jpg
https://en.wikipedia.org/wiki/Coherent_backscattering

https://www.hq.nasa.gov/alsj/a17/a17pan22493-19w_ej.jpg
https://en.wikipedia.org/wiki/Coherent_backscattering


Feature

Feature

# The crest of a high and beautiful wave

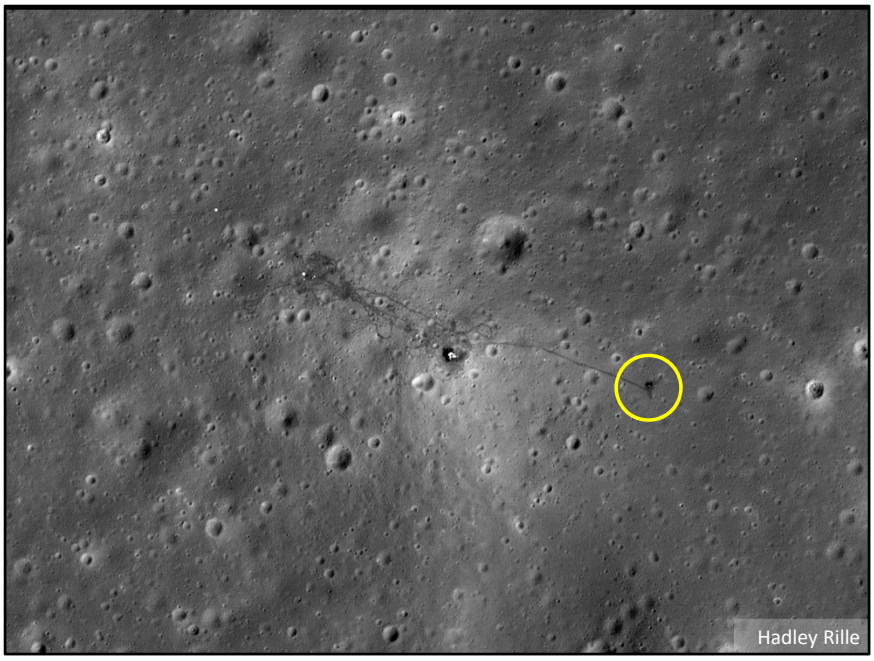
Feature

# The crest of a high and beautiful wave

Act VII

Act VII

# Where are they now

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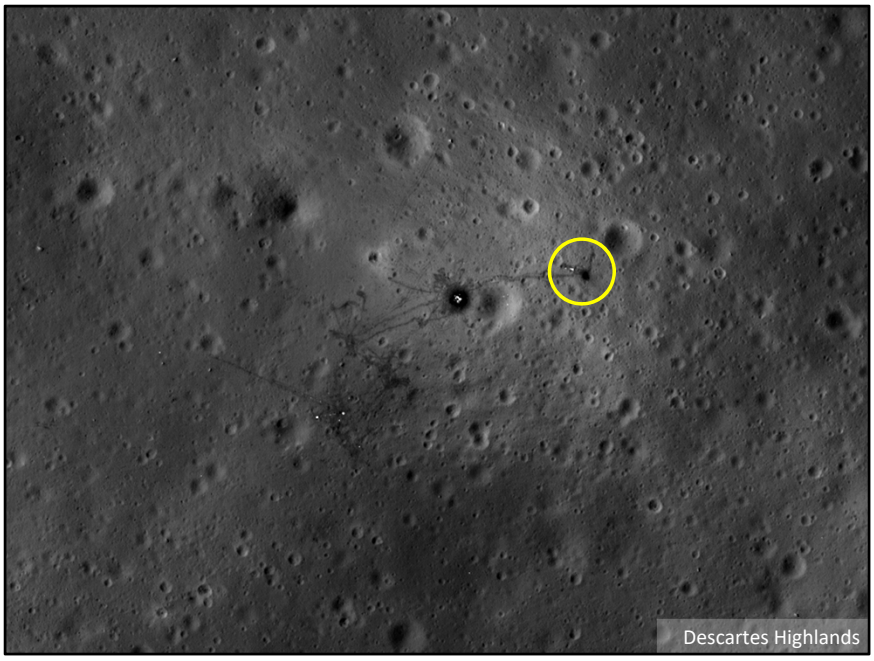


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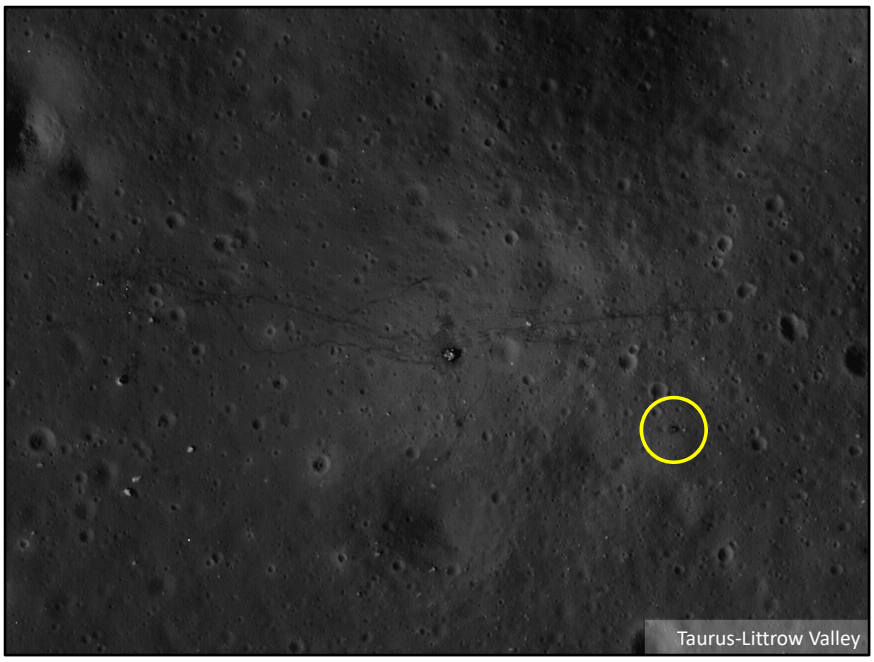


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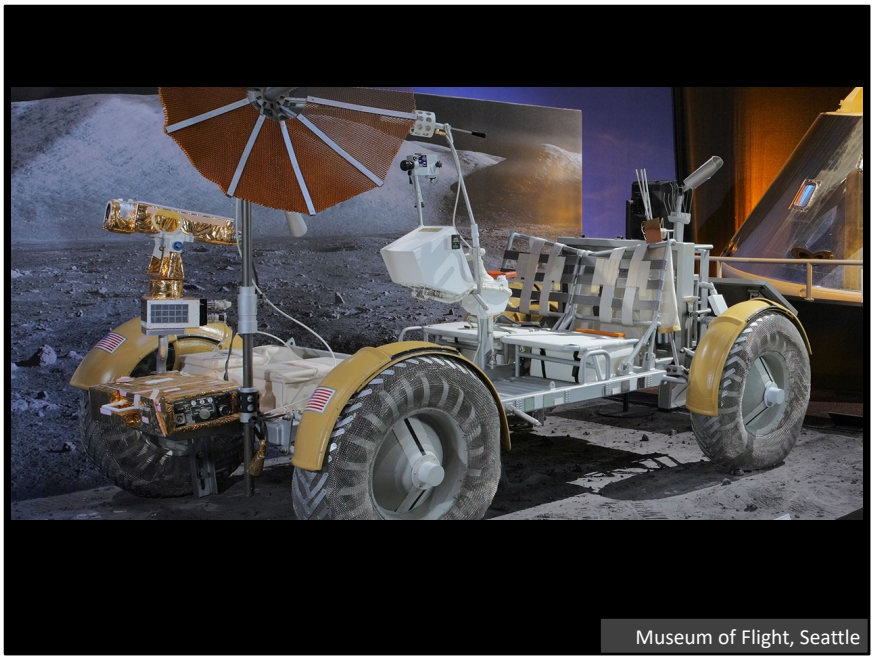


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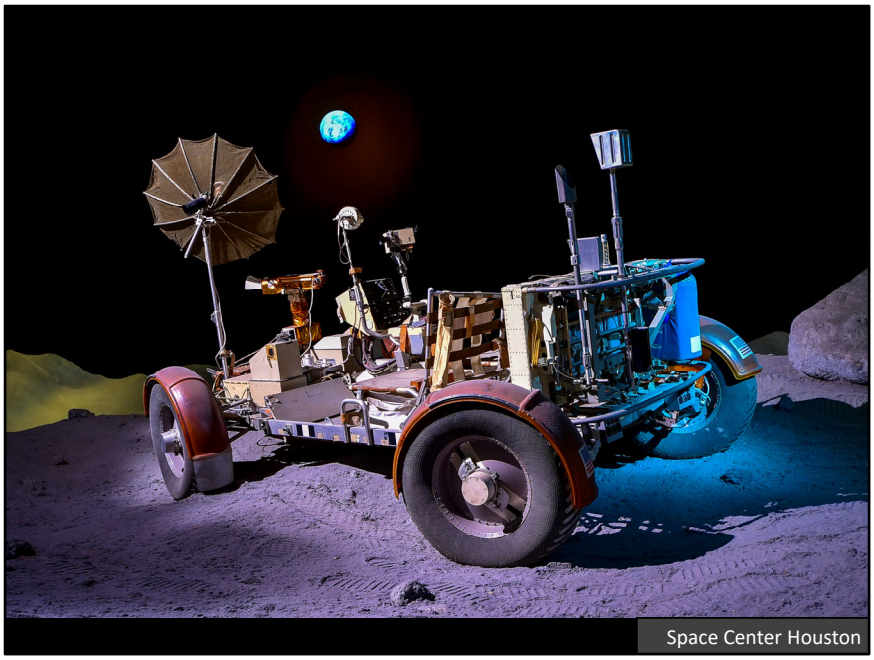


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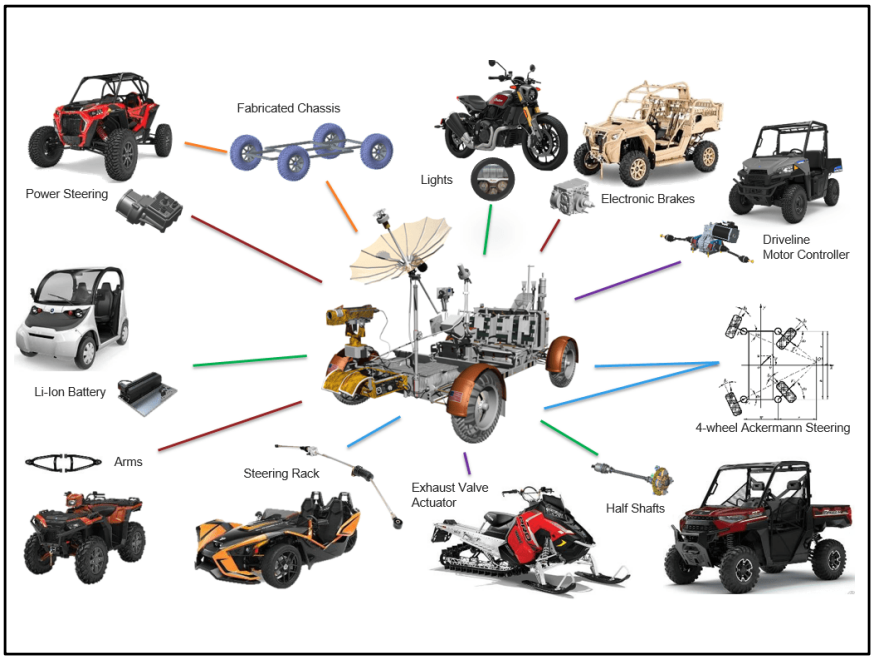


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Onward

Onward

# The age of Artemis

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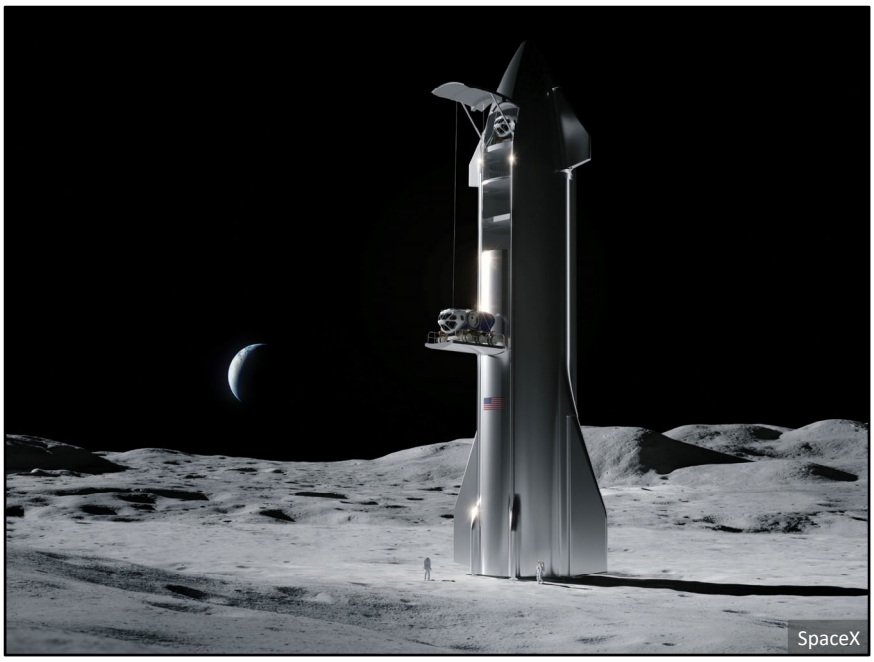
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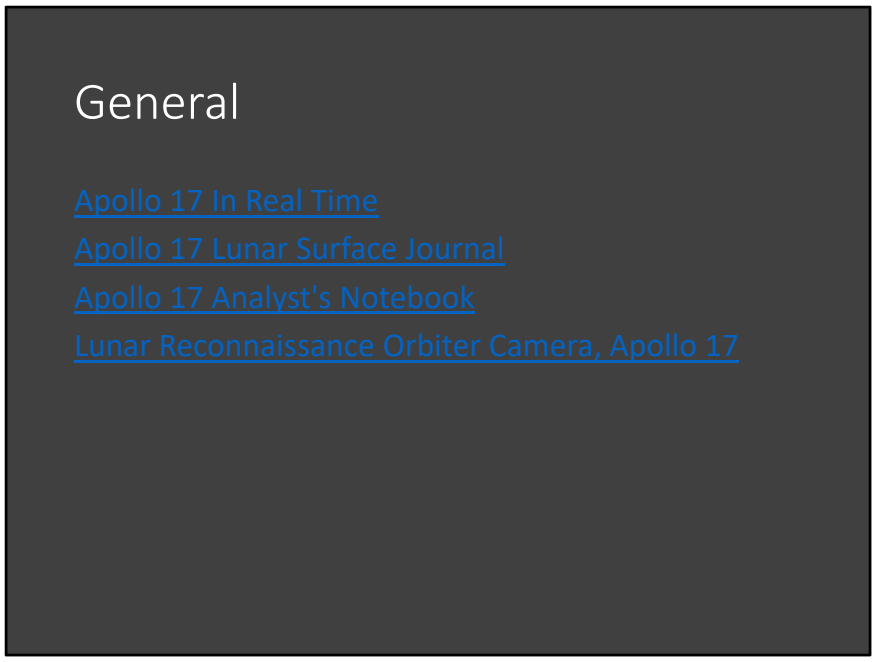


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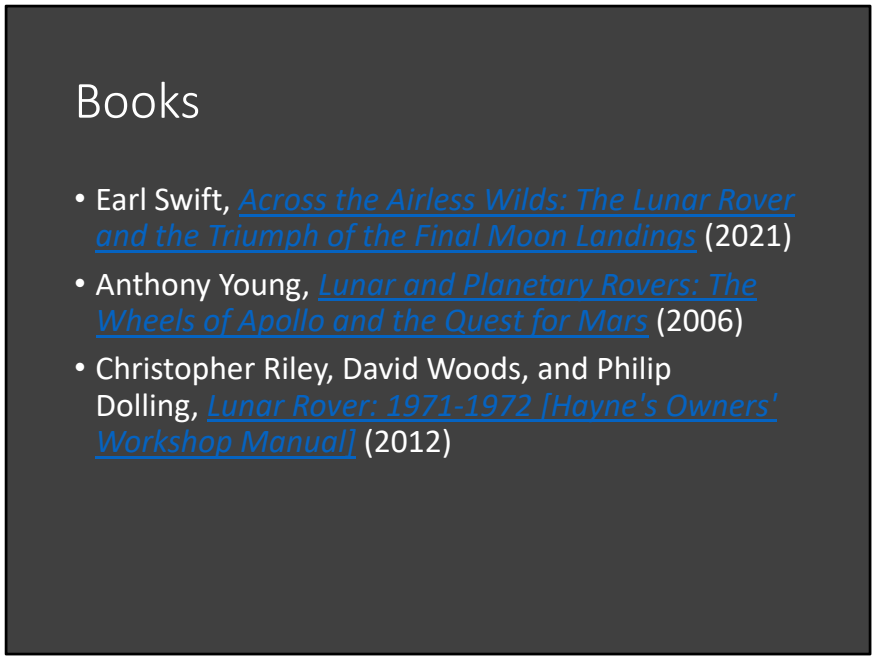


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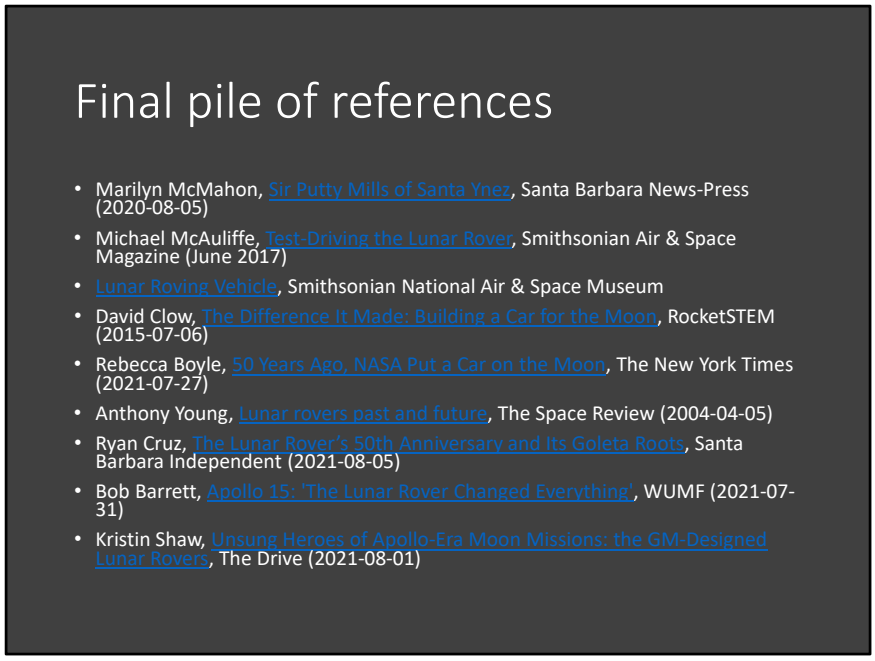


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