NASA-STD-3001 Technical Brief

Extraterrestrial Surface Transport Vehicles (Rovers)

OCHMO-TB-023
Rev A

Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev D

[V2 6154] Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits
[V2 6155] Extraterrestrial Surface Transport Vehicle Translation Jerk Limits
[V2 6156] Extraterrestrial Surface Transport Vehicle Blunt Trauma Limits
[V2 6160] Extraterrestrial Surface Transport Vehicle Vibration Limits for Health and Performance
[V2 Section 7.6] Stowage Provision and Accessibility
[V2 8033] Restraints for Crew Tasks
[V2 8038] Restraint and Mobility Aid Standardization
[V2 8106] Extraterrestrial Surface Transport Vehicle (ESTV) Dashboard and Control Lighting
[V2 Section 8.7] Lighting
[V2 Section 10.1] General for Performance and Crew Interfaces
[V2 Section 10.2] Layout of Displays and Controls
[V2 Section 10.3] Displays
[V2 Section 10.4] Control Design
[V2 10073] Control Operation Supports and Restraints
[V2 10083] Communications System Design
[V2 10084] Communication Capability
[V2 Section 10.6] Automated and Robotic Systems
[V2 Section 10.7] Information Management
[V2 12024] Restraints and Platforms

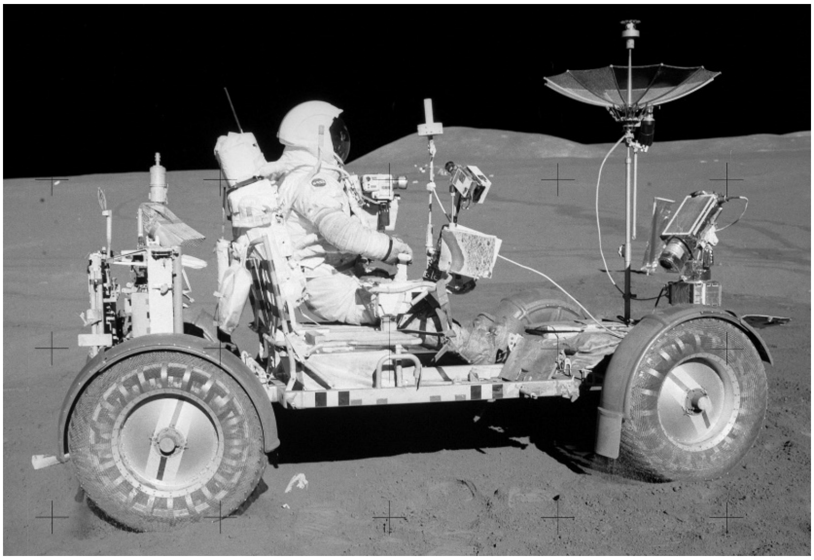
**To prevent the list of technical requirements from being bloated, many referenced individual technical requirements have been merged into references to sections within NASA-STD-3001.*

Executive Summary

During any mission to an extraterrestrial surface, the presence of a transport vehicle (rover) will allow crewmembers to travel farther from their lander or base, carry more equipment, and perform medical evacuations. The rover presents its own set of risks and challenges, which must be overcome in accordance with technical requirements listed in NASA-STD-3001. Lessons learned from the Apollo program can be applied to ongoing design and implementation of lunar and planetary rovers.

Background

Apollo Lunar Roving Vehicle (LRV)

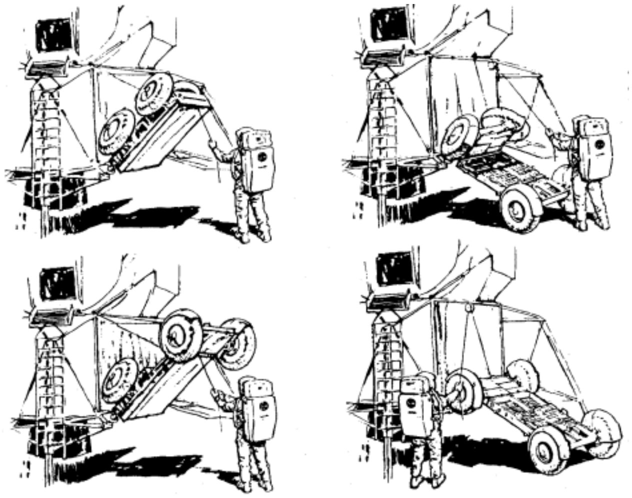


Features

- Empty mass: 210 kg
- Max payload: 490 kg
- Length x Width: 3.0 m x 2.1 m
- Ground clearance: 0.3 m
- Top speed: 18 km/h
- Range: 92 km
- Crew: 2

Walkback Limit

Even though the LRV battery allowed for a maximum range of 92 km, in practice crewmembers never drove it farther than the 7.6 km “Walkback Limit,” the maximum distance a crewmember would be able to travel on foot if the LRV stopped working.



Stowage and Deployment

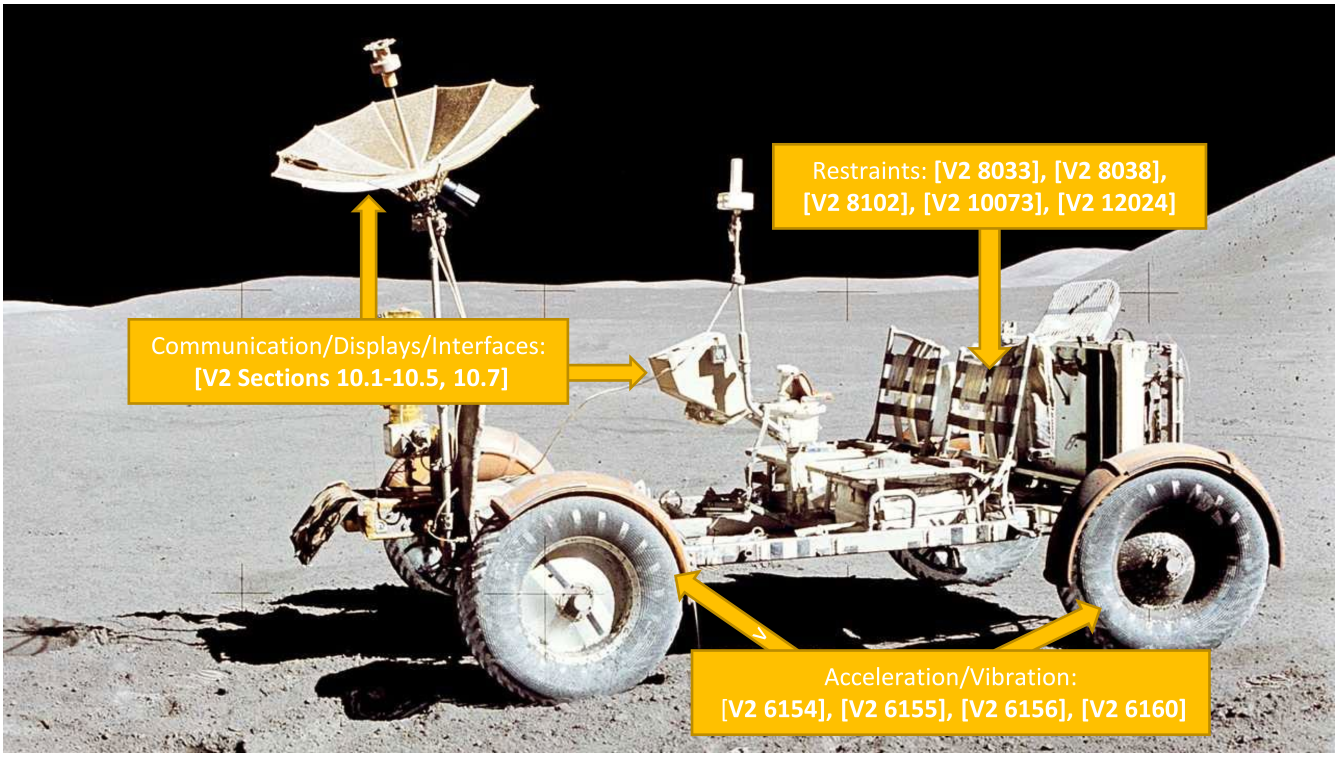
The LRV was designed to be folded and stored in an external panel of the Lunar Module. The diagram on the left shows a crewmember unfolding and lowering the LRV into position.

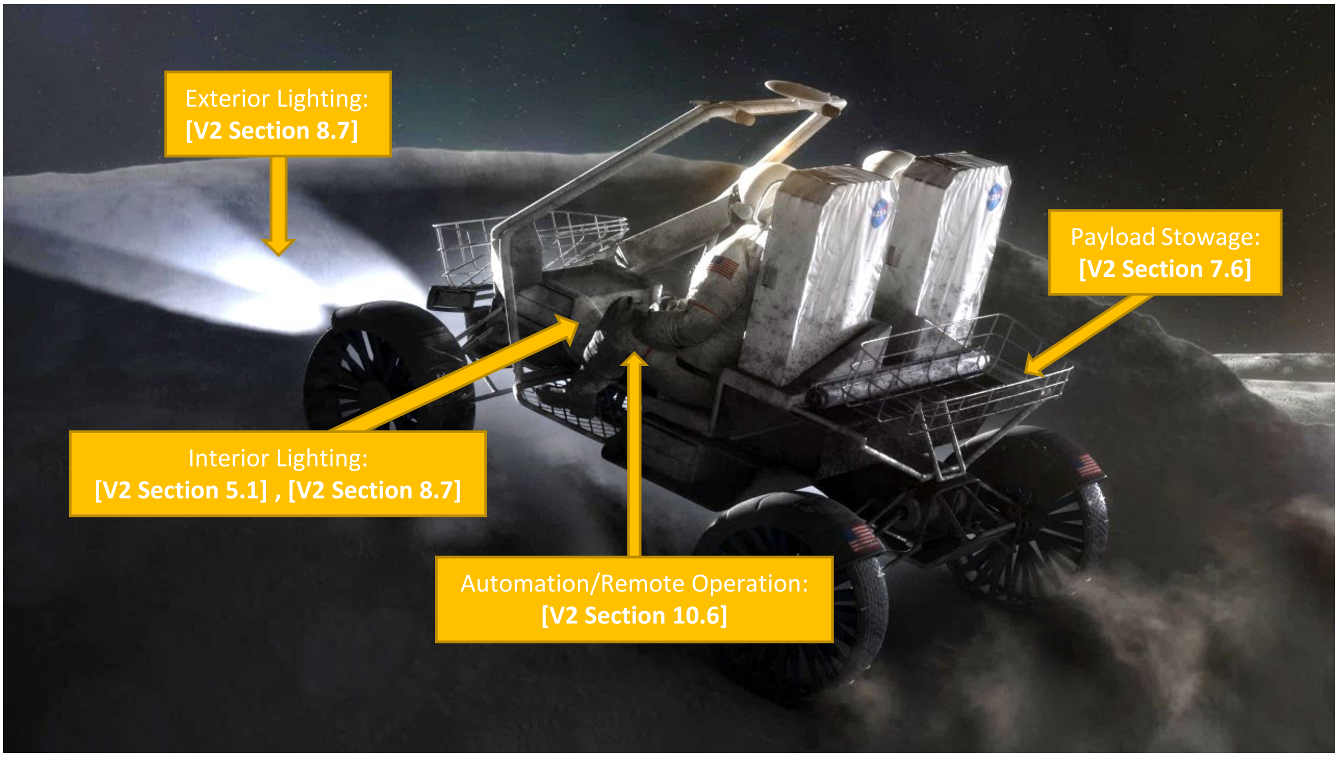
Mishaps

On three separate instances during Apollo 15-17, a fender broke, causing the crewmembers and equipment to be covered with Lunar dust during LRV operation. During Apollo 17, a makeshift fender was improvised to limited effect for the remainder of the mission.

Application

Required Capabilities





Application

Required Capabilities

Transportation

- The primary purpose of a rover is to transport crew and cargo safely. Maximum range, top speed, and crew capacity are among the considerations driven by mission requirements, surface environment, and design limitations.
- Crewmembers will be subject to acceleration and vibration while the rover is operating.

Payload stowage

- The crew must be able to transport tools and equipment in the rover, as well as any collected research material (e.g., soil samples).

Communication/Displays/Interfaces

- This includes communication to the lander/base camp, and communication to Earth-based ground crew.

Automation/Remote Operation

- Depending on the mission, the rover might need a remote operation capability, or a follow-along function. The same requirements that govern other automated systems would apply here.

Lighting

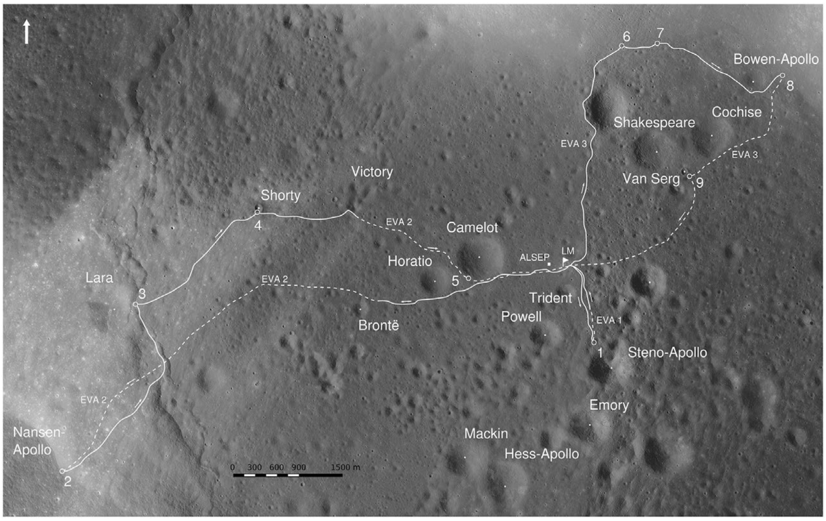
- For operations during Lunar night or located in shadowed areas, headlights or an equivalent lighting system can aid in navigation or illuminate a work area.

Application

Required Capabilities: Transportation

Maximum Operational Range

- Just like during Apollo, a rover may have a larger range than the maximum operational range to which it is deployed. If a mission abides by a Walkback Limit, that distance will be determined by the life support capabilities of the suit, physical conditioning of the crewmember, extraterrestrial terrain, etc. The risk assessment of the Walkback Limit will be affected by the reliability of the rover (the likelihood that it breaks) or mitigated if a mission has multiple rovers.



Apollo 17 EVA routes. The longest trip covered 20.1 km and reached a maximum distance of 7.6 km away from the lunar module.

Lunar surface showing rocks and uneven terrain

Terrain

- As a rover is being designed, an assessment of the expected extraterrestrial terrain must be performed. The Lunar surface, for example, is strewn with rocks and boulders, and extremely dusty. A Lunar rover will not only have to navigate obstacles, but also prevent dust from being flung onto crewmembers and equipment.

Crew Safety

- The crew will need to be restrained to the rover through seatbelts or other solutions that do not hinder any necessary activities, such as driving. Normal considerations for usability by suited crewmembers will need to be made.
- **[V2 8033] Restraints for Crew Tasks, [V2 8038] Restraints for Crew Tasks, [V2 10073] Control Operation Supports and Restraints, [V2 12024] Restraints and Platforms**

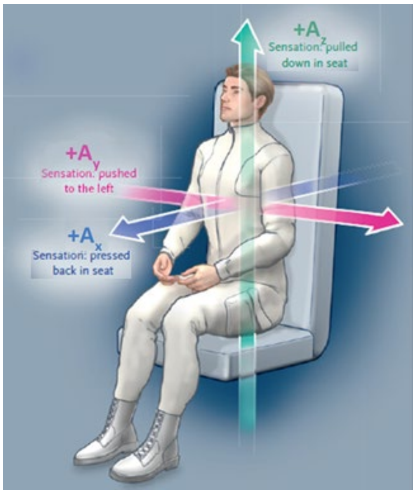
Application

Required Capabilities: Transportation

As with any moving vehicle, a rover will expose occupants to accelerations and vibrations during operation, the severity of which will be determined by velocity, turning radius, extraterrestrial terrain, seat design, etc. NASA-STD-3001 has general acceleration (linear and rotational) and vibration technical requirements, as well as ones specific to rovers. Any rover will have to limit accelerations and vibrations experienced by the crew to limits defined in those technical requirements.

- **Volume 2 Section 6.5: Acceleration and Dynamic Loads**
- **Volume 2 Section 6.7: Vibration**

Reference OCHMO-TB-024 Acceleration Technical Brief for additional information.



Human body-axis reference frame used in NASA STD-3001

Translational Acceleration and Jerk

- Similar to a terrestrial vehicle, a rover will primarily move in the X-axis relative to the driver and passengers when properly seated. However, experimental rover designs are showing some potential differences that would introduce new considerations, such as standing operators and omni-rotational wheels. In addition, the Lunar surface combined with lower gravity will introduce Z-axis accelerations that are experienced on earth.
- **[V2 6154] Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits, [V2 6155] Extraterrestrial Surface Transport Vehicle Translation Jerk Limits**

Car crash test showing blunt force to a dummy

Blunt Trauma

- The Lunar surface could present turbulent rides where crewmembers are rocked in their suits. Restraints within suits themselves are limited, so there will be a risk of blunt trauma when rocks and other obstacles are encountered.
- **[V2 6156] Extraterrestrial Surface Transport Vehicle Blunt Trauma Limits**

Vibration

- The same considerations from the above technical requirements will also apply to vibrations.
- **[V2 6160] Extraterrestrial Surface Transport Vehicle Vibration Limits for Health and Performance**

Application

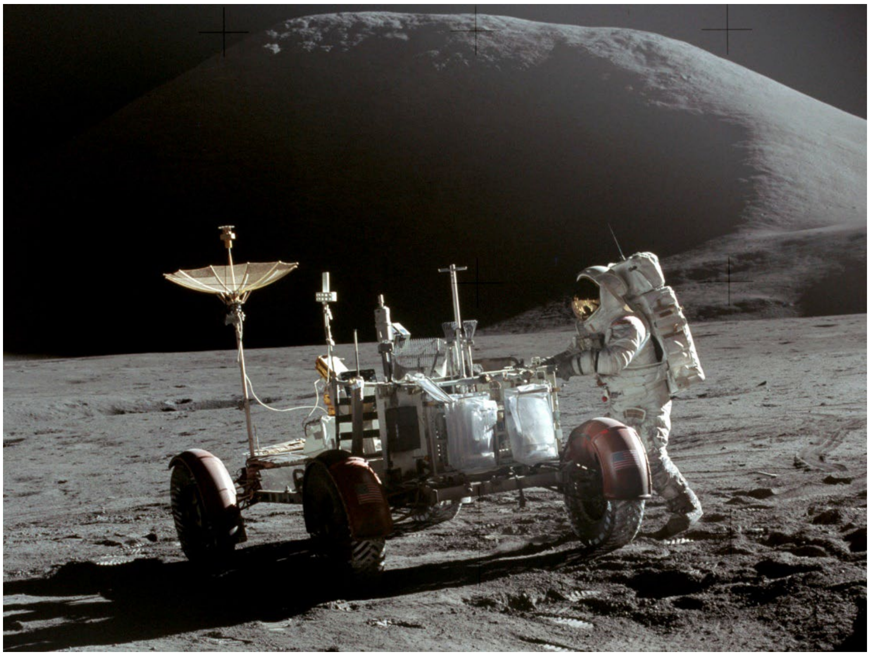
Required Capabilities: Payload Stowage

Integrated architecture

- The payload and stowage requirements of the system will be dictated by the needs of the mission. Those needs must be balanced with the capabilities of the rover (maximum payload, stowage volume, etc.).

Tools and equipment

- Each piece of equipment must be stored in a dedicated location accessible by a suited crewmember.



Apollo lunar rover with payload

Sample Storage

- The mission might require the collection and storage of samples and specimens. Volume must be allocated to accommodate these items, with appropriate containment and isolation.

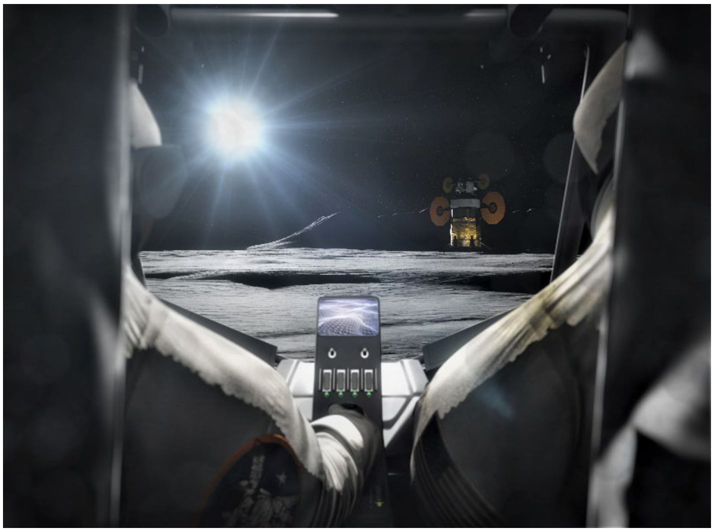
Stowage Technical Requirements

- **Volume 2 Section 7.6: Stowage Provision and Accessibility**

Reference OCHMO-TB-025 Cabin Architecture Technical Brief for additional information on stowage.

Application

Required Capabilities: Communication, Displays, & Interfaces



Rendition of Artemis lunar rover interface

Communications

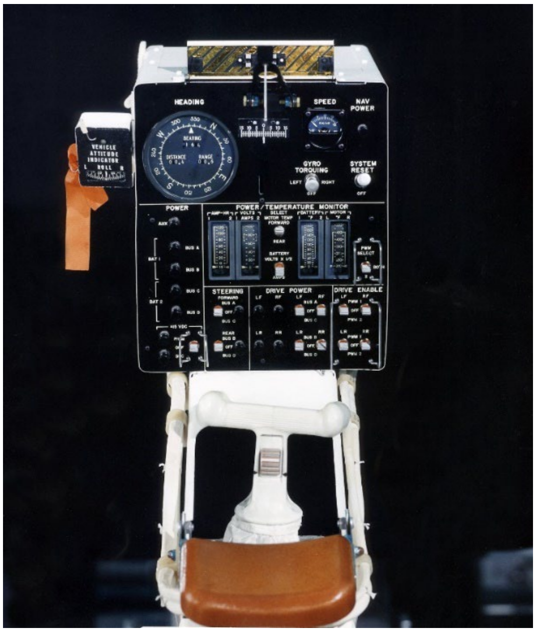
- Communications through the rover will be limited due to the restraints of space, but data can still be collected, sent, and received between the rover, crewmembers, lunar systems and ground control.
- **[V2 10083] Communication System Design, [V2 10084] Communication Capability**

Displays

- Displays must be legible by a suited crewmember; it must be designed with consideration for the helmet and visor worn during the mission. Display design must also take vehicle motion/turbulence into account.
- **[V2 Section 10.1: General for Performance and Crew Interfaces], [V2 Section 10.3: Displays], [V2 Section 10.7: Information Management]**

Interfaces

- Interfaces must be operable by a suited crewmember during all phases of vehicle operation. An ergonomic and anthropometric analysis will determine the placement and arrangement of interfaces to facilitate vehicle operation.
- **Volume 2 Section 10.2: Layout of Displays and Controls, Volume 2 Section 10.4: Control Design**

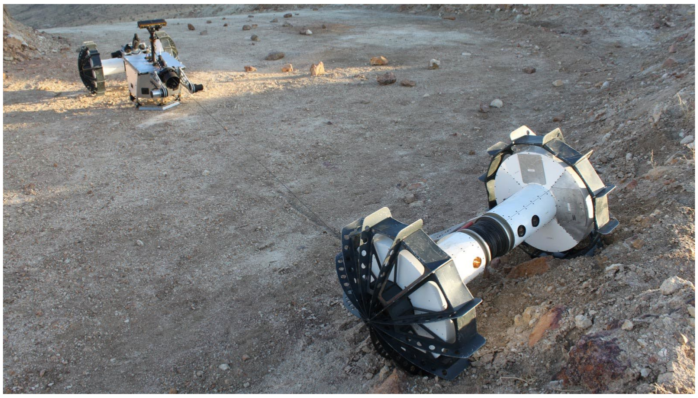


Apollo lunar rover control panel

Reference OCHMO-TB-005 Usability, Workload, and Error Technical Brief for additional information.

Application

Required Capabilities: Automation & Remote Operation



Remote Operation

- The mission may require the crew to operate the rover remotely to support EVAs. The rover may be delivered to the extraterrestrial surface during an uncrewed mission, and driven remotely to the human landing site, or the rover may be used to shuttle supplies between two worksites.

Follow-Along

- The rover may need to operate semi-autonomously, such as during follow-along tasks, where an uncrewed rover follows a crewmember traveling on foot at a set distance and behavior profile.

Automation Technical Requirements

- **Volume 2 Section 10.6: Automated and Robotic Systems**

Reference OCHMO-TB-017 Automated and Robotic Systems Technical Brief for additional information.

Application

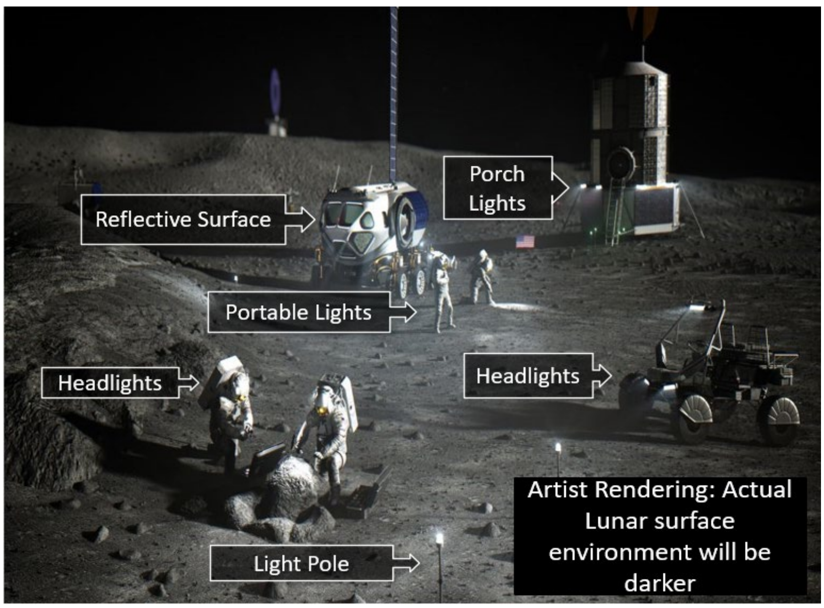
Required Capabilities: Lighting

Lighting

- For operations during Lunar night or located in shadowed areas, headlights or an equivalent lighting system can aid in navigation or illuminate a work area.

Headlights

- Like any vehicle, forward-facing lights will aid in navigation and help avoid obstacles.



Interior Lighting

- For unpressurized rovers, interior lighting refers to lighting for on-board items, such as displays and controls.
- Depending on if a display is backlight, it will either be unintelligible in areas that are exceedingly well lit or near complete darkness. Interior lighting, coupled with display design, must account for the large range of potential illumination levels.

Additional Lamps/Lighting

- The rover may be equipped to provide additional lighting at a task site. This could include active measures such as a posable spotlight, or passive measures such as reflectors to enhance existing natural light.

Lighting Technical Requirements

- **Volume 2 Section 8.7: Lighting**
- **[V2 8106] Extraterrestrial Surface Transport Vehicle (ESTV) Dashboard and Control Lighting**

Reference OCHMO-TB-001 Artemis Lighting Considerations Technical Brief and OCHMO-TB-026 Lighting Design Technical Brief for additional information.

Reference Data

The Dangers of Dust: Apollo 17 (1972) Rover Mishap

"Oh, you won't believe it. Ahh, there goes a fender! Oh, shoot!" - Gene Cernan

During EVA 1 for Apollo 17, a hammer on astronaut Gene Cernan's suit caught the rear passenger fender extension of the lunar rover and tore it off. This allowed a large amount of lunar to be flung at the Gene and equipment on the rover.

The broken piece was replaced using four maps of the lunar surface, duct tape, and telescope clamps.

Lunar rover with the fender replacement

Gene Cernan after EVA 3 with lunar dust on the lower half of his suit

For EVA activities, lunar dust can negatively impact visibility and performance.

Fender damage also occurred on Apollos 15 and 16, meaning that it has happened on all missions with EVA rover activity.

Future rover design should take events like this and other possible failures into consideration.

Reference OCHMO-TB-011 Lunar Dust Technical Brief for additional information.

Reference Data

Acceleration, Vibration and Jerk Requirements

Acceleration, Vibration and Jerk Technical Requirements were developed by tailoring information from various existing technical requirements

Acceleration and Jerk technical requirements were tailored from:

- SLS Emergency Egress System requirements which are based on ASTM F2291 standard for amusement park ride design

Vibration Health and Performance technical requirements were tailored from:

- NASA-STD-3001, Nasa Space Flight Human-system Standard, Volume 2: Human Factors, Habitability, And Environmental Health
- ISO 2631-1, Mechanical vibration and shock — Evaluation Of Human Exposure To Whole-body Vibration
- MIL-STD-1472H, and MIL-STD-1472G, Department Of Defense Design Criteria Standard: Human Engineering

Blunt Trauma technical requirements are based on NASA Anthropometry and Biomechanics Facility testing data

General Assumptions for all Requirements

- Unpressurized crewed ESTV/rover
- Crew will be wearing an EVA spacesuit
- Intra-suit restraints vs no intra-suit restraints
- Performance & Crew Health limits
- Foot restraints for all restraint configurations and considerations
- Design must include seatback
- Crew may not impact/contact each other laterally

Reference Data

Emergency Egress Acceleration and Jerk Limits

For ground emergency egress systems (EES), the system shall limit the magnitude and direction of crew exposure to accelerations according to following tables, EES Acceleration Limits – Sustained, and EES Acceleration Limits – Jerk.

Table 12.2-1—EES Acceleration Limits - Sustained

	NASA Category 0 Standing Unrestrained with Support Aids	NASA Category 1 Seated Unrestrained without Support Aids	NASA Category 2 Seated with Sufficient Support Aids	NASA Category 3 Seated with Restraints	NASA Category 4 Seated with Full Restraints
+/- Ax (Eyeballs In/Out)	|Ax| ≤ 0.3g	-0.3g ≤ Ax ≤ 1.8g If Az > 0.7g: -0.45g ≤ Ax ≤ 1.8g	-0.7g ≤ Ax ≤ 3.0g	-2.0g ≤ Ax ≤ 4.0g	|Ax| ≤ 4.0g
+/- Ay (Eyeballs Right/Left)	|Ay| ≤ 0.3g	|Ay| ≤ 0.3g If Az ≥ 0.7g: |Ay| ≤ 0.45g	|Ay| ≤ 1.0g	|Ay| ≤ 1.0g	|Ay| ≤ 1.0g
+/- Az (Eyeballs Down/Up) Gravity is +1.0g (Az)	0.7g ≤ Az ≤ 1.3g	0.2g ≤ Az ≤ 1.5g	0.2g ≤ Az ≤ 1.8g	-0.5g ≤ Az ≤ 2.0g If time > 30s: 0g ≤ Az ≤ 2.0g	-0.5g ≤ Az ≤ 2.0g If time > 30s: 0g ≤ Az ≤ 2.0g

Table 12.2-2—EES Acceleration Limits - Jerk

	NASA Category 0 Standing Unrestrained with Support Aids	NASA Category 1 Seated Unrestrained without Support Aids	NASA Category 2 Seated Unrestrained with Sufficient Support Aids	NASA Category 3 Seated with Restraints	NASA Category 4 Seated with Restraints
dAx/dt	3g/s	10g/s	20g/s	30g/s	40g/s
dAy/dt	3g/s	3g/s	10g/s	10g/s	10g/s
dAz/dt	4.5g/s	10g/s	12g/s	20g/s	20g/s

Verification will determine whether any of the sustained acceleration limits in Table 12.2-2 are exceeded for more than 200 ms for any passenger, given their assumed orientation and level of restraint. Per ASTM-F2291-20, section 7.1.1.2, all measured or simulated acceleration time histories will be post processed using a 4th-order, single pass, Butterworth low-pass filter with a corner frequency of 5 Hz.

ESTV/Rover applicability: With the existing suit designs at NASA, there are insufficient head and neck restraints to qualify for NASA Category 4 limits, so Category 3 was used to derive limits.

All referenced tables and figures are available in full in NASA-STD-3001 Volume 2 Revision D.

Reference Data

Sustained Translation Acceleration Requirements (> 0.5 seconds)

For acceleration, the physics of the celestial environment will limit the exposure duration to Az making the specified limits acceptable. With that, the following requirements were derived using the NASA Category 3 limits for EES. Refer to **[V2 6154] Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits** for the detailed technical requirement and rationale.

NASA Category 3 Seated with Restraints
$-2.0g \le Ax \le 4.0g$
$\lvert Ay \rvert \le 1.0g$
$-0.5g \le Az \le 2.0g$ If time > 30s: $0g \le Az \le 2.0g$

Sample Calculation

$+x$: $4g \times 9.81\ m/s^2 = 39.24\ m/s^2$

$-x$: $-2g \times 9.81\ m/s^2 = -19.62\ m/s^2$

Table 6.5-10—Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits

Acceleration Vector	Lap & Shoulder Restraint	Rigid HUT Attachment	
	Seated	Seated	Standing
+x	$Ax \le 39.24m/s^2$	$Ax \le 39.24m/s^2$	$Ax \le 39.24m/s^2$
-x	$Ax \ge -19.62m/s^2$	$Ax \ge -19.62m/s^2$	$Ax \ge -19.62m/s^2$
±y	$\lvert Ay \rvert \le 9.81m/s^2$	$\lvert Ay \rvert \le 9.81m/s^2$	$\lvert Ay \rvert \le 9.81m/s^2$
+z	$Az \le 19.62m/s^2$	$Az \le 19.62m/s^2$	$Az \le 9.81m/s^2$ *
-z	$Az \ge -4.9m/s^2$ if time < 30s $Az > 0m/s^2$ if time ≥ 30s	$Az \ge -4.9m/s^2$ if time < 30s $Az > 0m/s^2$ if time ≥ 30s	$Az \ge -1.57m/s^2$ *
*** Assumes occupant has had time to adjust to extraterrestrial gravity**			

The limits in the table below represent safe levels of sustained translational acceleration under nominal and off-nominal conditions. Exposure to accelerations above these limits could create a risk of occupant injury and significantly affect human performance for maneuvering and interacting with the rover. The physics of the lunar and/or Martian environment will limit the exposure duration to Az making the specified limits acceptable. The Ax and Ay limits must be met by a combination of vehicle design and con-ops (planned time versus distance of vehicle transits taking into consideration the traversed lunar/Martian terrain) which will limit exposure magnitude and duration.

Reference Data

Jerk Requirements

Following ASTM F2291-21, Section 7.1.1.2 guidance, the jerk limits were obtained by taking the differences between the +/- acceleration limits for the corresponding NASA Category 3 in the acceleration table and dividing the difference by the respective body axis's minimum onset duration (the minimum time before describing "transient" jerk) of 200ms for the x- and y-axes and 133ms for the z-axis. Information from that using the NASA Category 3 jerk limits were used to derive the following requirements. Refer to **[V2 6155] Extraterrestrial Surface Transport Vehicle Translation Jerk Limits** for the detailed technical requirement and rationale.

NASA Category 3 Seated with Restraints
$-2.0g \leq Ax \leq 4.0g$
$\lvert Ay \rvert \leq 1.0g$
$-0.5g \leq Az \leq 2.0g$ If time > 30s: $0g \leq Az \leq 2.0g$

Sample Calculation
X axis:
a) Difference of respective body axis
$4\ g - 2\ g = 6\ g$
b) Conversion to m/s^2
$6\ g \times 9.81\ m/s^2 = 58.86\ m/s^2$
c) Dividing by axis onset duration
$58.86\ m/s^2\ /\ 200\ ms = 294 m/s^3$

Table 6.5-11—Extraterrestrial Surface Transport Vehicle Translation Jerk Limits

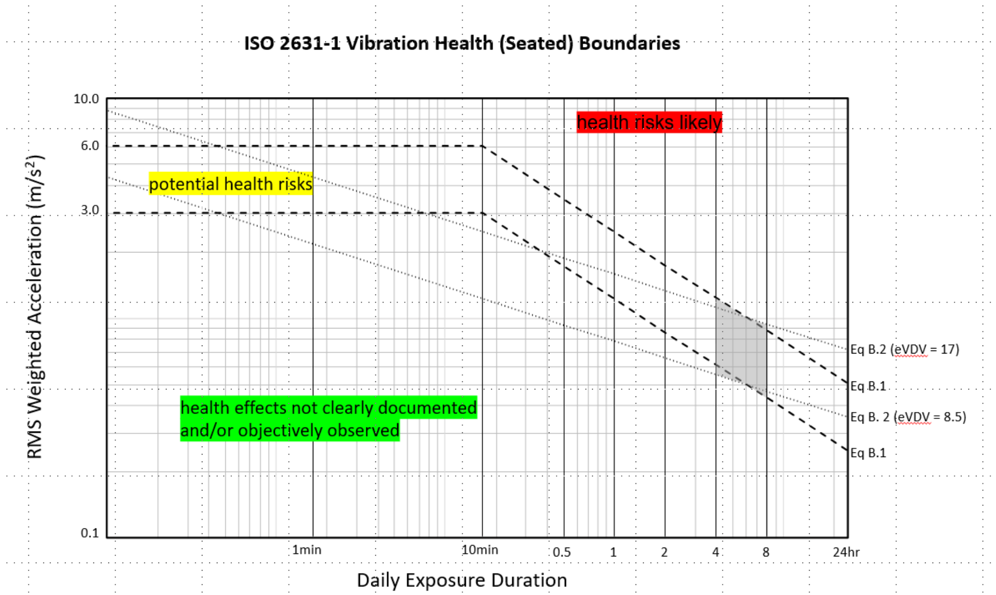
Jerk Vector	Lap & Shoulder Restraint	Rigid HUT Attachment	
	Seated	Seated	Standing
dAx/dt	294m/s^3	294m/s^3	294m/s^3
dAy/dt	98m/s^3	98m/s^3	98m/s^3
dAz/dt	196m/s^3	196m/s^3	98m/s^3

This requirement assumes 1) no intra-suit restraints other than a standard harness seen in previous iterations of the EMU-style suit configurations, 2) the vehicle provides proper foot restraints and back support in the proposed design, and 3) an occupant envelope that restricts the crew from contacting each other laterally. Additional occupant restraints in the form of inserts and suit modifications were not considered.

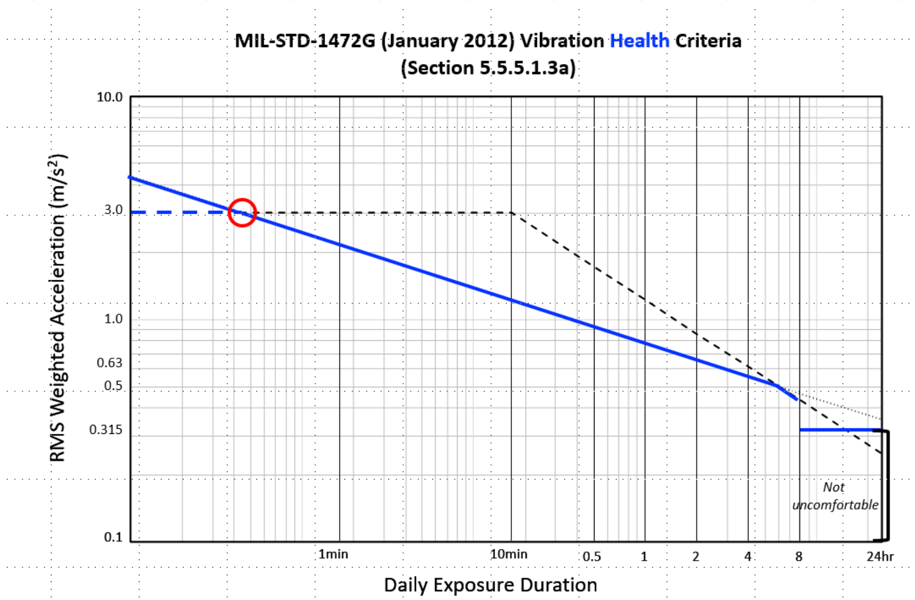
Reference Data

Vibration Requirements

For vibration requirements, data from ISO2631-1 was adopted to ensure health and safety of the crew members (Section A in graph below) , data from MIL-STD-1472G/H was adopted to determined levels for performance and comfort (sections B and C in graph below). Exposure to accelerations above these limits could create a risk of occupant injury and significantly affect human performance for maneuvering and interacting with the ESTV. Refer to **[V2 6160] Extraterrestrial Surface Transport Vehicle Vibration Limits for Health and Performance** for the detailed technical requirement and rationale.



Zone A
Derived Health and performance guidance from ISO2631-1 for short duration exposures ($1s \leq t \leq 17s$)



Zones B and C
Derived Health and performance guidance from MIL-STD-1472G/H

for Zone B
($17s < t \leq 6hr$)
and
Zone C
($6hr < t \leq 24hr$)

Reference Data

Special Considerations: Pressurized Rovers

For all intents and purposes, a pressurized rover (JAXA concept shown below) is functionally similar to any other habitable volume. It must keep unsuited crew alive and support mission tasks while adhering to program requirements.

Features Specific to Pressurized Rovers Compared to Unpressurized Rovers

Habitable Volume

- The crew must have space to perform intravehicular tasks while suited or unsuited, including vehicle operation, EVA suit donning/doffing, IVA translation, etc.
- Day-to-day tasks such as eating, sleeping, personal hygiene, and waste management must be accommodated.

Environmental Control and Life Support

- Temperature, pressure, and oxygen levels must be controlled.
- There will be a risk for dust inhalation by unsuited crewmembers.

Consumables

- Air, water, and food must be provided to crew for the duration of the mission.

Back-Up

Major Changes Between Revisions

Original → Rev A

- Updated information and standards to be consistent with NASA-STD-3001 Volume 1 Rev C and Volume 2 Rev D.

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

NASA-STD-3001 Volume 2 Revision D

[V2 6154] Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits The extraterrestrial surface transport vehicle (ESTV) system shall limit the magnitude of crewmember exposure to sustained (>0.5 seconds) translational acceleration by staying below the limits in Table 6.5-10—Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits, which specify the ±Ax, ±Ay, and ±Az translational acceleration limits appropriate for specific restraint conditions.

[V2 6155] Extraterrestrial Surface Transport Vehicle Translation Jerk Limits The extraterrestrial surface transport vehicle (ESTV) system shall limit the crewmember exposure to translational jerk to the limits given in Table 6.5-11—Extraterrestrial Surface Transport Vehicle Translation Jerk Limits, which specifies the ±Ax, ±Ay, and ±Az translational jerk limits appropriate for specific restraint conditions.

[V2 6156] Extraterrestrial Surface Transport Vehicle Blunt Trauma Limits The extraterrestrial surface transport vehicle (ESTV) system shall limit the crewmember exposure to blunt trauma forces to the limits given in Figure 6.5-9—Extraterrestrial Surface Transport Vehicle Blunt Force Maximum Allowable Depth of Compression Limits (Seated or Standing Vehicle Occupants), which specifies the maximum allowable depth of compression across the occupant body (seated or standing), and below 18 pounds-force (lbf) across boney locations of concern outlined in Figure 6.5-10—Anthropometric Locations for Blunt Trauma Limits & Boney Locations of Concern:

a. Manubrium of the Sternum – Point 1
b. Sternum (body) – Point 2
c. Clavicle – Points 10 & 11
d. Lateral aspect of the Thorax – Points 22 & 23
e. Vertebral Column – Points 40, 41, & 42
f. Cervical Spine (C7) – Point 48
g. Scapula – Point 31
h. Spine – Point 39
i. Acromion Process – Point 49
j. Elbow (olecranon process) – Point 61

[V2 6160] Extraterrestrial Surface Transport Vehicle Vibration Limits for Health and Performance The extraterrestrial surface transport vehicle (ESTV) system shall limit crewmember exposure to vibration to less than the limits given in Figure 6.7-2—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants) and Table 6.7-2—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants), which specify the allowable accumulated duration (dosage per 24-hour day) of vibration for both standing or seated crewmembers in all restraint conditions.

All referenced tables and figures are available in NASA-STD-3001 Volume 2 Revision D.

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

NASA-STD-3001 Volume 2 Revision D

[V2 Section 7.6] Stowage Provision and Accessibility

[V2 8033] Restraints for Crew Tasks The system shall provide restraints for expected crew operations.

[V2 8038] Restraint and Mobility Aid Standardization
Restraints and mobility aids shall be standardized, clearly distinguishable, and located to aid crewmembers in starting or stopping movement, changing direction or speed, or translating equipment.

[V2 8106] Extraterrestrial Surface Transport Vehicle (ESTV) Dashboard and Control Lighting The system shall provide active lighting and attenuation of solar light for manual controls (e.g., unpressurized surface transport vehicle joystick controls, switches and dashboard) and display screens to be visible in all potential natural light levels, including complete darkness.

[V2 Section 8.7] Lighting

[V2 Section 10.1] General for Performance and Crew Interfaces

[V2 Section 10.3] Displays

[V2 Section 10.2] Layout of Displays and Controls

[V2 Section 10.4] Control Design

[V2 10073] Control Operation Supports and Restraints The system shall provide body or limb supports and restraints that enable accurate crew control of applicable interfaces and prevent inadvertent control inputs during expected microgravity, acceleration, and vibration conditions.

[V2 10083] Communications System Design Communication systems shall be designed to support coordinated and collaborative distributed teamwork.

[V2 10084]Communication Capability The system shall provide the capability to send and receive communication among crewmembers, spacecraft systems, and ground systems to support crew performance, behavioral health, and safety.

[V2 Section 10.6] Automated and Robotic Systems

[V2 Section 10.7] Information Management

[V2 12024] Restraints and Platforms The system shall accommodate restraint and platform placement that ensures the reach and work envelope of the suited or unsuited ground support personnel for the required tasks.

All referenced tables and figures are available in NASA-STD-3001 Volume 2 Revision D.

Reference List

1. Campbell, M. (2015). Duct Tape Auto Repair on the Moon. National Air and Space Museum. https://airandspace.si.edu/stories/editorial/duct-tape-auto-repair-moon
2. Creel, R. (2005). Lunar Roving Vehicle (LRV) Missing Fender Extension Saga. NASA. https://www.hq.nasa.gov/alsj/LRV_Fender_Extensions.pdf