Desert Research and Technology Studies (D-RATS) 2022 Test Report

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ESDMD M2MADO HITL Test Team

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PURPOSE

- The primary purpose of the 2022 Desert Research and Technology Studies (D-RATS-22) analog mission field test was to provide data and recommendations regarding how pressurized rover (PR) design, cabin configuration, driving modes, timeline constraints, and mission operations can be acceptably implemented to support future Artemis missions that include a PR
- The goal of these evaluations was to provide first-order feedback and data on design concepts currently being traded as options for future pressurized rover flight prototypes
- The Japan Aerospace Exploration Agency (JAXA) may provide a PR for future Artemis missions
- One of the primary objectives of D-RATS 2022 was to share with the JAXA PR team the processes and protocols by which NASA has learned to successfully evaluate rover concepts through integrated HITL evaluations over the past 20+ years, so that JAXA could apply any applicable lessons learned to their PR design, development, testing, and evaluation
  - D-RATS-22 field testing incorporated JAXA design concepts under investigation, with JAXA's direction and support, and provided JAXA astronauts and engineers an opportunity to experience living and working from within a pressurized rover in an analog exploration operations environment
  - D-RATS-22 made use of the NASA GEN 1B rover as its analog PR, which was modified to incorporate some of the PR design concepts of interest to the JAXA PR team
  - NASA GEN 1B was not fully representative of the Artemis PR that JAXA might provide in the future, and this distinction was accepted by both the NASA and JAXA test teams prior to testing. That said, the NASA GEN1B rover provided an acceptable proxy for testing to address the specific objectives identified for D-RATS 2022

NASA's GEN 1B pressurized rover (PR) testbed was updated to include a "drive-by-cameras" driving mode, shown here with windows blocked in day (top) and night (bottom) tests

D-RATS 2022 provided hands-on experience for JAXA rover designers, engineers, and operators to work alongside NASA counterparts as well as a core integrated NASA/JAXA test team

Executive Summary (2 of 3)

BACKGROUND

- **Artemis Challenges –** NASA's concept of operations (ConOps) for the Artemis mission architecture brings new challenges for human exploration of the lunar surface, including: (1) Low-angle, natural lighting at lunar south pole; and (2) Exploration sites that challenge communication with Earth
- **International Partner Involvement –** NASA is working with JAXA to scope mission & functional requirements for an Artemis Pressurized Rover, which JAXA may provide
- **Charter –** HQ Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Development Office (M2MADO) Strategy and Architecture Office (SAO) chartered the Human-in-the-Loop (HITL) test team to investigate Artemis architectural questions related to pressurized rover ConOps
- **Rationale –** to inform the NASA/JAXA pressurized rover study-agreement

PLAN

- **High-Level Objectives** – The D-RATS analog tests conducted in October 2022 addressed three high-level objectives:
  1. Investigate PR ConOps and capabilities for Artemis exploration
  2. Integrate with JAXA engineers & astronauts and incorporate JAXA PR design elements into testing
  3. Re-establish analog field-testing skills & capabilities with rovers to investigate Artemis architecture ConOps
- **Secondary Objectives** – Work with other groups to leverage D-RATS field test for additional objectives
  4. Work with the Public Affairs Office (PAO) to perform D-RATS public outreach activities
  5. Coordinate with the Human Physiology Performance Protection & Operations (H-3PO) team to facilitate in-field evaluation of human health and performance (HHP) objectives
  6. Share D-RATS field-site and assets with Lunar LTE Studies (Lunar LiTES) team, to aid their study of the use of 4G/LTE communication protocols and devices for astronauts and robotic nodes on the lunar surface
- **Team –** Fully integrated test team comprised of members from 5 NASA centers, JAXA, and the United States Geological Survey (USGS)
- **Location –** Black Point Lava Flow, ~40 miles north of Flagstaff, AZ

Simulated low-angle sunlight/long shadows at lunar poles by testing at night with portable, high-intensity light

NASA crew performing night EVA

D-RATS 2022 re-established mission-class, terrestrial, field-analog capability with rovers and provided initial conops recommendations to support Artemis strategy and architecture objectives

Executive Summary (3 of 3)

HIGH-LEVEL OBJECTIVES ACCOMPLISHED

- **Investigated Pressurized Rover ConOps & Capabilities for Artemis Exploration** (Objective 1)
  - Completed testing with 3 crew pairs, each spending 3 days and 2 nights in the rover conducting Artemis PR day-in-the-life activities (2 JAXA astronauts, 2 JAXA engineers, 1 NASA astronaut, 1 NASA engineer)
  - Collected detailed objective & subjective data supporting 10 strategic questions related to Artemis PR operations
  - Geologists present in the field observed rover operations and EVAs
  - Science Team in Houston analog MCC communicated directly with crew
  - Demonstrated crew-led and MCC-led PR teleoperation use cases during EVAs
- **Integrated with JAXA Engineers & Astronauts and Incorporated JAXA PR Design Elements into Testing** (Objective 2)
  - NASA & JAXA engineers, flight controllers, scientists, roboticists, and astronauts directly participated in and/or observed testing both in field and in analog MCC-Houston
  - Incorporated JAXA PR design elements into both integrated and standalone testing at JSC and in the field
- **Re-established Analog Field-Testing Skills & Capabilities with Rovers to Investigate Artemis Architecture ConOps** (Objective 3)
  - Multiple teams successfully worked to establish and manage field-test base camp, monitor and maintain the rover, and plan and execute 2 weeks of consecutive field-testing with little to no breaks between crews

TEST OUTCOMES

- Results will inform Artemis architecture ConOps & capabilities related to pressurized rover operations (see sections 2 and 3 for more details)
- NASA delivered the raw data presented herein to the JAXA PR team immediately after the tests were completed, for their internal analyses as needed (NASA did not have a need to do their own parallel analyses)
- Summary and team detailed reports will be posted on the D-RATS 2022 wiki

Rover analog testbed climbing ~20-degree hill

JAXA crew performing night EVA, MCC teleoperating PR

Accomplished 3 high-level objectives: (1) investigated PR ConOps & Capabilities for Artemis exploration; (2) incorporated JAXA pressurized rover design elements in testing; and (3) re-established analog field-testing skills & capabilities with rovers

Section 2

Quicklook Report

2.1 Changes to Pressurized Rover Utilization Since D-RATS 2011

- **Artemis Architecture ConOps bring new challenges:**
  - **Low angle natural lighting at lunar poles** → Long Shadows & High-Contrast light/dark terrain
  - **Exploration sites that challenge communication** → Exploring craters can easily block line-of-sight communications (comm)
- **International Partner Involvement**
  - NASA working closely with JAXA to scope mission & functional requirements for an Artemis PR, which JAXA may provide
  - JAXA PR design concepts include new capabilities for development, testing and evaluation
- **Remote Analog Mission Control Center (A-MCC) in Houston**
  - Networked a remote A-MCC from the Einstein Room in Houston:
    - Lowered cost: (13+ people were able to support remotely instead of from the field)
    - Provided a more flight-like environment that could become a training environment
- **Involvement of Artemis-Assigned End-Operators**
  - Astronauts, CAPCOMs, Scientists, and EVA Officers, all actively assigned to Artemis-related work, supported testing from the A-MCC (13 NASA / 2 JAXA)
    - Brought real-world focus and quality to the D-RATS planning and tests
    - Provided multiple days of flight-like experience to Artemis operators
- **SMD-selected scientists drove exploration objectives using Artemis SMD priorities**
- **Rover Upgrades**
  - Upgraded PR testbed lighting, camera and navigation aids, based on preliminary results from FY21-22 M2MADO Integrated EVA-Lunar Terrain Vehicle (LTV) Lighting & Nav Simulation tests

High-Intensity Light Simulated Low-Angle Sun at Lunar Poles

A-MCC in Einstein Room in Houston

New challenges and capabilities yielded Artemis-specific lessons learned and forward work needs

2.2 Test Hardware Utilized

- **Rover -** Cabin 1B Pressurized Rover (PR) testbed
  - New external cameras & removable interior monitors for driving
- **Backpacks** - Shirtsleeve informatics backpacks with camera, lights, and comm
- **Tools** - EVA tool kit & tool carrying easel
- **Simulated Sunlight** - Light-weight, high-intensity, portable light to simulate low-angle sun (32K lumens)
- **Communications Equipment** - Radios, antennas, etc.

Cabin 1B Pressurized Rover Testbed

Removable Array of Driving Monitors

Next Gen Informatics Backpacks (~35 lbs.)

EVA Tools Stowed on Tool Easel

Toolbox w/ Tool Carrier & Sample Drawers

Portable "sun"

2.3 Objective-1 Summary (1 of 2)

"Investigate pressurized rover ConOps and capabilities for Artemis exploration"

- **Collected detailed objective and subjective data addressing 10 areas related to Artemis pressurized rover operations**
- **SMD team was integral in developing the science plan based on real precursor data for BPLF**
  - Terrain-appropriate rover traverses
  - Precision-selected science areas and EVA traverses
  - Real-time truthing of rover and crew exploration via in-field out-of-sim scientists
- **FOD EVA integral in developing EVA procedures**
  - Cuff checklists and sampling plans for each EVA site
- **Examination of PR teleoperations use cases during EVA**
  - Decision maker: Crew-directed or MCC-directed
  - Purpose:
    - Crew Leads (PR follows, providing enhanced lighting, comm link, SA camera views to A-MCC, and tool carrier support)
    - Crew Follows (PR leads, providing precision navigation to subsequent location of interest, plus all the above)

Data Collection Areas

1. Driving with windows and with camera-projected displays
2. Exterior lights and cameras for driving and EVA support
3. Interior cabin layout
4. Habitation activities
5. Logistics stowage and management
6. Trash stowage and management
7. Exterior stowage and management of EVA tools and samples
8. Rover teleoperations
9. Flight Rules for PR operations
10. Advantages and limitations of incorporating a SCICOM

Engineering crew performing night EVA ConOps

2.3 Objective-1 Summary (2 of 2)

"Investigate pressurized rover ConOps and capabilities for Artemis exploration"

- **High-Level ConOps Lessons Learned**
  - Development of plan and ops products is at reasonably high maturity level
  - Rover assets (e.g., exterior lights, cameras, tool & sample support, comm relay, precision nav) are highly enabling for EVA effectiveness and efficiency – in some cases even more essential than in the mid-latitude landing site case
  - MCC tools that allow for quick and efficient PR operations (e.g., remote driving, selection and control of exterior cameras and lights) will be essential to taking full advantage of the vehicle's presence near the crew
  - Direct Science communication with EV crew via a science communicator (SCICOM) is both more efficient and achieves better science than funneling science conversations through the capsule communicator (CAPCOM)
  - Exploration lessons learned would be largely just as applicable to the LTV rover (enabling capabilities are very similar)

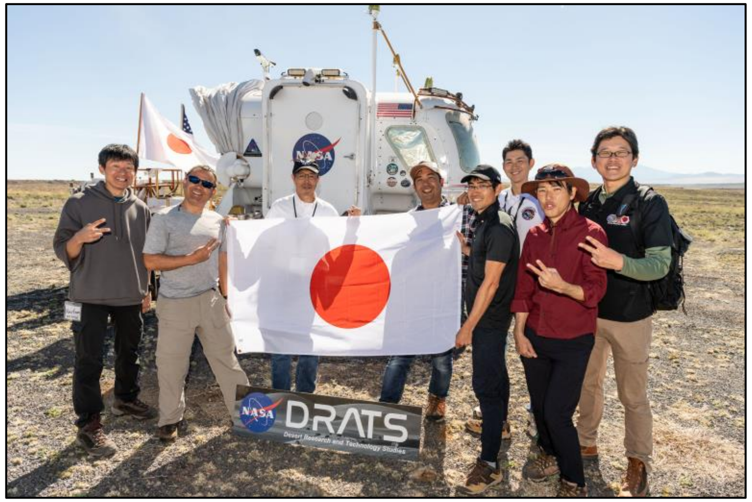
- **ConOps Caveats**
  - On Artemis missions, the Rover will provide the comm relay from the EVAS assets to Earth. Our setup was such that each suit and the Rover could independently transmit to "Earth" (MCC)
  - Crew and A-MCC did not have the ability to directly teleoperate the rover themselves; this was accomplished by out-of-sim rover support personnel who remotely controlled the vehicle from the field based on verbal direction from the crew or A-MCC
  - "Sim Quality" for the CAPCOM vs. SCICOM objectives was FAR TOO LOW to draw sweeping conclusions. For instance, there was only a single EVA operator, CAPCOM played dual roles as CAPCOM/FD, and no consumables or systems statuses were modeled. Thus, this conclusion represents the "perfect day" where the only thing going on was the science objective of the EVA in progress

- **Recommendations for Future Testing**
  - Re-architect the comm for D-RATS such that EV suit comm must be relayed through Rover assets
  - Implement the capability to do all rover teleoperations commanding remotely from A-MCC
  - Investigate using the M2MADO Integrated EVA-Rover Lighting & Nav sim with key Flight Controller staffing to better understand the Artemis ConOps with a PR

2.4 Objective-2 Summary (1 of 3)

"Integrate with JAXA engineers & astronauts and incorporate JAXA PR design elements into testing"

- **JAXA PR leads, engineers, flight directors, scientists, roboticists, and astronauts directly participated in and/or observed:**
  - Periodic coordination meetings with JAXA personnel FY22
  - Pre-mission training at JSC (lighting and nav VR simulation, science/geology training, rover driving)
  - Field testing
  - Standalone testing
  - A-MCC operations in Houston
- **Both business and personal relationships were forged**
- **JAXA design ideas were incorporated in rapid-prototyping fashion:**
  - Driving cameras + internal monitors
  - Steering angle limitations
  - Slope estimation and obstacle avoidance tests with driving cameras (standalone testing conducted in the field)
  - Toilet concept (standalone testing conducted in the field)
- **JAXA Test Report** is available upon request from JAXA



JAXA team photo by rover

JAXA Support team in field-site comm. center

2.4 Objective-2 Summary (2 of 3)

"Integrate with JAXA engineers & astronauts and incorporate JAXA PR design elements into testing"

- **Important note on PR Windows and Driving Cameras:**
  - Two "bookend" driving modes were evaluated this year: Driving with Cabin 1B windows (drive-by-windows) and driving with JAXA-specified driving cameras projected onto internal cabin monitors (drive-by-camera)
  - Please note, JAXA's PR concept is NOT "*no windows*" – but rather their goal was to understand if and how windows might be able to be minimized (because windows = mass + other pressure vessel design challenges), how windows can best be augmented with camera views (especially given the challenging lighting conditions of the lunar south pole), and what specifications those cameras and associated internal displays should have (including FOV, screen resolution, etc.)
- **High-Level Lessons Learned**
  - Driving with cameras-only in the as-tested camera configuration is, at best, half as fast as driving with windows:
    - There was a common perception among all test crews that they were driving faster than they actually were when camera driving mode was enacted because of the optical flow pattern of the camera imagery across the internal display screens
    - Also, because FOV of the camera mounted on the rover was limited and some of the driving cameras were closer to the ground than the crew physically were, they felt like they were going faster than they really were
  - Science results significantly suffered in the as-tested camera driving mode:
    - The crew provided less contextual and detailed science descriptions, and targets of interest were missed, as verified by scientists in the field observing from outside of the PR and scientists in A-MCC examining incoming footage from the rover mast cameras
    - The root cause could be monocular lens of camera with which a driver perceives the view as nearly "two-dimensional", as well as insufficient resolution of tested cameras

Driving rover in drive-by-camera mode at night w/ windows blacked out

Rover at night with windows coverings removed

Driving in "drive-by-camera" mode (at dusk)

Through D-RATS 22 participation, JAXA has a much better understanding of some of the design tradeoffs for integrating windows and cameras

2.4 Objective-2 Summary (3 of 3)

"Integrate with JAXA engineers & astronauts and incorporate JAXA PR design elements into testing"

- **Caveats**
  - Only the extreme bookends (windows only, cameras only) were tested this year
  - The camera mode tested at D-RATS-22 (external cameras feeding flatscreen monitors) is well below what today's high-end technology allows
    - Clearly, multiple huge windows lends superior mission performance over no windows, limited cameras, and flat screens to assimilate the camera views
- **Recommendations for Future Pressurized Rover Testing**
  - Future tests should evaluate alternate window, camera and visualization tool configurations to further explore the design trade space e.g.:
    - Other camera configurations (e.g., combinations of narrow and wide-FOV, higher resolution, different mounting locations)
    - Other monitor configurations (e.g., alternate number of displays, higher resolution, different mounting location)
    - Projection-mapping to rover front wall
    - Evaluate 3D HD 360 cameras with VR headsets
    - Evaluate High-mounted LiDAR
    - Driving-assist information overlayed on the displays
  - Alternate external lights should be evaluated (e.g., controllable illuminance, variable beam width and distance, high-beam switching)

The JAXA team was fully engaged and took many relevant lessons learned back with them. The stage has been set for productive future work.

JAXA crew driving rover at night

JAXA crew performing night EVA

2.5 Objective-3 Summary (1 of 3)

"Re-establish rover analog field-testing skills & capabilities to investigate Artemis architecture ConOps"

- **Next generation test team now experienced with:**
  - Basecamp organization, setup, and tear down
  - Field support
  - In-field rover refurb & maintenance
  - Comm infrastructure and support for in-sim (e.g., between crew & A-MCC) and out-of-sim needs
  - Remote A-MCC operations and operators
  - Mission management
- **Re-established logistics contacts and requirements**
  - Shipping
  - Mobilize (mob)
  - De-mobilize (de-mob)
- **NASA Cabin 1B+Chassis completely refurbished and once again habitable and mobile to serve as mockup Artemis PR**
  - **Chassis**: rebuilt suspensions, transmissions, steering; installed new batteries; added toolbox
  - **Cabin**: incorporated new camera systems and comm system; created removable multi-display system; repaired AC and PWS; replaced interior cushions, wall panels, window tint; insulated cabin skin; redesigned seat mechanism
- **Analog MCC capabilities developed in Houston**
  - Voice communication
  - Video
  - GPS tracking

Rover team members servicing rover in tent

Rover team member servicing rover steering unit in tent

D-RATS 2022 re-developed test team capabilities, skills, and partnerships

2.5 Objective-3 Summary (2 of 3)

"Re-establish rover analog field-testing skills & capabilities to investigate Artemis architecture ConOps"

- **High-Level Field-Test Execution Lessons Learned**
  - Having an analog-MCC team in Houston is the right answer for MCC support of an analog test; but the A-MCC facility we utilized had challenges, e.g.
    - Firewall we couldn't control, which caused video delays
    - Voice comm solution periodic instability
  - Numerous field comm challenges – most overcome in real-time. We think we understand how to solve the remainder before next time
  - Reinforced the need for locking down the detailed test objectives, associated test timeline, and vehicle telemetry metrics (e.g., GPS data, speed, rock hits, wheel angles, etc.) several weeks prior to crew training

Test Crew 1 Night EVA near Red Stone Outcropping

- **Recommendations for Future D-RATS Test Support**
  - Find a different facility for A-MCC or negotiate permissions that allow for clean video
  - Invest in-the-field comm hardware upgrades that were identified
  - Continue to include SMD filled science backroom with potential additional scientists from international partners

An analog-MCC in Houston, staffed with Artemis-Assigned End-Operators was the right solution, but more work is needed to improve hardware and connectivity

MCC Team Overseeing Night EVA from Analog MCC room

2.5 Objective-3 Summary (3 of 3)

"Re-establish rover analog field-testing skills & capabilities to investigate Artemis architecture ConOps"

- **Artemis ConOps Rover Lessons Learned**
  - A couple of crewmembers felt nausea while driving. It is unknown how possible factors like terrain roughness, night driving, lack of active suspension on the rover, and reliance on cameras may have contributed.
  - ConOps planning for stuck vehicles needs to be considered
  - Tool Refinement needed for Science Evaluation Room (SER) Situational Awareness (SA) (e.g., viewing and control of cameras)
    - Video resolution from mast cams
    - Triaging cameras back to A-MCC in support of science and operations

MCC Team Overseeing Night EVA from Analog MCC room

- **Recommendations for Future D-RATS Testing**
  - Isolate factors that contribute to motion sickness if it should occur in the future
  - Develop protocols and capabilities for freeing a stuck vehicle. Opportunity for standalone and integrated testing to free a stuck vehicle

Analog Rover Stuck in a Gully

A new generation of team members is now experienced in executing a D-RATS mission with Artemis unique challenges, IP involvement, and the logistical complexities that come with fielding rovers

2.6 Secondary Objective Summaries (1 of 2)

Objective-4 Summary: Worked with the Public Affairs Office (PAO) to perform D-RATS public outreach activities

- **Documentary teams from Felix & Paul Studios and National Geographic documented the crew missions**
- **Worked with PAO and held a D-RATS Media/Outreach Day the day after testing concluded**
  - Student Outreach was scheduled for the first half of the day
    - Over 190 home school, middle school, high school, college and community college students attended to learn about Desert RATS and take photos inside the rover
    - Students rotated between stations where they could see hardware that was used and ask questions of team experts
  - Media & Legislator Outreach was scheduled for the second half of the day
    - The Mayor of Flagstaff Paul Deasy, AZ State Sen. Theresa Hatathlie, and staffers for Sen. Sinema and Re. O'Halleran attended
  - 22 Media outlets attended and conducted interviews with mission managers and with rover operators during rover rides. Major outlets included:
    - Media spent time walking through the stations we had set up while 1:1 interviews took place and got the opportunity to ride in the rover. Approximately 25 interviews were supported on that day and in the weeks that followed.
    - Major outlets included: NBC, Fox, CNN, NPR, PBS, ITV
    - Japanese media included : NHK News Japan, Tokyo Broadcasting, Asahi Shimbun, Yomiuri Shimbun, Kyodo News and Nippon News
- See 3.7 for more details on D-RATS public outreach

Flagstaff Mayor Paul Deasy attended both the Lowell Observatory event and Media/Outreach Day. Arizona State senator Theresa Hatathlie and staffers for Sen. Sinema and Rep. O'Halleran also attended Media/Outreach Day

Media/Outreach succeeded in engaging the public and spreading the Artemis message

2.6 Secondary Objective Summaries (2 of 2)

- **Objective-5 Summary:** Coordinated with the Human Physiology Performance Protection & Operations (H-3PO) team and facilitated in-field evaluation of human health and performance (HHP) objectives
  - D-RATS crewmembers were fitted with a wearable monitor, which the H-3PO team retrieved data from after each test.
  - The initial report from H-3PO is included in Appendix C

- **Objective-6 Summary:** Shared D-RATS field-site and assets with Lunar LTE Studies (Lunar LiTES) team, to aid their study of the use of 4G/LTE communication protocols and devices for astronauts and robotic nodes on the lunar surface
  - D-RATS facilitated approval from the USGS/landowners for Lunar LiTES to operate near SP-Crater and included their team in safety planning
  - Provided field-tests dates to Lunar LiTES team and provided access to field facilities during tests
  - Provided a table for the Lunar LiTES team to perform public outreach during the media outreach day

Two engineering crewmembers collecting samples during an EVA while wearing H-3PO monitors

Lunar LiTES team performing tests in the field

Secondary objectives leveraged existing D-RATS 2022 testing

2.7 ConOps Takeaways (1 of 3)

Target Audience: FOD, Science, EVA, PR Project, LTV Project

Findings for surface ConOps involving human-class rovers

- **Future Flight Rules need to consider:**
  - Hazard Avoidance, e.g.,
    - Possibility of Rover going down slope and not being able to make it back up
    - Avoiding pitfalls such as: gullies, ridges, boulders, etc.
  - Safety rules, e.g.,
    - Rover tele-operation in proximity to EV crew
    - Keeping Crew from being downslope of Rover
  - Rover asset usage, e.g., to improve:
    - Lighting for crew
    - Ground control camera views
    - Comm
  - Operations during both expected and unexpected loss of signal (LOS)

- **Rover tele-operation capabilities can significantly enhance science EVAs, e.g.**
  - Leading the crew to a new location
  - Camera pointing for science team awareness – can enhance overall science team understanding of site context
  - Focused lighting on traverse path or science work site
  - Proximity to crew during EVAs can offload tool transport and sample stowage from crew

- **MCC tools should be developed to enable timely and efficient rover tele-operation, e.g.**
  - Driving tools
    - Tele-operation of rover from MCC
    - Ease of assimilating various camera views
    - Dashboard data (speed, light status, etc.)
    - Ease of commanding drive inputs (forward, reverse, steering, etc.)
  - Camera tools
    - Camera selection
    - Pan/tilt/zoom
  - Light controls
  - Navigation

2.7 ConOps Takeaways (2 of 3)

Target Audience: FOD, Science, EVA, PR Project, LTV Project

- **Understanding the best ConOps for rover use to support/enhance EVAs has much forward work to understand:**
  - **Basic Tradeoff:**
    - **It is full of features that support EVA objectives by being close to the EV crew:**
      - Precision nav
      - Toolbox and sample stowage
      - External lights (which are superior to xINFO lights for science and traverse safety)
      - SA cameras which MCC can control and monitor
      - Tele-operations capability from MCC
    - **And one that may often require it to be far from the crew (e.g., up on a ridge, crater rim, etc.)**
      - xEVA comm relay capability
  - **Secondary Tradeoff**
    - When EV crew followed the rover, it saved time by eliminating navigation confusion, but it minimized the number of opportunistic science observations made and overall science conversations when traversing between stations.

2.7 ConOps Takeaways (3 of 3)

Target Audience: FOD, Science, EVA, PR Project, LTV Project

- **Camera control conventions need to be developed**
  - Rover operator responsible while in motion?
  - Science team controls cameras and lights while stationary?
- **Crew science products in the future should include geologic maps and general base maps in the rover to help crew connect observations between stations**
- **Optimum roles of SCICOM vice CAPCOM**
  - D-RATS 22 split ops between a CAPCOM and SCICOM communicator, under the premise that during science focused EVA ops with no other distractors (e.g., suit issues, systems issues) a SCICOM would be a more efficient communicator
    - Akin to direct PI communication on ISS for some science ops
  - These efficiencies were seen in D-RATS 22, but “sim quality” was FAR TOO LOW to draw sweeping conclusions. For instance,
    - There was only a single EVA operator,
    - CAPCOM played dual roles as CAPCOM/FD, and
    - No consumables or systems statuses were modeled.
    - Thus, this conclusion represents the “perfect day” where the only thing going on was the science objective of the EVA in progress
  - Nonetheless, the ability to transfer comm responsibilities to a SCICOM on such nominal days might enable noticeable gain in science quality and should be investigated further

Significant future work is needed to define control conventions, ops products and communicator roles

2.8 PR/LTV Design Takeaways (1 of 2)

Target Audience: PR Project, LTV Project

- **Driving using Cameras only or Windows only**
  - *Using the test-configuration we had* for drive-by-camera driving (fixed external cameras, multiple flat screens in the rover, no external windows available for use), crew awareness of both terrain hazards and science opportunities suffered compared to fully open windows

    Note that existing technology that was not tested might have greatly enhanced crew situational awareness of terrain hazards, best traverse path selection, and science context, e.g.,
    - 3D 360 cameras
    - VR headsets with HUD info
    - LiDAR
    - Night vision cameras

    Note also that while a VR solution might enhance situational awareness, it may also be nausea provoking
  - Driving cameras were susceptible to a variety of failure modes in this testing (loose wires, terrain impact, etc.) => it is strongly recommended that at least a minimal window capability be planned

Driving rover by cameras at night with all windows covered/blacked out and flood lights on

Crew driving in "drive-by-camera" mode, using a bank of removable driving monitors as their guide

Rover at night with windows coverings removed

2.8 PR/LTV Design Takeaways (2 of 2)

Target Audience: PR Project, LTV Project

- **Cameras and External Lights**
  - If cameras (and/or related sensors) will be used for driving, MCC (e.g., SER) needs to be able to see those same views
  - Situational Awareness cameras need to be able to view the crew even when they're standing directly next to rover
  - Control of lighting illumination volume, temperature, and position would enhance EVA science return (and is desired)
- **Maintenance and stuck vehicle challenges**
  - Rover vehicles MUST be designed with EVA maintenance in mind
  - Our experience over ~ 8 days of testing included
    - 2 x Re-seated tires that popped off rims while driving over extremely rough terrain
    - 2 x Replaced wheel/tire assemblies when tire was punctured, or rim was too badly damaged to re-set
    - After the engineering run, upgraded front steering assemblies with stronger parts and larger bolts, which held up well for the three rounds of crew tests
    - Inspected steering bolts on all wheel modules between missions and replaced as needed
      - Replaced bolts in all wheel modules after engineering run and then replaced just the middle and read wheel module bolts in between the rest of the missions after front assemblies were upgraded
    - 1 stuck vehicle (small gulley) that took ~20 man-hours to extract (using hand tools in shirtsleeves)
      - Note: this occurred on during a daytime test using full windows
    - ~10 small boulders stuck between the dual-wheeled modules, but came out on their own
    - Several near misses occurred that the crew didn't even notice, which could easily have added to these totals
  - Consideration should be given to adding small gullies and ridges to the rockyard for training and testing purposes, as these occur frequently in the real world but are absent in the current rockyard


Flat tire on rover


Rover Maintenance


Analog Rover Stuck in a Gully

2.9 A big “Thank You” to our customer and partners!!!

- **Customer:** HQ Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Development Office (M2MADO) Strategy and Architectures Office (SAO)

- **Stakeholders & Contributors:**

JSC
HQ
KSC
GSFC
ARC
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Section 3

Detailed Test Report

3.0 Contents

Section 3.1

Overview

3.1.1 Purpose & Objectives

- The primary purpose of the 2022 Desert Research and Technology Studies (D-RATS-22) analog mission field test was to provide data and recommendations regarding how pressurized rover (PR) design, cabin configuration, driving modes, timeline constraints, and mission operations can be acceptably implemented to support future Artemis missions that include a PR
- The goal of these evaluations was to provide first-order feedback and data on design concepts currently being traded as options for future pressurized rover flight prototypes
- JAXA may provide a PR for future Artemis missions
  - D-RATS-22 field testing incorporated JAXA design concepts under investigation, with their direction and support, and provided JAXA astronauts and engineers an opportunity to experience living and working from within a pressurized rover in an analog exploration operations environment
  - D-RATS-22 made use of the NASA GEN 1B rover testbed, which was modified to incorporate some of the PR design concepts of interest to the JAXA PR team
- **Three major objectives were identified for D-RATS-22:**
  1) Investigate pressurized rover (PR) ConOps and capabilities for Artemis exploration
  2) Integrate with JAXA engineers & astronauts and incorporate JAXA PR design elements into testing
  3) Re-establish analog field-testing skills & capabilities with rovers to investigate Artemis architecture ConOps

GEN 1B PR testbed in "drive-by-cameras" driving mode with windows covered during a day test (top image) and a night test (bottom image)

NASA's GEN 1B PR testbed was updated to include a drive-by-cameras driving mode

3.1.1 Purpose & Objectives (cont.)

- **In addition to the major objectives of D-RATS-22, three secondary objectives were also identified, which leveraged the D-RATS presence in the field***

Integrated Secondary Objectives:

- **Conduct Public Affairs Office (PAO) and outreach activities**
  - Filming by documentary teams (National Geographic and Felix & Paul Studios)
  - VIP/Media/Outreach/Education Day
- **Evaluate Human Health & Performance (HHP) Human Physiology Performance Protection & Operations (H-3PO) objectives**
  - Characterization of EVA task types, durations, frequencies, and associated physical/cognitive workload and functional movements required to perform these tasks
  - Stretch: Incorporate cognitive workload and performance measures to assess fatigue effects

  (The H3PO report on their D-RATS 2022 tests, "*H3PO EVA Heart Rate Data Analysis*" is included in Appendix C)

Standalone Secondary Objective:

- **Demonstrate Lunar LTE Studies (Lunar LiTES) that is studying the use of 4G/LTE communication protocols and devices for astronauts and robotic nodes on the lunar surface**

  (The Lunar LiTES report will be available upon request)

**See section 2.6 for more details on secondary objectives*

Secondary objectives leveraged existing D-RATS 2022 testing

3.1.2 Scope

- The test protocol describes the strategic questions, objectives, methods, metrics, and results reporting by which the NASA Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Development (M2MAD) Strategy and Architectures Office (SAO) Human-In-The-Loop (HITL) Test Team evaluated operations concepts and capabilities for an Artemis pressurized rover
- JAXA may provide a pressurized rover (PR) for Artemis in the future. JAXA proposed multiple concepts for a rover during their 2021-2022 design cycle and through feedback with NASA at multiple Technical Interchange Meetings (TIMs)
- NASA is working closely with the Japan Aerospace Exploration Agency (JAXA) to scope mission and functional requirements for an Artemis PR
- D-RATS-22 testing evaluated how to incorporate a pressurized rover for Artemis exploration while incorporating as many aspects of current JAXA rover design concepts as possible
- Testing included astronaut and engineering subject matter expert (SME) crewmembers conducting day-in-the-life (DITL) activities inside (i.e., intravehicular activity [IVA] tasks) a NASA-built PR testbed, as well as shirtsleeve science extravehicular activity (EVA)
- These DITL activities will help inform future requirements and recommendations for PR design features and operations
- This testing also provided the opportunity to integrate with JAXA engineers and provide first-hand experience living in a rover and conducting PR operations at a lunar-analog field site
- NASA delivered the raw data presented herein (section 3.6) as well as video logs, telemetry data, and over 3000 photos to the JAXA PR team immediately after the tests were completed, for their internal analyses as needed (NASA did not have a need to do their own parallel analyses)

3.1.3 Caveats

- The analog pressurized rover (PR) used for this test (i.e., the NASA GEN 1B rover) was not necessarily representative of the Artemis pressurized rover that JAXA might provide in the future, and this distinction was accepted by both the NASA and JAXA test teams prior to testing
- That said, the NASA GEN1B rover provided an acceptable proxy for testing to meet the specific objectives of D-RATS 2022
- One of the primary objectives of D-RATS 2022 was to share with the JAXA PR team the processes and protocols by which NASA has learned to successfully evaluate rover concepts through integrated HITL evaluations over the past 20+ years so that JAXA could apply any applicable lessons learned to their PR design, development, testing, and evaluation
- D-RATS 2022 opportunity provided hands-on experience for JAXA rover designers, engineers, and operators to work alongside NASA counterparts, in addition to a core integrated NASA test team whose combined analog field experience was on the order of multiple hundreds of years

Section 3.2

PR Background

This report begins with a summary of the concept of operations for a pressurized rover during the Artemis program, then follows with the test plan details for the DRATS 2022 field test, including the strategic questions and associated test objectives to be evaluated, study design and limitations, metrics and methods for evaluation, and summary of results reporting.

3.2.1 Pressurized Rover Concept of Operations Summary

- The PR is a mobile habitation vehicle whose primary purpose is to support crewed Artemis Program science and exploration objectives
- The PR concept offers numerous health and safety advantages that accrue from having a pressurized safe-haven/radiation shelter in close-proximity to the crew at all times, during exploration and EVA operations
- The PR will:
  - Provide reliable and safe transportation for two crewmembers inside a pressurized cabin
  - Support all basic habitation functions (e.g., sleep, toileting, hygiene, meal prep, exercise, etc.) as well as accommodate various payloads; work packages, logistics, science tools and instruments, samples, etc.
  - Be able to be driven manually by a single IVA crewmember, as well as remotely by teleoperators on Earth, elsewhere on the lunar surface (e.g., inside the Human Landing System (HLS) or a Surface Habitat), and in cislunar space (e.g., at Gateway)
  - Travel distances compatible with multi-stop EVA exploration traverses, as well as uncrewed traverses at maximum safe available speeds;
  - Be able to operate at high lunar latitudes, an environment which features low-angle sunlight and extended periods of darkness due to shadowing by the polar terrain
  - Store adequate logistics to support two crewmembers for 28 days plus 3 days' worth of contingency
- Initial missions using the PR will support crew ingress and egress either through a rover side hatch or via an adjacent airlock; a study is planned with JAXA to trade these EVA options and their effects on overall PR vehicle design
- Based on initial timeline analysis work conducted by the Lunar Architecture Team (LAT) in the ESDMD M2MADO, it is anticipated that only 1 EVA per day will be able to be conducted (as opposed to 2 or more EVAs per day) due to the expected overhead time performing PR egress/ingress via a side hatch or airlock
- Hence the goal is to reduce EVA prep and post overhead in terms of both crew time and consumables lost to cabin/airlock depressurization while also maximizing boots-on-surface exploration time

3.2.1 Pressurized Rover Concept of Operations Summary (cont.)

A typical EVA exploration day using the PR was envisioned to proceed as follows (HEOMD-404):

- **After concluding post-sleep activities (e.g., personal hygiene, breakfast), the crew will:**
  - don their liquid cooling and ventilation garments (LCVGs)
  - conduct their morning daily planning conference (DPC) with the ground
  - complete their morning prep work

  The pre-EVA private medical conference (PMC) for the day's EVA typically occurs the day prior, either as part of the previous day's post-EVA PMC, or as a get-ahead task for the next day's EVA
- **The crew then:**
  - drive to their science station (if not parked there the night before)
  - perform a general inspection of the surrounding area from within the PR using windows and/or camera views
  - confirm with ground support personnel that they are at the desired location for EVA
- **Once the field excursion location has been identified, the crew:**
  - prepare the cabin for depressurization
  - stow any PR contents that cannot be exposed to vacuum inside a small, pressurized compartment
  - don their suits (either in rover cabin itself or in an airlock attached to the rover)
  - egress the PR
  - commence the required surface investigations

  EVA tools, science instruments, and sample stowage containers will be distributed across the PR and unpressurized lunar terrain vehicle (LTV, if available) to support the crew as they conduct their EVA. Depending on EVA objectives, the crew may drive the LTV to nearby locations while the PR maintains a different vantage point, serves as a communication relay, etc.
- **Once EVA objectives are complete, the crew will:**
  - stow their tools and samples
  - clean their suits
  - ingress the PR, either via the side hatch or airlock
- **The crew will complete their post-EVA activities:**
  - doff LCVGs
  - clean and inspect the inside of their suits
  - refill drink bags in preparation for the next EVA, etc.
  - post-EVA PMC
  - unpack the items previously stowed in preparation for cabin depressurization
  - conduct their daily close-out tasks, such as exercise, housekeeping, evening prep work, evening DPC, and pre-sleep activities

3.2.2 JAXA Proposed Pressurized Rover Concept

- JAXA and Toyota conducted joint research to develop a human pressurized rover from June 2019 through March 2022, with an expected launch date in the latter half of the 2020s [1]
- Together, they are working to manufacture test parts for each technological element, as well as the prototype rover itself
- The work involves the use of simulations to confirm power and heat dissipation performance while driving, the manufacture and assessment of prototype tires, and the use of virtual reality and full-scale models to consider the layout of equipment in the vehicle cabin
- They are investigating several design concepts, including fuel cell electric vehicle technologies, the use of camera systems and sensors with virtual windows instead of (or in addition to) physical ones, and various methods for executing EVAs
- The NASA D-RATS 2022 test team worked closely with JAXA to help evaluate and test some of their proposed PR design features and capabilities

Artist rendering of a notional JAXA Toyota Rover

Section 3.3

Strategic Questions & Test Objectives

3.3.1 M2MADO Strategic Analysis HITL Questions/Gaps/Risks Applicable to D-RATS

- The ESDMD M2MADO maintains a matrix of strategic questions, gaps, & risks (QGRs) relevant to Artemis architecture, ConOps and capabilities
- This matrix identifies QGRs that can be addressed through various types of analyses and testing
- A subset of the QGRs applicable to D-RATS field testing is shown on the right
- From this matrix, strategic questions were derived, which then guide detailed test objectives and test plans for the 2022 study

HSEI SA HITL Tracking Number	Categories	Title of Question/Gap/Risk	HSEI SA Priority	Year Results are Needed
new	Mobility: Pressurized Rover (Lunar/Mars)	Virtual vs. Real Windows for PR	1-high	2022
new	OpsCons: Lunar Surface	LTV and PR working together on ABC traverses	1-High	2022
new	Mobility: Pressurized Rover (Lunar/Mars)	Working w/ a new International Partner for the PR	1-High	2022
new	Science: Rover Traverse Planning	Plan science-driven PR rover traverses with SMD team	1-High	2022
new	Science: Operations within Flight Control Team (FCT)	Understand the best way for the Science Evaluation Room (SER) to monitor and support EVAs	1-High	2022
HITL-ARCH-010	Architecture: Surface (Lunar, Mars; near-, mid-, long-term)	Artificial lighting for south pole traverse	1-High	2021
HITL-ARCH-020	Architecture: Surface (Lunar, Mars; near-, mid-, long-term)	Navigation aids for EVA traverse beyond LoS with lander	1-High	2021
HITL-ARCH-030	Architecture: Surface (Lunar, Mars; near-, mid-, long-term)	Crew transfer from/to lander to/from pressurized surface asset	1-High	2021
HITL-GENOPS-010, HITL-GENOPS-030	General Operations: Logistics	Integrated logistics management and transfer conops	1-High	2021
HITL-LTV-010	Mobility: Unpressurized Rover (Lunar/Mars)	Crew utlization of an unpressurized rover	1-High	2022/23?
HITL-EVA-100	EVA: Rescue (self and ICM)	Incapacitated Crewmember Operations	2-Med	2021
HITL-EVA-070	EVA: Tools and Equipment	Tool Transport on Surface EVAs	2-Med	2021/2022
HITL-GENOPS-020	General Operations: Offloading	Offloading	3-Low	2021
HITL-ARCH-040	Architecture: Communications	Roles of Gateway IV, ground MCC, for lunar missions	2-Med	2022
HITL-GENOPS-040	General Operations: Logistics	Site to site transport of samples, tools, and other payloads	2-Med	2022
HITL-SCI-030	Science: Science Operations	Communication latency mitigation	2-Med	2022
HITL-SCI-010	Science: Sampling (selection, collection, high-grading, curation)	Sample collection, hi-grading, and selection	2-Med	2022
HITL-EVA-090	EVA: ConOps	EVA ConOps	3-Low	2022/2023
HITL-EVA-030	EVA: EVA Architecture	Suit don/doff in PR	3-Low	2023
HITL-ARCH-050	Architecture: Communications	Video and Imagery Architecture	3-Low	
HITL-EVA-050	EVA: EVA Architecture	Suitport System Development & Integration	3-Low	
HITL-EVA-080	EVA: Tools and Equipment	Evaluate use of geology tools	3-Low	
HITL-EVA-110	EVA: Suited Performance	EVA Injury & Risk Mitigation	3-Low	
HITL-EVA-150	EVA: Suited Performance	EVA Crew Required Capabilities	3-Low	
HITL-EVA-160	EVA: Suited Performance	EVA Suit Design for Human Health & Performance	3-Low	
HITL-EVA-170	EVA: Suited Performance	Suited crew performance	3-Low	
HITL-EVA-180	EVA: System/Suit Capabilities	EVA Informatics for Health & Performance	3-Low	
HITL-EVA-190	EVA: Tools and Equipment	EVA repair strategies and suit maintenance	3-Low	
HITL-EVA-200	EVA: Tools and Equipment	Evaluate use of maintenance tools	3-Low	
HITL-EVA-210	EVA: Tools and Equipment	Tools/equipment stowage	3-Low	
HITL-LTV-020	Mobility: Unpressurized Rover (Lunar/Mars)	Emergency life support package and consumables recharge on LTV	3-Low	
HITL-SCI-020	Science: Science Operations	Planetary protection (baseline characterization)	3-Low	

This subset of M2MADO Strategic Analysis HITL Question/Gaps/Risks was used to formulate High-Level Strategic Questions

3.3.2 Strategic Questions related to Pressurized Rover ConOps & Capabilities

Nine (9) overarching PR strategic questions (SQ)s and one (1) Artemis operations SQ related to pressurized rover ConOps and capabilities were formulated from the matrix of QGRs:

- SQ1: What combination of windows and/or externally mounted cameras projected onto internal cabin displays best support PR operational and scientific objectives?
- SQ2: What exterior lighting configurations best support PR tasks (e.g., driving, IVA science observations, EVA, etc.)?
- SQ3: How does the interior layout of a PR contribute to human performance and habitation?
- SQ4: How is waste and trash managed inside a pressurized rover, and what is the method and frequency of removal for a 30-day mission?
- SQ5: How much time per day is spent on overhead tasks for rover operations, crew habitation, and EVA prep and post activities?
- SQ6: What operational concepts best support rover teleoperations during EVA, and who (i.e., crew-to-ground, or within the ground team) should direct rover movements when deemed necessary?
- SQ7: How important is the ability to “crab” the rover while driving, and what crab wheel angles are needed?
- SQ8: How are EVA tools and samples managed and stored outside of a PR?
- SQ9: What flight rules are needed to safely operate the rover during traversing and EVA?
- SQ10: What are the advantages and limitations of switching between a SCICOM and a CAPCOM, depending on the ops, during pressurized rover operations?

Specific D-RATS-22 test objectives and associated metrics were directly mapped to each of these high-level strategic questions

3.3.3 D-RATS-22 Specific PR Questions

None of these strategic questions can be completely addressed by a single analog field test

For SQ1, SQ2, SQ4, and SQ8, sub-questions specific to D-RATS-22 PR testing were derived, so that relevant data could be gathered to help inform follow-on trade studies, analyses, HITL testing, and, ultimately, flight prototype DDT&E:

- **D-RATS-22 Specific Questions derived from SQ1***:*
  - How acceptable are the GEN 1B windows for supporting driving and science operations?
  - How acceptable is a JAXA-proposed camera and internal display system for supporting driving and science operations?
- **D-RATS-22 Specific Question derived from SQ2**:
  - How acceptable are the GEN 1B rover lights and their associated specifications for supporting PR operations and science?
- **SQ3/D-RATS-22 Question**: How does the interior layout of a PR contribute to human performance and habitation?
- **D-RATS-22 Specific Question derived from SQ4**: How should waste and trash be managed inside a PR?
- **SQ5/D-RATS-22 Question**: How much time per day is spent on overhead tasks for rover operations, crew habitation, and EVA prep and post activities?
- **SQ6/D-RATS-22 Question**: What operational concepts best support rover teleops during EVA, and who (i.e., crew-to-ground, or within the ground team) should direct rover movements when deemed necessary?
- **SQ7/D-RATS-22 Question**: How important is the ability to "crab" the rover while driving, and what crab wheel angles are needed?
- **D-RATS-22 Specific Question derived from SQ8**:
  - How are EVA tools and samples managed and stored outside of a PR?
- **SQ9/D-RATS-22 Question**: What flight rules are needed to safely operate the rover during traversing and EVA?
- **SQ10/D-RATS-22 Question:** What are the advantages and limitations of switching between a SCICOM and a CAPCOM, depending on the ops, during pressurized rover operations?

Specific questions to be addressed by D-RATS-22 were derived from the 10 Strategic Questions and test objectives, and associated metrics were directly mapped to each of these high-level questions

3.3.3 D-RATS-22 Specific Questions (cont.)

Additional D-RATS-22 Questions

In addition to collecting data relevant to Artemis pressurized rover ConOps, D-RATS-22 re-initiated terrestrial field analog testing with rovers. As such, two D-RATS-specific strategic questions were considered, and feedback on each was solicited from all D-RATS-22 participants:

- What are your concerns and recommendations with respect to our ability to simulate the lunar surface environment and Artemis mission operations in these D-RATS analog tests?
- Any other feedback?

Addressing the D-RATS-22 Questions

Subsections 3.3.3.1 through 3.3.3.10 describe how each strategic question or derived D-RATS question was addressed, and include: a problem description; restated D-RATS question(s); overview of test objectives and data collection; and in some cases, a discussion of the metrics used

3.3.3.1 Addressing SQ1 D-RATS Questions

Problem Descriptions

- JAXA is investigating augmenting its PR with a *camera and sensor-based system** to provide virtual views of the outside environment for the crew and/or remote operators, displayed on monitors or a projection system
- There was significant data from prior rover analog tests using *windows* as the primary means of observing the external environment; however, no prior rover testing had evaluated the efficacy of a *camera-based projection system* for supporting driving and other PR operations (e.g., science observations by the crew while IVA, teleoperation, etc.)

D-RATS Questions

- How acceptable are the GEN 1B windows for supporting driving and science operations?
- How acceptable is a JAXA-proposed camera and internal display system for supporting driving and science operations?

**JAXA's proposal for the camera and display system is motivated by the limited mass of the rover that can be carried on the launch vehicle. In particular, windows and supporting structures are very heavy. JAXA understands that windows are necessary for the crew's mental health and contingency response. The purpose of the test was to investigate driving with a camera and display system and to gather associated data and feedback. By no means was the purpose of this study to determine whether or not to install windows in a future pressurized rover.*

No prior rover testing had evaluated the efficacy of a camera projection system for supporting driving ops

3.3.3.1 Addressing SQ1 D-RATS Questions (cont.)

Test Objectives & Associated Data Collection

- As an initial investigation of SQ1 and the two associated D-RATS questions, the GEN 1B rover was configured in 2 primary states:
  - The nominal GEN 1B design that relied primarily on windows for operations (the so-called “drive-by-windows” mode); and
  - Same cabin, but with windows covered and the addition of 3 interior monitors that displayed views from 2 exterior, forward-facing cameras (the so-called “drive by cameras” mode)
- Due to limited time to incorporate a camera-display system into the GEN 1B rover and limited time in the field for D-RATS 22, only two “book-end” configurations were studied this year:
  - A single, specific “drive-by-windows” configuration; and
  - A single, specific “drive-by-cameras” configuration (developed in collaboration with the JAXA PR team)
- Future testing (including VR and other analog testing) will incorporate various combinations of windows and cameras

“Drive-by-windows” mode test setup – large open windows with a single situational awareness (SA) screen flanked by pilot and copilot instrument panels

“Drive-by-camera” mode test setup - windows covered and three internal displays added, which displayed exterior driving camera views (SA view displayed on center top screen)

D-RATS 22 tested two “book-end” configurations: a single, specific “drive-by-windows” configuration and a single, specific “drive-by-camera” configuration

3.3.3.1 Addressing SQ1 D-RATS Questions (cont.)

Metrics

- **Objective Metrics**

  Objective rover-related metrics (e.g., driving distance and speed, obstacles hit and strike location on vehicle, number of science targets identified, etc.) were collected for each configuration with respect to driving and navigation, IVA observations, and impact to human factors and habitability

- **Subjective Metrics**

  Subjective metrics of acceptability and capability assessment of the cameras were also collected for both configurations (drive-by-windows and drive-by-camera) with respect to:

  – Driving and navigation

  – IVA observations

  – Impact to human factors and habitability

Crew driving in "drive-by-camera" mode, using bank of monitors as their guide

3.3.3.2 Addressing SQ2 D-RATS Question

Problem Description

- The Artemis PR will need to operate in an environment comprised of bright, low-angle sun intermixed with dark, contrasting long shadows
- The PR will need to be outfitted with various exterior lights to support driving, science, EVA, remote observations, etc.
- The quantity, location, intensity, beamwidth, tunability, etc. of these lights need to be investigated to best meet the needs of the rover's crew and remote operators and observers

D-RATS Question

- How acceptable are the GEN 1B rover lights and their associated specifications for supporting PR operations and science?

Test Objectives & Associated Data Collection

- As an initial baseline evaluation, the GEN 1B rover lights (see images at right) were assessed for their ability to support Artemis mission tasks and objectives, which includes operations in a low-angle sunlight environment
- Testing occurred at night with an analog portable "sun" for EVA operations
- Subjective data was collected on the acceptability of the number, location, illumination area, and type of lighting available to crew, MCC, and science teams to help inform future PR lighting capabilities that are mission enhancing

View of PR analog lights from forward port

View from aft, with EVA crew following teleoperated PR analog utilizing its lights

Multiple exterior lights located on the front, sides, beneath and aft of the PR were utilized during testing and evaluated

3.3.3.3 Addressing SQ3 D-RATS Question

Problem Description

- The rover cabin interior will need to maximize functionality and enable optimal human performance while simultaneously staying within overall vehicle mass and dimensional limitations
- Prior testing has shown that the minimal acceptable habitable volume for a pressurized rover housing two crewmembers for multiple weeks at a time is on the order of 9m^3 [2]
- Proper layout, organization, and distribution of functions within such a small volume is essential for ensuring all IVA operations can be conducted efficiently and do not result in significant overhead for the crew
- Logistics management and stowage organization can be a big contributor to the crew timeline, and so understanding the following factors is necessary to scope mission planning and logistics activities:
  1) How much volume should be allocated for logistics (the amount of which will vary based on mission duration, as well as mid-mission logistics resupply options), and
  2) Where should that stowage space be located to support efficient crew operations (including internal and external pressurized volumes)

D-RATS Question

- How does the interior layout of a PR contribute to human performance and habitation?

Test Objectives & Associated Data Collection

- Since the JAXA PR design was still in formulation, the GEN 1B cabin was assessed for its ability to support rover IVA operations relevant to Artemis mission objectives, including driving, habitation tasks, and IVA science tasks
- The GEN 1B rover was designed to support 2 crew for 14 days, so the rover was outfitted with 28 crew-days' worth of logistics
- Task timing data as well as subjective acceptability data on design features and functions associated with a small rover cabin interior, including overall cabin layout, overhead associated with reconfiguration for various IVA tasks, logistics management, etc. were collected
- Such design guideline data will be applicable to any number of future pressurized rover designs

PR analog with soft cargo storage bags visible in cabin (when simulating EVA, crew must move cargo away from hatch into driving compartment to egress

Gen 1B design allowed for a meaningful logistics volume assessment

3.3.3.4 Addressing SQ4 D-RATS Question

Problem Description

- Managing waste and trash over the course of a mission will be essential for crew health and safety, and proper management (including on a daily and per-mission basis) has impacts to crew efficiency
- One of the key current capabilities assumed for the PR is that it will be able to stow up to 30 days of solid waste and trash for 2 crew
- Where this waste and trash should be stowed and the volumetric impacts to crew operations are still TBD

D-RATS Question

- How should waste and trash be managed inside a PR?

Test Objectives & Associated Data Collection

- Crewmembers assessed the acceptability of trash management methods (including daily management and storage) in the GEN 1B rover; but D-RATS-22 did not look at trash removal or frequency
- Since the Gen 1B rover is designed for only 14 days, data collected will be used for future studies that extend durations up to the planned 30-day missions*

*Note that this will be an initial assessment only, since flight food packaging, etc. are still in pre-formulation

After completing their missions, crewmembers assessed acceptability of trash management methods used during the tests

3.3.3.5 Addressing SQ5 D-RATS Question

Problem Description
- A rover serves multiple functions including providing mobility, habitation, a platform for science, and supporting EVA
- Living in the rover will require being able to perform all the nominal daily habitation activities currently conducted on ISS, such as exercise, waste collection and hygiene operations, housekeeping, sleep, etc.
- Due to the limited volume inside the rover cabin, setup and teardown of various equipment may be required
- The design and layout of the rover can directly impact the duration of these overhead tasks, as well as whether or not crew hours need to be allocated for conducting these tasks
- Furthermore, understating how those overhead times impact the overall mission timeline has direct implications for time available for exploration activities
- JAXA was interested in collecting data on overhead tasks and requested it be collected during D-RATS-22

D-RATS Question
- How much time per day is spent on overhead tasks for rover operations, crew habitation, and EVA prep and post activities (e.g., reconfiguring the cabin interior for EVA, exercise, sleep, waste collection operations, conducting housekeeping tasks, etc.)

Test Objectives & Associated Data Collection
- Objective data (e.g., timeline analysis) and subjective data (e.g., acceptability) were collected and provided to JAXA
- The data can be used to assess overhead tasks and crew time requirements while considering their impacts on overall exploration

Engineering Crewmember Exercising

Engineering Crewmember Resting

Timing and task acceptability data were collected for overhead tasks throughout D-RATS-22 testing and was provided to JAXA

3.3.3.6 Addressing SQ6 D-RATS Question

Problem Description

- The Artemis PR will need to be capable of remote operation from: Earth; other lunar surface assets; and possibly cislunar space (e.g., from Gateway)
- The optimal teleoperation approach while crew performs EVA is currently unknown

D-RATS Question

- What operational concepts best support rover teleoperations during EVA, and who (i.e., crew-to-ground, or within the ground team) should direct rover movements when deemed necessary?

Test Objectives & Associated Data Collection

- This question was addressed by testing two remote control configurations:
  1) EVA crew directs ground to relocate the rover as needed to support EVA objectives
  2) Ground can directly control the rover and relocate as needed without direction from EVA crew (while maintaining crew safety)
- Acceptability and capability assessment ratings were collected for both tele-ops control methods

Rover analog following EVA crew via teleoperation during daytime EVA test

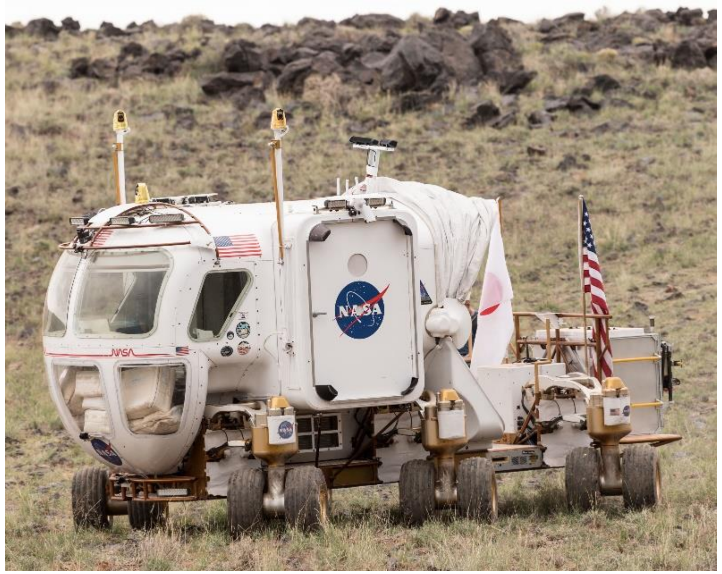
EVA Crew following teleoperated rover analog during night EVA test

Two remote control configurations for PR teleoperations and several commanding and lead/follow modes were tested during EVAs

3.3.3.7 Addressing SQ7 D-RATS Questions

Problem Description

- The PR will be required to navigate different terrain types and hazards including various slopes, boulders, and craters that are present in the lunar south pole environment
- The degree to which the rover can crab, i.e., translate in a direction different from the direction the rover is pointed, has impacts on turning radius and potential implications on terrain trafficability
- JAXA proposed an 18-degree maximum crab angle for their rover design concept; whereas, prior NASA rover concepts, including the Gen 1B rover used for these tests were capable of crabbing at from zero to 360 degrees



PR testbed demonstrating crabbing at ~45 degrees (rover is moving towards the camera while the nose is pointed 45 degrees to the left of the viewer)

D-RATS Question

- How important is the ability to “crab” the rover while driving, and what crab wheel angles are needed?

Test Objectives & Associated Data Collection

- To tested this question the rover was operated in 2 crab angle design configurations: 18° and 360°
- Acceptability of driving in each crab angle setting was assessed for conducting rover driving operations and scientific observations
- In addition, objective data, including total translation distance and angle range used by the crew for various driving tasks was collected

Crew tested two extremes of crab driving capability: 18-degree-maximum and 360-deg-maximum

3.3.3.8 Addressing SQ8 D-RATS Questions

Problem Description

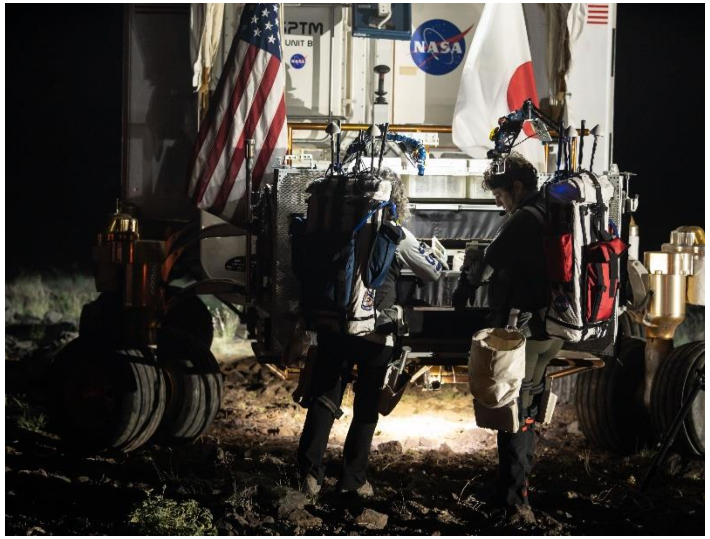
- Throughout Artemis PR missions, crews will perform EVA science and collect various geologic samples from the lunar surface.
- In this test, crew had a tool and sample stowage system located on the aft deck of the rover which they used when performing EVA in the field

D-RATS Question

- How are EVA tools and samples managed and stored outside of a PR?

Test Objectives & Associated Data Collection

- Subjective data was collected related to acceptability of the current sample stowage system, as well as methods for sample curation and interior rover design to support analysis inside the rover if a sample were brought in with the crew post EVA



Crew on EVA utilizing aft deck tool and sample stowage system

Each crew pair tested EVA tools and sample collection and management tools and assets during simulated EVAs

3.3.3.9 Addressing SQ9 D-RATS Questions

Problem Description

- Safely operating the rover will be essential for protecting the crew and vehicle while driving on the lunar surface and during EVA
- Understanding the constraints that the rover might be operated under can drive out specific rover design recommendations to mitigate risks and/or drive changes to timelines and tasks to accommodate those constraints

D-RATS Question

- What flight rules are needed to safely operate the rover during traverses and EVAs?

Test Objectives & Associated Data Collection

- In coordination with rover, FOD, and EVA stakeholders, draft flight rules governing PR operations were established for initial evaluations during this field test
- The efficacy of these flight rules was assessed through the collection of objective performance data and subjective feedback from the crew and A-MCC personnel
- Outcomes will serve as the starting point to iterate and improve future flight rules

D-RATS-22 mission control team supporting field-tests from analog MCC in Houston

Draft flight rules for operation of a PR during traverses and EVAs were utilized during testing and assessed afterwards

3.3.3.10 Addressing SQ10 D-RATS Questions

Problem Description

- Current ISS operations have made use of direct communication between the crew and subject matter experts (SME), as opposed to all communication going thru a CAPCOM
- Similarly, science mission analog field tests have made use of a science communicator (SCICOM), i.e., a scientist by training who can speak directly with the crew about science priorities and objectives, without relaying through a CAPCOM
- Artemis-3 planning does not currently have a SCICOM, due primarily to mission objectives and duration, but later Artemis missions when a pressurized rover is involved may benefit from a SCICOM

D-RATS mission control team on console during testing, including CAPCOM and SCICOM

D-RATS Question

- What are the advantages and limitations of switching between a SCICOM and a CAPCOM, depending on the ops, during pressurized rover operations?

Test Objectives & Associated Data Collection

- Evaluate the advantages and limitations of incorporating a SCICOM, including considerations for training the crew and MCC personnel, identifying comm-related flight rules, etc.
- Capability assessment ratings on the level of mission enhancement afforded by a SCICOM were collected from both the crew perspective and MCC perspective

D-RATS 2022 tested and evaluated the usefulness of incorporating a SCICOM for Artemis-4 and beyond

Section 3.4

Study Design

3.4.1 HITL Test Team Rigorous Testing Philosophy

- Since 2008, the core DRATS test team has successfully conducted multiple spaceflight analog mission evaluations utilizing a consistent set of operational products, tools, methods, and metrics to enable the iterative development, testing, analysis, and validation of evolving exploration architectures, operations concepts, and vehicle designs.
- This has been achieved by ensuring that the required level of rigor and consistency is applied before, during, and after the operational field tests so that the data collected remains highly relevant to NASA's strategic architecture and technology development goals, and provides data-driven, actionable recommendations. Key points of this methodology include:
  - Definition of the strategic questions that need to be answered and the rationales behind each
  - An understanding of how results will be used and the decisions that need to be made
  - Development of specific objectives related to the questions being tested
  - Prospective definition of metrics that will be used to assess the objectives
  - Development of a study design that incorporates all necessary tasks to address the questions and objectives, and a plan to collect the appropriate data
  - Selection of crewmembers that are representative of the target population (e.g., flown astronauts, subject matter experts) and provision of sufficient training so that crewmembers understand the objectives, tasks, and methods for collecting their input
  - Execution of the study design with adequate fidelity of the operational environment and relevant capabilities to address the strategic questions and objectives
  - Use of test subject consensus results to form a single set of data that reflect the agreed-upon results of any subjective input provided
  - Mapping of the results to specific, actionable hardware, software, and/or procedural recommendations

This rigorous methodology was applied to the DRATS 2022 field test planning and preparation to ensure that actionable recommendations for each of the strategic questions of interest were attained

3.4.2 DRATS Field Test Overview

- DRATS 2022 HITL testing was performed at the Arizona Black Point Lava Flow (BPLF) field site and in the Analog Mission Control Center (A-MCC) at NASA Johnson Space Center (JSC)
- During the field test, 2-person crews lived and worked inside the NASA GEN 1B rover
- Crews executed an Artemis PR reference mission timeline that had been systematically developed to incorporate the major ground test objectives and was aligned with the latest reference timeline developed by the ESDMD SAO Lunar Architecture Team (LAT)
- The operational mindset the analog crewmembers and MCC personnel were trained on was to presume the testing took place on Mission Days 10-12 of a 30-day lunar surface mission, where the crew live solely out of the PR once egressing HLS
- Flight-like communications were simulated, including communication links between the crew and ground-based A-MCC flight control team and science team
- Objective rover and human factors data was collected throughout the test
- Crewmembers also provided subjective feedback on their experiences living in (i.e., conducting daily habitation tasks) and working (i.e., conducting rover operations and science exploration tasks) from the PR
- The following sections provide an overview of: *test limitations; test personnel and training; team leadership structure; test location; facilities; equipment; detailed test timelines and tasks; data metrics; and collection methods*

3.4.3 Test Limitations

- This analog testing had several limitations that were accounted for in study design preparation (including procedures, methods, and metrics) and were communicated to the crewmembers during pre-test briefings:
  - The NASA GEN 1B rover that was used in DRATS testing this year is not a formal representation of the JAXA PR concept design, which was still in formulation; however, it is a working prototype of a PR that has similar functions and capabilities to the notional JAXA PR concept and served as a reasonable facsimile for the objectives outlined in this test
  - All test objectives, procedures, methods, and metrics for evaluation were developed in collaboration with the JAXA PR team, and they understood the limitations associated with using the NASA GEN 1B rover for this test
  - The GEN 1B rover didn’t have all sensors and cameras that JAXA has proposed for potential driving operations, but it did have the sensors and cameras necessary for a first-order evaluation of driving with camera views projected onto a series of internal displays
  - The GEN 1B rover is designed to support 2 crew for 14 days without logistics resupply, whereas the current Artemis PR baseline is a rover that can support 2 crew for 30 days without resupply; therefore, there are some tasks where it is not possible to fully represent a two-crew, 30-day Artemis mission, including: trash generation over 30 days; logistics resupply/reconfiguration for 30-days’ worth of supplies; etc.
  - In this testing, the rover was configured to support 14-days without resupply, but crewmembers were asked to extrapolate their experiences to provide feedback on accommodations that might be needed to support 30-day missions (e.g., overall cabin size, trash removal frequency, volume allocation for trash and logistics stowage, logistics resupply cadence, etc.).
  - Field testing is currently unable to support the use of pressurized suits during EVA simulations; however, the objectives of this test were focused on driving configurations and IVA activities and did not warrant the use of pressurized suits
  - Different analog environments such as ARGOS or the NBL are better suited for incorporating pressurized suits, and test objectives associated with PR egress/ingress operations, suit maintenance, etc. will be conducted as part of future studies

3.4.4 Test Personnel & Training

Engineering Dry Runs

- A critical component of full team readiness prior to commencing any of the crewed sortie traverses in the field is conducting engineering dry runs
- Two engineering dry runs were executed to prepare for DRATS 2022:
  - **Onsite**: onsite engineering runs at JSC focused primarily on GEN 1B rover readiness
  - **In-Field**: Three days of in-field engineering runs at BPLF provided:
    - Opportunity for all in-sim and out-of-sim personnel to dry run (i.e., practice) their respective roles
    - Opportunity to test all rover systems after its cross-country trek from Houston to Flagstaff and to field-test remotely controlling rover driving
    - Opportunity to test EVA tools, lights, and comm systems
    - Time to resolve any issues prior to arrival of test crews

Engineering Crew

- Engineering team members were recruited and trained to support the engineering dry runs
  - Taylor Phillips-Hungerford / NASA JSC SF
  - Marc Ciupitu / NASA JSC DI
  - Backup: Omar Bekdash / NASA JSC ER

Engineering Dry Run at JSC rockyard

Engineering Dry Run at BPLF

Engineering dry runs at JSC and in-field prior to arrival of crew allowed time to discover/resolve any issues

3.4.4 Test Personnel & Training (cont.)

Crew Selection

- The subjective nature of many of the HITL test objectives and evaluations makes the selection and training of appropriate crewmembers important.
- For DRATS 2022, 4 NASA and JAXA astronauts with previous flight experience and 2 NASA and JAXA engineering subject matter experts were selected as PR crewmembers
  - NASA
    - Jessica Meir / Astronaut
    - Sarah Shull / Engineer
  - JAXA
    - Akihiko “Aki” Hoshide / Astronaut
    - Norishige “Nemo” Kanai / Astronaut
    - Naofumi Ikeda / JAXA Pressurized Rover Team
    - Yusuke Yamasaki / JAXA Pressurized Rover Team

Crew assignments

- These individuals were paired together, and individuals from each pair were assigned the roles of Commander (CDR) and Mission Specialist-1 (MS1)
  - Crew-1: Nemo & Naofumi
  - Crew-2: Aki & Yusuke
  - Crew-3: Jessica & Sarah
- Each pair completed a 2-to-3-day PR mission in the field with traverses, EVAs and overnight stays in the PR

Crew Backups:

- Engineering team members were recruited and trained to serve as backups in the event any of the primary crew were unable to participate:
  - Taylor Phillips-Hungerford
  - Tamra George
  - Phil Curell

Akihiko “Aki” Hoshide

Norishige “Nemo” Kanai

Naofumi Ikeda

Yusuke Yamasaki

Jessica Meir

Sarah Shull

3.4.4 Test Personnel & Training (cont.)

Crew Training

- All crewmembers participated in training sessions at JSC and refreshers in the field prior to commencing their test and were trained on the rationale and objectives of tests, including familiarization with the equipment, methods, and data collection metrics
- They conducted hands-on skills training specific to rover driving, IVA operations (including all GEN 1B habitation activities and IVA science tasks), EVA tool usage, and EVA tasks, and how to complete their test subjective questionnaires

MCC Team

- During the multiday traverses, the A-MCC was staffed by a capsule communicator (CAPCOM) to communicate with the crewmembers in the PR, an EVA officer, a rover SME, and SMD and JAXA scientists (who served as SCICOM)

MCC Training

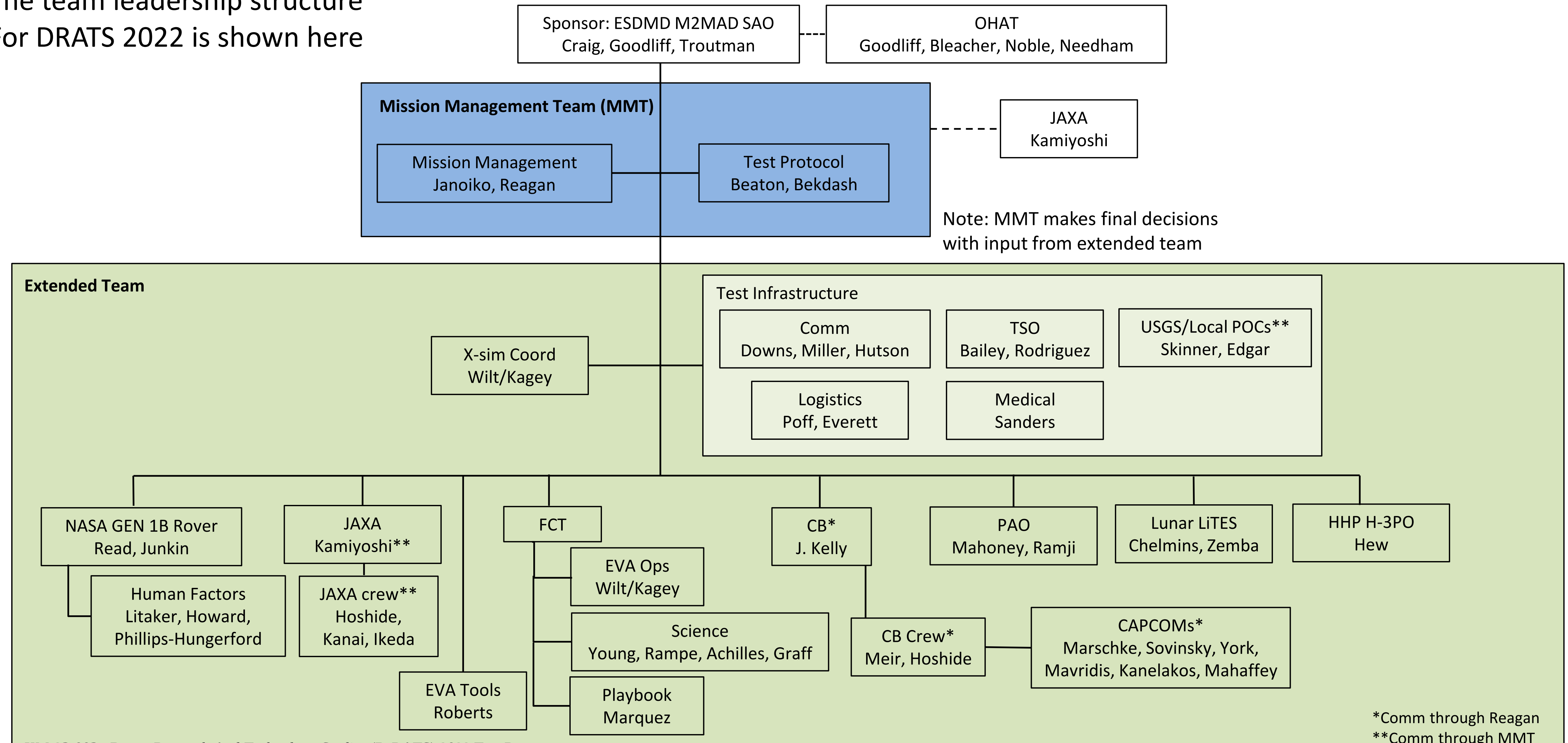
- Prior to testing, MCC personnel were trained on the rationale and objectives of the tests and provided time to review the crew timeline, IVA and EVA task procedures, experience rover operations, etc., and were given time to set up their console workstations in the A-MCC and experienced observing rover and EVA operations (including rover camera views, exterior lighting, etc.)

Crew learning to drive PR analog at JSC rockyard

Crew taking Geology & EVA Tool Training at JSC Rockyard

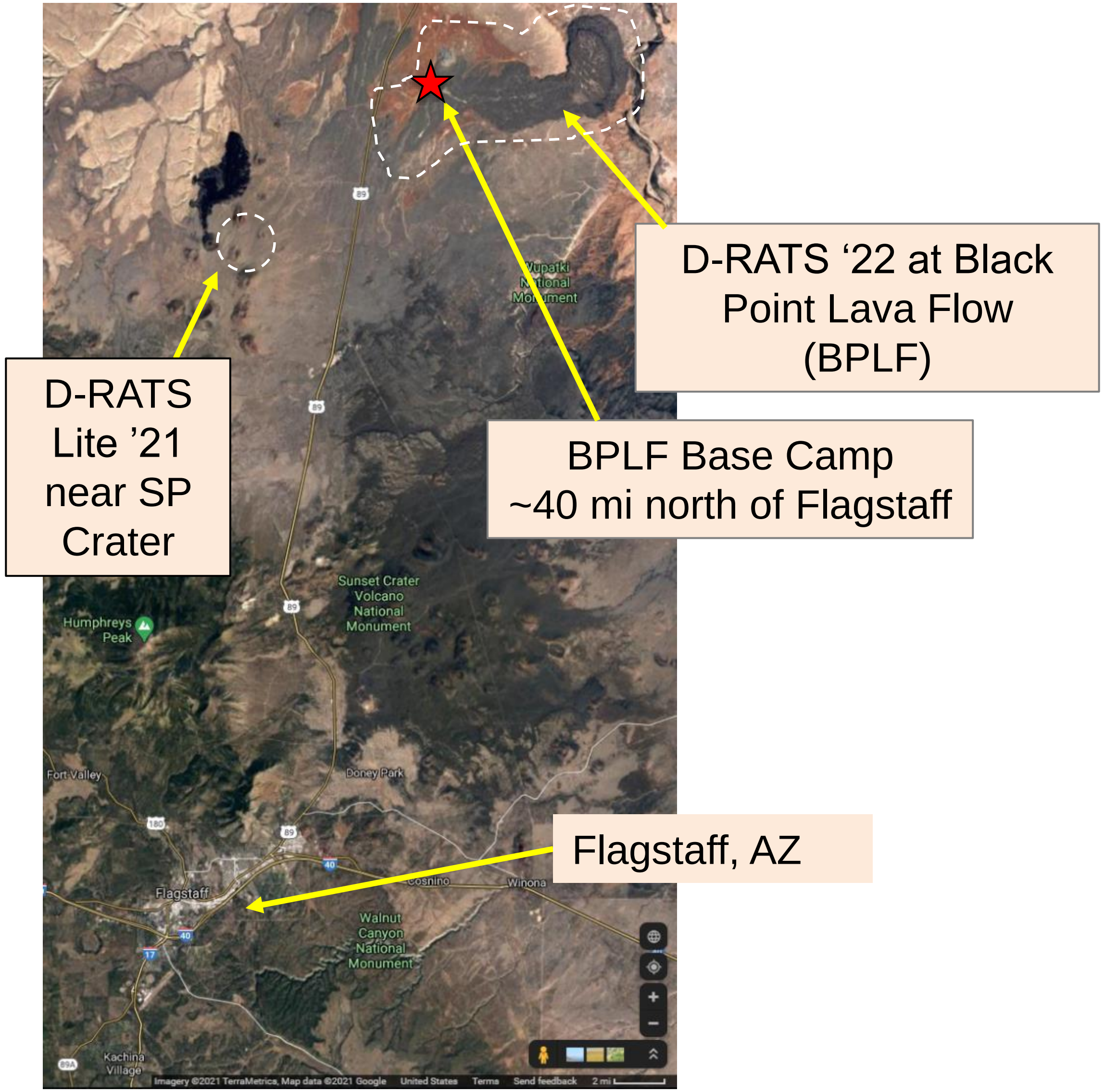
3.4.5 Team Leadership Structure

The team leadership structure
For DRATS 2022 is shown here



3.4.6 Test Location

- There are at least nine potential test sites located within 75 miles of Flagstaff, AZ
- Two previous D-RATS locations that enable macro-scale operations, large-scale relevant terrain, and high-fidelity science are:
  - **Black Point Lava Flow** (BPLF)
  - **SP Crater** area
- Field testing for D-RATS-22 was conducted at BPLF, which is ~40 miles north of Flagstaff



Map of Flagstaff and nearby Test Areas

3.4.7 Facilities

3.4.7.1 Analog MCC

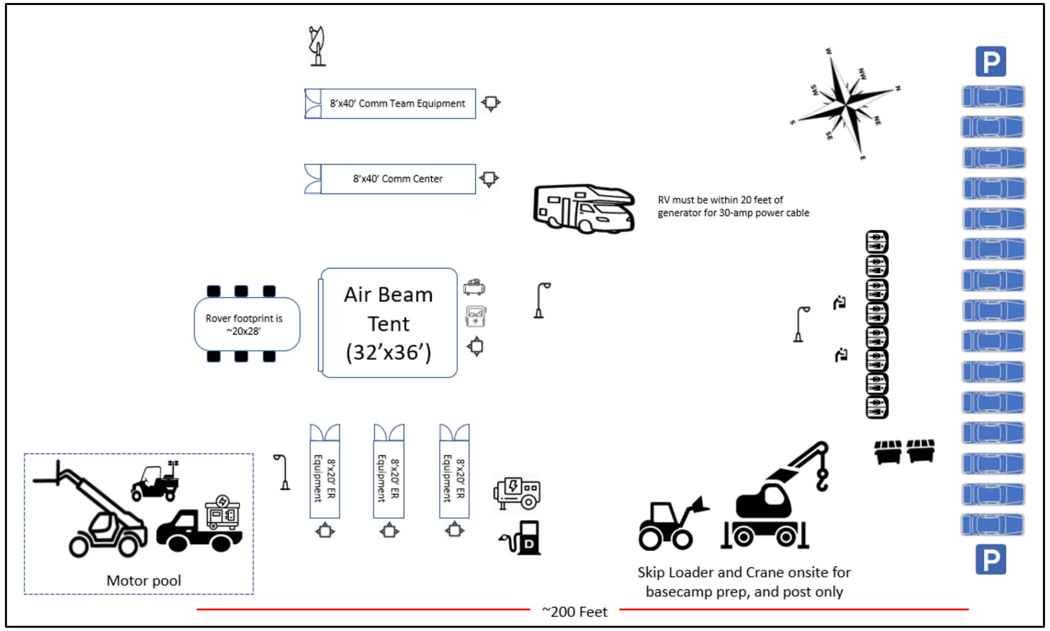
- An analog mission control center (A-MCC) was set up in the Einstein Room at NASA JSC
  - It is a one-room facility in Building 30 that enables the coordination, monitoring and execution of test activities and crews within JSC, as well as at remote locations
  - It consists of individual consoles with multi-monitor computer workstations
  - The consoles are linked by a high-speed data network, and each is identified by the call sign of the operator who uses it
- The A-MCC was staffed with actual Astronauts, CAPCOMs, Scientists, and EVA Officers, *(all actively assigned to Artemis-related work)*, who supported the in-simulation operations (13 NASA / 2 JAXA)
  - NASA Flight Operations Directorate provided the flight directors/CAPCOMs and EVA planning/execution support
  - NASA Ames Research Center Playbook team provided timeline planner support
  - NASA Science Mission Directorate (SMD) provided science personnel support (including traverse/EVA planning and execution)
- During testing, two-way communication (including voice, text, video, and data) was exchanged between test subject crews and A-MCC personnel
- All audio, video, text, and data traffic traveled across the NASA SNRF network and were managed by several console support positions to ensure connectivity (in-field comm setup and support was provided by Information Technology and Communications Services (KSC-ITC))

Personnel supporting D-RATS-22 field-tests from the A-MCC in Houston

3.4.7 Facilities (cont.)

3.4.7.2 Base Camp

- A base camp was set up atop a mesa at BPLF
- A large air-beam tent outfitted with repair stations and tools, with room to store the rover inside during inclement weather and for making in-field repairs was erected at base camp
- Multiple Conex boxes containing supplies and spare rover parts were delivered to the site
- One Conex box was outfitted as a field-site communications & command center



Basecamp Layout

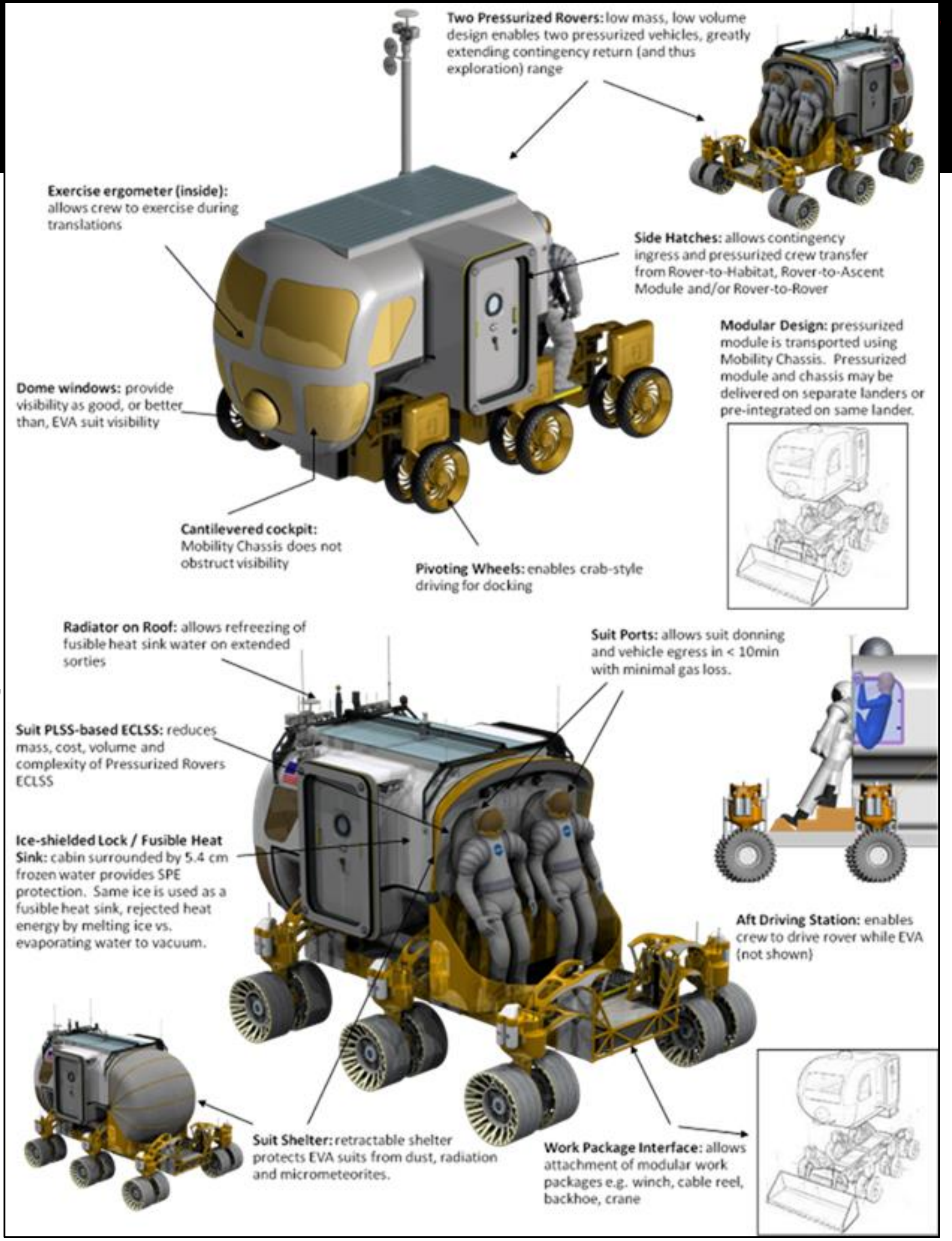
PR at base camp near giant air-beam tent

NASA and JAXA Support team in field-site comm center

3.4.8 NASA Gen 1B Rover

3.4.8.1 Gen 1B Rover Overview

- D-RATS analog missions and exploration traverses were conducted using the NASA GEN 1B pressurized rover analog testbed (figure at right)
- The GEN 1B PR concept combines a comfortable shirtsleeve (i.e., not wearing a space suit) cabin environment (at the same pressure and atmospheric composition of the lander and/or habitat) from which two crewmembers can conduct multi-day sortie missions (i.e., extended traverses and geological/mapping observations while IVA) while also maintaining the ability to egress and ingress the vehicle via hatch
- The interior cabin includes a functional cockpit with windows, operational displays and hand controllers, a water dispenser for drinking water and rehydrating food, two large benches that double as individual sleep stations, two side hatch areas for stowage, bench stowage, floor stowage, a waste collection system (WCS), and an aisle to support exercise and other IVA activities (see figures on this slide and following slide)
- The GEN 1B cabin's total pressurized interior volume is 10.8 m^3, with a net habitable volume of approximately 8.6 m^3, resulting in 79% functional volume (note: the GEN 1B PR is slightly larger than the unpressurized Apollo rover)
- While the GEN 1B concept primarily utilizes suitports for cabin ingress and egress, the latest Artemis program baseline architecture assumes that the first PR will not have suitports and that PR ingress/egress will be done either via a side hatch or an attached airlock



NASA GEN 1B pressurized rover concept and associated capabilities

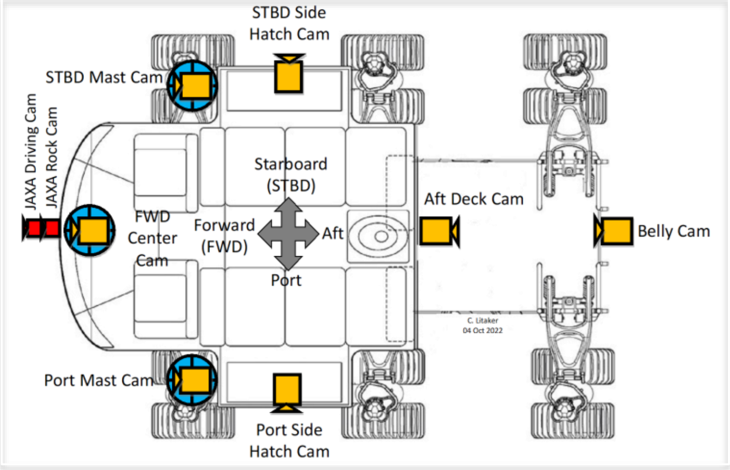
3.4.8 NASA Gen 1B Rover (cont.)

3.4.8.2 Cameras

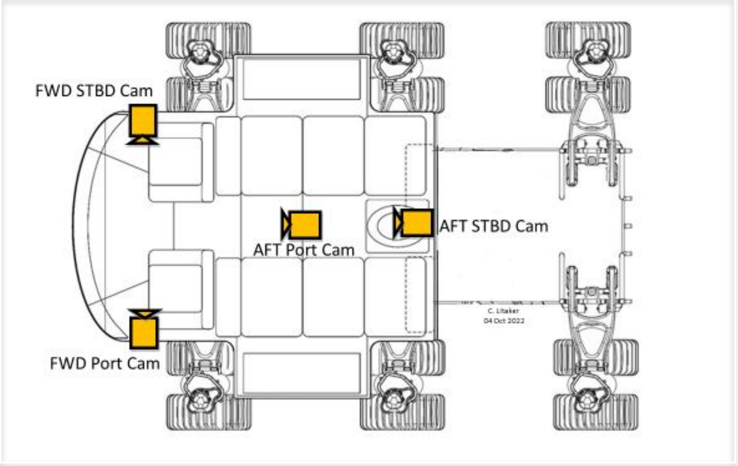
- The GEN 1B rover baseline exterior and interior camera locations are illustrated in the figures to the right and their specs are listed in the table below (note: two JAXA driving cameras are discussed later and are not included in this table)

Camera Name	Lens	Angle Canted (°)	Location	Notes
ALL ACCESS				
FWD Center Cam	4.7-94mm	Variable	Center Front Exterior PTZ Camera	Pan/Tilt/Zoom (PTZ); x20 Optical Zoom
Port Mast Cam	4.7-94mm	Variable	Right Exterior PTZ Mast Camera	Pan/Tilt/Zoom (PTZ); x20 Optical Zoom
STBD Mast Cam	4.7-94mm	Variable	Left Exterior PTZ Mast Camera	Pan/Tilt/Zoom (PTZ); x20 Optical Zoom
Port Side Hatch Cam	2.8mm	75	Left Exterior Side Hatch Camera	Prime Lens
STBD Side Hatch Cam	2.8mm	75	Right Exterior Side Hatch Camera	Prime Lens
AFT Deck Cam	2.8mm	75	Center Aft Exterior Camera	Prime Lens
Belly Cam (Chassis)	180°	0	Center Exterior Chassis Camera	Lipstick camera with light
RESTRICTED ACCESS - FOR CREW PRIVACY				
Interior FWD Port Cam	1.56mm	0	Forward Left Operator Cockpit Seat	Has digital zoom; can be assigned upon MCC request
Interior FWD STBD Cam	1.56mm	0	Forward Right Operator Cockpit Seat	Has digital zoom; can be assigned upon MCC request
Interior AFT Port Cam	1.56mm	0	Center Aft Bulkhead btw Suitport Hatches	Has digital zoom; can be assigned upon MCC request
Interior AFT STBD Cam	1.56mm	0	Center Cabin on Ceiling	Has digital zoom; can be assigned upon MCC request

GEN 1B PR Camera Data



GEN 1B PR exterior cameras



GEN 1B PR interior cameras

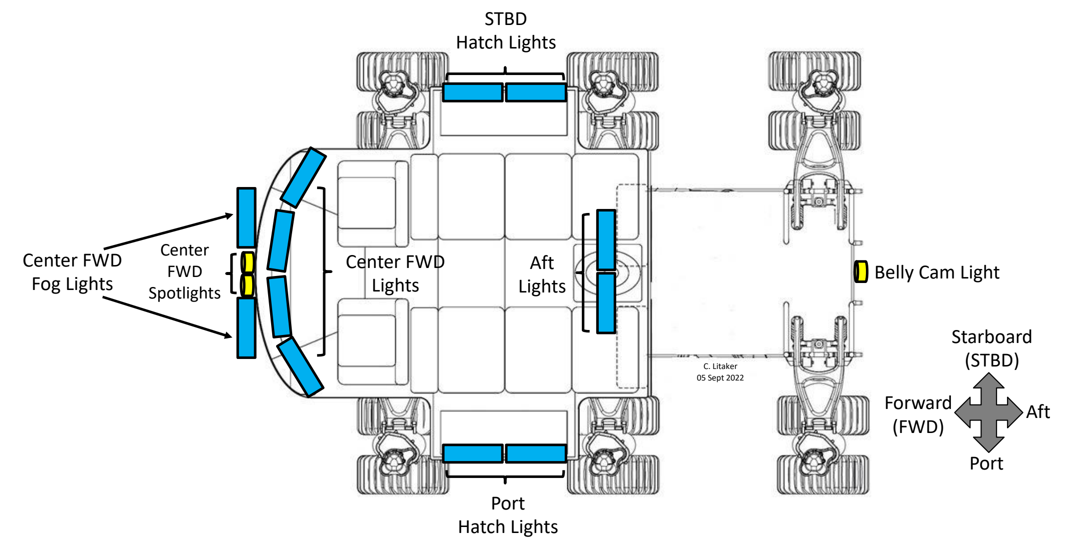
3.4.8 NASA Gen 1B Rover (cont.)

3.4.8.3 Exterior Lights

- The GEN 1B rover exterior light locations are illustrated in the figure on the right, and their specs are listed in the table below

Light Name	Location	Quantity	Lenses	Angle Canted (°)	Power Consumption per light (W)	Notes
Center FWD lights	Port and Starboard Vehicle Front (on cabin)	2	12” Narrow	~10	60	Facing Forward
Center FWD lights	Port and Starboard Vehicle Front (on cabin)	2	12” Wide	~45	60	Facing Forward
Center FWD Fog Lights	Fog Lights Vehicle Front (on chassis)	2	12” Wide	0	60	Facing Forward
Center FWD Spotlights	Spotlights Vehicle Front (on chassis)	2	4” Spots	0	24	Facing Forward
Aft Lights	Above Suit Ports (on cabin)	2	8” or 12” Wide	~10	60	Facing Aft
Port Hatch Lights	Over Port Side Hatch (on cabin)	2	8” Wide	~ 55	60	Over hatch
STBD Hatch Lights	Over starboard side hatch (on cabin)	2	8” Wide	~55	60	Over hatch
Belly Cam Light	Belly camera light (on aft bottom of chassis)	1	4” Spots	0	24	Facing Forward

GEN 1B PR Exterior Light Data

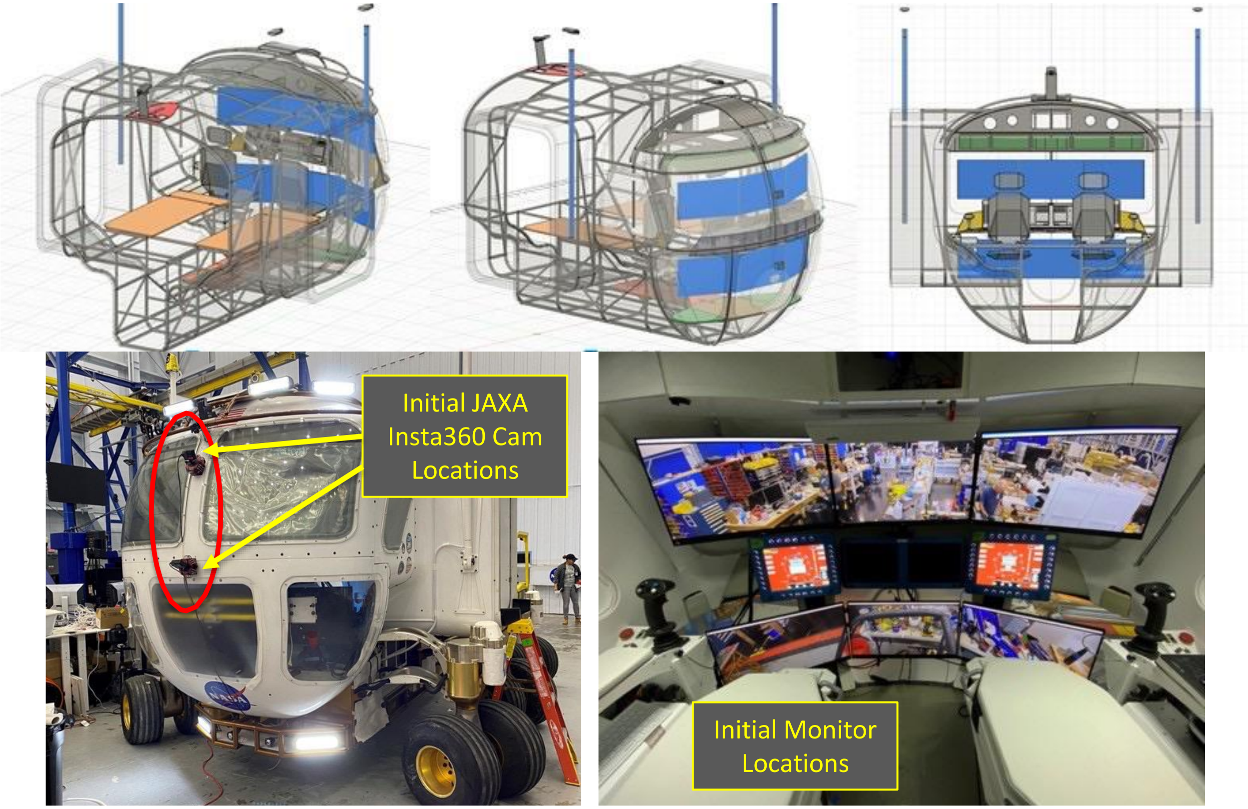


GEN 1B PR Exterior Lights

3.4.8 NASA Gen 1B Rover (cont.)

3.4.8.4 Implementation of Proposed JAXA Camera System for Driving Operations

- The initial JAXA concept for implementing a windowless driving system for the GEN 1B rover is shown below
- JAXA performed initial evaluations of this system, then NASA worked with JAXA to perform further studied in a VR environment to gather initial impressions and confirm camera position before installing the cameras and display screens into GEN 1B
- Initially, six display screens were installed in the forward nose, as two banks of three (upper & lower)
- Each bank was tied to a single exterior Insta360, 360° camera, whose imagery was displayed on the respective screens



Initial JAXA camera and display screen locations

3.4.8 NASA Gen 1B Rover (cont.)

3.4.8.4 Implementation of Proposed JAXA Camera System for Driving Operations (cont.)

- **During initial tests with the six-screen setup, the following observations were made by an expert GEN 1B driver** (who had hundreds of driving hours in 1B)**:**
  1) Driving with the camera and center line of the vehicle not aligned with the driver's seat made it feel like the rover was moving sideways,
  2) Stretching the camera image across 6 monitors resulted in poor resolution,
  3) It was difficult to discern slope angles, depth, size, and distance of objects,
  4) If was difficult to judge the width of the rover relative to objects on the screen, and
  5) Field of view was limited in all directions.,
  6) Some latency in the camera images appearing on the screens was visible
  7) Having the second (non-driving) crewmember available to pull up camera views requested by the driver was very helpful
- **As a result, modifications to exterior camera positioning and their projection onto the internal displays were reviewed with JAXA and made prior to the second test drive:**
  - Shifted camera image displayed on monitors so that it is centered with the driver seat and only stretched the images across the monitors closest to the driver (to address Observations #1 & 2)
  - Provided two separate "high" and "low" views that the driver/passenger could switch between for better resolution to address Observations #2 & 3
  - Added physical overlays to the monitors as a first attempt to provide additional driving aids for judging rover width to address Observation #4
  - Moved cameras from original configuration to lower on the rover and modified their angles of view to address Observation #5 (see image on right to final camera configuration used for D-RATS tests)
  - Switched to better cabling and using GoPro camera (Hero 10) instead of insta360 to address Observation #6
  - Trained subjects to use camera system and select multiple viewing angles as needed to address Observation #7

Final JAXA Cam Locations

3.4.8 NASA Gen 1B Rover (cont.)

3.4.8.4 Implementation of Proposed JAXA Camera System for Driving Operations (cont.)

- **The final camera/internal display configuration that NASA and JAXA arrived at for used at D-RATS-22 is shown in the photos on the right**
- **Additional modifications implemented after the 2nd round of pre-mission testing included:**
  - Removed the lowermost row of three displays entirely (top right photo) due to crew preference
  - The upper left display (directly in front of EV1) and the upper right display (directly in front of EV2) were configured to both display the same forward view by default, with green driving guidelines projected on them (bottom right photo), though the views were completely reconfigurable
  - The center top display was configured by default to display a situational awareness (SA) composite feed composed of the views from 5 rover cameras (see section 3.4.8.5 for more on the SA screen)
  - All displays were customizable, and alternate camera views could be displayed on each via keyboard input, including views from the port and starboard mast cameras, which were the only cameras that had pan-tilt-zoom capability

Interior view with windows covered and driving screens installed

Interior view with displays configured in default drive-by-camera mode

3.4.8 NASA Gen 1B Rover (cont.)

3.4.8.5 Driving Modes

- Due to limited time to incorporate a camera-display system into the GEN 1B rover and limited time in the field for D-RATS 22, only two “book-end” configurations were tested this year:
  - **Drive-by-Windows Mode**
    - A single, specific “drive-by-windows” configuration of the nominal GEN 1B design that relied primarily on windows for operations
    - A single central monitor was provided with a SA composite view of the rover’s surroundings
  - **Drive-by-Cameras Mode:**
    - A single, specific “drive-by-cameras” configuration developed in collaboration with the JAXA PR team (see previous section)
    - Windows were covered and 3 additional interior monitors that displayed views from 2 exterior, forward-facing cameras
    - The SA composite view was also provided
- The GEN 1B rover was modified so the two driving modes could be quickly configured in the field to allow crews to test both modes back-to-back in a fairly short span of time

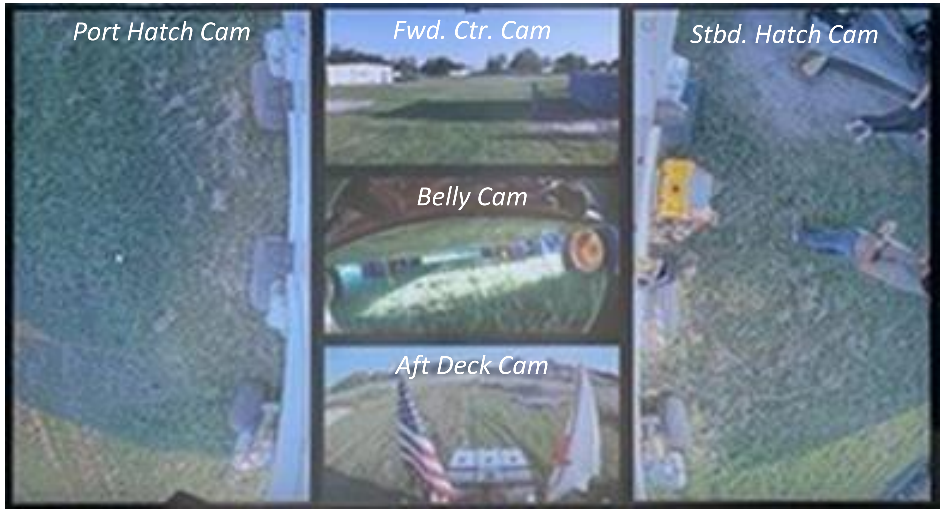
“Drive-by-windows” mode configuration – large open windows with a single situational awareness (SA) screen flanked by pilot and copilot instrument panels

“Drive-by-camera” mode configuration - windows covered and three internal displays added, which displayed exterior driving camera views (SA view displayed on center top screen)

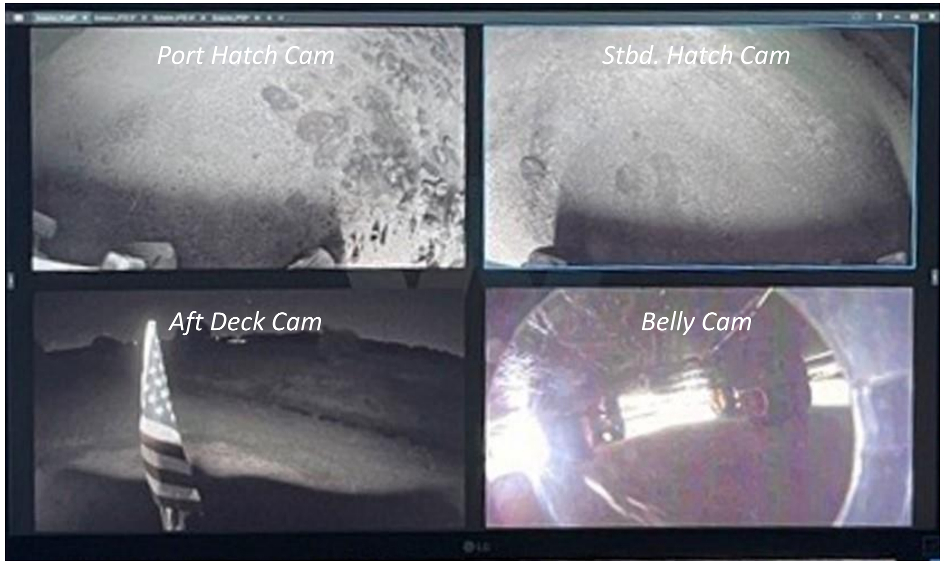
3.4.8 NASA Gen 1B Rover (cont.)

3.4.8.6 Situational Awareness Display

- A situational awareness (SA) display configuration was provided for both driving modes (see images on right)
- The default SA display consisted of five camera views:
  - **Forward Center Cam** (displayed at top center of monitor)
    - Located high on the front looking forward
    - Provided a wide FOV ahead
  - **Belly Cam** (displayed at middle center of monitor)
    - Located on the undercarriage looking forward along the belly
    - Provided awareness of height of rocks ahead of the rover as they are approached and pass under the rover
  - **Aft Deck Cam** (displayed at bottom center monitor)
    - Located on aft deck, pointing behind the rover
    - Provided a view aft of the rover looking over the toolbox and flags
  - **Port Hatch Cam** (displayed on the left side of the monitor)
    - Located above the port hatch, looking down at the ground
    - Provided a view of the port wheels and ground immediately left of the vehicle
  - **Starboard Hatch Cam** (displayed on the right side of the monitor)
    - Located above the starboard hatch, looking down at the ground
    - Provided a view of the starboard wheels and ground immediately right of the vehicle
- As shown on the bottom figure, the view can be configured by crew to display these cameras in any desired configuration



Situational Awareness (SA) Display captured during training at JSC Rockyard



Situational Awareness (SA) Display captured during training at JSC Rockyard

3.4.9 Test Conditions

3.4.9.1 Vehicle Configurations

- To address Strategic Question 1, the rover was configured to support the two vehicle configurations described in section 3.4.8.5:
  - **(1) Drive-by-Windows**, which utilized the standard GEN 1B windows; and
  - **(2) Drive-by-Camera**, which incorporated external cameras displayed on internal monitors
- For each configuration, two maximum crab angle options (18° and 360°, per Strategic Question 7) and two different directors for remote control of the rover (by the crew or by the ground, per Strategic Question 6) were tested and evaluated
- Each test crew pair experienced all test conditions during their 3-day traverse and had the opportunity to provide feedback on each
- A matrix of these test cases is shown below at the right

Rover Configuration	Driving using Windows or Cameras + Internal Displays	Maximum Crab Angle (deg)	Who Provides Rover Teleoperation Requests During EVA?
A	Internal Displays	360	Crew Directed
B	Internal Displays	360	MCC Directed
C	Internal Displays	18	Crew Directed
D	Internal Displays	18	MCC Directed
E	Windows	360	Crew Directed
F	Windows	360	MCC Directed
G	Windows	18	Crew Directed
H	Windows	18	MCC Directed

PR Vehicle Configurations for D-RATS-22

3.4.9 Test Conditions (cont.)

3.4.9.2 Teleoperation of the PR

- Rover teleoperations were only performed while the crew were outside the rover conducting an EVA
- Two different teleoperations methods were explored:
  - **Crew-Directed**
    - In this mode, the crew requested MCC move the rover in a certain manner that was helpful for them (e.g., “Rotate the rover 20° clockwise so that it can project better lighting onto my EVA worksite.”)
  - **MCC-Directed**
    - In this mode, MCC directed the rover’s movement during EVAs without crew direction, for the purpose of enhancing science (e.g., getting a better vantage point to oversee the science station), or operations (e.g., safety – such as being able to see both crewmember working in their camera FOVs, or position the rover so that it could serve as a comm relay for one crewmember who might otherwise be out of comm range)
    - The requests typically came from the EVA or Science Lead consoles, depending on what the current objectives were, and had to be approved by the Flight Director before the rover was moved
    - Note: the A-MCC did not actually possess the ability to teleoperate the rover remotely from Houston during field testing this year; however, this capability was simulated by contacting the rover chase team in the field and making the request to move the rover on behalf of the MCC - the rover chase team listened for the crew or MCC to call out what they wanted the rover to do, and teleoperated the rover accordingly via an in-field laptop over Wi-Fi

3.4.10 Tasks and Test Timeline

- Detailed test tasks and timelines stemmed from the ESDMD Lunar Architecture Team (LAT) reference timelines and were drafted, reviewed, and refined by the test team and all stakeholders (including rover, science, and FOD SMEs)
- Timelines included both habitation and operations-related tasks and were meant to provide a flight-like mission cadence
- Habitation tasks included post-sleep, meal prep, eating, WCS operations, hygiene, exercise, housekeeping, and pre-sleep
- Operation tasks included rover systems checks, driving, IVA science, EVA prep, post- EVA cleanup and suit servicing, EVA, housekeeping, daily planning conferences, private medical conferences, and PAO
- The table at right shows a summary of tasks that made up the detailed timelines

Task	High-Level Task Summary
Rover Operations	
Driving and Navigation	Navigate and drive the rover across various terrain types to scientific regions of interest
Rover System Checks	Perform checks of rover power level, navigation state, systems performance, and consumables
Science	
IVA Science	Perform IVA science tasks such as observations, scout for targets of opportunity, use science instruments, etc.
EVA Science	Perform surface science tasks such as sample collection, curation, photography, and instrumentation utilization
EVA	
EVA Prep	Suit checks, suit don, leak checks, communication checks, pre-breathe, tether configuration, egress
EVA	Execute an EVA and perform surface science and operations tasks
Tool and Sample Stowage	Utilize the aft deck tool and sample stowage system to support EVA activities
Post EVA	Ingress, suit doff, suit checks, suit cleaning and recharge
Ground Input	
Daily Planning Conferences (DPC)	Daily morning & evening tags between space & ground
IVA Operations	
Post-Sleep	Tasks including sleep station stow, hygiene, WCS ops, meal prep, meal
Exercise prep, Exercise, Post-exercise cleanup & reconfig.	Exercise device setup, change clothes, conduct exercise, stow exercise equipment, hygiene/change clothes
Meal Prep, Meal, Meal cleanup	Unstow food/utensils, rehydrate food, prepare drink; eat food; clean/stow utensils, dispose of trash
Trash management	Collection of trash throughout the rover, co-locating into single container for stowage or removal
Housekeeping	Routine cleaning and inspection of rover interior. Wipe down surfaces, check vent inlets/outlets, inspect WCS, sleep stations, PWS, and other habitation systems.
Inflight Maintenance	Perform inflight maintenance task in rover interior
Private Medical Conference	Private calls between each crew and flight doctor

High-level task summaries

3.4.10 Tasks and Test Timeline (cont.)

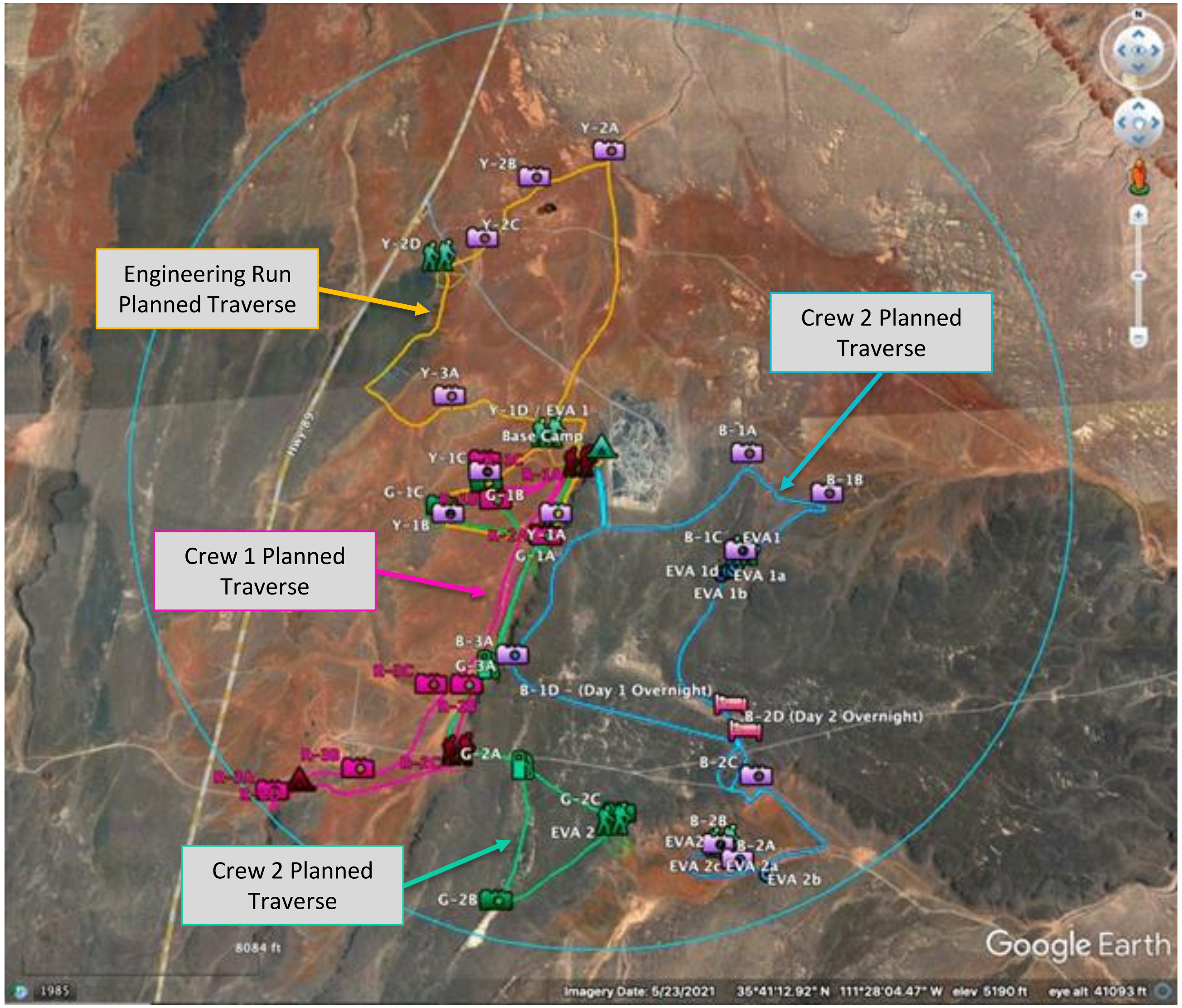
- **An example of a subject of one of the mission summary timelines is shown below**

<table>
<tr><th></th><th colspan="4">Test Day 1</th><th colspan="7">Test Day 2</th><th colspan="7">Test Day 3</th></tr>
<tr><td>Day</td><td>Pre-Mission Prep</td><td colspan="7">Mission Day 1</td><td colspan="9">Mission Day 2</td><td>End of Mission Activities</td></tr>
<tr><td>Time of Day, PDT</td><td>13:00</td><td>17:30</td><td>20:00</td><td>23:00</td><td>1:00</td><td>12:00</td><td>13:40</td><td>14:00</td><td>17:30</td><td>20:00</td><td>23:00</td><td>1:00</td><td>10:00</td><td>11:40</td><td>12:10</td><td>15:00</td><td>15:30</td><td>16:40</td></tr>
<tr><td>Rover Crew</td><td>Pre-Mission Prep, Fam, and Driving to the Worksite</td><td>Driving to Different Sites, Site Surveys, IVA Observations</td><td>EVA Operations</td><td>IVA Operations</td><td>Crew Sleep in Rover</td><td>IVA Ops</td><td>Driving</td><td>IVA Ops</td><td>Driving to Different Sites, Site Surveys, IVA Observations</td><td>EVA Operations</td><td>IVA Ops</td><td>Crew Sleep in Rover</td><td>IVA Operations</td><td>Driving</td><td>IVA Operations</td><td>Driving</td><td>Signoff DPC with MCC</td><td rowspan="2">Crew Drive Home, Rover Cleanup, Base Camp Safing</td></tr>
<tr><td>Field Team</td><td>Drive to Field Site, Final Prep of Rover and Mission Support Systems</td><td colspan="3">Field Support Activities</td><td>Sleep/Minimal Field Team Remains</td><td colspan="6">Field Support Activities</td><td>Sleep/Minimal Field Team Remains</td><td colspan="5">Field Support Activities</td></tr>
<tr><td>MCC/SER</td><td>MCC Set Up</td><td colspan="3">MCC Ops</td><td>No MCC</td><td colspan="6">MCC Ops</td><td>No MCC</td><td colspan="5">MCC Ops</td><td>End of Mission Activities</td></tr>
</table>

Example summary timeline with high-level activities

3.4.11 Rover Traverse Planning

- During the planning stages of D-RATS-22, SMD scientists and ops planning experts planned three sets of traverses for three crew pairs, each to last three days
- They identified sites of scientific interest based on satellite imagery and designated the sites for IV photography stops or full EVA exploration
- Sites for overnight stays were chosen based on estimated traverse distance and timelines, as well as local geography
- These activities gave the planning teams an opportunity to exercise their skills and tools in a real-world environment very similar to the process they will face when planning actual lunar exploration
- The image at right shows four 3-day PR traverses that were planned for the D-RATS-22 field test
  - The orange traverse was planned for the engineering dry run, to put the rover and team through their paces
  - The magenta-, cyan-, and teal-colored traverses were designed for Crew 1, Crew 2, and Crew 3 respective
  - A camera icon denotes planned photo opportunities, hiking icons denote planned EVA sites, and text or icons denote planned overnight stays
- Prior to commencing each traverse, the D-RATS science and operations teams briefed the crew on the specific science and EVA objectives associated with their respective traverse



D-RATS 2022 planned PR traverses

3.4.12 Metrics and Data Collection Methods

- **This section outlines the metrics and data collection methods used to evaluate the study objectives**
- **Vetted detailed test protocol through all sponsors and stakeholders**
  - Included clearly defined strategic questions, test objectives, metrics, procedures, data analyses, and reporting
- **Objective + Subjective data were collected during testing in real-time and post-test**
  - Collected individual subjective data on as-needed basis throughout testing (including informal “think aloud” comments + formal rating scale metrics and associated comments)
  - Collected subjective consensus data at the end of the field-test
- Employed a combination of objective rover and human factors metrics, and customized timeline-specific questionnaires to evaluate the acceptability of PR operations
- Integrated objective and subjective data where applicable, to provide a more complete picture of options that should be considered for future design, test, and evaluation
- Collected most data in real-time during testing, either automatically in the background (e.g., rover performance data via rover telemetry streams) or during specific crew timeline tasks
- The table on the right contains a summary of the data metrics collected during testing, mapped to each strategic question

Strategic Question	Subjective Data				Objective Data										
	Acceptability	Capability Assessment	Workload	Handling Qualities	Task Timing	Rover Speed	Distance Driven	Time Spent Driving	Time spent stationary: navigating	Time spent stationary: contextual observations	Crab angle range used	Power Used	Number and Location of Vehicle Collisions	Number and Context of Vehicle Near Misses	Number and Context of E-Stop Uses
1. What combination of windows and/or externally mounted cameras projected onto internal cabin displays best support PR operational and scientific objectives?	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2. What exterior lighting configurations best support PR tasks?	X				X	X	X	X	X	X	X	X	X	X	X
3. How does the interior layout of a PR contribute to human performance and habitation?	X		X		X										
4. How is waste and trash managed inside of a PR?	X		X		X										
5. How much time per day is spent on overhead tasks for PR operations, crew habitation, and EVA prep and post?	X		X		X										
6. What operational concepts best support PR teleoperations during EVA, and who should direct rover movements?	X		X		X	X	X	X	X		X	X	X	X	X
7. How important is the ability to “crab” the rover while driving, and what crab wheel angles are needed?		X	X	X	X	X	X	X	X		X	X	X	X	X
8. How are EVA tools and samples managed and stored outside of a PR?	X				X										
9. What flight rules are needed to safely operate the rover during traversing and EVA?	X														
10. What are the advantages and limitations of switching between a SCICOM and a CAPCOM, depending on the ops?		X													

Data products mapped to strategic questions

3.4.12 Metrics and Data Collection Methods (cont.)

3.4.12.1 Practical Significance

- Subjective ratings of acceptability, capability assessment, workload, and fatigue, as well as objective crew performance metrics were collected
- Descriptions of these metrics, including examples of the types of data analysis products derived from each, are provided in the following sections
- Subjective ratings are based on a 10-point Likert scale divided into 5 distinct categories, with 2 ratings within each category to discriminate preferences (see 3.4.12.3.1 for definition of acceptability rating scale)
- In this HITL testing, sample sizes were not large enough to use inferential statistics - for this reason, we prospectively defined practical significance as a categorical difference on the 10-point rating scales
  - For example, as shown in figure below, the difference between 5 and 6 is not considered practically significant whereas the difference between 2 and 3 is considered significant
- For objective metrics, such as timeline task completion times, we prospectively defined practical significance to be a 10% difference.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Categorical difference

No categorical difference

Acceptability rating scale describing practically significant differences

3.4.12 Metrics and Data Collection Methods (cont.)

3.4.12.2 Objective Data

- Objective timeline data, vehicle performance data, and trash generation data were collected in real-time during the test and are summarized in the table below
- Detailed timeline data, including start and stop times and task durations, was collected manually by test observers
- Rover driving data, including traverse distance, duration, and speed and how those metrics vary with slope and other terrain features were generated automatically from vehicle GPS
- Crab angle used and overall vehicle power consumption was provided by vehicle telemetry streams and correlated with GPS data
- Time spent stationary for navigation, contextual observations, and habitation activities was identified
- The number and location (on rover) of vehicle collisions, as well as the number and context of any e-stop utilizations were noted manually.

Collection Method			
Manually by SME Test Observer	Automatically from Vehicle Telemetry	Automatically from Vehicle GPS	METRIC
X		X	Vehicle Traverse Duration
		X	Vehicle Distance driven
		X	Vehicle Time spent moving - both crew IVA
		X	Vehicle Speed while Moving (max, mean incl. stops, mean excl. stops)
		X	Vehicle Distance Teleoperated
	X		Crab Angle Range Used
	X		Power utilized
X			Vehicle Time spent stationary, navigating
X			Vehicle Time spent stationary, contextual observations
X			Vehicle Time spent stationary, resting/eating/other
X			Vehicle Time Spent Teleoperated
		X	Vehicle Speed while Teleoperated
X			Number and Location of Vehicle Collisions
X			Number and Context of E-Stop utilization
		X	EVA Distance walked (total, mean per EVA)

Objective data collected during DRATS 2022

3.4.12 Metrics and Data Collection Methods (cont.)

3.4.12.3 Subjective Data

- The following subjective ratings were collected from all test subjects:
  - Acceptability Ratings (see 3.4.12.3.1 for discussion)
  - Capability Assessment Ratings (see 3.4.12.3.2)
  - Workload Ratings (see 3.4.12.3.3)
  - Rover Handling Qualities (see)
- These ratings and associated comments were collected individually in real-time throughout the test, as specified in the detailed timelines
- Acceptability and capability assessment ratings were also provided collectively by the full team of test subjects during a post-test consensus discussion
- Consensus ratings ensure consistent interpretation of the questions
- If desired, an individual test subject can note a dissenting opinion in the test crew consensus
- Whereas there is information content in the individual ratings and comments, the consensus ratings provide the actionable data and forward recommendations

3.4.12.3 Subjective Data (cont.)

3.4.12.3.1 Acceptability Ratings

- A 10-point Likert scale of acceptability has been developed and used by the investigator team during analog field testing since 2008 to measure the acceptability of different prototype systems and tasks to inform requirements and operations concepts (see figure below)
- The scale consists of 5 categories, with 2 ratings within each category to discriminate preferences:

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- Any rating of 4 or lower is considered acceptable
- Ratings of 3 or greater require subjects to provide recommendations on specific desired, warranted, and/or required improvements that would make the test condition and/or task totally acceptable
- In this testing, test subjects used acceptability ratings and associated comments to describe the overall acceptability of conducting their tasks
- Subjects were queried for their individual ratings following completion of various tasks
- A test subject consensus was obtained after all subjects had completed their individual tests

3.4.12.3 Subjective Data (cont.)

3.4.12.3.2 Capability Assessment Ratings

- A primary objective of this study was to identify which capabilities are required for rover design to support science and exploration and which capabilities might enhance exploration but are not essential
- It is also important to identify capabilities that provide marginal or no meaningful enhancement, and can therefore be excluded, resulting in cost savings without impact to mission success
- Thus, a 10-point Capability Assessment rating scale (figure below) was devised to rate the extent to which candidate capabilities are expected to enable and enhance future exploration missions

Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement	
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.	
1	2	3	4	5	6	7	8	9	10

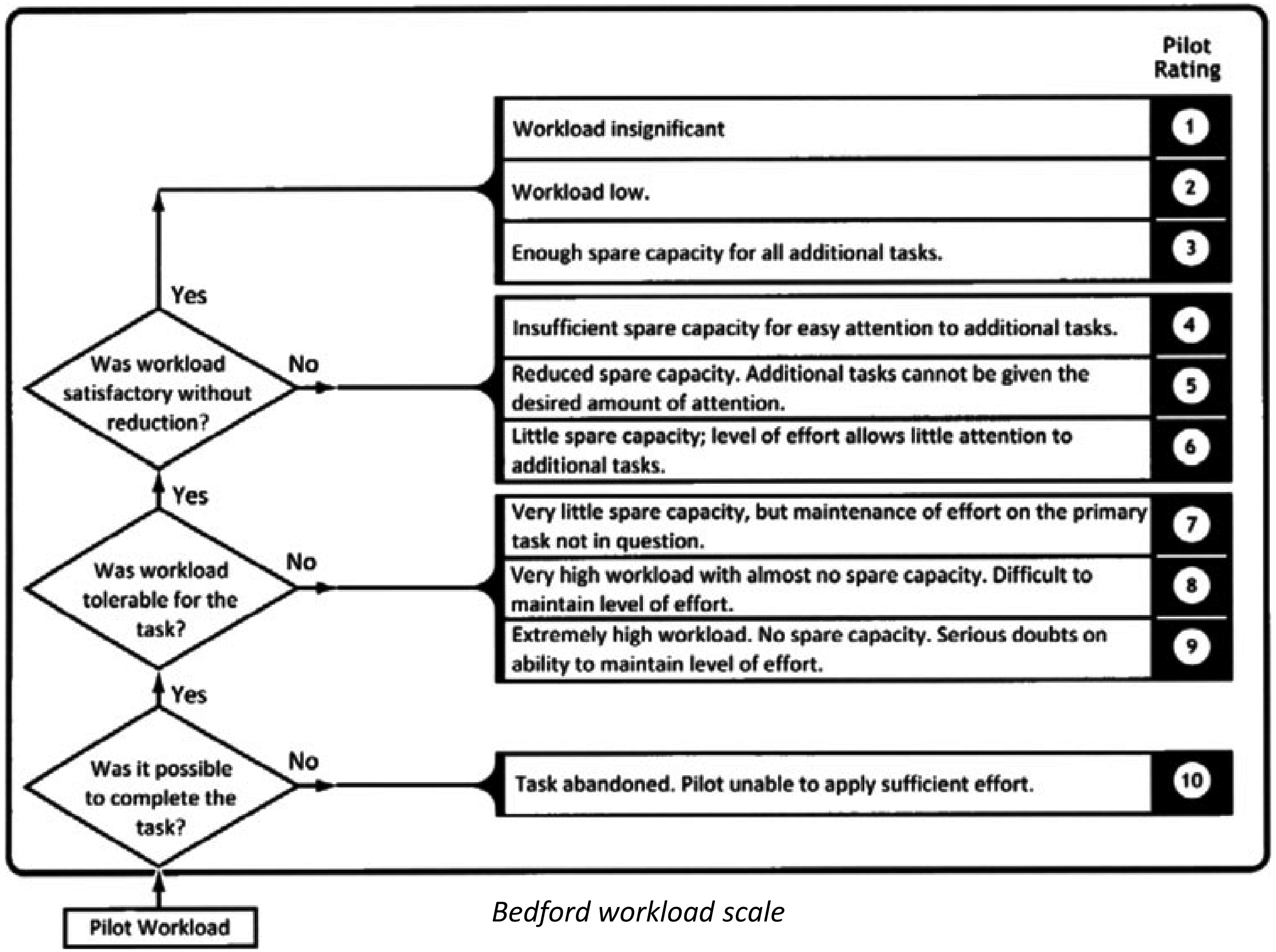
Capability assessment rating scale

- This scale consists of 5 categories: *Essential/Enabling, Significantly Enhancing, Moderately Enhancing, Marginally Enhancing,* and *Little or No Enhancement*, with 2 ratings within each category to discriminate preferences
- Throughout testing, the test subjects used capability assessment ratings to rate the level of mission enhancement provided by a given capability (e.g., camera configuration to support driving, navigation, and science; exterior rover lights to support EVA; etc.)

3.4.12.3 Subjective Data (cont.)

3.4.12.3.3 Bedford Workload Ratings

- The Bedford Workload Rating Scale integrates mental, physical, and environmental factors into a 10-point scale (see figure below)
  - Workload refers to an individual's ability to maintain task performance under a specific condition or set of conditions (e.g., workload required to drive a rover while viewing the external environment through windows)
  - During this test, subject were prompted for workload ratings upon completion of driving tasks under the different vehicle configuration conditions, and the resulting data was analyzed to identify which configurations may lend themselves more naturally to lower workload requirements on the crew



Bedford workload scale

3.4.12.3 Subjective Data (cont.)

3.4.12.3.4 Handling Qualities Ratings

- Rover handling qualities were assessed by incorporating the SAE J1441 subjective rating scale for vehicle ride and handling, which has been used for the last 40 years in the automotive industry as well as with DoD vehicle testing (figure below)
- This rating scale was used to evaluate vehicle handling qualities under the different window, camera, and crab angle configurations

Rating Scale		Event Type: Disturbance	Event Type: Control
10	Desirable	Imperceptible	Excellent
9	Desirable	Trace	Very Good
8	Desirable	A Little	Good
7	Desirable	Some	Acceptable
6	Desirable	Moderate	Fair
5	Borderline		
4	Undesirable	Annoying	Poor
3	Undesirable	Strong	Moderately Poor
2	Undesirable	Severe	Very Poor
1	Undesirable	Not Acceptable	

Disturbance: The degree to which disturbances are felt by the driver and/or affect the driver (e.g., driving over a rock or small crater, does it tweak the driving controls to a minimal or to a significant degree).

Control: The controllability of the vehicle. I.e., the way in which the vehicle responds to driver inputs, with predictable responses.

Scoring: Raters will be asked to provide 2 ratings for each task being rated – one for 'disturbance' and one for 'control.' These ratings are independent and are not combined. To pass evaluation for a given task, the ratings for the vehicle must be in the desirable category along both dimensions (disturbance and control). If either dimension receives a borderline or undesirable rating, then that would indicate a failure.

Subjective Comments: Subjective comments should also be collected for every task being scored, in order to provide some diagnosticity for mitigating any potential issues in resilience to disturbances or controllability.

SAE J1441 handling qualities rating scale

Section 3.5

Schedule

3.5.1 FY22 HITL Test Preparation Schedule

- Planning, preparation, and test readiness reviews for the FY22 D-RATS analog mission took much of the early calendar year
- Crew training and dry runs were performed during September
- Crewed analog missions were performed in October (see next slide for details)

SEPTEMBER 2022

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				1 JSC Testing TRR (ER) Engineering Crew Training Day 1 (classroom & RY)	2 Draft Field ops products due	3
4	5 Holiday	6 Engineering Crew Training Day 2 (B9)	7	8 D-RATS Field TRR (XA/CB) Team Integration Mtg	9 No B9 Access VVIP drive Aki Day & Night Training	10 Rover at Rice
11 Rover at Rice	12 Rover at Rice (returns 7pm for initial outfitting)	13 VIP drive D-RATS Engineering Dry Run Tests with Internal NASA Test Subjects (JSC Rock Yard) [13–16] Setup/Comm Checkout +MCC fam Aki Night Driving (b/u)	14 Engr Run (Eng. Crew for night & full day) [14–15]	15 Aki Night Driving (b/u)	16 Contingency Day	17
18	19 Debrief Engr Run ASCAN/Astronaut Geology Training - Field (SMD not available) [19–23]	20	21	22 D-RATS Team Integration Mtg (final)	23 All Field ops products due	24
25	26 JAXA Travel to Houston [25–26]	27 NASA & JAXA Test Subject Training on PR Systems and Test Protocol (JSC Rock Yard, no MCC) [27–30] Classroom Trng (Engr & 3 Crews) Crew-1 night (2.5 hrs)	28 Crew-1 (am) Crew-2&3 (pm) Crew-2&3 night (3 hrs)	29 1 CM night (2hrs) Add'l trng as requested	30 Contingency Day	

t Geology Training - JSC (SM

Legend
Product and Rover Milestones
Training
XM / ER Shipping & Travel
XM / ER work and tests
MCC Support day
Contingency Days
Major Constraint
Flexible Date

3.5.2 FY22 HITL Test Execution Schedule

- **Equipment was packed and shipped to AZ the first week of October**
- **Base camp setup and equipment setup took ~5 days**
- **Tests began with 2.5 days of engineering runs and field checkouts**
- **Performed three sets of crewed, analog missions**
  - Missions were ~2.5 days long and followed predefined mission plans
  - Day & night driving was performed by all crew in both drive-by-camera and drive-by-windows modes
  - EVAs were performed by all crew (mostly at night, with the lunar pole, low-elevation sunlight simulated by a high-intensity light source in the field
  - All aspects of the missions were monitored by scientists and engineers from NASA, JAXA, and USGS (both in-field and remotely from the HITL mission control center at JSC)
- **Equipment maintenance/repairs performed in-field, during and between missions**

Legend

- XM / ER Shipping & Travel
- XM / ER work and tests
- MCC Support day
- Contingency Days
- Major Constraint
- Flexible Date

Section 3.6

Results

Results Contents

- Objective data is presented in section 3.6.1, grouped by Crew 1, Crew 2, and Crew 3 tests, with each grouping covering traverse, odometry, wheel angle usage, and crab angle usage
- Subjective data is presented in section 3.6.2
- A summary of the data breakout is given below for reference

3.6.1 Objective Data

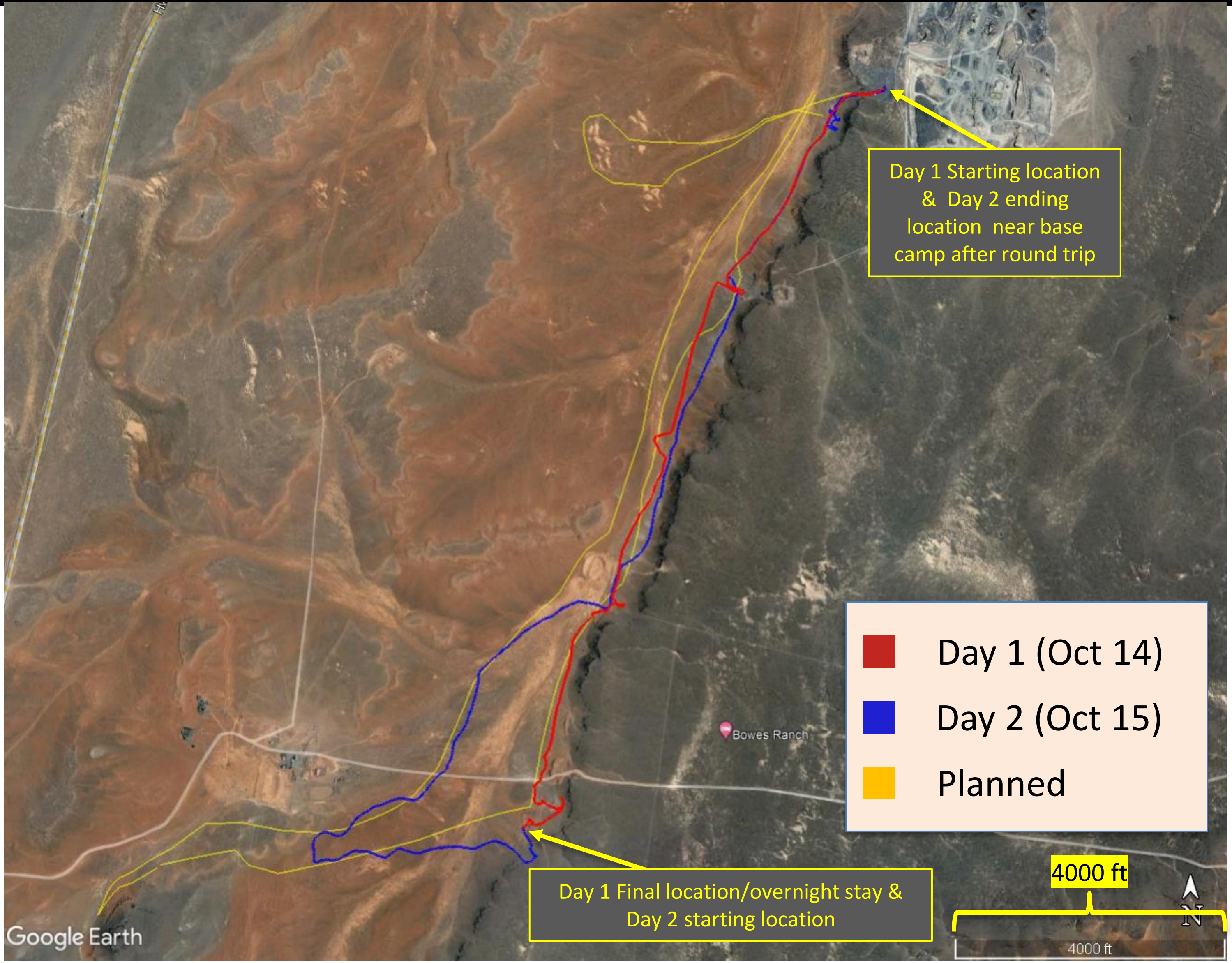
Comments on objective data collected from rover during traverses

- Time spent moving was calculated by detecting when the vehicle was moving at least 0.1 meters per second
- The average vehicle velocity was calculated by taking the total distance traveled / (total time spent moving (seconds) + total time spent not moving (seconds))
- The average vehicle velocity with no stops was calculated by taking the total distance traveled / (total time spent moving (seconds))
- The Vehicle Crab Angle Range was calculated using the Crab Angle of the Vehicle, which was calculated by taking the Arctangent (Y Velocity in meters per second / X Velocity in meters per second) for each row. If the Y Velocity is not zero but the X Velocity is zero, then we would say the crab angle for the vehicle is 90 degrees
- Power Used was calculated by taking the current power wattage for each second as (BMS 1 Voltage * BMS 1 Current) + (BMS 2 Voltage * BMS 2 Current). Then adding up the total amount of watts per second and converting that to kilowatt hours
- The data is presented in the following subsections, grouped by crew number:
  - Section 3.6.1.1 for Crew 1 driving data
  - Section 3.6.1.2 for Crew 2 driving data
  - Section 3.6.1.3 for Crew 3 driving data

3.6.1.1 CREW 1 DRIVING DATA

3.6.1.1.1 Crew 1 - Traverse

- The graphic on the right shows the Crew 1 planned traverse in yellow and the actual traverses for days 1 and 2 (in red and blue respective)
- Data was collected from the PR GPS and overlaid on Google Earth maps*
- Day 3 testing for Crew 1, slated for October 16th, was cancelled due to rain
  - Crew and team felt enough data had been gathered on the first two days, so a decision was made to not extend the schedule to capture a 3rd day
  - This prevented Crew 1 from testing some modes of operation, but was deemed acceptable
  - The actual traverses therefore lack the third day of planned driving and activities



Aerial map of Crew 1 traverse region, with overlays of daily traverses (planned & actual)

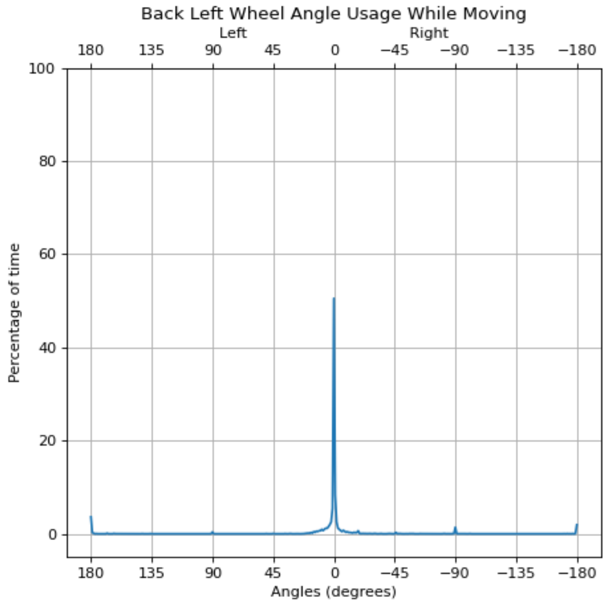
** From SEV D-RATS 2022 Chassis Odometry Preliminary Report*

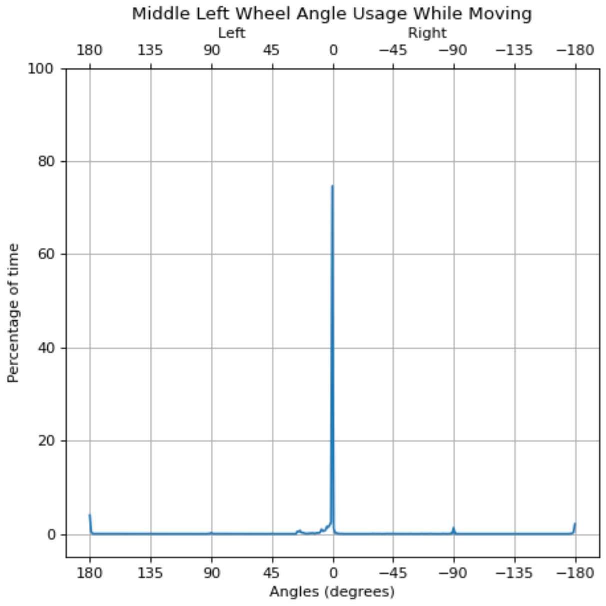
3.6.1.1.2 Crew 1 - Odometry

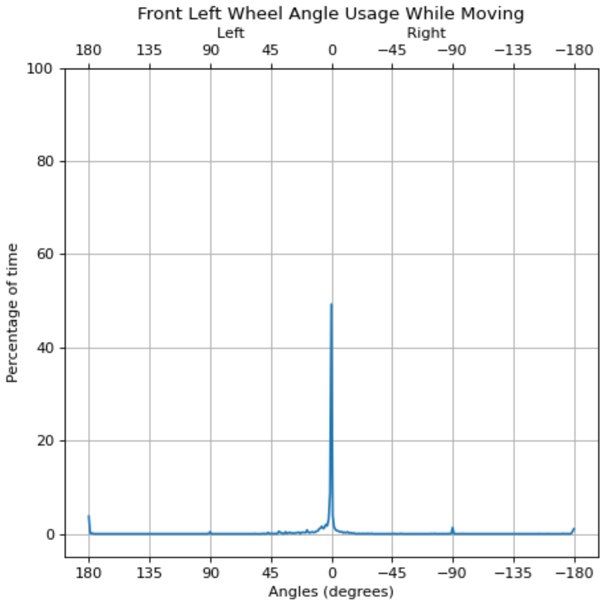
Parameter	Day 1 (Oct 14)	Day 2 (Oct 15)	Day 3 (Oct 16)
Vehicle Traverse Distance (km)	4.63	6.78	Day 3 was canceled due to rain
Vehicle Time Spent Moving (hr:min:sec)	1:28:15	2:58:46	
Vehicle Time Spent Stationary (hr:min:sec)	3:08:51	3:52:01	
Vehicle Speed While Moving - Max (kph)	12.16	12.63	
with Windows Covered	N/A	12.63	
with Windows Uncovered	12.16	12.11	
Vehicle Speed While Moving - Avg (kph)	1.0	0.99	
with Windows Covered	N/A	1.13	
with Windows Uncovered	1.0	0.52	
Vehicle Speed While Moving - Avg with no stops (kph)	3.15	2.28	
with Windows Covered	N/A	2.22	
with Windows Uncovered	3.15	2.8	
Vehicle Crab Angle Range Used	-88.14˚ to 90˚	-87.06˚ to 90˚	
with Windows Covered	N/A	-52.28˚ to 90˚	
with Windows Uncovered	-88.14˚ to 90˚	-87.06˚ to 90˚	
Power Used (Kilowatt Hours)	18.36	11.93	

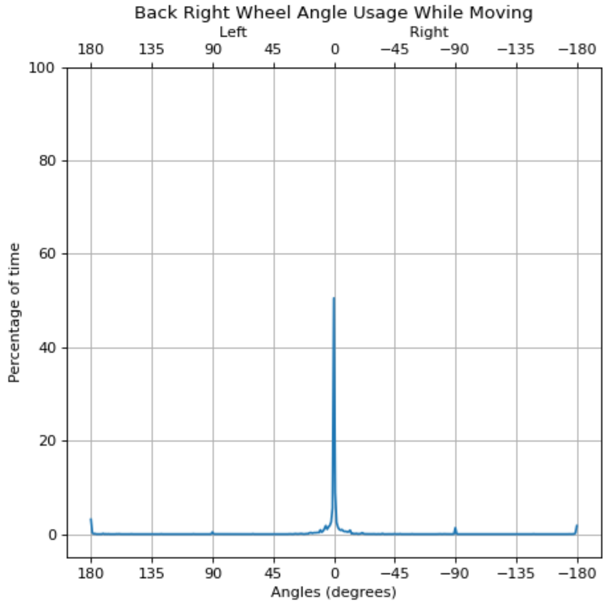
Crew 1 – Odometry Data

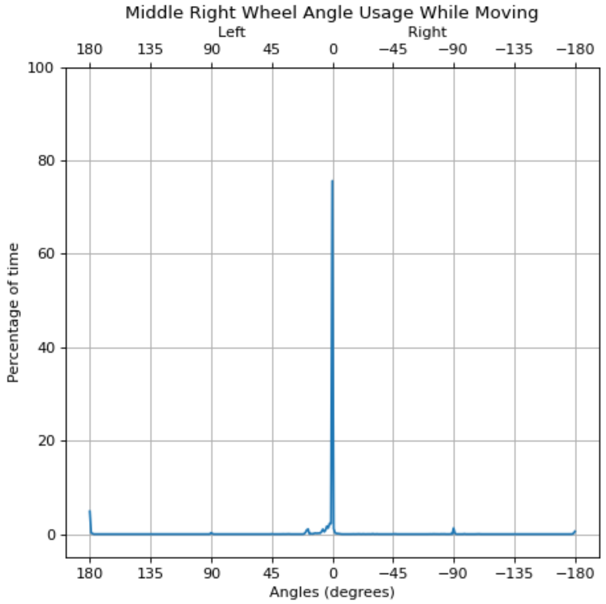
3.6.1.1.3 Crew 1 Wheel Angle Usage - Day 1 (Oct 14) - Windows Covered

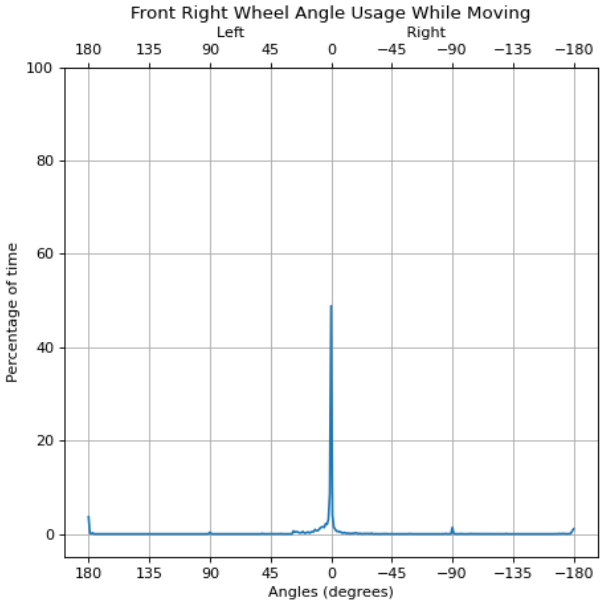




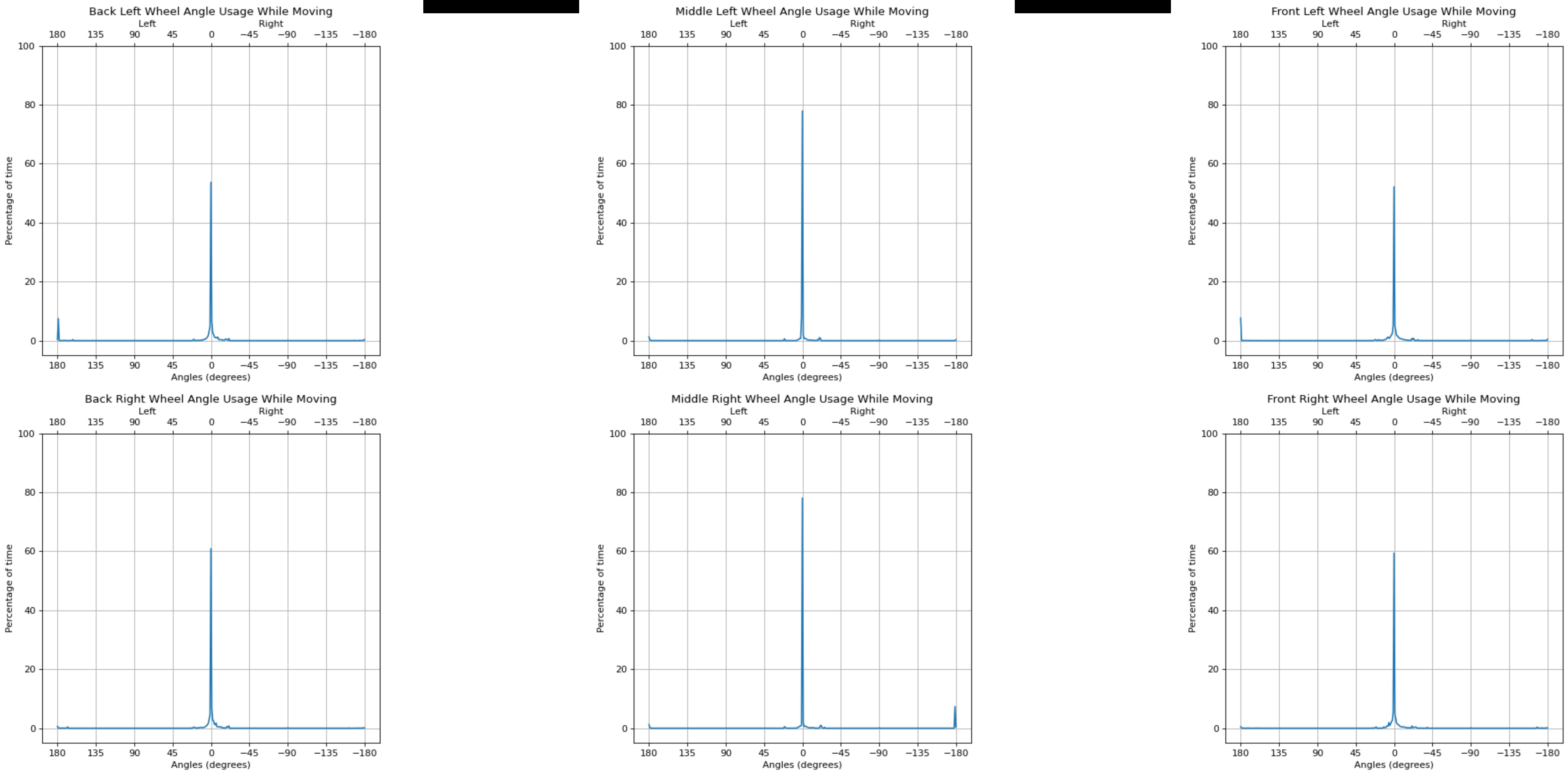




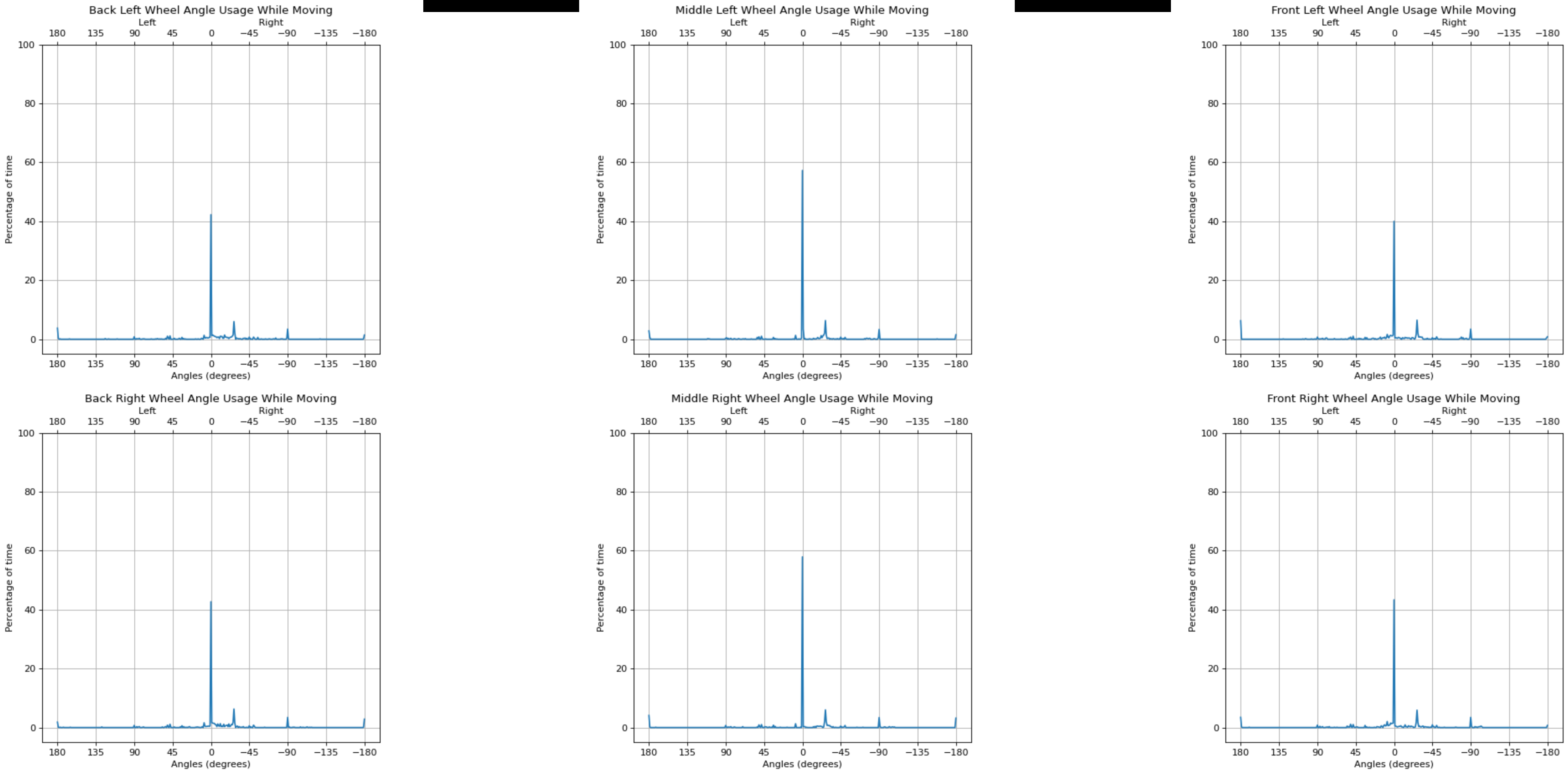




3.6.1.1.3 Crew 1 Wheel Angle Usage - Day 2 (Oct 15) - Windows Covered

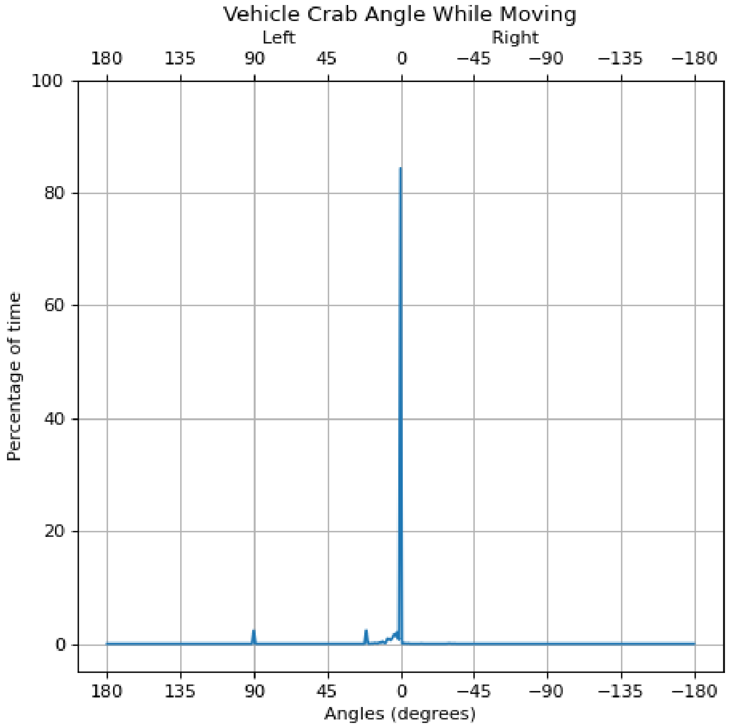


3.6.1.1.3 Crew 1 Wheel Angle Usage - Day 2 (Oct 15) - Windows Exposed

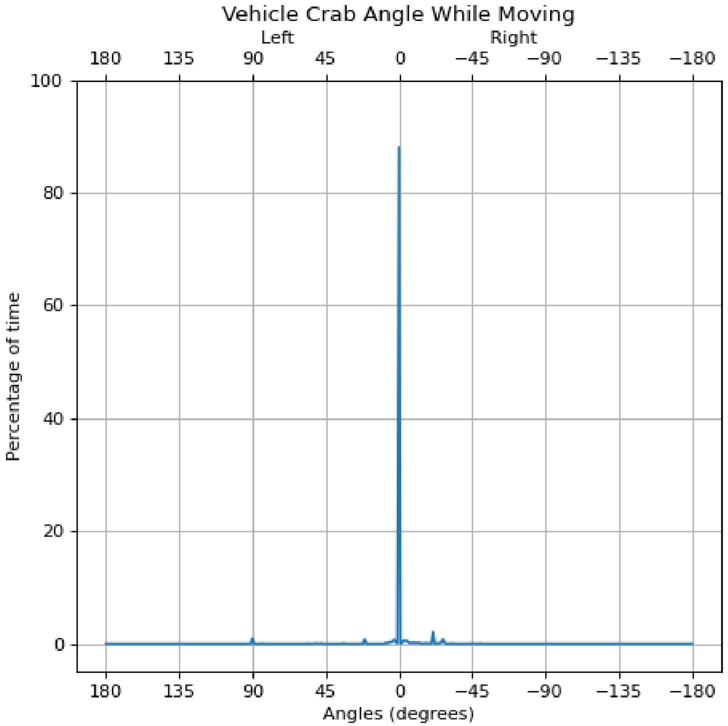


3.6.1.1.4 Crew 1 Vehicle Crab Angle Usage

Day 1 (Oct 14)



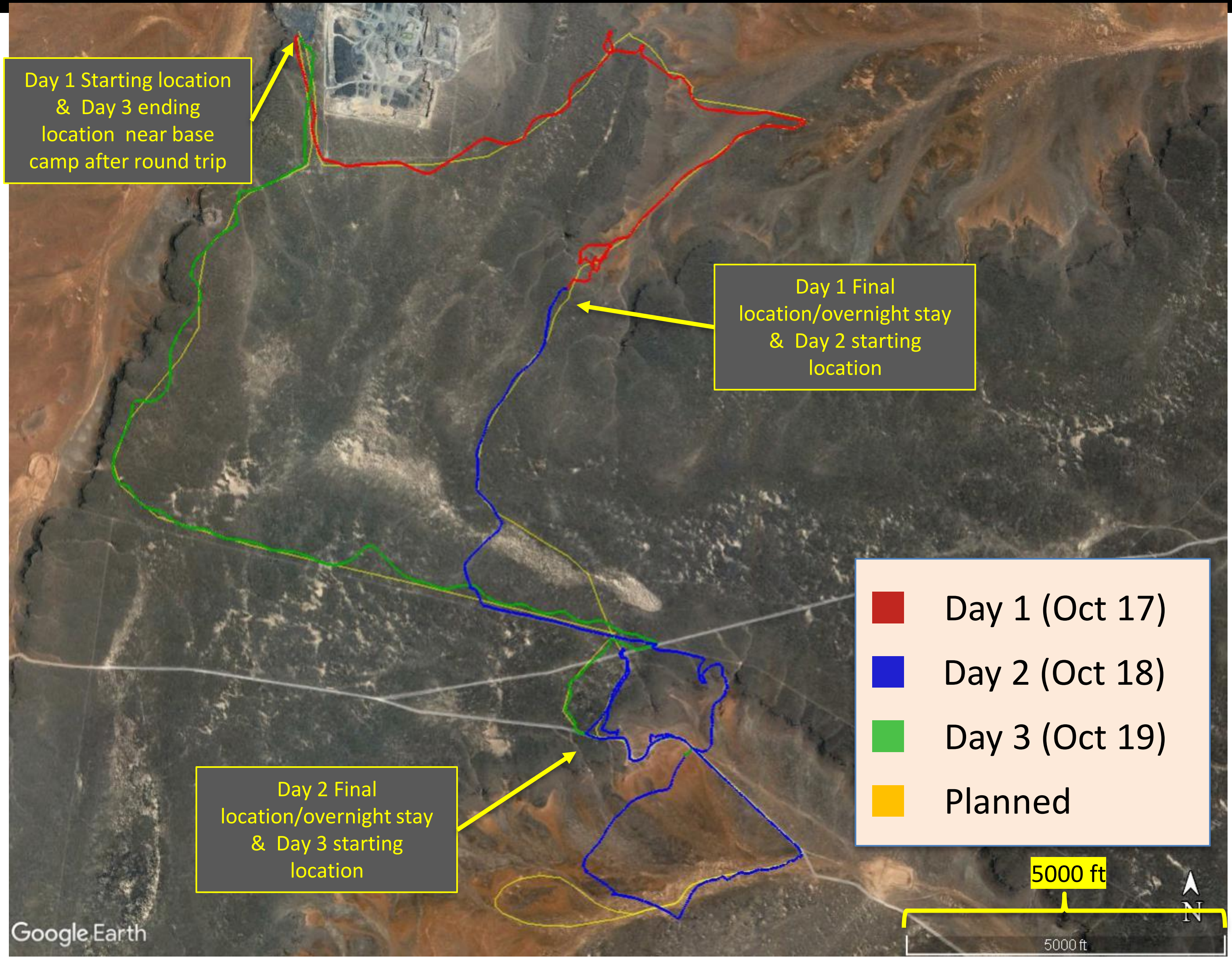
Day 2 (Oct 15)



3.6.1.2 CREW 2 DRIVING DATA

3.6.1.2.1 Crew 2 - Traverse

- The graphic on the right shows the Crew 2 planned traverse in yellow and the actual traverses for days 1-3 (in red, blue, and green respective)
- Data was collected from the PR GPS and overlaid on Google Earth maps
- Crew stopped and performed EVAs at sites of scientific interest each day (which were identified by SMD scientists prior to testing based on satellite imagery)



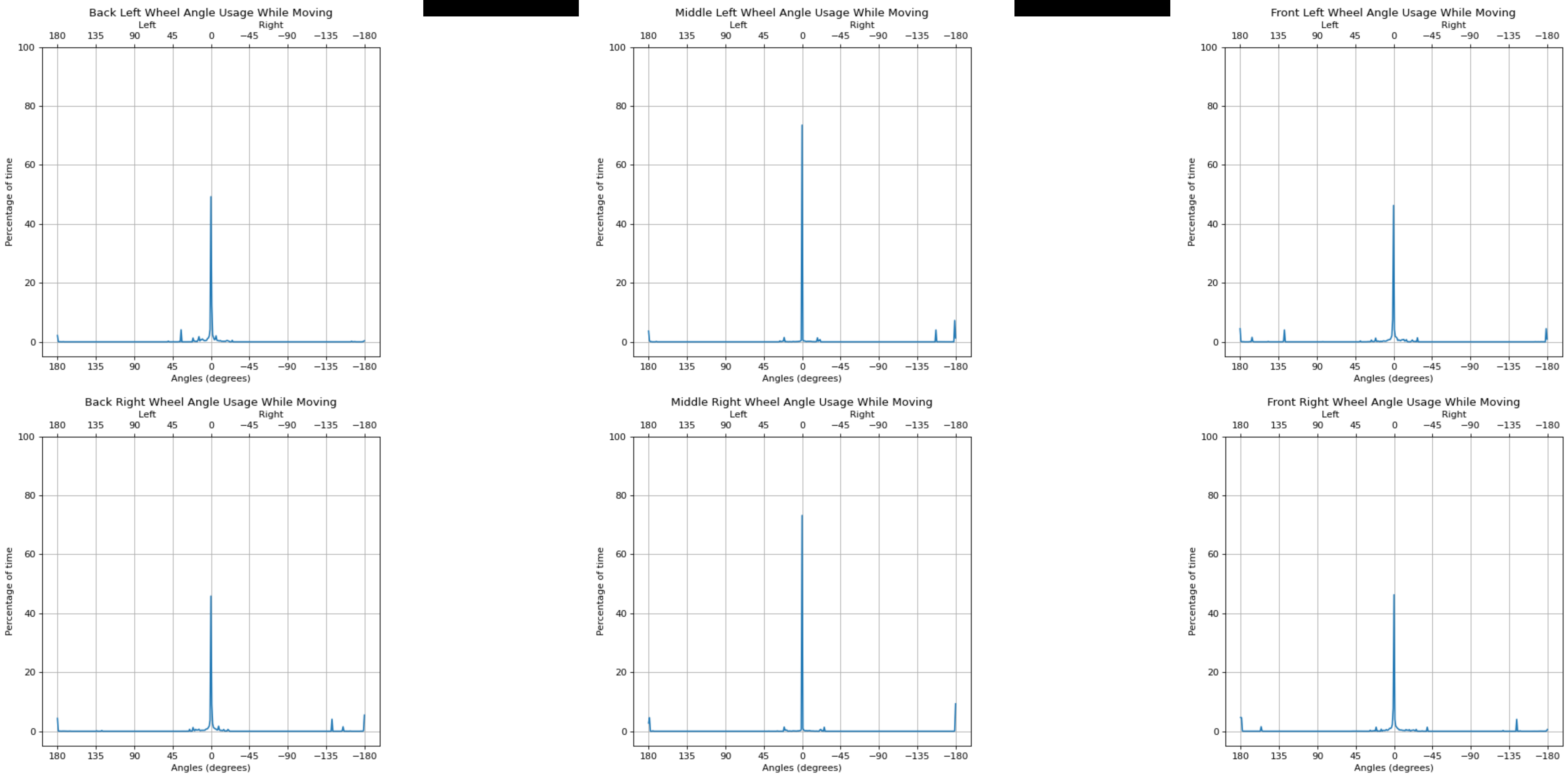
Aerial map of Crew 2 traverse region, with overlays of daily traverses (planned & actual)

3.6.1.2.2 Crew 2 - Odometry

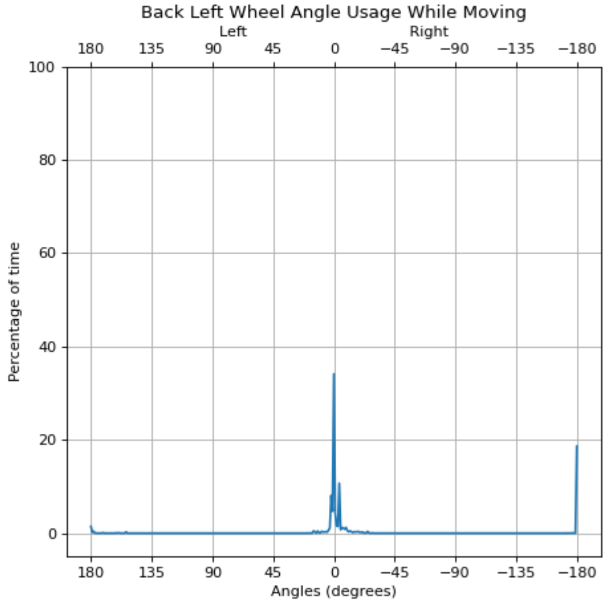
Parameter	Day 1 (Oct 17)	Day 2 (Oct 18)	Day 3 (Oct 19)
Vehicle Traverse Distance (km)	6.05	9.21	7.13
Vehicle Time Spent Moving (hr:min:sec)	1:58:55	3:50:51	2:05:46
Vehicle Time Spent Stationary (hr:min:sec)	3:51:39	5:54:46	0:55:04
Vehicle Speed While Moving - Max (kph)	7.89	10.08	10.38
with Windows Covered	N/A	10.08	10.38
with Windows Uncovered	7.89	3.59	N/A
Vehicle Speed While Moving - Avg (kph)	1.03	0.94	2.37
with Windows Covered	N/A	0.74	2.37
with Windows Uncovered	1.03	1.34	N/A
Vehicle Speed While Moving - Avg with no stops (kph)	3.05	2.39	3.40
with Windows Covered	N/A	2.14	3.40
with Windows Uncovered	3.05	2.74	N/A
Vehicle Crab Angle Range Used	-35.3˚ to 90˚	-47.74˚ to 90˚	-88.58˚ to 90˚
with Windows Covered	N/A	-41.67˚ to 90˚	-88.58˚ to 90˚
with Windows Uncovered	-35.3˚ to 90˚	-47.74˚ to 90˚	N/A
Power Used (Kilowatt Hours)	22.48	18.66	16.43

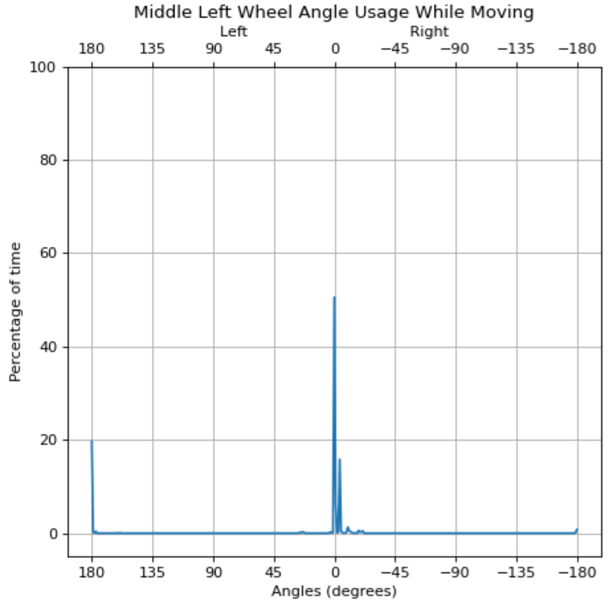
Crew 2 – Odometry Data

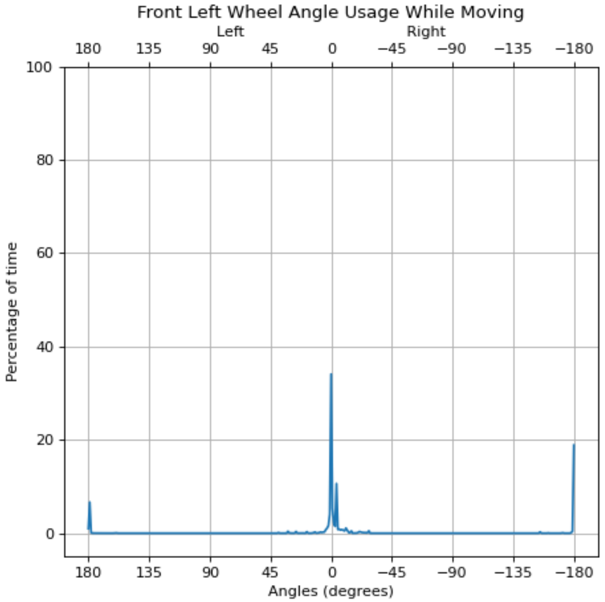
3.6.1.2.3 Crew 2 Wheel Angle Usage - Day 1 (Oct 17) - Windows Exposed

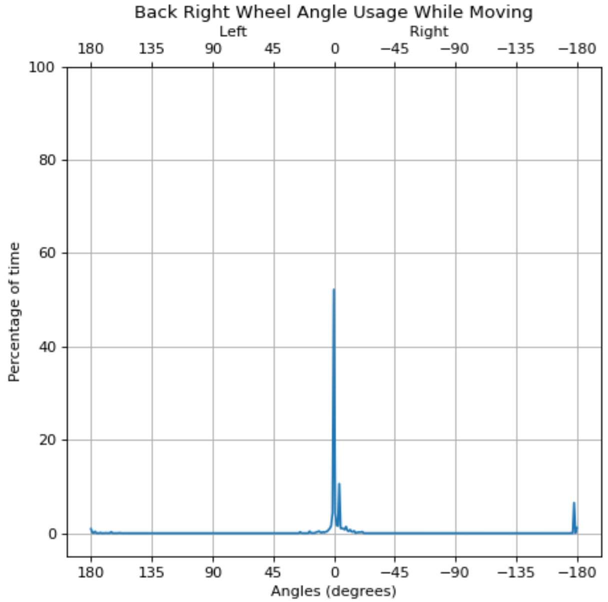


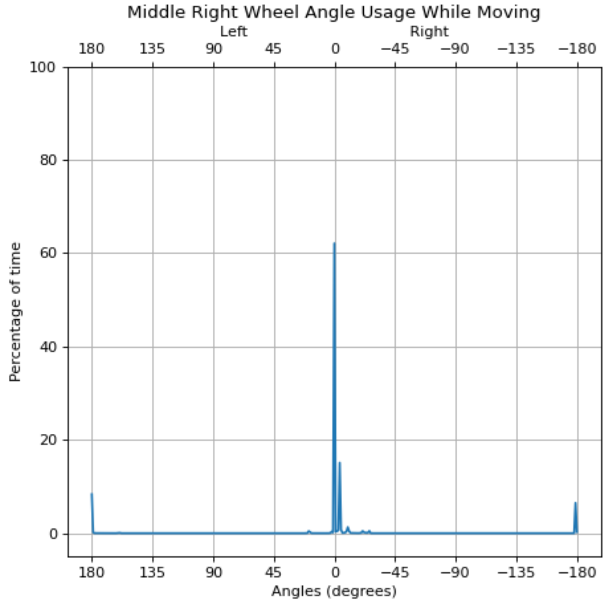
3.6.1.2.3 Crew 2 Wheel Angle Usage - Day 2 (Oct 18) - Windows Covered

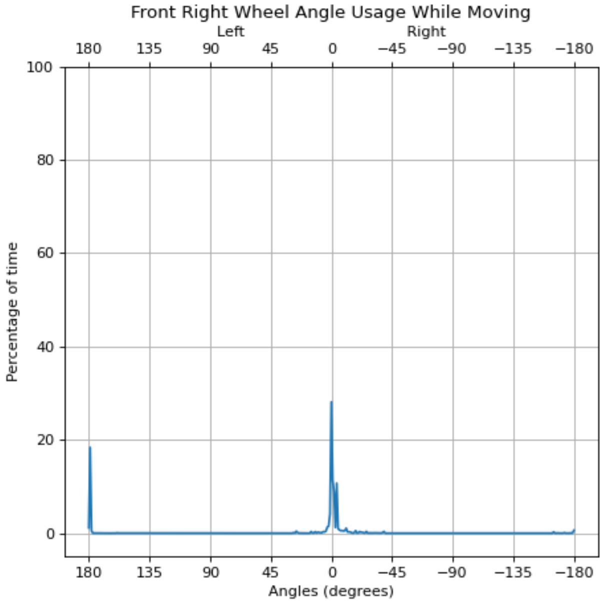




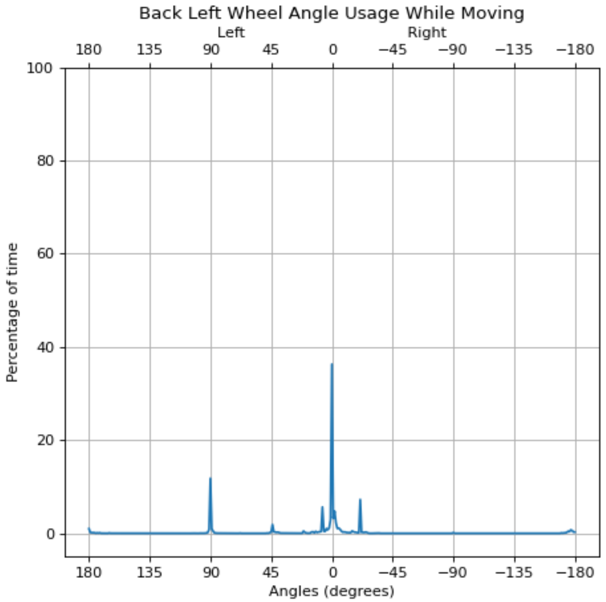


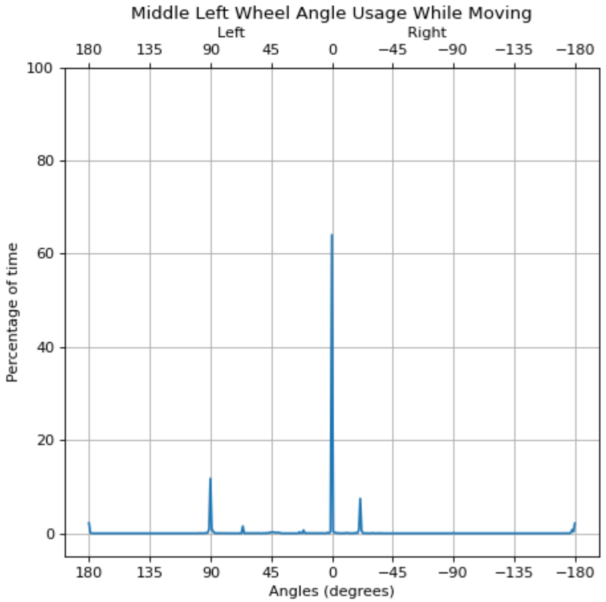


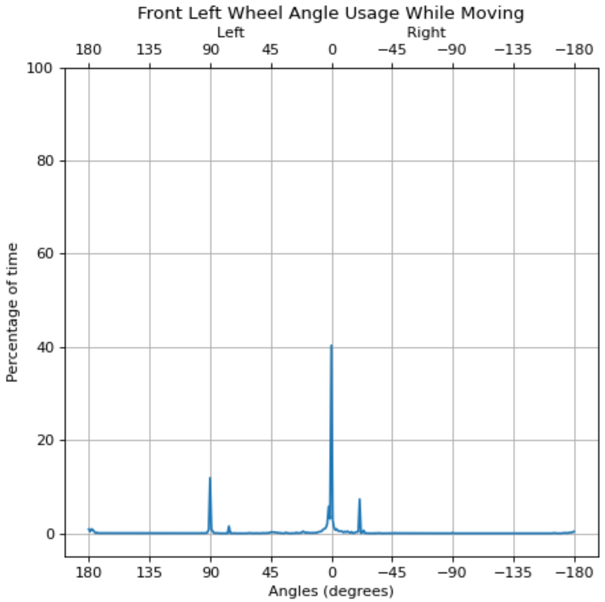


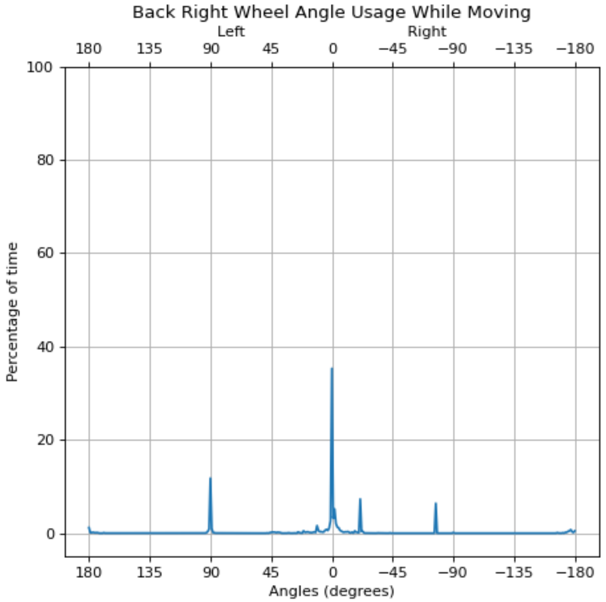


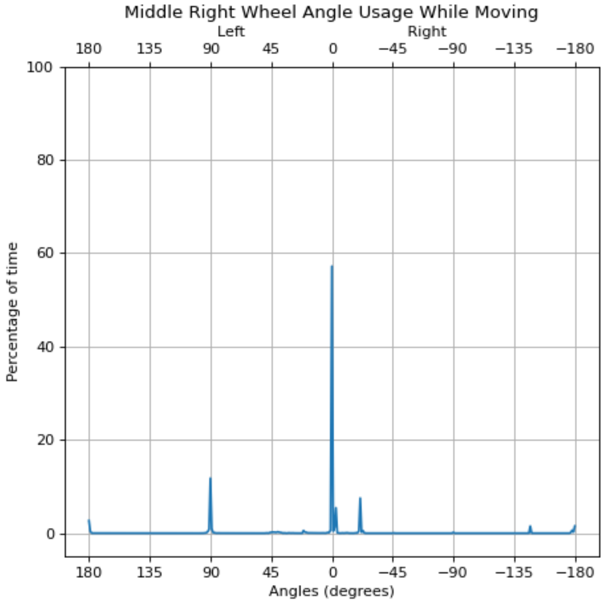
3.6.1.2.3 Crew 2 Wheel Angle Usage - Day 2 (Oct 18) - Windows Exposed

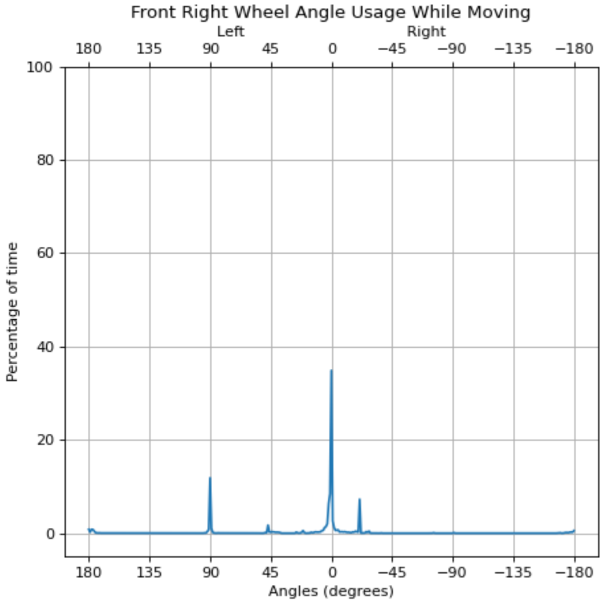




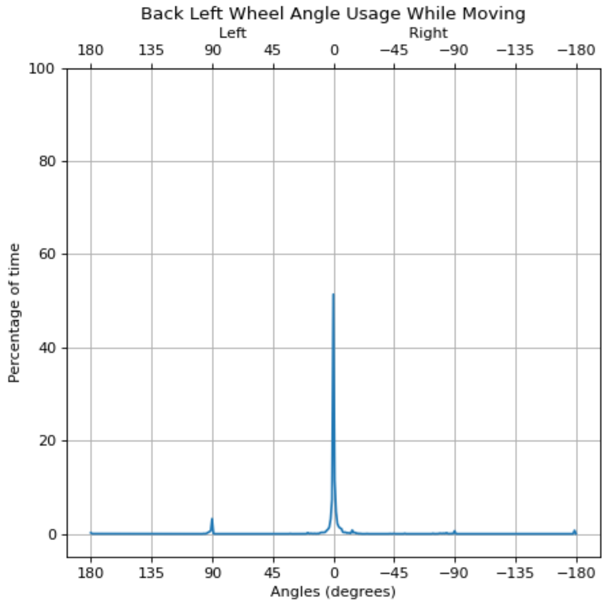


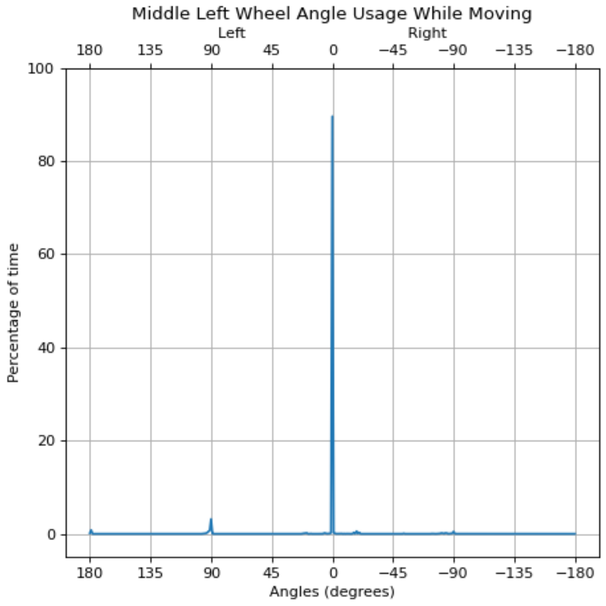


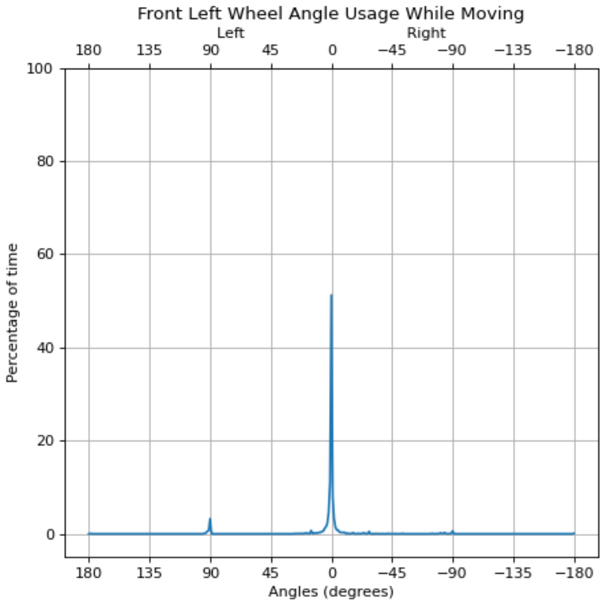


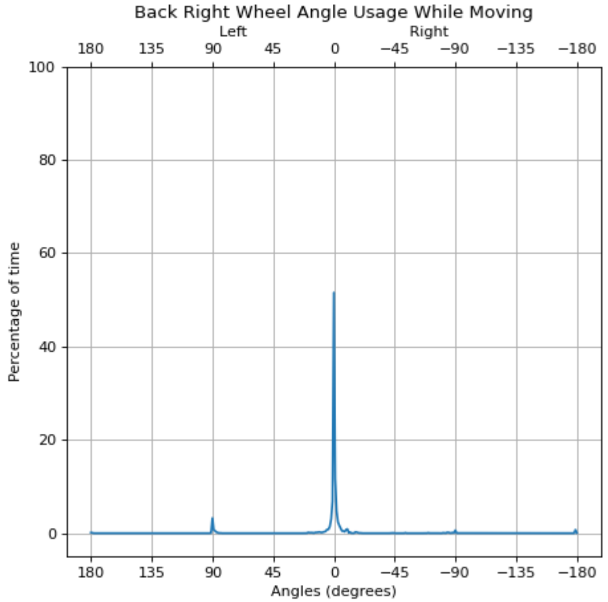


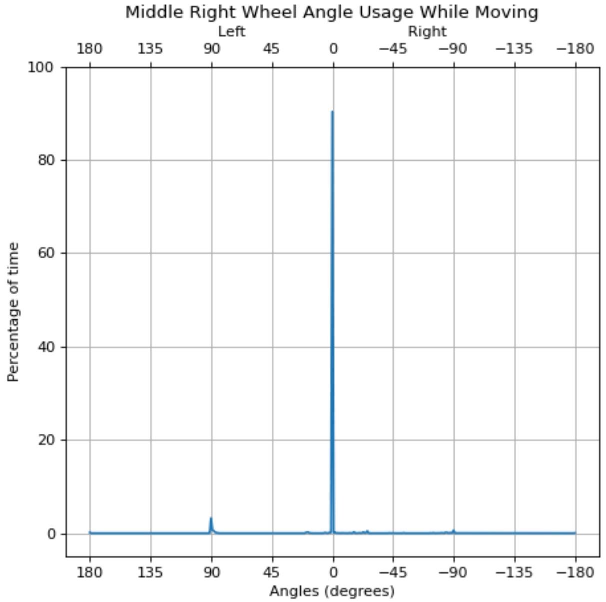
3.6.1.2.3 Crew 2 Wheel Angle Usage - Day 3 (Oct 19) - Windows Covered

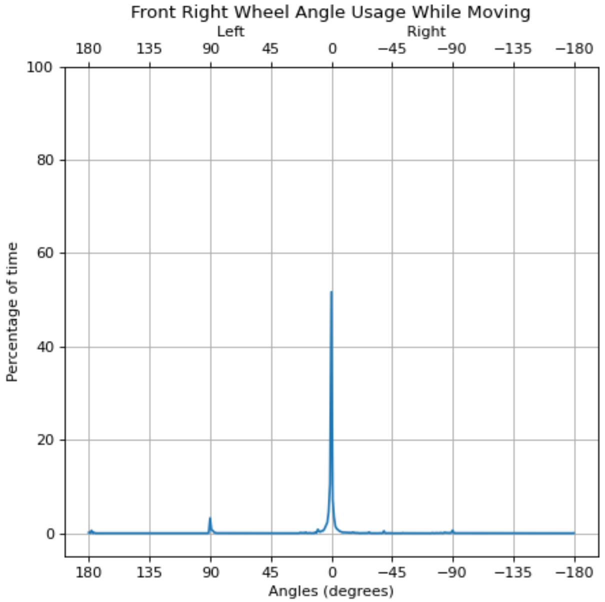






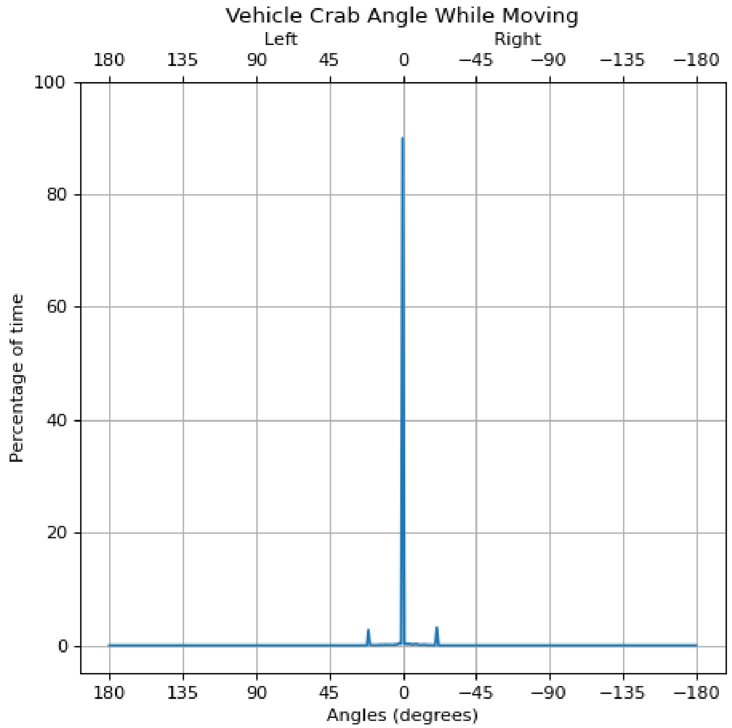




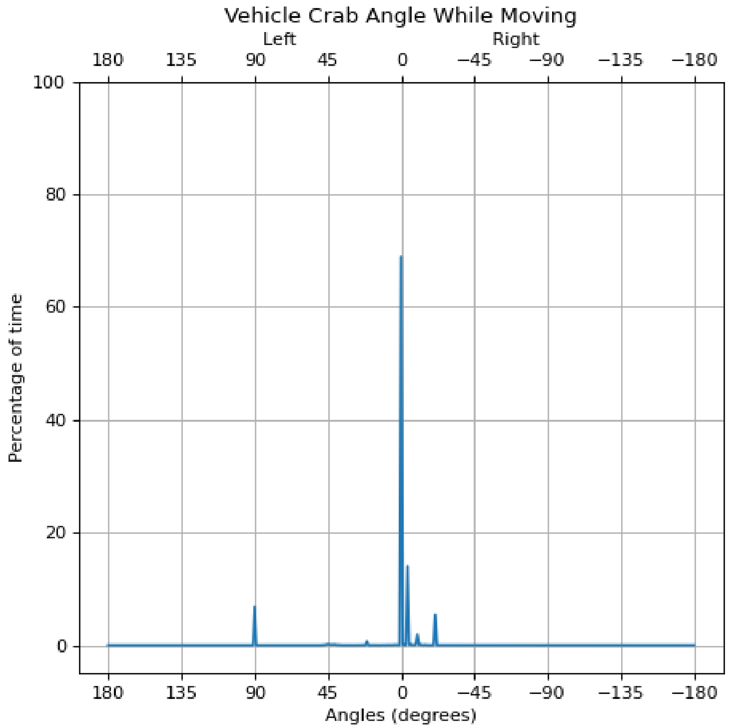


3.6.1.2.4 Crew 2 - Vehicle Crab Angle Usage

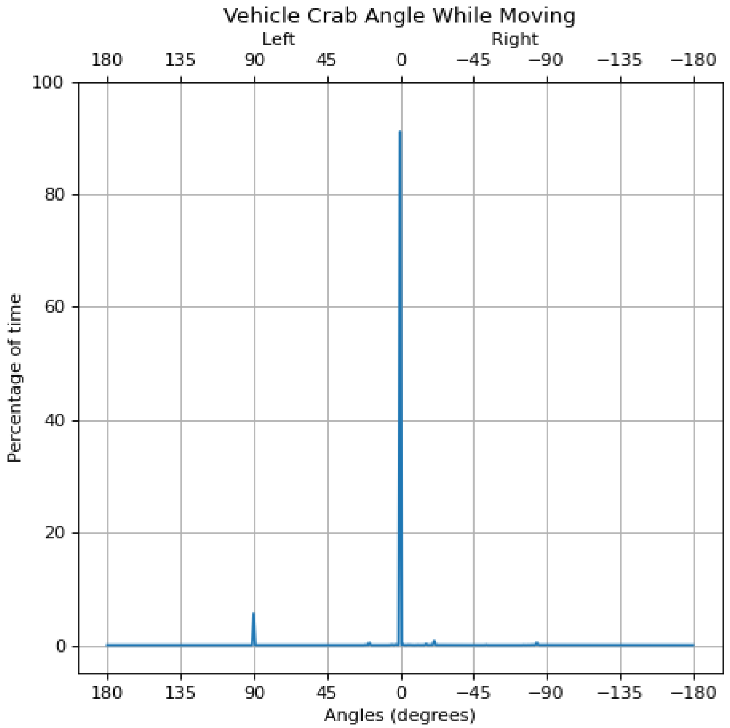
Day 1 (Oct 17)



Day 2 (Oct 18)



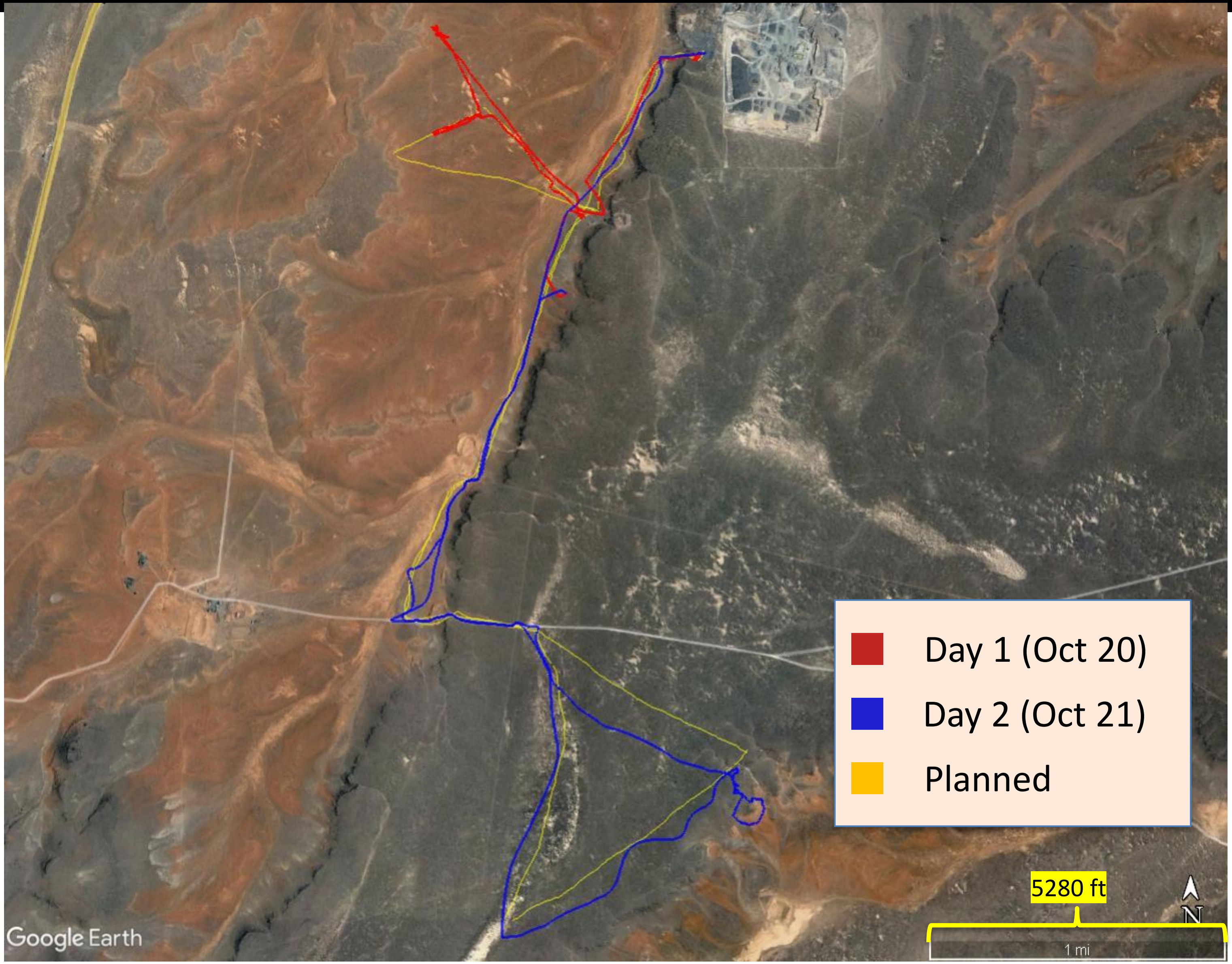
Day 3 (Oct 19)



3.6.1.3 CREW 3 DRIVING DATA

3.6.1.3.1 Crew 3 - Traverse

- The graphic on the right shows the Crew 3 planned traverse in yellow and the actual traverses for days 1-2 (in red and blue respective)
- Data was collected from the PR GPS and overlaid on Google Earth maps
- Crew stopped and performed EVAs at sites of scientific interest each day (which were identified by SMD scientists prior to testing based on satellite imagery)
- All primary test objectives were completed in the first two days, so the 3rd test day for Crew 3 was not conducted
  - The map therefore lacks the third day of planned driving and activities



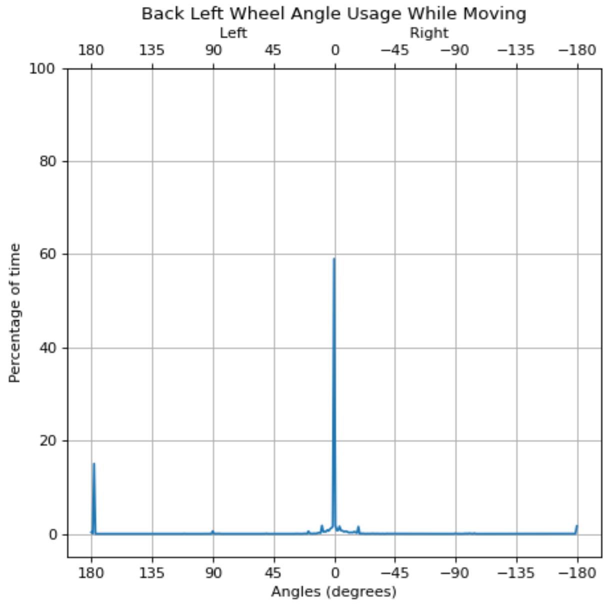
Aerial map of Crew 3 traverse region, with overlays of daily traverses (planned & actual)

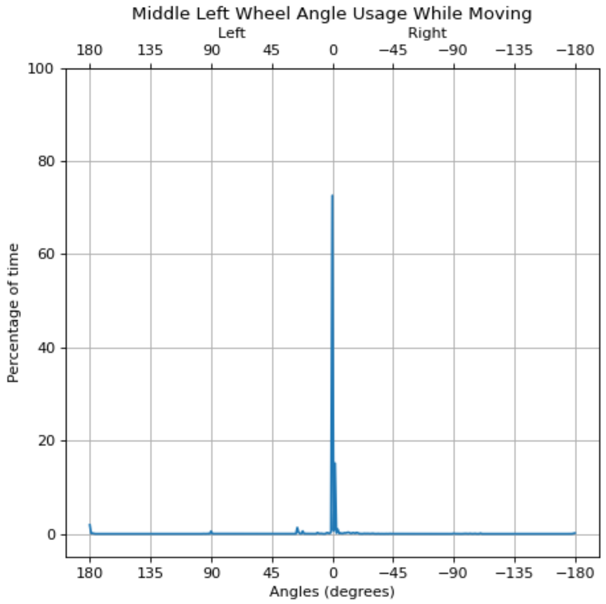
3.6.1.3.2 Crew 3 - Odometry

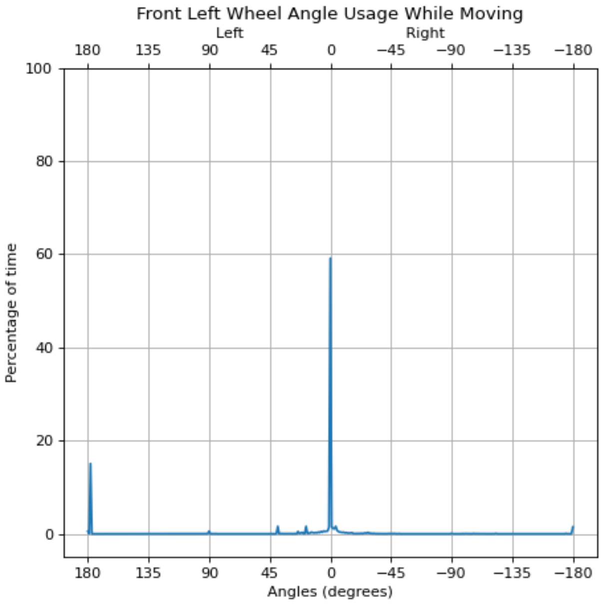
Parameter	Day 1 (Oct 20)	Day 2 (Oct 21)	Day 3 (Oct 22)
Vehicle Traverse Distance (km)	5.77	13.26	Completed all objectives by Day 2, so Day 3 test was cancelled
Vehicle Time Spent Moving (hr:min:sec)	1:51:57	3:03:58	
Vehicle Time Spent Stationary (hr:min:sec)	2:55:29	7:42:12	
Vehicle Speed While Moving - Max (kph)	5.68	12.44	
with Windows Covered	5.68	11.56	
with Windows Uncovered	N/A	12.44	
Vehicle Speed While Moving - Avg (kph)	1.20	1.23	
with Windows Covered	1.20	0.90	
with Windows Uncovered	N/A	1.40	
Vehicle Speed While Moving - Avg with no stops (kph)	3.09	4.32	
with Windows Covered	3.09	4.53	
with Windows Uncovered	N/A	4.26	
Vehicle Crab Angle Range Used	-85.57˚ to 90˚	-88.76˚ to 90˚	
with Windows Covered	-85.57˚ to 90˚	-48.49˚ to 90˚	
with Windows Uncovered	N/A	-88.76˚ to 90˚	
Power Used (Kilowatt Hours)	19.32	19.18	

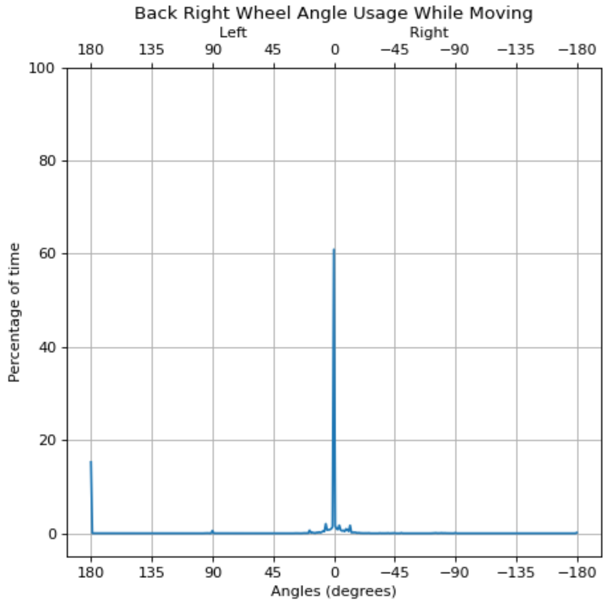
Crew 3 – Odometry Data

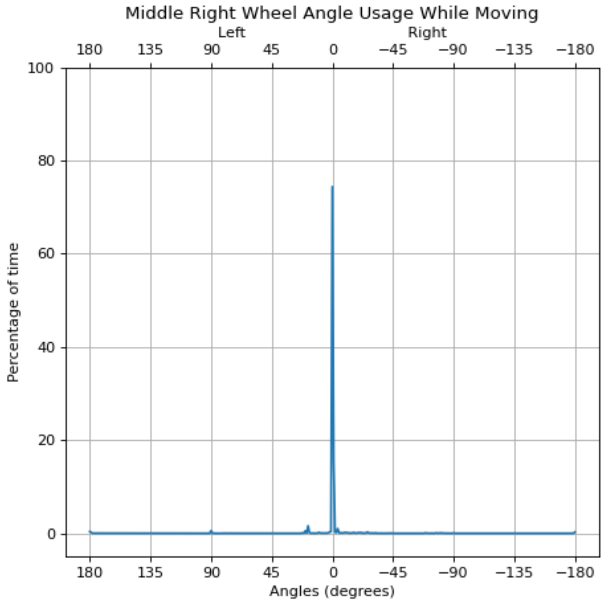
3.6.1.3.3 Crew 3 Wheel Angle Usage - Day 1 (Oct 20)

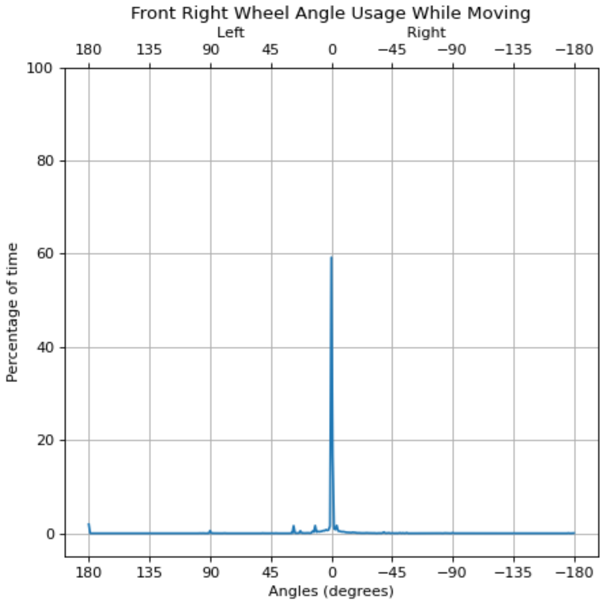




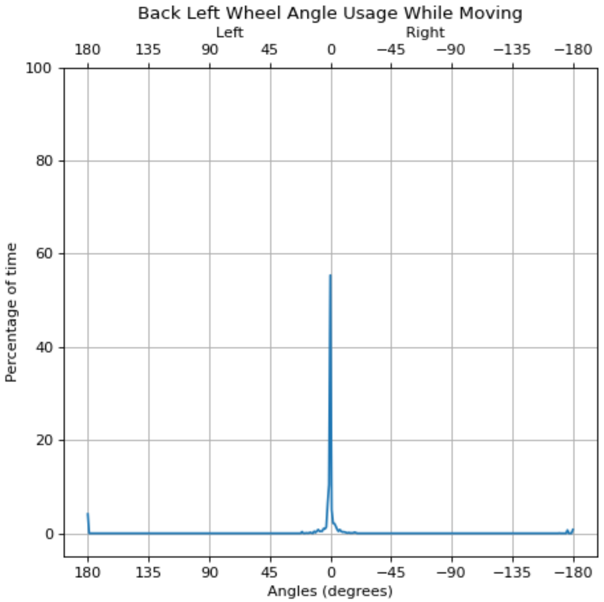


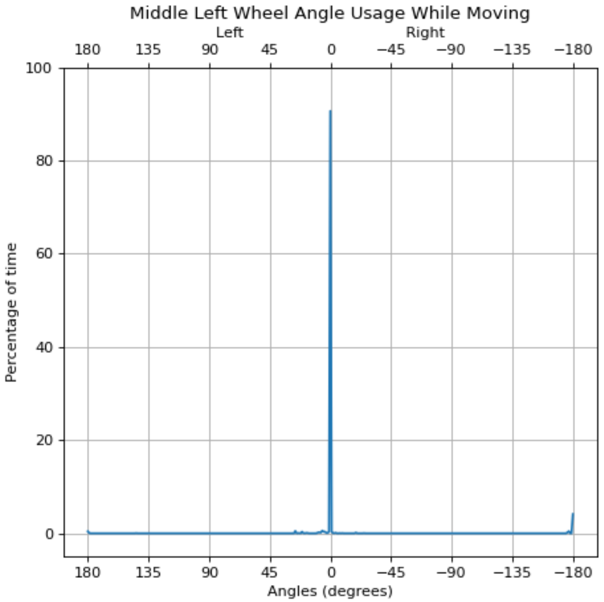


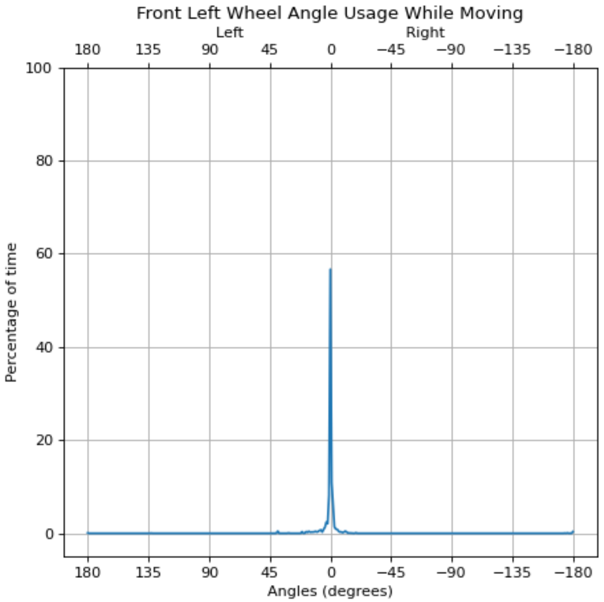


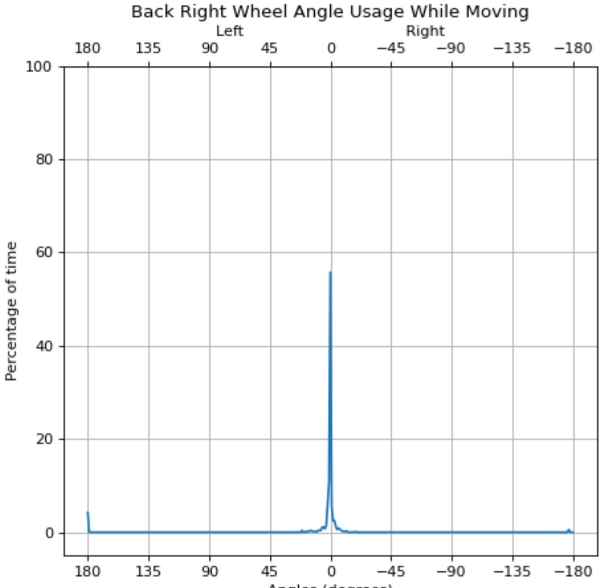


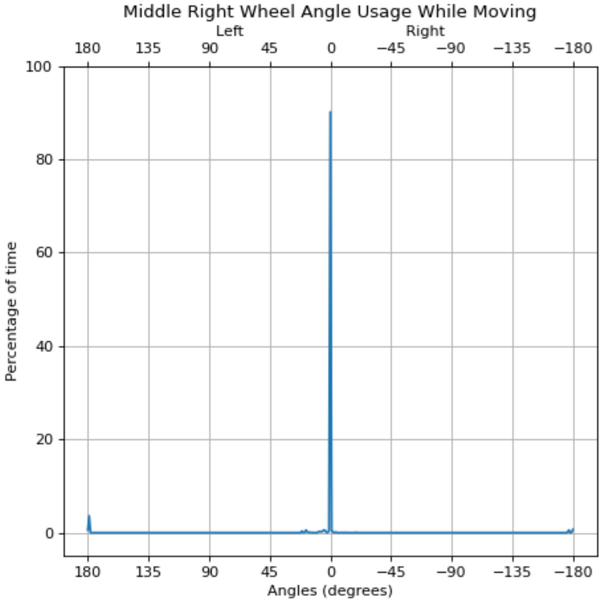
3.6.1.3.3 Crew 3 Wheel Angle Usage - Day 2 (Oct 21) - Windows Covered

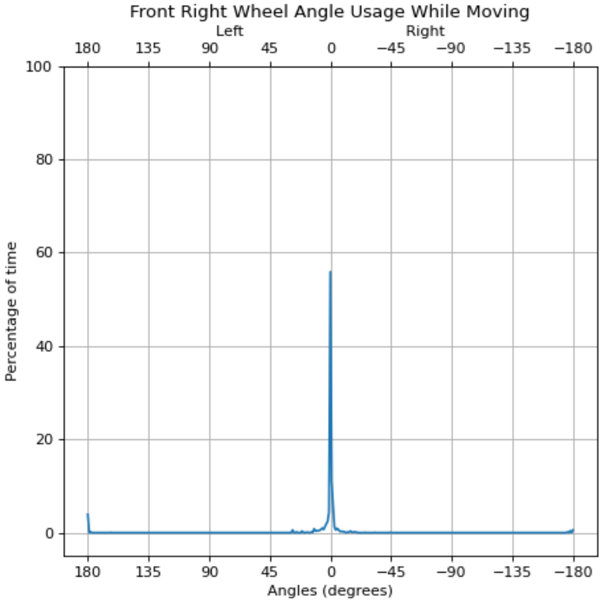




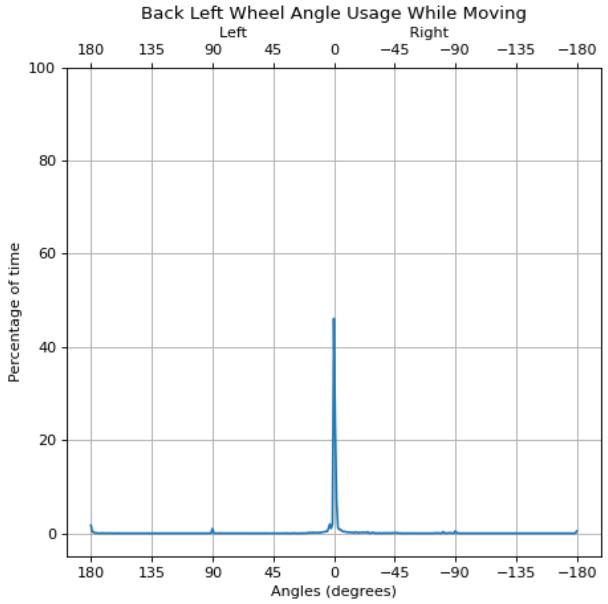


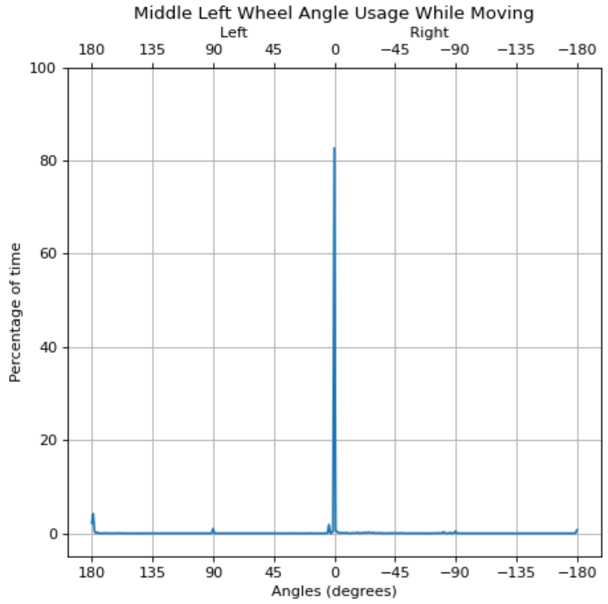


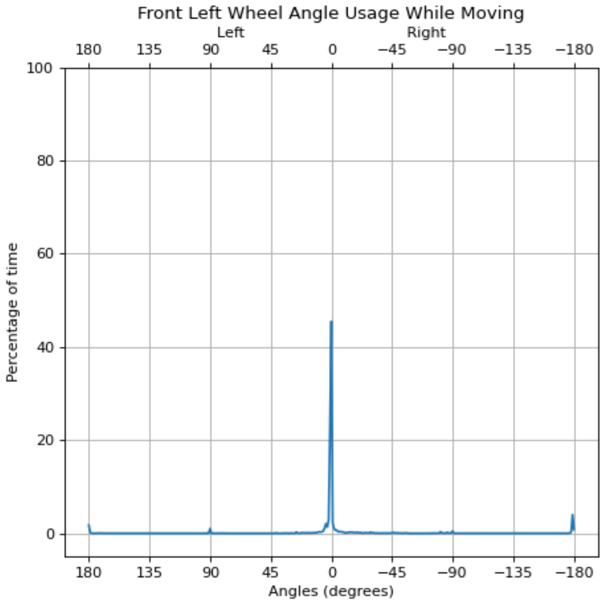


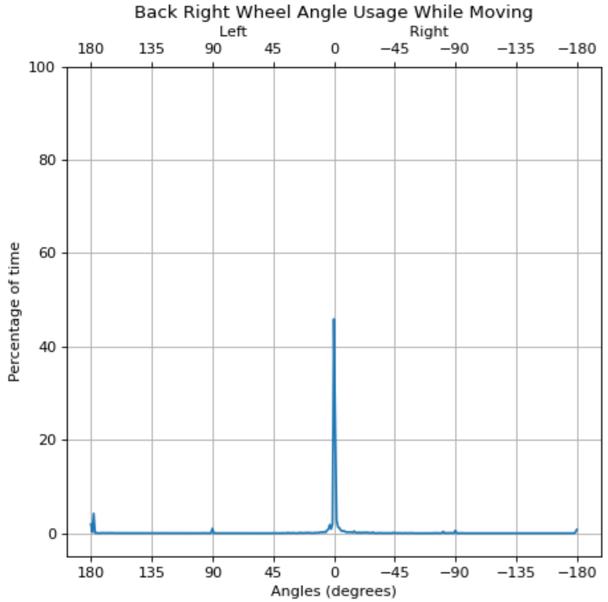


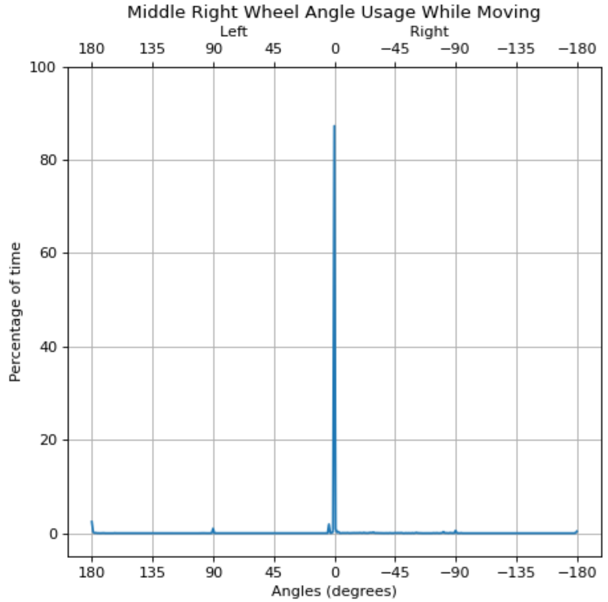
3.6.1.3.3 Crew 3 Wheel Angle Usage - Day 2 (Oct 21) - Windows Uncovered

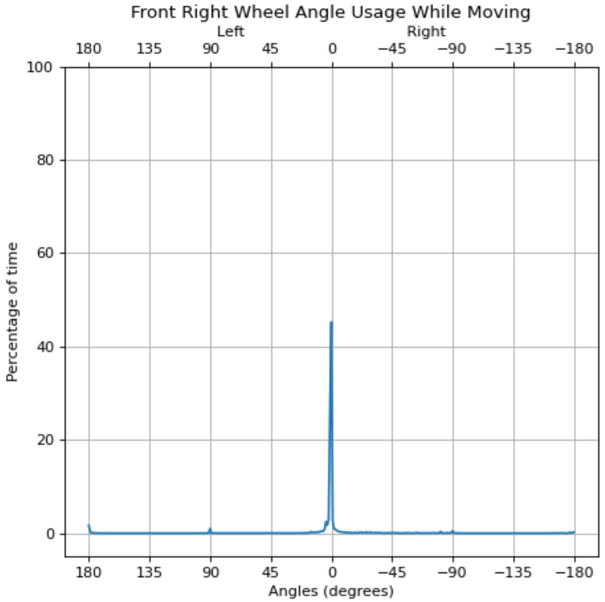






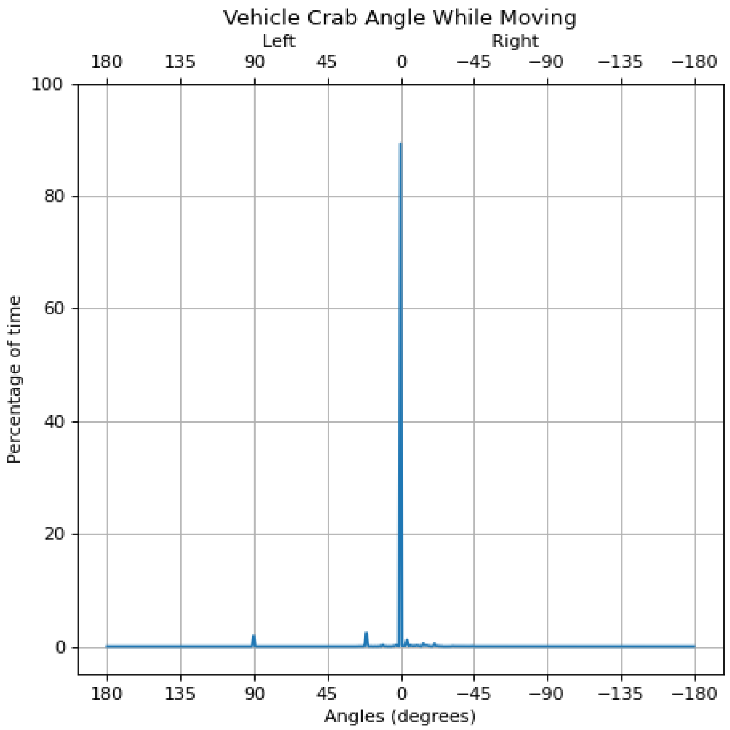




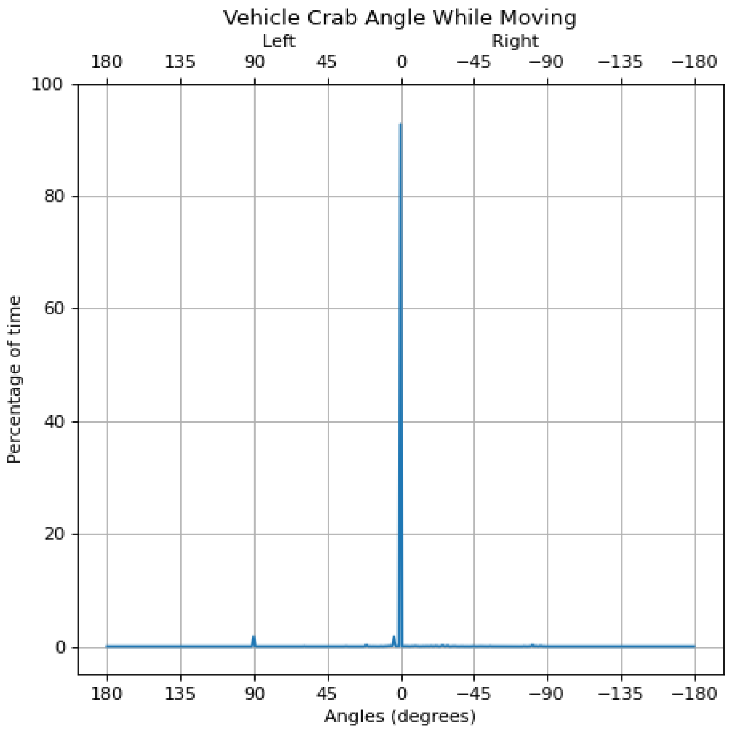


3.6.1.3.4 Crew 3 - Vehicle Crab Angle Usage

Day 1 (Oct 20)



Day 2 (Oct 21)



3.6.2 Subjective Data

- This section presents the subjective data that was collected during the D-RATS-22 tests
- Each subsection address one of the Strategic Questions and related D-RATS-22 specific questions outlined in Section 3.3
- A summary of the data breakdown is included below for reference

3.6.2.1 Driving & Science Objectives

M2MADO Strategic Question #1:

What combination of windows and/or externally mounted cameras projected onto internal cabin displays best support PR operational and scientific objectives?

DRATS-22-Specific Sub-Questions Related to Strategic Question #1:

- ***How acceptable are the GEN 1B windows for supporting driving and science operations?***
- ***How acceptable is a JAXA-proposed camera and internal display system for supporting driving and science operations?***

3.6.2.1 Driving & Science Objectives

The subsections under this section each address a different area related to Strategic Question 1 and the D-RATS-22 questions (previous slide) - these areas and the specific subjective questions the crew were asked are listed below

Driving with Windows

- *Rate the overall acceptability of driving with windows. Consider your ability to: identify terrain features of interest for navigation and driving, avoid terrain obstacles, have adequate FOV. Note any differences in acceptability when driving during the day vs. at night.*

Driving with Cameras + Interior Displays

- *Rate the overall acceptability of driving with cameras + interior displays. Consider your ability to: identify terrain features of interest for navigation and driving; avoid terrain obstacles; and have adequate FOV. Note any differences in acceptability when driving during the day vs. at night.*

Science Observations

- *Rate the overall acceptability of conducting science observations of the external world while IVA with windows. Consider: your ability to identify terrain features of interest for scientific exploration while driving and while stopped. Note any differences in acceptability when driving during the day vs. at night.*
- *Rate the overall acceptability of conducting science observations of the external world while IVA with cameras + interior displays. Consider: your ability to identify terrain features of interest for scientific exploration while driving and while stopped. Note any differences in acceptability when driving during the day vs. at night.*

Cockpit Displays & Controls

- *Rate the overall acceptability of the displays and controls in the rover cockpit when operating with windows. Consider: location, layout, and usability.*
- *Rate the overall acceptability of the displays and controls in the rover cockpit when operating with cameras + interior displays. Consider: location, layout, and usability.*
- *Rate the overall acceptability of the hand controller design and operation when operating with windows. Consider: location and hand/wrist fatigue.*
- *Rate the overall acceptability of the hand controller design and operation when operating with cameras + interior displays. Consider: location and hand/wrist fatigue.*

Cockpit Layout & Volume

- *Rate the overall acceptability of the cockpit volume for 2 crew to support driving operations when operating with windows.*
- *Rate the overall acceptability of the cockpit layout for 2 crew to support driving operations.*

3.6.2.1.1 Driving with Windows

<u>Driving in Drive-by-Windows Mode</u>

Rate the overall acceptability of driving with windows.

Consider your ability to: identify terrain features of interest for navigation and driving, avoid terrain obstacles, have adequate FOV. Note any differences in acceptability when driving during the day vs. at night.

Cockpit view: Drive-by-Windows

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Crew Consensus Acceptability Ratings + Comments**
- **Rating: 3**
- **Comments specific to windows:**
  - The field of view was wide, and the travel speed felt slow.
  - Obstacle avoidance was possible if the obstacle was visible.
  - Human eye has more sensitivity than any camera.
  - Not enough fault tolerance achieved thru cameras to be as robust a solution as one gets with windows.
  - We need windows for safety (e.g., if all cameras fail) – windows are a mission essential capability. At a minimum, we need windows in the front that enable you to see for driving (e.g., including if primary driving cameras fail); also want to be able to see outside with my own eyes thru a window and not just thru a camera.
  - One configuration of windows/cameras to evaluate in the future: two levels of windows: eye level windows = mission critical; lower windows and side windows could be cameras … to save mass
  - If we have 360° vehicle pivoting capability, might need less windows; side mirrors would also help.
  - 1B has very large windows - can we achieve requirements with smaller windows, e.g., smaller vertical window for slope estimation? need more testing for this config.
  - Would not want to drive extended periods without being able to estimate slope – windows are the only way you can provide slope estimation easily.
  - Windows were useful for conducting science.
  - Desired window change -- more accommodations aft for 1B to be able to see wheels if you're shorter than 6'3"; rear view window would be nice to test for camera failure.
  - Having side windows for peripheral vision is key.
  - Driving surface conditions are easier to judge with windows than with the camera system.

- **Additional general crew comments noted during this discussion:**
  - Lighting:
    - As when driving by cameras, the range of lights was limited when driving with windows only. In addition, it was difficult to judge distant conditions. This became easier when using a mast camera in combination with a (nose-mounted) driving camera. However, when the FOV was narrowed, it became difficult to judge the situation in the same way as with a camera system. Therefore, training is necessary.
    - It was difficult to see objects at a distance in the dark. Recommend having a high/low beam capability which can be switched as needed for far/close objects.
    - It is better to have high beam lights for a forward view, for example when we faced slopes during night driving (it may be difficult to estimate the steepness and recognize potential obstacles). Also, we found that turning off all interior lights gave us a better view, similar to normal cars and the "dark cockpit" concept for airplanes.
    - When driving with windows at night, it seemed like the driving lights were set for drive-by-camera mode. If the light reached farther, I could have driven more efficiently. Desired improvement = ability to switch the light low/high. Mast Cam was great for seeing things at a distance (just as it was when in drive-by-camera mode).
  - Digital display guides:
    - We found the track guides (green center line and blue lines for wheels) in drive-by-camera mode very helpful. We realized [afterwards] that we could have configured these on our display in drive-by-windows mode too, so that would be good to have as a default regardless of driving mode.
  - Seats:
    - Seat height could be further optimized for visibility out windows for crewmembers with shorter torsos … more flexibility in seat height is desired.
    - When the speed was slow, no vibration was felt.

Driving using the large windows provided by the Gen-1-B PR analog rover was acceptable, with only minor improvements desired

3.6.2.1.2 Driving with Cameras + Interior Displays

Driving *(in Drive-by-Cameras Mode)*

Rate the overall acceptability of driving with cameras + interior displays.

Consider your ability to: identify terrain features of interest for navigation and driving; avoid terrain obstacles; and have adequate FOV. Note any differences in acceptability when driving during the day vs. at night.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Consensus Acceptability Ratings + Comments**
- **Rating: 7**
- **Comments:**
  - FOV was not enough to look at obstacles while driving. Distance, size, and velocity was difficult to assess via camera and monitors. Resolution of the camera/monitor was good. Monitor was too big and too close to driver and was difficult to drive - ended up reducing image size (about 40% of the display monitor) for ease of use. Guidelines on forward camera monitor were useful.
  - Terrain features at long distances could not be identified without high resolution camera, especially during night driving. Reference line of the rover width on the monitor screen when moving backward helped driver's situational awareness.
  - Driving with the cameras was easier than anticipated (as also expressed during training), however, as the sense of speed seemed much greater with the camera view, I anticipate that rates will be slower driving with cameras than driving with windows. It also seemed more difficult to judge slope using the camera views. Most of our driving was at night, so I do anticipate camera views.
  - It was very difficult to gauge slopes with just cameras at night. Some way for the display to gauge slope is needed. Screen resolution and positioning was acceptable. I was worried about getting motion sick but … did not. The video-only mode made our speed seem faster than it was.
  - Most of the time we drove on the flat road and didn't need to check the surrounding environment for Rover movement. Sometimes, in rough terrain, we needed to stop and check obstacles/ find a good pathway with cameras. Mast Cams were really good for getting SA but controlling with keyboard was not easy. I would suggest Play Station (or similar video game controller) to pan/tilt the Mast Cams. Also using Upper center monitor for MAST Cams, mid-center monitor for side/belly/rear, and Lower-center monitor (which did not exist during the mission) for Rock Cam.
  - Speed thru camera view felt faster than you were actually going. If camera FOV were wider and camera position higher, this might help? Need to test more.
  - It was difficult to judge the situation with a driving camera alone; but the use of the mast camera in combination with the driving camera greatly enhanced the ease of driving. It was difficult to judge the size of obstacles and the angle of slopes because the FOV differed from the window configuration. Training is required. Is it because the window and camera have different FOVs or because the camera is monocular?
  - Could recognize the condition of the road surface. Obstacle avoidance was possible for objects which were visible and recognizable. The camera's field of view was narrow, and perceived vehicle speed felt faster than actual speed. The monitor layout did not cause any problems. Did not feel any vibration such as shaking.
  - It was very difficult to estimate both horizontal and vertical distance, but especially vertical distance; the terrain seemed to be flat when in fact there was steep incline/decline. Depth perception was difficult to estimate using current camera views; stereo views enabling depth perception should be considered. Additionally, peripheral views would be very helpful to mimic the front side window views. Also, farther reaching light is required and having higher resolution cameras at the port and starboard sides is needed as the views at night were very dark and the current cameras did not show high resolution. For the last question, we did not drive during the day so n/a.
  - The cameras flattened everything out at night, we couldn't tell how steep, or how big things were before we hit them, or were right up on them. It was hard to back away or turn away when your primary SA is just what was in front of you, a VR headset would allow more stereo viewing and more angles of view.
  - When driving in drive-camera mode, it became like a video game, and generally, people are not friendly to their video game vehicles. They just bash them around.
  - Unacceptable: 7/8
  - Difficult to judge distance, size, depth, and slope – might be partially improved with more training? Need to test. Additional overlays would help. Mitigations likely, but fully enabling these with cameras might be unlikely.
  - Very slight time lag led to some motion sickness symptoms. Explore further and resolve.
  - Speed thru camera view felt faster than you were actually driving. If camera FOV were wider and camera position higher, this might help? Need to test more.

The specific camera/display choices for D-RATS-22 were unacceptable and require improvement

3.6.2.1.3 Conducting Observations of External World via Windows

Science Observations *(in drive-by-windows mode)*

Rate the overall acceptability of conducting science observations of the external world while IVA with windows.

Consider: your ability to identify terrain features of interest for scientific exploration while driving and while stopped. Note any differences in acceptability when driving during the day vs. at night.

Consensus Acceptability Ratings + Comments

- **Rating: 6-7**
- **Comments:**
  - Difficult to see side views in darkness without lights pointing that direction. Although we had side windows, the lack of light in that direction while driving made it difficult to observe.
  - Window configuration gave us better visual info than the camera driving screens. When driving at night the contrast in camera view allowed better terrain recognition (e.g., more contrast than was detectable with human eyes through the windows).
  - Windows improved ability to assess terrain and operate - the human eye is the most sensitive instrument to accommodating various lighting conditions! Much easier to assess surroundings during daytime (obviously).
  - All I could observe [at night] was rocks and ground very close to the Rover through the bottom window. I could kind of see generic landscape, but it was very hard to tell color. To my surprise I could not distinguish gradual slope from complete flat surface. (Note that this was also partially limiting due to the artificial lighting available.)
  - With the mast camera, it was difficult to determine the size of obstacles and slopes because they differed from the normal field of view. With a window, it was easy to determine the size of the obstacle, but the color of the obstacle was affected by the light, so a detailed study is needed to determine the exact color of the obstacle. For color discrimination, natural colors are preferable.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Exterior view of rover driving at night with windows exposed, utilizing rover exterior lights – crew visible in cockpit

During night driving (which best simulates conditions expected in shadow at the lunar south pole) the ability to make IVA observations and interpret their surroundings through the windows was borderline to unacceptable with the specific external lights that were provided, warranting significant improvements for an actual PR

3.6.2.1.4 Conducting Observations of External World via Cameras + Interior Displays

Science Observations *(in drive-by-cameras mode)*

Rate the overall acceptability of conducting science observations of the external world while IVA with cameras + interior displays.

Consider: your ability to identify terrain features of interest for scientific exploration while driving and while stopped. Note any differences in acceptability when driving during the day vs. at night.

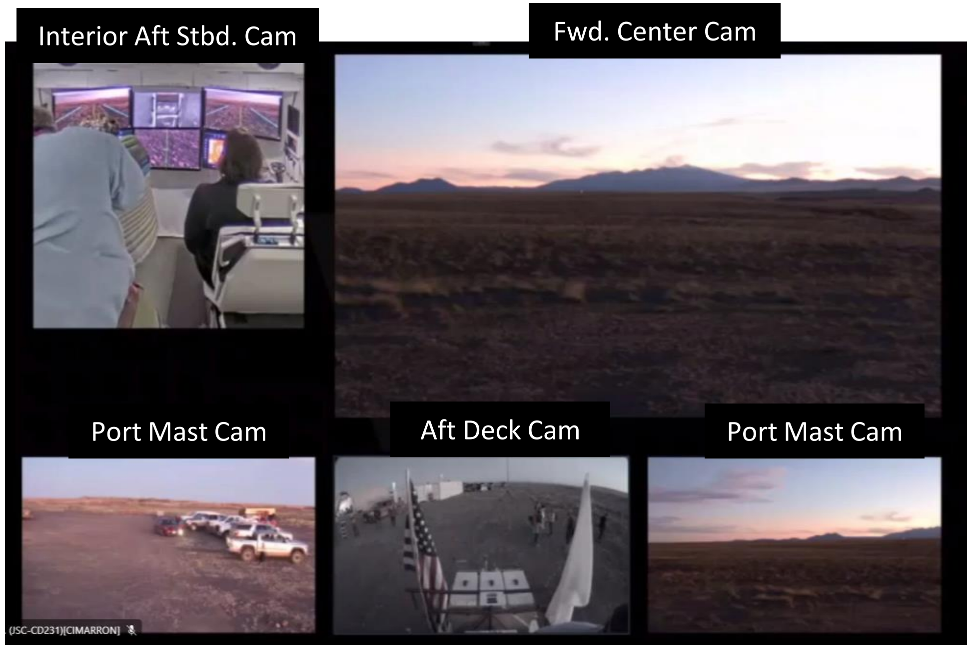
Consensus Acceptability Ratings + Comments

- **Rating: 6-7**
- **Comments:**
  - Difficult to see size and color on camera/monitor config. Side cameras did not provide enough lighting/resolution for observations.
  - Science observation during night driving was challenging as the view with the rover light beam was not enough to identify colors or contrasts. Better to have higher resolution for the mast camera.
  - Camera views were adequate for assessing terrain features. As we had not yet driven with only windows, it was difficult to compare whether the camera views were degraded compared to window view. FOV of cameras was adequate, especially given the options for camera angles and placements, and the number of simultaneous camera views.
  - Conducting IVA science with the cameras and displays was adequate with the ability to yaw the rover and have good lighting. In 18-degree-maximum crab mode [where the rover was limited to 18-degree crabbing] it was more cumbersome to do a survey of an area from a stationary position.
  - With the mast camera, it was difficult to determine the size of obstacles and slopes because they differed from the normal field of view, great for SA as well as Science Observation. Difficult to control, especially while pilot was driving.
  - When using driving cameras and mast cameras, had difficulty judging obstacle size and slope, because they have different FOVs than normal. Training is required. Was it because the window and camera have different FOVs or that the camera is monocular? When using the science camera, I could easily determine the size of the object but needed to get closer. IVA Observation using only cameras was acceptable because the science camera could determine colors, etc.
  - Can make general observations: improvements … warranted to include better resolution, lighting, etc. Anywhere from borderline to unacceptable depending on what the science objectives are.

During night driving (which best simulates conditions expected in shadow at the lunar south pole) the ability to make IVA observations and interpret their surroundings via the specific cameras, displays, and external lights provided, was borderline to unacceptable, warranting significant improvements for an actual PR

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- More light and higher resolution cameras are required in the port and starboard sides as the current views at night were very dark and the current cameras did not show high resolution. In addition, having both port/starboard camera views on the monitors would help with science observations during traverses. For the last question, we did not drive during the day so n/a.
- Lighting washed things out, would be nice to be able to cycle through color temperatures of externals lights to be able to see different hues. Cameras would not focus when deciding between low light, and lit areas, seemingly switching between night vision and visual light, and that meant the quality kept dropping.



Examples of Interior & Exterior camera views available in drive-by-camera mode

3.6.2.1.5 Cockpit Displays & Controls with Windows

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Displays & Controls *(in drive-by-windows mode)*

Rate the overall acceptability of the displays and controls in the rover cockpit when operating with windows.

Consider: location, layout, and usability.

Consensus Acceptability Ratings + Comments

- **Rating: 7**
- **Comments:**
  - Improve control for GPS map and video operation. Dealing with two keyboards was difficult. Suggest wireless mice. Also, suggest adding capability for the "co-pilot" to be able to change rate/command cruise while "pilot" drives. Sometimes hard for pilot to command while driving. Another option would be to use the buttons on control stick for these commands.
  - The combination of vehicle attitude indicator and GPS were useful to understand how and where we were going. Camera operation could be improved by integrating the control features into joystick.
  - No difference in rating or comments for this question between window mode and camera mode.
  - We frequently used Mast Cam to check our surroundings and see at a distance when driving. Driving monitor was great but switching Driving monitor to Mast Cam was really painful. It would be great if we had a Mast Cam dedicated monitor.
  - Even when using windows, mast cameras were frequently checked when driving. Others did not need to be operated and were more sophisticated than the camera system.
  - The manner in which 1B specific keyboards were used to control displays was unacceptable -- modern controller/trackpads would be much better.
  - If seat height were adjustable, fixed-height displays would be acceptable; otherwise there needs to be an adjustment in display height
  - Touch screens would be helpful in most conditions; critical execute functions can be hard buttons.
  - [Consider] heads-up display for windows that include seeing edges of rover?

The specific cockpit displays and controls in the GEN 1B analog PR were deemed unacceptable for drive-by-windows mode - the actual PR would require significant improvements

Interior cockpit view with windows exposed and control screens active

3.6.2.1.5 Cockpit Displays & Controls with Windows (cont.)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Hand Controller Design/Operation *(in drive-by-windows mode)*

Rate the overall acceptability of the hand controller design and operation when operating with windows.

Consider: location and hand/wrist fatigue.

Consensus Acceptability Ratings + Comments

- **Rating: 2**
- **Comments:**
  - No issues in 18-degree-maximum crab mode. Used cruise and changed rate quite often for ease of operation during relatively long ride. Cruise + rate also provided smooth, constant, velocity, while it was jerky under manual control even without any change in inputs. Twist may be not intuitive when starting out on a stick but becomes second nature in 18-degree-maximum crab mode after a while.
  - Wrist fatigue can be addressed by using cruise control. It might be simpler to drive if camera control were integrated into the joystick.
  - No difference in rating or comments for this question between window mode & camera mode.
  - I used cruise control as much as possible and used the hand controller only for steering most of the time. Still, sometimes I felt fatigue after driving. Yaw input was really tiring.
  - Like the camera system, the one-controller system is simple and easy to understand and operate. However, when driving at high speeds or over large undulations the system is susceptible to disturbance due to the input of the control system caused by the shaking of the vehicle, since speed and steering are not separated.
  - No strong opinions to change anything for next time -- was OK to switch between right and left sides.

Interior cockpit view with windows exposed and control screens active

The specific hand controller in the GEN 1B analog PR was deemed totally acceptable for drive-by-windows driving, and its inclusion in the actual PR would be acceptable

3.6.2.1.6 Cockpit Displays & Controls with Cameras + Interior Displays

Displays & Controls *(in drive-by-cameras mode)*

Rate the overall acceptability of the displays and controls in the rover cockpit when operating with cameras + interior displays.

Consider: location, layout, and usability.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Consensus Acceptability Ratings + Comments

- **Rating: 6**
- **Comments:**
  - Command and control of cruise/rate while driving on control monitor was slightly difficult and should be either commandable from co-pilot's monitor, or assign button on hand controller, so pilot can easily command. Command and control of video, GPS map via different keyboard pads was cumbersome - suggest either wireless mice/trackball or pad mounted on console closer to drivers, so they don't need to reach down to the monitor.
  - General layout was okay.
  - Display layout was fine, hand controller fine, but track pad of keyboards was difficult to use.
  - The displays were fine but there needs to be a better solution than the keyboard and touchpad for controlling the displays. A touch display would be much, much better.
  - It was good overall. It would be even better if we had dedicated MAST Cam monitor on the Upper middle.
  - Mast cameras were checked more frequently when driving, and it was better to have a separate control screen. Aft camera and Belly camera were used infrequently. There was too much keyboard use required … the controls need to be refined. Also, the screen was difficult to use because part of the screen was hidden by the speaker.
  - Using keyboards to control the screens was cumbersome and at times very difficult. Using edge keys or touch screens would improve functionality and efficiency and ease of use.
  - Would be nice if the screens and inputs were a complete system instead of 3 separate interfaces. This would allow for any information to be put on any display at any time, instead of stacking 15 years' worth of ideas into a pile of information. The keyboards were alright, but a single input system would be nice.
  - Did not notice reduced volume in cockpit due to addition of camera displays
  - Would like the flexibility to arrange monitors/display layout based on individual preferences
  - Big monitor in front of driver felt too close -- used this for camera views.
  - Didn't use lower display as much (might make you nauseous to look at ground moving by quickly?) – may be useful for science observations or careful rock clearances, but less useful for general driving
  - Having driver look straight at display in front of them is useful, navigator can use other screens/screen real-estate

The specific cockpit displays and controls in the GEN 1B analog PR were deemed borderline for drive-by-cameras mode – the actual PR would need improvements

Interior cockpit view with windows covered & driving screens installed and active

3.6.2.1.6 Cockpit Displays & Controls with Cameras + Interior Displays (cont.)

Hand Controller Design/Operation *(in drive-by-cameras mode)*

Rate the overall acceptability of the hand controller design and operation when operating with cameras + interior displays.

Consider: location and hand/wrist fatigue.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Consensus Acceptability Ratings + Comments

- **Rating: 2**
- **Comments:**
  - Cruise was beneficial in limiting fatigue, as well as providing smoother motion (somehow manual steady input on HC gave jerky motion). Yaw/crab motion by twist/tilt is not 100% intuitive, and needs training/experience, but can be overcome.
  - Good controllability.
  - For 18-degree-maximum crab mode, when initiating a large turn, it could be fatiguing for hand (no fatigue concerns for default mode). I assumed I would have a preference for the controller in right hand since I am right-handed, but I was fine with this controller in my non-dominant hand.
  - Cruise mode makes this score so well; without it hand fatigue would be an issue.
  - It took a bit of time to adjust how much input was needed. In the beginning it was a bumpy ride but after some time, my control improved. As an aviator, throttle and control stick were more familiar controls to me. Using cruise control felt a lot like controlling an airplane. It was easier than using just a joystick for speed and turning.
  - The single controller was simple and easy to understand and operate. However, when traveling at high speeds or over large swells, the lack of separation between speed and steering made the system susceptible to disturbances due to input from the operating system caused by the shaking of the vehicle.
  - Current design required specialty training and hands-on experience to master the driving (however the cruise function worked well). To simplify the training, I would prefer separating the steering control from the speed (throttle) control, rather than having both controls in one joystick.
  - Control input for turning was annoying, taking too much force to twist the stick - in car mode the yaw should be the turn, not the rotation.
  - No difference from windows mode

The specific hand controller in the GEN 1B analog PR was deemed totally acceptable for drive-by-camera driving, and its inclusion in the actual PR would be acceptable

Interior cockpit view with windows covered & driving screens installed and active – port and starboard hand controllers visible

3.6.2.1.7 Cockpit Volume & Layout with Windows

Cockpit Volume *(in drive-by-windows mode)*

Rate the overall acceptability of the cockpit volume for 2 crew to support driving operations when operating with windows.

Consensus Acceptability Ratings + Comments

- **Rating: 2**
- **Comments:**
  - Acceptable
  - Seemed like it had enough room and was comfortable to drive.
  - No difference in rating or comments for this question between window mode & camera mode.
  - No problems. Seat was simple and not enough seat restraint, but acceptable with little shaking.

Cockpit Layout *(in drive-by-windows mode)*

Rate the overall acceptability of the cockpit layout for 2 crew to support driving operations

Consensus Acceptability Ratings + Comments

- **Rating: 5**
- **Comments:**
  - Warranted improvement: need flexibility in seat and/or displays to accommodate heights
  - Adopting joystick control provided more room between driver seats and it was comfortable.
  - No difference in rating or comments for this question between window mode & camera mode.
  - A dedicated Mast Cam monitor would enhance our driving efficiency. We used Mast Cam quite a lot during driving for checking surroundings and for seeing in the distance.
  - Each seat had its own control/steering system, which made it easy for drivers to switch and take control.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10
	Volume			Layout					

Cockpit layout with windows exposed and control screens active
(Note: stowage bags temporarily stowed in pilot/co-pilot driving area for EVA)

Cockpit volume in the GEN 1B analog PR, when configured for drive-by-windows, was deemed totally acceptable for driving ops (a similar volume would be acceptable in the actual PR); however, the cockpit layout was borderline, warranting layout improvements wrt the actual PR

3.6.2.1.8 Cockpit Volume & Layout with Cameras + Interior Displays

Cockpit Volume *(in drive-by-cameras mode)*

Rate the overall acceptability of the cockpit volume for 2 crew to support driving operations when operating with cameras + interior displays.

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - Acceptable.
  - Had enough volume for driving.
  - Good distance between crewmembers. Easy to communicate, pass keyboards. (Having to exchange keyboards every time the pilot changed was not preferred though).
  - No problems. Seat was simple and there was not enough seat restraint, but it was acceptable with little shaking.
  - Inboard armrest would be nice, and a foot bar, otherwise you start to sprawl and that can get into your buddy's volume.

Cockpit Layout *(in drive-by-cameras mode)*

Rate the overall acceptability of the cockpit layout for 2 crew to support driving operations.

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - Acceptable
  - Command and control of cruise/rate while driving on control monitor was slightly difficult and should be either (1) commandable from co-pilot's monitor, or (2) assign button on hand controller, so pilot can easily command.
  - Command and control of video, GPS map via different keyboard pads was cumbersome - suggest either (1) wireless mice/trackball, or (2) pad mounted on console closer to driver, so they don't need to reach down to the monitor.
  - Layout sufficient for driving.
  - It was good overall. It would be even better if we had dedicated MAST Cam monitor on the Upper middle.
  - Each driver's seat had its own control/steering system, which made it easy for drivers to switch and take control.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Volume & Layout

Cockpit layout with windows covered and driving screens installed

Cockpit volume in the GEN 1B analog PR, when configured for drive-by-cameras, was deemed acceptable for driving ops (a similar volume with minor improvements desired would be acceptable for the actual PR); but the cockpit layout was borderline, warranting layout improvements wrt the actual PR

3.6.2.2 Exterior Lighting

M2MADO Strategic Question #2:

What exterior lighting configurations best support PR tasks (e.g., driving, IVA science observations, EVA, etc.)?

DRATS-22-Specific Sub-Question Related to Strategic Question #2:

– ***How acceptable are the GEN 1B rover lights and their associated specifications for supporting PR operations and science?***

Crew Questions: ***Rate the acceptability of the GEN 1B exterior lights (including location, intensity, beam width, etc.) for supporting the following:***

- *Driving in all terrain types when windows were available*
- *IVA observations in all terrain types when windows were available*
- *Driving in all terrain types when cameras + interior displays were available*
- *IVA observations in all terrain types when cameras + interior displays were available*
- *Extravehicular Activity*

3.6.2.2.1 Exterior Lighting for Supporting Driving & IVA Observations with Windows

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Exterior Lights for Driving *(in drive-by-windows mode)*

Rate the acceptability of the GEN 1B exterior lights (including location, intensity, beam width, etc.) for supporting driving in all terrain types when windows were available

Consensus Acceptability Ratings + Comments

- **Rating: 7**
- **Comments:**
  - Difficult to see far distances in the dark. Recommend having a high beam capability for distance lighting, which can be switched to low beam for closer objects.
  - Front beam light should be modified to include a high-beam function to improve situational awareness.
  - Of course, overall SA is poorer at night - more penetrating lights would be useful. Is there a way to improve belly cam lighting? This camera is very useful during the day, but at night is not nearly as useful.
  - We'd like to see further when driving with windows. The light doesn’t reach far enough for window driving. Mast Cam is still useful but not quite enough.
  - The mast camera view was bright and fine for driving. However, the main lights had a range of only about 10 meters from the large window, so the forward visibility was limited when driving. I felt that a wide illumination range like that of high beams or car lights was necessary.
  - Required lighting: extend bright driving lights out to 40-50m for driving. Light from mast camera location should extend out to 50m with wider FOV (minimum = width of rover at 50m but need more testing to refine this number). Need more testing on distance of light/speed relationship.
  - More light, closer to aft end of rover would be helpful (nice to have).
  - Mast camera light improvements are sufficient for side hatch views.

Crew driving analog PR at night with windows exposed using exterior lights for driving and IVA Observations

The specific exterior lights (including location, intensity, beam width, etc.) on the GEN 1B analog rover were unacceptable for supporting driving ops with windows, meaning an actual PR would need significant improvements to be acceptable

3.6.2.2.1 Exterior Lighting for Supporting Driving & IVA Observations w/ Windows (cont.)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Exterior Lights for IVA Observations *(in drive-by-windows mode)*

Rate the acceptability of the GEN 1B exterior lights (including location, intensity, beam width, etc.) for supporting IVA observations in all terrain types when windows were available

Consensus Acceptability Ratings + Comments

- **Rating: 7**
- **Comments:**
  - Difficult to see side views in darkness without lights pointing that direction. Although we had side windows, the lack of light in that direction while driving made it difficult to observe.
  - Front beam light could be modified to have a high-beam function so that situational awareness can be improved.
  - Lights are adequate, but depending on sun angle, can still be limiting.
  - All I could observe was rocks and ground very close to the rover through the bottom window. I could kind of see generic landscape, but it was very hard to tell color. To my surprise I could not distinguish gradual slope from complete flat surface.
  - IVA science observations could be made in front of the rover; however, observations beside the rover were difficult because the side lights only illuminated terrain really close to the rover.
  - Would like adjustable/different temperature lights to avoid washout (similar to xINFO lights) -- need to be able to identify different rock colors; better to use natural color temp (e.g., sunlight) for science.

Crew driving analog PR at night with windows exposed using exterior lights for driving and IVA Observations

Note: individual comments may be inconsistent, but the overall rating reflects the consensus that was reached.

The specific exterior lights (including location, intensity, beam width, etc.) on the GEN 1B analog rover were unacceptable for supporting IVA observations with windows, meaning an actual PR would need significant improvements to be acceptable

3.6.2.2.2 Exterior Lighting for Supporting Driving & IVA Observations with Cameras + Interior Displays

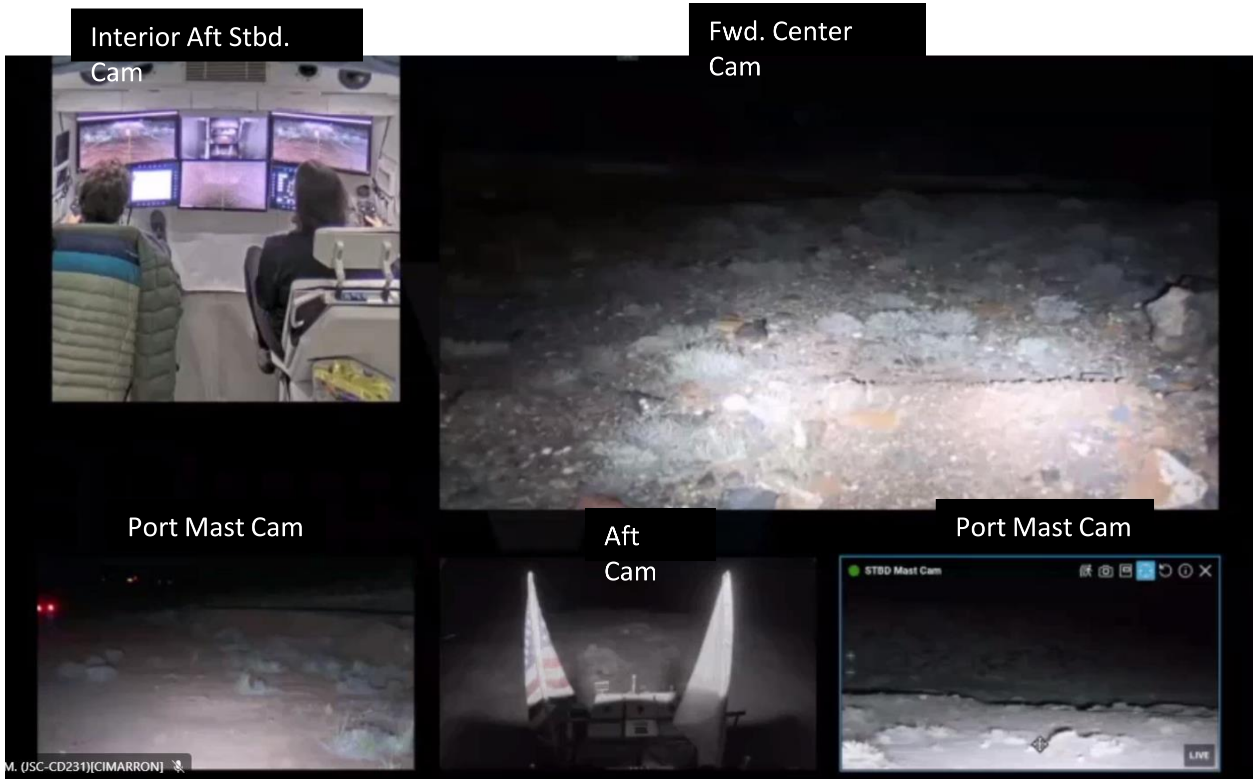
Exterior Lights for Driving *(in drive-by-cameras mode)*

Rate the acceptability of the GEN 1B exterior lights (including location, intensity, beam width, etc.) for supporting driving in all terrain types when cameras + interior displays were available

Consensus Acceptability Ratings + Comments

- **Rating: 7**
- **Comments:**
  - Need lighting for far field (i.e., high beam) forward.
  - It is better to have high-beam mode since it will help to estimate the approaching terrain. Light intensity was good for driving.
  - Lights were fine.
  - Most of the time we used Drive Cam and Mast Center Cam at the same time. Lights for both cams are just right to see what we wanted to see.
  - The mast camera view is bright enough for driving.
  - Farther reaching light in all directions is required to help make driving decisions early and often.
  - They need to be farther flung or take that low slung spot and put it onto a PTZ that will allow for long route planning instead of, come-what-may driving. Light color is too cold, washes out everything - it also blows out the PTZs as they struggle to switch between IR and Visual Light at the edge of the light radius.
  - No different from windows mode recommendations

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10



Interior and Exterior Camera View Examples

The specific exterior lights (including location, intensity, beam width, etc.) on the GEN 1B analog rover were unacceptable for supporting driving ops with cameras and interior displays, meaning an actual PR would need significant improvements to be acceptable

3.6.2.2.2 Exterior Lighting for Supporting Driving & IVA Observations with Cameras + Interior Displays (cont.)

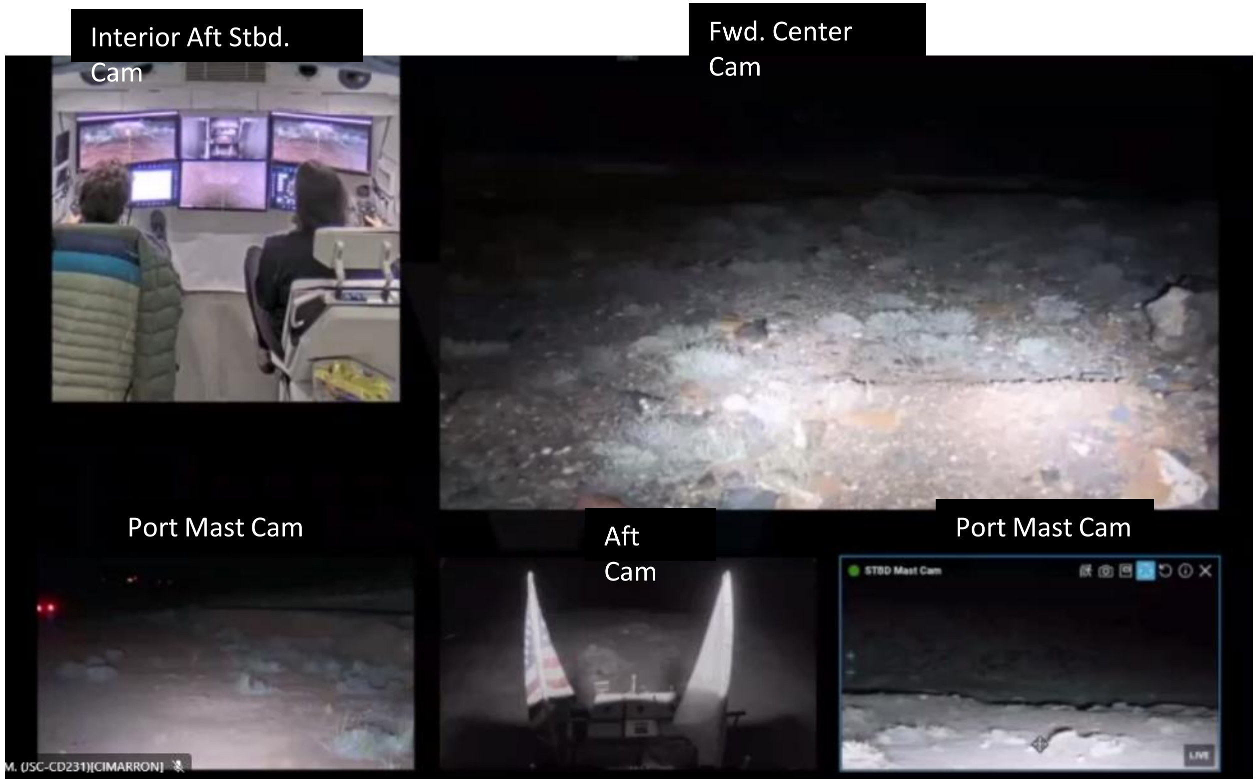
Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Exterior Lights for IVA Observations *(in drive-by-cameras mode)*

Rate the acceptability of the GEN 1B exterior lights (including location, intensity, beam width, etc.) for supporting IVA observations in all terrain types when cameras + interior displays were available

Consensus Acceptability Ratings + Comments

- **Rating: 7**
- **Comments:**
  - Very difficult to see far field on sides with current light config.
  - Most of the time we used Drive Cam and Mast Center Cam at a same time. Lights for both cams are just right to see what we wanted to see.
  - During IVA observation while moving, it is difficult to observe the lateral directions [port and starboard], because the beam shed light only at close range. Front observation was possible.
  - Higher intensity light in port and starboard directions is required to help make accurate observations (current light intensity is not enough for the PTZ cameras to focus/show required resolution.
  - Lighting was acceptable for the rock cam and nose cam, however the PTZs could not take advantage of the lights. In combination, the lighting and the PTZ resulted in very grainy views which shifted as the cameras auto focused.
  - No different from windows mode recommendations.



Interior and Exterior Camera View Examples

The specific exterior lights (including location, intensity, beam width, etc.) on the GEN 1B analog rover were unacceptable for supporting IVA observations with cameras and displays, meaning an actual PR would need significant improvements to be acceptable

3.6.2.2.3 Exterior Lighting for Supporting EVA

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Exterior Lights for Supporting EVA

Rate the acceptability of the GEN 1B exterior lights (including location, intensity, beam width, etc.) for supporting EVA

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - Acceptable with rover teleoperation.
  - Enough light was provided.
  - Lights were very useful to enhance EVA - could see much more in the distance using rover lights (still dependent on sun angle).
  - Lighting to supplement the EVA was great
  - Night EVA was tough to see surroundings and report geological observation. Although we didn't use rover light much while working on the site, it is a great asset to help visibility. During daytime EVA we did geological observation of the side view of the cliff from a distance. Powerful Rover lights would be very useful if we were to try same observation at night. Need to determine adequate brightness and beam distance for such situation.
  - By moving the rover closer to the search point, the overall view and the object became much easier to observe. However, the [artificial] sun's light and the rover's light mixed together, causing a white halation in the color, so care must be taken with the angle of the light and the color of the light.
  - Current rover lights suffice for general SA during EVAs, however higher intensity (spot) lights are warranted to support EVA worksite tasks and EVA traversing.
  - I would push for a multi-spectrum or temperature light, and having the rover equipped with a tight, far-flung spotlight, would also be really helpful, as the rover would be able to point, and partially illuminate an area of interest or direction simply by rotating.
  - Acceptable as is for what we tested

Two crew performing night EVA assisted by lights from rover

The specific exterior lights (including location, intensity, beam width, etc.) on the GEN 1B analog rover were acceptable for supporting EVA in dark regions, meaning they would be acceptable on an actual PR with only minor desired improvements

3.6.2.3 Interior Layout

M2MADO Strategic Question #3:

How does the interior layout of a PR contribute to human performance and habitation?

Crew Questions: *Rate the overall acceptability of the following:*

- *Driving Seats (consider location, overall comfort, stability while driving, height/width/depth of seat, location of foot and/or arm rests, space between crewmembers, etc.);*
- *Location & Volume Available for Exercise;*
- *Accessibility of non-exercising crewmember to work in other stations within vehicle during exercise;*
- *Overhead associated with setup/teardown of exercise device (i.e., cabin reconfiguration);*
- *Sleep station (consider overall volume and dimensions, comfort of benches for sleep, privacy, light leaks, sound proofness);*
- *Cabin reconfiguration for sleep (i.e., curtain stow/deploy operations);*
- *Galley operations (consider access to food stowage, volume to prepare and consume a meal, access to PWS for food rehydration, and any other food/eating capabilities you would want in a small pressurized rover); and*
- *Waste Collection System (consider WCS location, volume, usability (e.g., access to hygiene items), and privacy).*

3.6.2.3.1 Driving Seats

Rate the overall acceptability of the driving seats.

Consider: location, overall comfort, stability while driving, height/width/depth of seat, location of foot and/or arm rests, space between crewmembers, etc.

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - General seat comfort is good while more restraints (shoulder harness etc.) are required, especially when the rover goes over rough terrain.
  - Overall comfort/design of seats was fine. When driving with windows, would be nice if seat height could be adjusted for shorter torso-ed crewmembers (would be a better alternative than just using various pads as boosters). Not important when driving in cameras only mode, but it was difficult to see over displays when driving with windows.
  - Seats are great
  - No issue with the driving seats. Size, comfort, and distance between the seats are good.
  - For Gen. 1B, armrests are important because elbow position has a significant impact on drivability. The armrests are adjustable, so they are not inconvenient.
  - No physical complaints.
  - Generally fine to get the job done. Could use softer/thicker cushions to improve comfort.
  - Sufficient adjustability for all aspects for all body types/heights
  - Slightly softer cushions preferred

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Cockpit area showing seat and hand-controller

The specific seats/seating arrangement in the GEN 1B analog rover cabin were acceptable, meaning something similar would be acceptable in an actual PR with only minor desired improvements, such as softer cushions, adjustable height, and restraints

3.6.2.3.2 Exercise

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Rate the overall acceptability of the location and volume available for exercise.

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - Not optimal but can work around as needed.
  - Had enough space to perform this specific type of exercise.
  - Doesn't seem like there is really another option, but not ideal to block use of the toilet when a crewmember is exercising. Otherwise, the location/space was fine for this type of exercise device.
  - Acceptable
  - With limited volume, location and types of exercise seem just right. I'm personally OK with bike and limited weight training for 30-day 1/6g mission.
  - Very good for both aerobic and strength training. If necessary, the workout can be done on the bed, which would allow for adequate exercise. During In-Flight Maintenance (IFM) of air conditioning, it is very hot, and not suitable for exercise.
  - Ceiling in exercise area too low for taller people
  - Limited by not being able to use toilet at the same time (but not sure where else you could put exercise station)

Photo of one crewmember performing exercise inside the cabin, while the other crewmember performs work

The overall location and volume available for exercise in the GEN 1B analog rover cabin were acceptable, meaning a similar arrangement would be acceptable in an actual PR with only minor desired improvements

3.6.2.3.2 Exercise (cont.)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Rate the acceptability of the accessibility of non-exercising crewmember to work in other stations within vehicle during exercise.

Consensus Acceptability Ratings + Comments

- **Rating: 4**
- **Comments:**
  - Depends on task. Need to plan to avoid space constraints.
  - If the non-exercising crewmember is working close to the exercising crewmember, the volume may not be enough to conduct other tasks.
  - Blocked some access areas (and main concern being blocking toilet, but overall acceptable, doesn't seem to be another option for better location.
  - Access to stowage in/under the benches is restricted while the other crewmember is exercising so the timeline needs to accommodate that. Given the small volume there is likely little that can be done to improve this.
  - No issue. In the limited volume, working next to exercising crew member is inevitable.
  - During exercise, it felt too close to perform IFM on the PWS. When performing IFM on the air conditioning, it is very hot and not suitable for concurrent exercise.
  - It's a tight space, but crew workarounds can be achieved to minimize interference with good planning beforehand.

Photo of one crewmember performing exercise inside the cabin, while the other crewmember performs work

The accessibility of the non-exercising crewmember to work at other stations during exercise in the GEN 1B analog rover cabin was on the low end of acceptable, meaning a similar setup would be acceptable in an actual PR with minor improvements

3.6.2.3.2 Exercise (cont.)

Rate the acceptability of the overhead associated with setup/teardown of exercise device (i.e., cabin reconfiguration)

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - Desired improvement: Consider using latches instead of bolts for easier installation. Also, would be nice to have an adjustment mechanism instead of having to remove and reinstall for different size crewmember.
  - Ergometer was a bit heavy, but overall usability was good.
  - Acceptable
  - The first time, it took a while, but thereafter it became really easy with minimal impact on overall daily schedule.
  - Cleanup is easy. When stowing, it was necessary to bend way down, which was burdensome.
  - Current exercise routines require minimal cabin reconfiguration.
  - Doing it every day for a month will likely get tedious -- would you just leave it set up for some days at least?

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Photo of one crewmember performing exercise inside the cabin, while the other crewmember performs work

The overhead for setup/teardown of the specific exercise device tested in the GEN 1B analog rover cabin was acceptable, meaning it would be acceptable in an actual PR with only minor improvements desired

3.6.2.3.3 Sleep Stations

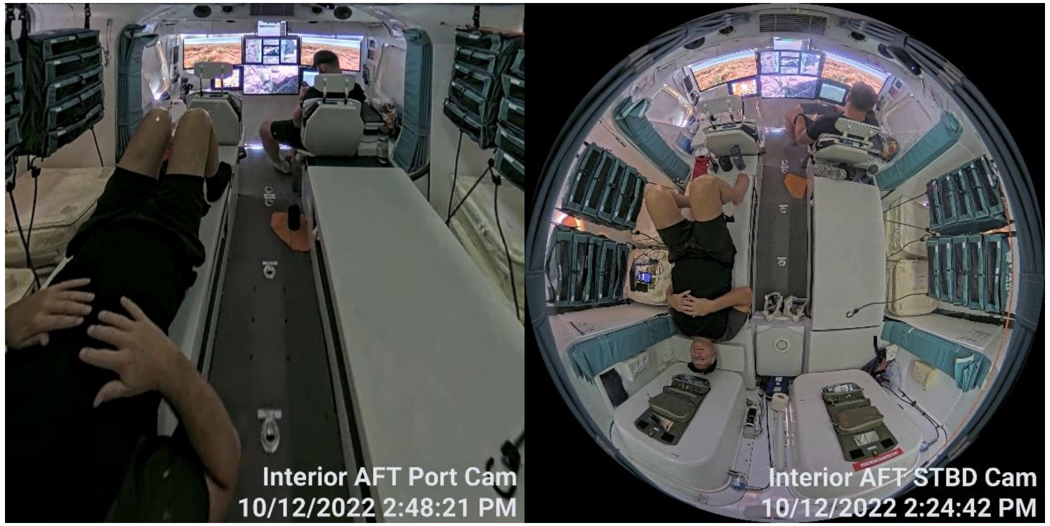
Rate the overall acceptability of the sleep station.

Consider: overall volume and dimensions, comfort of benches for sleep, privacy, light leaks, sound proofness.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Consensus Acceptability Ratings + Comments

- **Rating: 2**
- **Comments:**
  - Tried both with and without individual curtains. Both configs worked fine; depends on whether the crewmembers want privacy or camping tent configuration.
  - Volume was enough and privacy was maintained by using curtains. Bench comfort was also acceptable.
  - Found the sleep stations very comfortable (but I know I may be an outlier in preferring very firm mattresses!) Privacy curtain gave a complete feeling of privacy, while still not taking up much space when not in use. Not soundproof but using ear plugs were adequate. The only surprising thing was how much the rover moved when the other crewmember shifted position in their sleep station or got up to use the toilet (would have thought the rover would have been more stable and prevented that).
  - The layout is good, the volume is fine, the privacy barriers are great and do block light and dampen sound. I had to use the toilet several times at night, and it was a tight space with the barriers down but workable. The bench hardness is great for the day but not very comfortable at night.
  - There was enough space and volume for sleeping. The bed was not too hard, and I slept well at night. I really liked the way personal items were organized. Easy to access and easy to sort.
  - I slept with my head toward the rear of the vehicle. The restroom is clean, and odor is not an issue. I would like to have a high pillow so that my head is not on the low side when I go to bed. The hardness of the bed is fine for 14 days. The window shades we used in the drive-by-camera configuration worked very well to block out light in the morning. Sound and light leakage were not a concern.
  - Bench cushions were too hard for sleep on Earth, but might be good enough for lunar gravity
  - Generally acceptable with some crewmembers desiring softer sleep cushions. I feel like we had a lot of room with the side hatches; curtains provided lots of privacy, were super easy to deploy and didn't take up much space. I was surprised that the whole rover moved if someone rolled over in their bunk (we did have big incline of the cabin that night). Dimensions for sleep space were acceptable - 95% male length (need to check on width--slightly wider would be nice for sleeping but bounded based on desired aisle width and hatches) - important compatibility to maintain for 30-day missions. good to be able to roll over and adjust.



Photos showing one crewmember resting on the port sleep station, while the other crewmember performs work

The overall aspects of the sleep station provided in the GEN 1B analog rover cabin was totally acceptable, meaning a similar arrangement would be totally acceptable in an actual PR

3.6.2.3.3 Sleep Stations (cont.)

Rate the acceptability of cabin reconfiguration for sleep (i.e., curtain stow/deploy operations).

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - No issue.
  - Curtain was bit heavy but other operations were quite smooth.
  - As above, very easy to deploy, and given how well they work to provide privacy, was very impressed by how little room they took. Very easy to deploy/stow.
  - Acceptable– No issue.
  - Curtain was bit heavy but other operations were quite smooth.
  - As above, very easy to deploy, and given how well they work to provide privacy, was very impressed by how little room they took. Very easy to deploy/stow.
  - Acceptable
  - Curtain at the side of the bed is heavy and difficult to stow by one crew member. Instead, it is thick enough to separate two sleep stations. It makes me feel as if I was in a private room.
  - A sheet blocking the window felt necessary for both privacy and insulation. With the sheet, the PORT-STBD curtains would be more open if they were not tightened. A center curtain would suffice.
  - An easier method for curtain unstow/stow would be preferred.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
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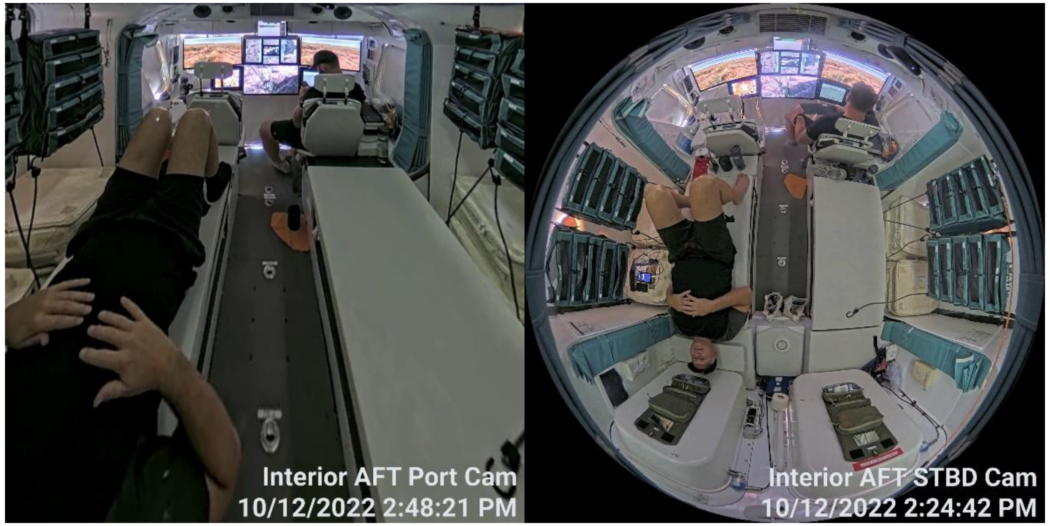


Photos showing one crewmember resting on the port sleep station, while the other crewmember performs work

The cabin reconfigurability for sleep as implemented in the GEN 1B analog rover cabin was acceptable, meaning a similar arrangement would be acceptable in an actual PR with only minor improvements desired

3.6.2.3.4 Galley & Meal Preparation

Rate the overall acceptability of galley operations.

Consider: access to food stowage, volume to prepare and consume a meal, access to PWS for food rehydration, and any other food/eating capabilities you would want in a small pressurized rover.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Consensus Acceptability Ratings + Comments

- **Rating: 4**
- **Comments:**
  - Potable water supply (PWS) is at a low location. Would be nice to have it higher if possible.
  - General galley operation was good. A 3D food printer may provide more variable food options than typical space food.
  - Didn't love the location of the PWD given how close it was to floor, bending down to use, etc. However, I can't think of another location that would work better. Sounds like previous crews didn't think hot water was hot enough - believe this was because they may not have drained the line prior to use. Recommend emphasizing that in training and pre-mission or putting a small sign as reminder. When line was drained, water was sufficiently hot for food rehydration.
  - The PWS location near the floor is not ideal. I accidentally sprayed water on the floor more than once. Also, the drain is really small and awkward to use.
  - Food was OK. It was very well organized by types and crewmembers and easy to use. No issue with water/ hot water use. MCC reminded us when the hot water button was ON. It was very helpful.
  - PWS cannot be used when toilet is in use, but ease of use and placement is not a problem. The nozzle length could be slightly shorter for easier storage and use in the space. The dishes mounted on the unit were easy to smell. (The smell of the patties was very strong).
  - Meals were prepared on the benches since no dedicated area is available. A food warmer would be nice.
  - Ergonomics + hygiene point to having the PWS a bit higher off the floor. Appreciate not having it next to the toilet for sanitation reasons

Photo of crew eating a meal in analog PR cabin

The overall acceptability of galley operations as implemented in the GEN 1B analog rover cabin was acceptable, meaning a similar arrangement would be acceptable in an actual PR with only minor improvements desired

3.6.2.3.5 Waste Collection System (WCS)

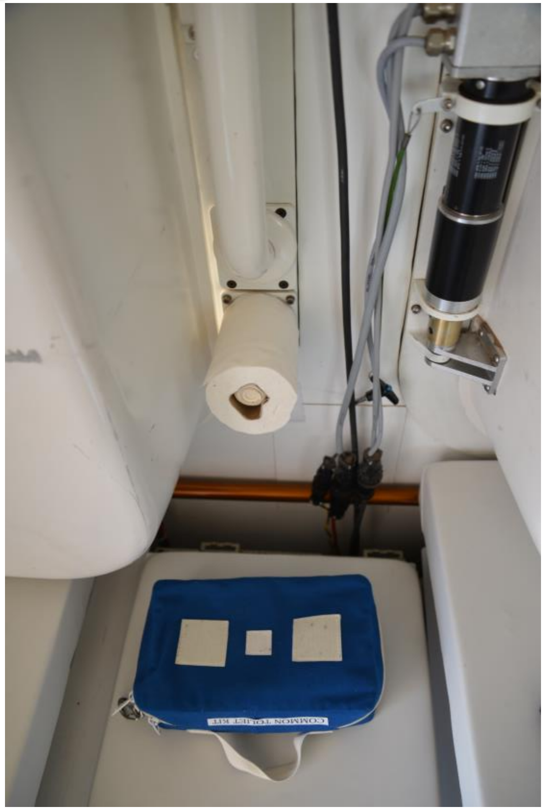
Rate the overall acceptability of the WCS.

Consider: WCS location, volume, usability (e.g., access to hygiene items), & privacy.

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - Fine for a short duration mission. Consider having a closer curtain for privacy so the crewmember not using the WCS can use more cabin space. Maybe use a roll up curtain installed on the ceiling.
  - Waste collection and sealing for trash takes time and impacts crew time. Is good to have a waste collection bag with odor protection capability which can last for weeks.
  - WCS was comfortable and easy to use and felt private enough. As mentioned, mesh bag on toilet was ripped, so need to watch for that (at one point a bag with urine in it got caught in between panels when stowing the toilet). Powder works well to jellify urine, but of course takes a lot of volume for storage. Urine processing would be ideal!
  - Accommodating a WCS in such a small volume is always going to be difficult so I think the current design is about as good as it's going to get. The privacy is fine. Thinking about some way to help mitigate odors would be the only improvement I can think of.
  - Clean, simple, and easy to use the toilet. Accessory kit is easy to access and well organized. Personal toilet kit was also great when I needed something extra. Privacy curtain is easy to deploy, thick enough to separate volumes. Toilet space is large enough to do toilet Ops.
  - The WCS is simple and easy to use. The packs are replaced with new packs immediately after use, so there is no smell, and they feel clean. When a crewmember uses the WCS, the rover space is occupied for about 10 minutes including the exchange time, so it would be better if the exchange time could be made as quickly as possible. The portable WCS was effective; however, if the other crew member was sleeping, the layout required waking them to use it.
  - WCS seat was on the small size for larger crewmembers. Current privacy curtain separates cabin and cockpit, which means the crewmember not using the WCS is confined to the cockpit.
  - Critical to have sufficient trash management for waste, especially depending on how often cabin containing WCS waste needs to go to vacuum.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10



Analog PR Waste Collection System (WCS)

The WCS as implemented in the GEN 1B analog rover cabin was acceptable, meaning a similar arrangement would be acceptable in an actual PR with only minor improvements desired

3.6.2.4 Waste & Trash

M2MADO Strategic Question #4:

How is waste and trash managed inside a pressurized rover, and what is the method and frequency of removal for a 30-day mission?

DRATS-22-Specific Sub-question Related to Strategic Question #4:

- ***How should waste and trash be managed inside a PR?***

Crew Questions*:*

- *Rate the acceptability of the volume of interior stowage to support 14 days of trash/solid waste*
- *Rate the acceptability of the PR trash/solid waste management system (i.e., ad hoc bags placed around vehicle). Consider cross contamination risks, odor control, etc.*

3.6.2.4.1 Volume of Interior Stowage for Waste & Trash

Rate the acceptability of the volume of interior stowage to support 14 days worth of trash/solid waste

Consensus Acceptability Ratings + Comments

- **Rating: 7**
- **Comments:**
  - Need to consider how to manage trash with containment for a 14-day mission. Need a better way to contain trash for long duration.
  - Stowage volume for trash may not be enough to cover 14-day mission.
  - I believe trash would become an issue for 14 days. Given the mass/volume of human waste together with food/hygiene trash, I believe the main trash locker wouldn't last anywhere near that long. Unless there was an alternative site with which I wasn't familiar? The main deck locker space didn't seem very big for that duration. Again, main contributor is considerable volume of human waste (especially for contingency situations if crewmember is ill, etc. - needs to accommodate for that).
  - I struggle to see that 14 days of waste can be accommodated in the current floorboard trash location. The current food and hygiene system generates a decent amount of trash.
  - Trash Compartment is too small for 30-day mission. For 7-day OK. For 14-day may be not enough space or odor may become problematic.
  - The toilet used about 1/3 of the Stowage volume in about 3 days, so we felt that with the current system and volume, it would need to be emptied every 7 days. Wet trash could be smelled in 2 days, although the volume was higher from the food and health. The smell was noticeable in 2 days. Toilet trash could not be smelled with the floorboards closed, but with the floorboards open, the odor could be smelled.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

No photo available

The interior trash/solid waste stowage capacity in the GEN 1B analog rover was unacceptable to support 14 days of trash/solid waste, meaning an actual PR would need significantly more storage capacity to be acceptable

3.6.2.4.2 Trash/Waste Management System

Rate the acceptability of the PR trash/solid waste management system (i.e., ad hoc bags placed around vehicle). Consider cross contamination risks, odor control, etc.

Consensus Acceptability Ratings + Comments

- **Rating: 7**
- **Comments:**
  - Need to consider better trash management.
  - Stowage volume for trash may not be enough but odor was not noticeable.
  - Had no issues for trash management, but smells would likely start becoming a concern for 14 days.
  - The system of storing trash under the floor was very convenient. The Dry and Wet box in front of the tray was inconvenient because it needed to be moved when using the toilet.
  - More volume is required for waste in general. May need to separate solid and wet waste and recycle the wet waste.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

No photo available

The trash/solid waste management system as implemented in the GEN 1B analog rover was unacceptable, meaning an actual PR would need significantly more storage capacity to be acceptable

3.6.2.5 Overhead Tasks

M2MADO Strategic Question #5:

How much time per day is spent on overhead tasks for rover operations, crew habitation, and EVA prep and post activities (e.g., reconfiguring the cabin interior for EVA, exercise, sleep, WCS operations, conducting housekeeping tasks)?

3.6.2.5.1 Timing Data for Overhead Tasks

- NASA was interested in showcasing to JAXA how objective data, such as task times, can be used to corroborate subjective data
- This included timing data on how much time per day was spent on overhead tasks for rover operations, crew habitation, and EVA prep and post activities (e.g., reconfiguring the cabin interior for EVA, exercise, sleep, WCS operations, conducting housekeeping tasks)
- Raw data was collected during D-RATS-22 and made available to JAXA
  - Days 01-03 contain engineering dry run timing data
  - Days 04-06 contain Crew 1 Test timing data
  - Days 07-09 contain Crew 2 Test timing data
  - Days 10-12 contain Crew 3 Test timing data
- An example of the timing data that was collected for Day 04 (Day 1 of Crew 1 Tests) is shown in the figure on the right and is continued on the next two slides
- To date, NASA has not had a need to perform any analyses on this timing data, and is therefore not presented in full here; but the raw data can be provided upon request

1	Task	Start	Stop	Total	Notes
2	Sim start	17:55:00	17:59:00	0:04:00	
3	crew prepping rover for mission	17:59:00	18:03:00	0:04:00	looking over nav and traverse route
4	crew will start in JAXA mode with cdr driving	18:03:00	18:05:00	0:02:00	
5	ms1 nav and avoidance	18:03:00	18:05:00	0:02:00	
6	mcc wanting rover to stick to route. Rover stopped	18:05:00	18:06:00	0:01:00	
7	crew will start in JAXA mode with cdr driving	18:06:00	18:22:00	0:16:00	
8	ms1 nav and avoidance	18:06:00	18:09:00	0:03:00	
9	MS1 doing sci obs	18:09:00	18:10:00	0:01:00	
10	ms1 nav and avoidance	18:10:00	18:16:00	0:06:00	
11	mcc having rover go high gear	18:15:00	18:16:00	0:01:00	
12	cdr driving	17:16:00	18:21:00	1:05:00	
13	MS1 doing sci obs	18:16:00	18:17:00	0:01:00	ms1 was using the camera for the obs
14	mcc wants additional details	18:17:00	18:18:00	0:01:00	
15	MS1 doing sci obs	18:18:00	18:19:00	0:01:00	
16	mcc copy's	18:19:00	18:20:00	0:01:00	
17	MS1 doing sci obs	18:19:00	18:20:00	0:01:00	
18	mcc copy's	18:19:00	18:20:00	0:01:00	
19	ms1 nav and avoidance	18:20:00	18:21:00	0:01:00	
20	mcc wants cdr to drive to 2a	18:21:00	18:22:00	0:01:00	
21	rover stopped	18:21:00	18:22:00	0:01:00	
22	cdr copy's and starts driving	18:21:00	18:24:00	0:03:00	
23	mcc copy's	18:23:00	18:23:00	0:00:00	
24	ms1 nav and avoidance	18:21:00	18:24:00	0:03:00	
25	rover stopped cdr to find Roma to Alpha	18:24:00	18:26:00	0:02:00	
26	mcc helping with nav	18:25:00	18:26:00	0:01:00	
27	cdr driving	18:25:00	18:28:00	0:03:00	
28	ms1 nav and avoidance	18:25:00	18:26:00	0:01:00	
29	MS1 doing sci obs	18:26:00	18:27:00	0:01:00	
30	mcc copy's	18:26:00	18:27:00	0:01:00	
31	ms1 nav and avoidance	18:27:00	18:28:00	0:01:00	
32	cdr telling NCC heading	18:28:00	18:28:00	0:00:00	
33	mcc copy's	18:28:00	18:29:00	0:01:00	
34	rover stopped and crew looking at surroundings	18:28:00	18:29:00	0:01:00	
35	cdr sci obs	18:29:00	18:30:00	0:01:00	
36	mcc copy's	18:30:00	18:30:00	0:00:00	
37	cdr sci obs	18:30:00	18:31:00	0:01:00	
38	mcc copy's	18:30:00	18:31:00	0:01:00	
39	cdr sci obs	18:31:00	18:32:00	0:01:00	
40	MS1 working cameras	18:31:00	18:32:00	0:01:00	
41	mcc copy's and asking crew to change drivers and giving instructions	18:31:00	18:33:00	0:02:00	
42	cdr copy's	18:33:00	18:34:00	0:01:00	
43	Mcc copy's	18:33:00	18:34:00	0:01:00	
44	cdr copy's and Jaxa MODE and MS1 driving	18:33:00	18:47:00	0:14:00	
45	cdr nav and avoidance	18:33:00	18:42:00	0:09:00	
46	Mcc wants rover in high gear	18:36:00	18:37:00	0:01:00	
47	mcc wants crew to verify all lights are on	18:38:00	18:39:00	0:01:00	
48	cdr response all lights are on	18:38:00	18:39:00	0:01:00	
49	mcc guides crew about traverse	18:40:00	18:41:00	0:01:00	
50	crew copy's	18:41:00	18:41:00	0:00:00	
51	cdr sci obs	18:42:00	18:43:00	0:01:00	

Day 01 | Day 02 | Day 03 | Day 04 | Day 05 | Day 06 | Day 07 | Day 08 | Day 09 | Day 10 | Day 11 | Day 12

Ready Accessibility: Investigate

Timing Data Collected on Day 04 (Day 1 of Crew 1 Tests) [items 2-51]

3.6.2.5.1 Timing Data for Overhead Tasks (cont.)

1	Task	Start	Stop	Total	Notes
52	cdr nav and avoidance	18:43:00	18:47:00	0:04:00	
53	mcc copy's sci obs	18:43:00	18:43:00	0:00:00	
54	mcc wants crew to go to low gear and new directions	18:46:00	18:47:00	0:01:00	
55	cdr copy's mcc	18:46:00	18:47:00	0:01:00	
56	rover stops for gear change	18:47:00	18:50:00	0:03:00	
57	crew reset lights	18:49:00	18:50:00	0:01:00	
58	ms 1 driving in jaxa mode	18:50:00	18:55:00	0:05:00	
59	cdr sci obs	18:50:00	18:52:00	0:02:00	
60	mcc copys	18:53:00	18:53:00	0:00:00	
61	cdr nav and avoidance	18:53:00	18:55:00	0:02:00	
62	rover stopped	18:54:00	18:55:00	0:01:00	
63	ms 1 driving in jaxa mode	18:55:00	19:00:00	0:05:00	
64	cdr nav and avoidance	18:55:00	19:00:00	0:05:00	
65	cdr nxwitness has lost camera view	18:59:00	19:00:00	0:01:00	
66	mcc wants them to start nxwitness procedures	19:00:00	19:00:00	0:00:00	
89	cdr driving	19:17:00	19:22:00	0:05:00	
90	ms 1 nav and avoidance	19:17:00	19:19:00	0:02:00	
91	ms 1 sci obs	19:19:00	19:20:00	0:01:00	
92	mcc said comm from rover is difficult to understand	19:19:00	19:20:00	0:01:00	
93	ms 1 nav and avoidance	19:20:00	19:28:00	0:08:00	
94	mcc to rover comm check	19:21:00	19:21:00	0:00:00	
95	rover to mcc comm check good	19:21:00	19:21:00	0:00:00	
96	mcc to rover comm check	19:22:00	19:22:00	0:00:00	
97	rover has mcc clear	19:22:00	19:22:00	0:00:00	
98	mcc copy	19:22:00	19:22:00	0:00:00	
99	rover stopped	19:22:00	19:23:00	0:01:00	
100	mcc head south	19:23:00	19:23:00	0:00:00	
101	cdr driving	19:23:00	19:27:00	0:04:00	
102	mcc redirecting rover	19:24:00	19:25:00	0:01:00	
103	rover stopped	19:27:00	19:28:00	0:01:00	
104	cdr driving again	19:28:00	19:33:00	0:05:00	trying to find opening in fence
105	ms 1 nav and avoidance	19:28:00	19:31:00	0:03:00	trying to find opening in fence
106	cdr finds opening to fence	19:29:00	19:30:00	0:01:00	
107	mcc copy's	19:30:00	19:30:00	0:00:00	
108	ms1 sci obs	19:31:00	19:32:00	0:01:00	
109	mcc copy's	19:32:00	19:32:00	0:00:00	
110	ms1 sci obs	19:32:00	19:33:00	0:01:00	
111	rover stopped	19:33:00	19:34:00	0:01:00	
112	cdr driving again	19:34:00	19:35:00	0:01:00	
113	ms 1 nav and avoidance	19:34:00	19:35:00	0:01:00	
114	mcc want high gear and swap drivers	19:35:00	19:35:00	0:00:00	
115	crew copy's	19:35:00	19:36:00	0:01:00	
116	changing drivers ms1, high gear, default mode	19:36:00	19:37:00	0:01:00	
117	ms 1 driving in default mode	19:37:00	19:41:00	0:04:00	
118	cdr nav and avoidance	19:37:00	19:41:00	0:04:00	
119	rover stopped checking out area	19:41:00	19:42:00	0:01:00	
120	ms1 driving again	19:42:00	19:43:00	0:01:00	
121	cdr nav and avoidance	19:42:00	19:43:00	0:01:00	
122	rover stopped	19:43:00	19:44:00	0:01:00	
123	mcc wants them to continue description	19:44:00	19:44:00	0:00:00	
124	ms1 driving again	19:44:00	19:57:00	0:13:00	
125	mcc wants to know if rover knows has close	19:45:00	19:46:00	0:01:00	
126	crew 200 meter north of 2 C	19:46:00	19:46:00	0:00:00	
127	cdr nav and avoidance	19:44:00	19:52:00	0:08:00	
128	cdr sci obs	19:52:00	19:52:00	0:00:00	
129	cdr nav and avoidance	19:52:00	19:54:00	0:02:00	
130	mcc close to 2a	19:54:00	19:54:00	0:00:00	
131	cdr sci obs	19:54:00	19:55:00	0:01:00	
132	cdr notes they are doing a 360 and continues sci obs	19:55:00	19:56:00	0:01:00	
133	mcc copy's	19:56:00	19:56:00	0:00:00	
134	cdr sci obs	19:57:00	19:57:00	0:00:00	
135	rover stopped	19:57:00	20:04:00	0:07:00	
136	crew prepping for eva, looking at ipads and procedures	19:57:00	20:07:00	0:10:00	
137	mcc to give eva prep procedures	19:59:00	20:00:00	0:01:00	
138	cdr copys and going to BLS unit for CTBs	19:59:00	20:02:00	0:03:00	
139	reconfig cabin	20:03:00	20:04:00	0:01:00	
140	changing for eva	20:04:00	20:07:00	0:03:00	covering cameras
141	reconfig cabin	20:07:00	20:22:00	0:15:00	
142	umbicals	20:22:00	20:24:00	0:02:00	
143	getting ready for egress	20:24:00	20:25:00	0:01:00	
144	crew egressing hatch	20:25:00	20:28:00	0:03:00	
145	eva	20:28:00	22:46:00	2:18:00	
146	mcc teleops moving rover for crew to 2b site	21:07:00	21:08:00	0:01:00	
147	mcc teleops moving rover to follow crew	21:10:00	21:13:00	0:03:00	
148	mcc driving rover to site 2b to aid crew in finding site	21:14:00	21:16:00	0:02:00	crew is following the rover
149	crew wants rover to move 180 degrees for better lighting	21:19:00	21:21:00	0:02:00	
150	crew wants rover to follow them to next site 2c	21:36:00	21:40:00	0:04:00	
151	rover moving again following crew	21:40:00	21:41:00	0:01:00	
152	mcc moving rover to 2c site	21:42:00	21:44:00	0:02:00	
153	mcc had rover rotate to assist crew with better lighting	22:00:00	22:01:00	0:01:00	
154	mcc having rover move to 2d and crew will follow	22:01:00	22:07:00	0:06:00	
155	mcc, moving rover as crew is following the rover	22:25:00	22:31:00	0:06:00	
156	mcc will move the rover to a flat area for the night	22:42:00	22:46:00	0:04:00	
157	crew ingressing vehicle	22:46:00	22:47:00	0:01:00	
158	crew is starting rover cabin reconfig	22:47:00	22:59:00	0:12:00	
159	Starboard hatch stowage reconfig	22:55:00	22:56:00	0:01:00	
160	Crew conducting PMC	23:06:00	23:16:00	0:10:00	
161	Crew standing by for DPC	23:16:00	23:23:00	0:07:00	
162	Crew beginning meal prep - picked out some bags and made drinks	23:17:00	23:20:00	0:03:00	
163	DPC begins	23:23:00	23:32:00	0:09:00	
164	Meal prep	23:36:00	23:59:00	0:23:00	
165	Surveys	23:37:00	24:52:00	1:15:00	Assuming finished at this time because covered cameras - CDR had been off and on typing on laptop while moving around cabin until then
166	Crew driving/END OF DAY	0:09:00	0:47:00	0:38:00	MS1 was the last to finish; snacked on dessert for a while

Day 01 | Day 02 | Day 03 | Day 04 | Day 05 | Day 06 | Day 07 | Day 08 | Day 09 | Day 10 | Day 11 | Day 12

Timing Data Collected on Day 04 (Day 1 of Crew 1 Tests) [items 52-151]

3.6.2.5.1 Timing Data for Overhead Tasks (cont.)

1	Task	Start	Stop	Total	Notes
152	mcc moving rover to 2c site	21:42:00	21:44:00	0:02:00	
153	mcc had rover rotate to assist crew with better lighting	22:00:00	22:01:00	0:01:00	
154	mcc having rover move to 2d and crew will follow	22:01:00	22:07:00	0:06:00	
155	mcc, moving rover as crew is following the rover	22:25:00	22:31:00	0:06:00	
156	mcc will move the rover to a flat area for the night	22:42:00	22:46:00	0:04:00	
157	crew ingressing vehicle	22:46:00	22:47:00	0:01:00	
158	crew is starting rover cabin reconfig	22:47:00	22:59:00	0:12:00	
159	Starboard hatch stowage reconfig	22:55:00	22:56:00	0:01:00	
160	Crew conducting PMC	23:06:00	23:16:00	0:10:00	
161	Crew standing by for DPC	23:16:00	23:23:00	0:07:00	
162	Crew beginning meal prep - picked out some bags and made drinks	23:17:00	23:20:00	0:03:00	
163	DPC begins	23:23:00	23:32:00	0:09:00	
164	Meal prep	23:36:00	23:59:00	0:23:00	
165	Surveys	23:37:00	24:52:00	1:15:00	Assuming finished at this time because covered cameras - CDR had been off and on typing on laptop while moving around cabin until then
166	Crew driving/END OF DAY	0:09:00	0:47:00	0:38:00	MS1 was the last to finish; snacked on dessert for a while

Day 01 | Day 02 | Day 03 | Day 04 | Day 05 | Day 06 | Day 07 | Day 08 | Day 09 | Day 10 | Day 11 | Day 12

Timing Data Collected on Day 04 (Day 1 of Crew 1 Tests) [items 152-166]

3.6.2.6 TELEOPERATION

M2MADO STRATEGIC QUESTION #6:

What operational concepts best support rover teleoperations during EVA, and who (i.e., crew-to-ground, or within the ground team) should direct rover movements when deemed necessary?

Crew Questions:

- *Rate the overall acceptability of crew commanding MCC to move the rover using the following referencing systems:*
  - *Crew leads (rover follows)*
  - *Rover leads (crew follows)*
  - *“Move rover to map grid J8”*
  - *“Move rover toward EV2 XX meters”*

3.6.2.6 Teleoperation

Teleoperation

Rate the overall acceptability of crew commanding MCC to move the rover using the following referencing systems:

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Rover leads (crew follows)

Crew leads (rover follows)

Crew leads (rover follows)

Consensus Acceptability Ratings + Comments

- **Rating: 7**
- **Comments:**
  - Without any portable navigation aids, it was very difficult for crew to determine a precise point to lead the rover.
  - Since there were no means provided for crew to navigate (detailed maps with headings or other designation), it would have been very difficult to use config of crew leading. Given the complexity of navigating on the Moon, this will likely be similar.
  - Since crew navigation capabilities are crude, it is much better for the rover to lead.
  - Rover/Crew interaction needs to be explored in more detail.
  - Even when the destination was clearly specified, it was difficult for the crew to know their own position. Since the surrounding terrain was also difficult to fully understand in the darkness, the rover leading method was very effective during night EVAs.
  - Used this and it worked well.
  - It would be cool if the crew had laser pointers and could designate a spot for the rover to navigate to, and the MCC could direct it to that spot.

Rover leads (crew follows)

Consensus Acceptability Ratings + Comments

- **Rating: 3**
- **Comments:**
  - Easier to follow teleoperated rover with navigation aids. Recommend reporting when in position and also direction rover is facing for orientation.
  - Allowed for precise/easy navigation to site, however why not also have option for crew to hop on back of rover when desired?
  - Because EV crew does not have precise Navigation, we utilized the Rover as a Navigator send it to the point and follow it to identify exact point.
  - Crews can reach their destinations without getting lost. This is a very effective means in terms of executing objectives and reducing time and crew load.
  - Used this and it worked well
  - Useful, and easy to follow, you can wonder with a large area light source that is preceding you and that lets you find cool rocks or weave back and forth behind the rover. If the rover can get there, I, on foot can definitely get there.

The teleoperation mode where crew <u>followed</u> the PR while MCC controlled it remotely was acceptable, with minor improvements desired &/or minor deficiencies
The mode where crew <u>led</u> and MCC teleoperation the PR to follow them was unacceptable, with improvements required and/or unacceptable deficiencies

Teleoperation (cont.)

Rate the overall acceptability of crew commanding MCC to move the rover using the following referencing system:

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

"Move rover to map grid J8"

Consensus Acceptability Ratings + Comments

- **Rating: 4**
- **Comments:**
  - Used to teleoperate rover to a predetermined point. Recommend reporting when in position, and direction rover is facing for orientation.
  - Acceptable.
  - We heavily utilized this (kind of) method. Tell MCC where we want the Rover goes. While the Rover is traversing, EV crew can focus on their tasks. Easy and reliable. Unlike the Rover EV Crew does not have capability of positioning themselves, directing the Rover to the desired position needs improvement.
  - With Night EVA, it is very difficult to know where you are and where your observation station is located, and it is also difficult to determine how far you must travel. It is a very good way to have the rover move ahead of you to your destination.
  - Did not use. Instead used "move rover x deg to right/left" or "move rover to sample location x".
  - Worked Well, the rover went to places we were only guessing at and that saved us a lot of time on way-finding and wondering if we were, in fact in the right spot.

Rover analog following EVA crew via teleoperation during daytime EVA test

The teleoperation mode where crew requested MCC move the PR to a predefined location was acceptable, with only minor improvements desired and/or minor deficiencies

Teleoperation (cont.)

Rate the overall acceptability of crew commanding MCC to move the rover using the following referencing systems:

"Move rover toward EV2 XX meters"

Consensus Acceptability Ratings + Comments

- **Rating:** Not all crew were able to perform this test, so no consensus was reached
- **Comments:**
  - Used orientation (not distance), no issues.
  - Acceptable.
  - We didn't practice this method, but GCA seems the safest way to tele operate the Rover. Down-side of this method is it takes long time and eats up EVA time. Terrain can be difficult/dangerous for Rover while EV crew can traverse relatively easy.
  - The crew finds it very difficult to coordinate with the rover because it is difficult to see the surroundings and the crew has difficulty moving. It is better to move the rover first and let the crew move.
  - Did not use. Instead used "move rover x deg to right/left" or "move rover to sample location x".
  - Worked well, just had to wait for the timing, but the chain of communication was clear, and it was hugely helpful to have the rover move.

"Move rover South XX meters"

Consensus Acceptability Ratings + Comments

- **Rating:** Did not exercise this mode in D-RATS 22
- **Comments: NA**

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

No Consensus Reached

EVA Crew following teleoperated rover analog during night EVA test

The teleoperation mode where crew requested MCC move the PR X-meters towards or away from EV1 or EV2 or X-meters in a particular heading was not exercised by all crew in D-RATS 2022, so no consensus was reached

3.6.2.7 Crab Driving Modes

M2MADO Strategic Question #7:

How Important is the ability to "crab" the rover while driving, and what crab wheel angles are needed?

Test and gather inputs for both "drive-by-windows" and "drive-by-camera" modes

3.6.2.7.1 Rover Crab in Drive-by-Windows Mode

Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement	
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.	
1	2	3	4	5	6	7	8	9	10

Crab 360

Provide capability assessment ratings and comments on the ability to crab up to 18 degrees when driving in "Drive-by-Windows" mode.

Consensus Assessment Ratings + Comments

- **Rating:** No consensus reached for 18-degree-maximum crab mode. Opinions differed among crew. Some found this to be sufficient while others did not. Of importance, Not all ConOps for which this capability might be most useful were evaluated during DRATS22 (e.g., circumnavigating a target of interest, docking/berthing to support logistics transfer, etc.).
- **Comments:**
  - Requires a larger radius but is doable.
  - This could be useful when we are driving a vast field, while in fields with lots of obstacles it may be better to have much higher degree of crab angle to efficiently avoid obstacles with minimum traverse.
  - The crab limitation of 18 degrees is cumbersome/slow when making large turns (> 90 degrees).
  - When in 18-degree-maximum crab mode, we drove it just like a car. Never needed 18-degree crabbing mode.
  - I used it to move around a rock, but I need windows to be more effective at it as 18 deg reduces your effective radius to dodge an obstacle.
  - For reference:
    - < 40 deg = car turning radius
    - 18 deg results in a ~10m turn radius
  - We anticipate needing significantly less than 10m turning radius, but TBD exactly on how much without more testing and knowledge of the terrain - 18 deg is probably too little.

Provide capability assessment ratings and comments on the ability to crab up to 360 degrees when driving in "Drive-by-Windows" mode.

Consensus Assessment Ratings + Comments

- **Rating: 4**
- **Comments:**
  - This crew did not use crab 360.
  - This capability was very useful, especially for rover traverses in a narrow area where it cannot make a large turn or move backwards, and for avoiding obstacles with minimum traverse.
  - This enhanced crab ability is highly desirable to drive efficiently, especially in unknown terrain in which directional changes/surveys will be necessary.
  - Useful for narrow area for turn. Also useful for scientific observation from inside the rover. Easier to maneuver the vehicle in 360-degree crab mode compared to 18-degree-maximum crab mode.
  - Really important for getting out of a tight spot - need to be prepared for any terrain because we won't be sure of what's there.
  - Better to have 360-degree crab, but not essential - if you can get into a spot, you should be able to back out of it.
  - Also important for ground to be able to have this when crew is EVA - yaw for lighting is helpful, including when ground doesn't have full situational awareness.

The ability to crab up to 360 degrees when driving in drive-by-windows mode was found likely to significantly enhance one or more aspects of a mission
No consensus was reached when driving in drive-by-windows mode for the driving mode that limited crabbing to a maximum of 18 degrees

3.6.2.7.2 Rover Crab in Drive-by-Camera Mode (Cameras + Interior Displays)

Provide capability assessment ratings and comments on the ability to crab up to 18 degrees when driving in "Drive-by-Camera" mode.

Consensus Assessment Ratings + Comments

- **Rating:** No consensus reached. Opinions differed among crew. Some found this to be sufficient while others did not. Of importance, not all ConOps for which this capability might be most useful were evaluated during DRATS22 (e.g., circumnavigating a target of interest, docking/berthing to support logistics transfer, etc.)
- **Comments:**
  - Did not use when needed, but only to experience [the mode].
  - In some terrains, 18 degree is not enough to make a sharp turn and avoid obstacles with minimum effort.
  - 18-deg-maximum crab is adequate but requires a sizable turning radius and is not very practical when stopped and trying to do an IVA survey.
  - The crab limitation of 18 degrees is cumbersome/slow when making large turns (> 90 degrees)
  - In 18-degree-maximum crab mode, I always drove it like a car and didn't use crabbing at all. Would it be useful for docking to the Lander in 18-degree-maximum crab mode? Need to test.
  - When driving with 18-degree-maximum crab mode, crab mode may not be useful, since driver expects the turning characteristic to be similar to that of regular cars. This function could be useable but seems not mandatory.
  - The car mode did not lend itself to crabbing - would be nice, but it was not really used. With the cameras, you would only crab if you came up to the edge of something and wanted to continue without going backwards

When driving in drive-by-camera mode, opinions differed among crew; and no consensus was reached for either the 18-degree-maximum crab mode or the 360-degree crab mode

Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement	
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.	
1	2	3	4	5	6	7	8	9	10

No Consensus Reached

Provide capability assessment ratings and comments on the ability to crab up to 360 degrees when driving in "Drive-by-Camera" mode.

Consensus Assessment Ratings + Comments

- **Rating:** No consensus reached. Opinions differed among crew. Some found this to be significantly mission enhancing while others did not find it practical due to FOV or useful in general. Of importance, not all ConOps under which this capability might be most useful were not evaluated during DRATS22 (e.g., circumnavigating a target of interest, docking/berthing to support logistics transfer, etc.)
- **Comments:**
  - Not possible due to inadequate/insufficient [camera] side views.
  - Very useful function which can be used in many situations, such as obstacle avoidance.
  - 360 deg crab capability is very useful!
  - This enhanced crab ability is highly desirable to drive efficiently, especially in unknown terrain in which directional changes/surveys will be necessary.
  - Crabbing is very useful at rough terrain or supporting EVA.
  - This mode was neither used frequently nor necessarily required in straight, long-distance drive.
  - Sure, this is super useful, but if you can't see left or right, you are asking for trouble, the best thing this mode gives you is the ability to turn around and go back along a known path, forwards.
  - More important to pivot/spin in place when you're unsure about the slopes you're on/next to.
  - Would not use crab (i.e., moving straight sideways) unless you can see out to the side via cameras or windows.

3.6.2.8 Sample Management

M2MADO Strategic Question 8:

How are EVA tools and samples managed and stored outside and inside of a PR?

DRATS-22-Specific Sub-question Related to Strategic Question #4:

How are EVA tools and samples managed and stored outside of a PR?

Crew Questions:

- *Rate the overall acceptability of the tool stowage and management system. Consider tool location, ease of access to tools, tool stowage mechanisms.*
- *Rate the overall acceptability of the sample stowage and management system. Consider location, ease of access, stowage system, and management.*
- *Provide capability assessment ratings and comments on an external work surface on the rover for EVA tools and sample management*

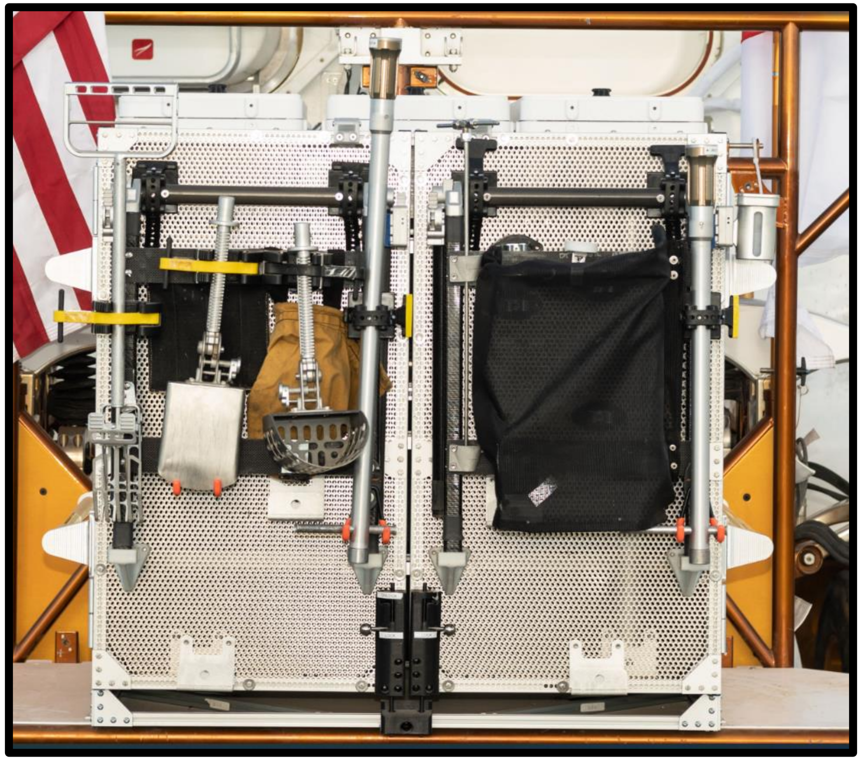
3.6.2.8.1 EVA Tools Stowage & Management System

Rate the overall acceptability of the tool stowage and management system. Consider tool location, ease of access to tools, tool stowage mechanisms.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Consensus Acceptability Ratings + Comments

- **Rating: 4**
- **Comments:**
  - Need to evaluate with actual space suit.
  - Generally, tools are easy to use.
  - It was difficult to avoid touching the collection surfaces of the tools when removing/stowing tool easel due to the location and layout. Recommend design improvement. Bottom locking mechanism also broke during mission, likely in need of improvement.
  - Toolbox seemed large for what it needs to accommodate. Perhaps for an entire 14+ day mission that size is merited. We didn't use the easels on EVA 1 as it was easy to just get the tools we needed off the back of the rover at each stop. It is difficult to guarantee you don't touch the bottom (sample interaction end) of the tools with the current design.
  - Easel was heavy to carry and difficult to handle. The “no touch area” is not well protected, and possibility of unintentional contamination is high.
  - Tools installed on the storage door are very easy to remove, including the easel. There is room for improvement in the orientation of the band that holds the easel in place.
  - The current tool stowage solution would not meet EVA compatibility requirements; however, the tool designs and stowage solutions are sound conceptually and were a good simulation/mockup for us to use for this test series. One consideration is to utilize additional workstation attachments rather than the leg holsters as the holsters are cumbersome to use when traversing long distances. The tool carrier volume is appropriate but needs to be designed more efficiently. Having the portable light attached to the easel benefits worksite tasks, so that's a good addition.
  - Given that we didn’t use a donnable suit, the main issues were carrying the easel and issues with the secure placement of the holsters and hip mounts. Tool stowage worked well, and tools were fairly easy to access without interfering with one another. The easels worked really well with the tool cabinet mounted to the rear of the rover, which in turn was a great place for short- and long-term stowage. Less reliance on attaching anything to the legs in a bulky suit will be better since anticipate a lot of walking on lunar surface - prefer nothing on the legs
  - Tool cart to pull tools? How to interface with PR?
  - Holsters + easel not comfortable in combination
  - If rover is close and terrain allows, just leave tools on the rover and walk back and forth?
  - Toolbelt/mini workstation?
  - More testing required for tool management and stowage.
  - Lots of terrain dependencies for what you can use. Different options will be needed (e.g., cart may work well in some terrain but not others).



Tool stowage and management system

The tool stowage/management system provided for this analog was found acceptable with only minor improvements desired and/or minor deficiencies

3.6.2.8.2 EVA Stowage & Management (cont.)

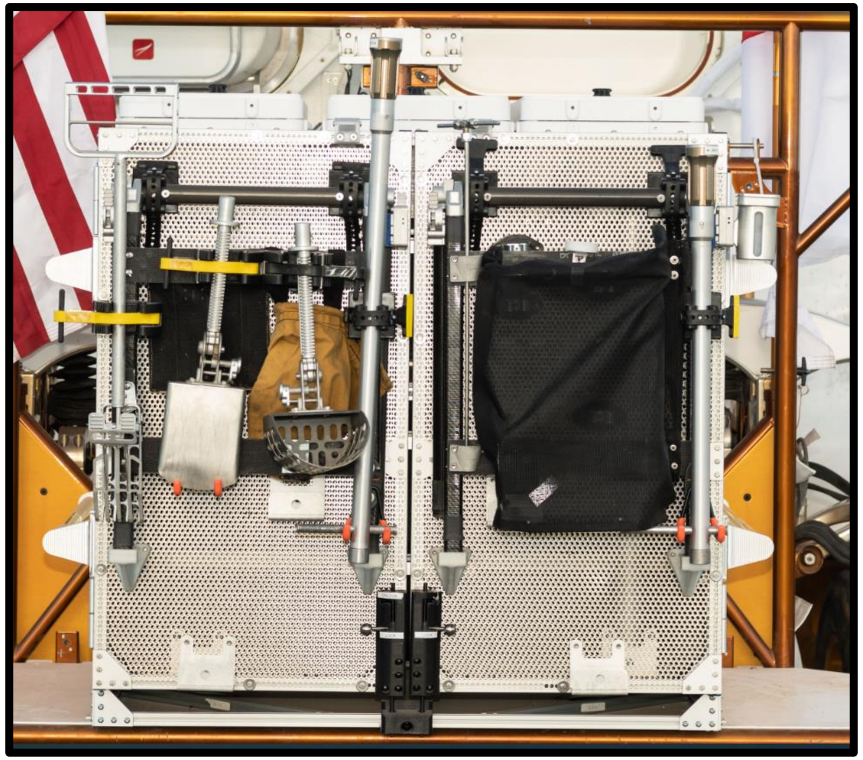
Rate the overall acceptability of the sample stowage and management system. Consider location, ease of access, stowage system, and management.

Consensus Acceptability Ratings + Comments

- **Rating:** No consensus reached.
- **Comments:**
  - Need to evaluate with actual spacesuit.
  - No problems identified during use.
  - Acceptable
  - Putting samples into a tray is easy but do we need to organize precious samples? How to return these samples (transfer them to the lander then the spacecraft)? We need to think about more detailed scenario. But in general, I think more care is needed to protect and organize important samples.
  - Because the door is designed to be a double-slide door, the EVA backpacks interfere when two crew members approach. We felt that improvements were needed, such as dividing the toolbox into two or avoiding this problem by operation. Also, the latch of the inner drawer is on the left side, which makes it difficult for a right-handed crew member to open the drawer with the left hand while pulling the latch with the right hand.
  - The sample stowage attached onto the crew workstations work well, however the sample stowage in the tool cabinet warrants more efficient design for stowing the samples.
  - The lettering and reflectivity of the pigment was great, the bags were great, the only issue I had was with the real-estate the sample bags took up. They were very square, instead of conforming to the sharp curve of the hip, they just stick out into your arm swing space, and if you are carrying something, they end up interfering.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

No Consensus Reached



Tools used for collecting and stowing samples

3.6.2.8.3 EVA External Work Surface

Provide capability assessment ratings and comments on an external work surface on the rover for EVA tools and sample management

Consensus Assessment Ratings + Comments

- **Rating:** External work surface not used enough to provide numerical rating, only some comments below.
- **Comments:**
  - Suggest assessment with real spacesuit design.
  - No problem identified.
  - Mission essential/enabling
  - No chance to use external work surface. SCICOM/ CAPCOM did not give us tasks where the external work surface was needed. If we do end up with tasks like that, it may improve EVA efficiency.
  - The tools are concentrated in one place and very easy to use. There is a little room for improvement in the direction of the band that holds the easel in place. There is room for improvement in the opening and closing of the door and the drawer of the sample tool. (Hardware, Operation).
  - Would be useful for displaying (many) samples to scientists or for potential assembly/disassembly of EVA hardware.
  - While only used once, it was good to be able to place things on and take stock. Also, if there are payloads that need to be EVA configured or maintenance, having a work surface that is off the surface at a good height, will go a long way to enable efficient and useful work.
  - Potentially significantly enhancing even though we didn't use in DRATS-22. It might be critical for weighing samples where a large surface is needed; EVA reconfigure of science payloads (e.g., set up of science instruments prior to deployment) and EVA maintenance (neither of which were simulated in DRATS-22). more testing needed to answer definitively.

Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement	
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.	
1	2	3	4	5	6	7	8	9	10

No Consensus Reached

Crew utilizing external work surface on analog PR during night EVA

3.6.2.9 Flight Rules

M2MADO Strategic Question 9:

What flight rules are needed to safely operate the rover during traversing and EVA?

3.6.2.9 Flight Rules

- A set of flight rules were developed for D-RATS-22 based on past experience and tests
- The efficacy of these flight rules was assessed through the collection of objective performance data and subjective feedback from the crew and MCC personnel
- The results will serve as the starting point from which future versions are iterated and improved upon

DRATS-22 Flight Rules	Recommended modifications to future DRATS Flight Rules from MCC ops & science perspectives
1. MISSION PRIORITIES	
a. Evaluate driving and science inspections in "cameras" and "windows" configs	Develop a "trickle-down" plan in case we lose any priorities
b. Exercise driving and science inspections in both crab modes	
c. Conduct 2 EVAs w/ MCC support (night not required)	
d. Perform 1 EVA/inspection with Capcom lead, and another with Scicom lead	
e. Conduct one overnight stay	
2. COMMUNICATION	
a. In the event of unexpected loss of comm between EV1 and EV2 for more than 5 minutes, EV crew will co-locate to ensure good communications, until RF comm returns.	
b. In the event of an anticipated loss of comm (e.g., going behind a known obstacle), the crew shall regain comm with MCC within 15 min (PR ops and EVA).	
c. A single crewmember can move out of sight of the PR as long as desired, provided the other crewmember maintains line-of-site and can act as a relay.	
d. If a traverse is expected to pass through LOS for more than 15 minutes, the crew and MCC will discuss the situation and expectations prior to proceeding.	
e. If voice comm is lost between EVA crew and MCC any rover teleoperations in proximity to the crew will be suspended until comm is restored.	

3.6.2.9 Flight Rules (cont.)

- The main additions to the existing flight rules that were identified during D-RATS-22 were:
  - Develop a "trickle-down" plan in case we lose any priorities
  - Do not allow crew to work down-slope of a rover (to avoid the possibility of it sliding onto them)
  - Care needs to be taken to fully consider both slope and ground conditions (e.g., loose regolith or hard rock) when either the crew or ground drives the PR down a slope for the first time, to ensure it's possible to get back out

DRATS-22 Flight Rules	Recommended modifications to future DRATS Flight Rules from MCC ops & science perspectives
3. Crew PR OPERATIONS	
a. The crew will have prime responsibility for	Care needs to be taken to fully consider both slope and ground conditions (e.g., loose regolith or hard rock) when either the crew or ground drives the PR down a slope for the first time, to ensure it's possible to get back out.
i. On the spot determination of best traverse path to achieve end goal destination	
ii. Decisions to depart from the established traverse plan to investigate unexpected or unusual features	
b. Crew is authorized to stop or refuse PR operations at any time they feel uncomfortable continuing, and resume if/when they become comfortable again	
c. Rover will only use high gear on smooth roads	
d. Rover will use low gear on any off-road drives, including where surface condition is hard to assess due to plant growth	
e. Cruise control can be used at crew discretion regardless of terrain	
f. The Rover will not be driven on slopes exceeding 20 degrees	
4. MCC PR OPERATIONS	
a. MCC Teleoperations of the PR will happen only when both crewmembers are out of the vehicle on EVA	Care needs to be taken to fully consider both slope and ground conditions (e.g., loose regolith or hard rock) when either the crew or ground drives the PR down a slope for the first time, to ensure it's possible to get back out.
b. MCC may tele-operate the rover with consent of the crew	
c. MCC will tele-operate the rover:	
i. To the extent that they have sufficient situational awareness of potential hazards via external camera views, or	
ii. As directed by the crew via ground-controlled approach verbiage	
iii. To a specific destination independent of crew involvement as desired by either MCC or the crew	
d. MCC will maintain a minimum of 15m distance from the crew unless positive voice comm is established and the crew is giving guidance to proceed closer	

3.6.2.9 Flight Rules (cont.)

DRATS-22 Flight Rules	Recommended modifications to future DRATS Flight Rules from MCC ops & science perspectives
5. PR CONFIGURATION FOR EVA	
a. PR shall be in the "Power Disabled" and "Command OFF" mode prior to egress.	
6. EVA	
a. When both crewmembers intentionally move out of sight of the PR, they will discuss their plans first with MCC.	Do not allow crew to work down-slope of a rover (to avoid the possibility of it sliding onto them)
b. Crew distance from PR shall not exceed 2km	
c. EV crew distance from one another will not exceed 100 meters, not be greater than 5 minutes apart, and not exceed the field of view of the “sun”	
d. The crew will have prime responsibility for:	
i. Selection of a suitable location for performing EVA communications test.	
ii. Selection of samples to be collected	
iii. Decisions to depart from the operational EVA plan to investigate unexpected or unusual features.	
iv. On the spot determination of best traverse path to provide mobility ease.	
v. On the spot determination of accessibility of features of interest.	
vi. Selection of appropriate places for surface closeup or context camera photography.	

3.6.2.10 SciCom

Strategic Question #10:

What are the advantages and limitations of switching between a SCICOM and a CAPCOM, depending on the ops?

3.6.2.10 SCICOM Advantages and Limitations

Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement	
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.	
1	2	3	4	5	6	7	8	9	10

Provide CA ratings and comments on advantages and limitations of SCICOM

Consensus Assessment Ratings + Comments

- **Rating:** Split perspective: some crew rated this mission critical (1-2) others rated it significantly mission enhancing (3-4)
- **Comments:**
  - Expert instruction will enhance scientific operation - need to control for overall mission.
  - It is important to have dedicated science specialist to navigate crew to adequately carry out the mission.
  - Mission essential/enabling.
  - Moderately enhancing - more test data is needed to determine if communication with SCICOM is better than communication through a traditional CAPCOM.
  - Just like Ground IV and CAPCOM works together during EVA, SCICOM and CAPCOM working together would help the Crew. We had both communicators on Day2 EVA. While SCICOM talks geology, CAPCOM informed us of EVA time, took care of Rover Ops and managed overall timeline change. I personally felt CAPCOM took care of everything while I was focusing on geology. Offloading burden for me.
  - Good in that the coordinates of the destination during exploration are often not a specific location but the surrounding area, so the science objective can be achieved based on comments from the crew, which is efficient in that the crew can be guided, and therefore easy to carry out the exploration. Good in that the objective of exploration is not to just reach the exploration site.
  - Mission essential/enabling.
  - Would not go out into the field without them [SCICOM]
  - As long as you get the information when it is needed, SCICOM or CAPCOM makes no difference. When going into detailed science, probably more helpful to go thru SCICOM unless CAPCOM is very knowledgeable on science. Need SCICOM to be equally trained in communications (training limitation for DRATS-22).
  - Just focusing on science with SCICOM was helpful.
  - Need to preserve CAPCOM for all ops-related comm (including contingencies).
  - SCICOM was significantly enhancing for benefit of science.

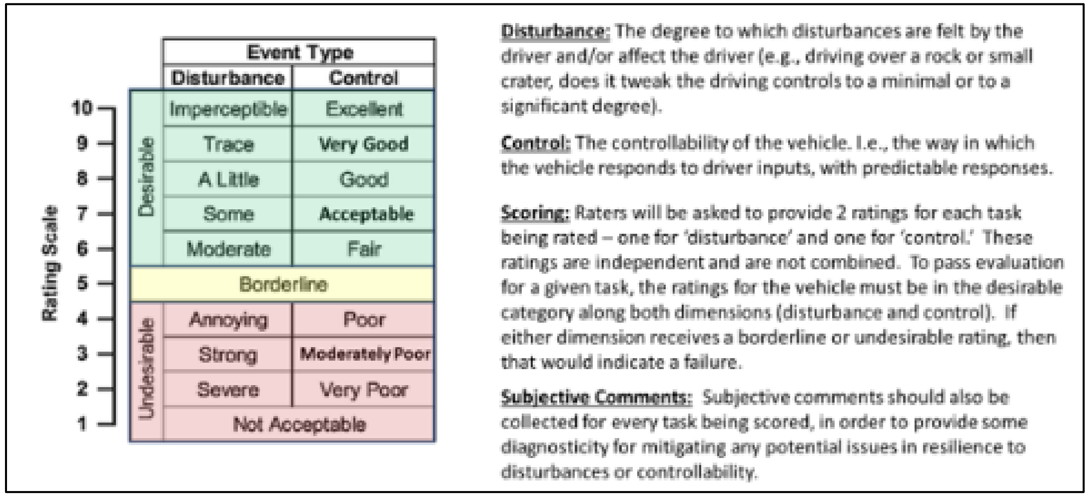
Analog MCC personnel playing the roles of CAPCOM and SCICOM

Personnel in the remote analog MCC in Houston played the roles of CAPCOM or SCICOM, switching depending on the ops to provide crews the opportunity to assess pros/cons, and the crew found this capability to be from significantly enhancing to essential/enabling

3.6.2.11 HANDLING QUALITIES & WORKLOAD

3.6.2.11 Handling Qualities & Workload

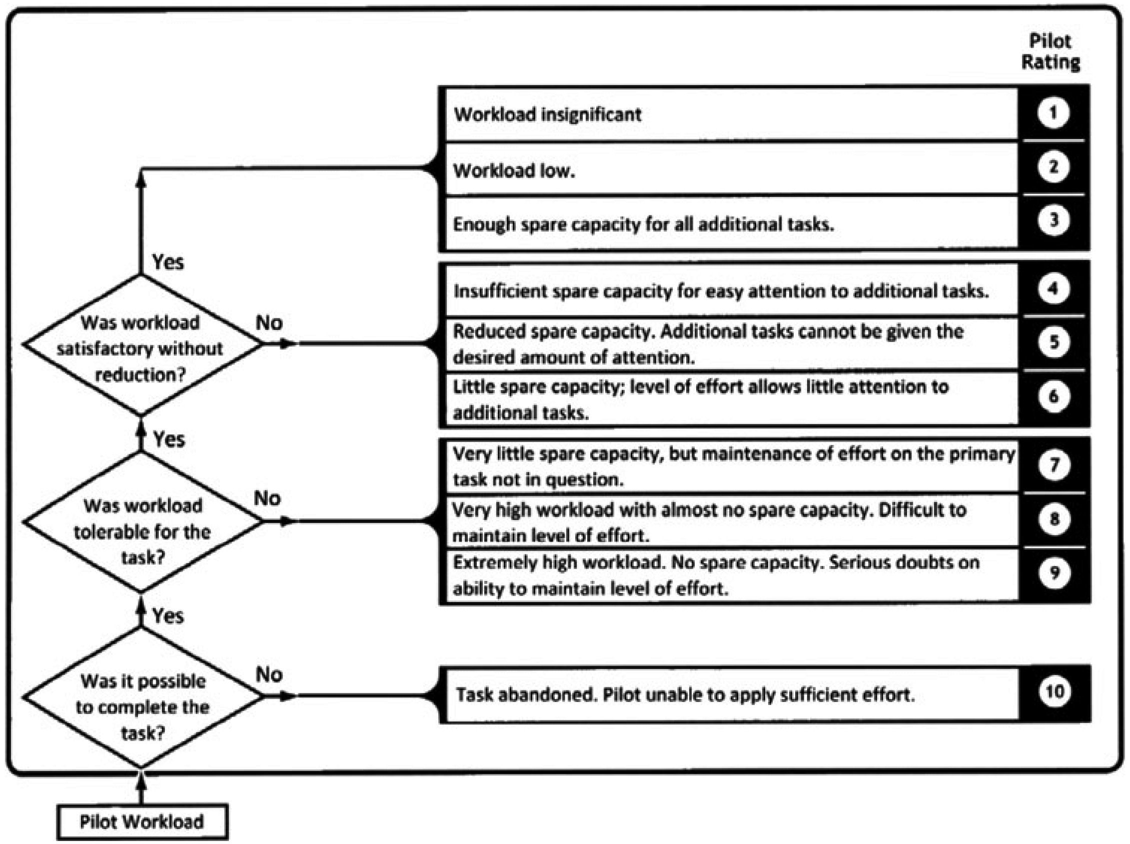
- During the DRATS FY22 field trials, investigators conducted a preliminary handling qualities and workload test of the GEN 1B Pressurized Rover (PR) and collected data on the two different window/driving configurations
- With the rover being essentially an off-road vehicle, human factors engineers decided to use the Society of Automotive Engineering (SAE)1441 Subjective Rating Scale for Vehicle Ride and Handling, which the LTV/PR program chose to use as well stating, *"The system shall exhibit desirable vehicle ride and handling performance, as defined by the SAE 1441 Subjective Scale for Vehicle Ride and Handling. Desirable ratings of 6 to 10 are required for both 'Disturbance' and 'Control' dimensions for driving related tasks"*
  - SAE1441 is a subjective rating scale for evaluating vehicle ride and handling
  - The scale is applicable for the evaluation of specific vehicle ride and handling properties, for specified maneuvers, road characteristics and driving conditions, on proving ground and public roads [3]
  - The validity of the evaluation is restricted to individual ride and handling disciplines defined by the maneuver(s) and to the combination of vehicle conditions (e.g., equipment) and of the environment (e.g., road, weather) [3]
  - SAE1441 provides investigators a means to assign a numerical value to subjective judgments about the vehicle's ride and handling performance (figure below)
- Test subjects were asked to provide two ratings for each driving task being evaluated, one for '**disturbance**' and one for '**control**.' These ratings are independent and are not combined
  - Disturbance Rating is an assessment of the degree to which instabilities are felt by the driver and/or affect the driver during a driving task (e.g., for example, if the driver drives over a rock or small crater, does this action tweak the driving controls to a minimal or to a significant degree?)
  - The rating of 'Control' is an assessment of the controllability of the vehicle during a driving task, i.e., the way in which the vehicle responds to driver inputs (e.g., with predictable vs unpredictable responses)
- To pass the evaluation for a given task, the ratings for the vehicle must be in the desirable category (6-10) along both dimensions (disturbance and control)
- If either dimension receives a borderline or undesirable rating, then that would indicate a failure for that task [3]



SAE1411: Subjective Rating Scale for Vehicle Ride and Handling

3.6.2.11 Handling Qualities & Workload

- Workload is defined as the integrated mental and physical effort (i.e., spare capacity) required to satisfy the perceived demands of the specific task (figure below)
- The concept of "spare capacity" refers to arousal, time, and fatigue of accomplishing a task [4] [5]
- Measurement of workload enables a standardized assessment of whether temporal, spatial, cognitive, and perceptual aspects of tasks and the crew interfaces for these tasks are designed and implemented to support each other
- The Bedford scale is appropriate for assessing workload as it provides anchors for every rating, is familiar to the crew population, and provides a decision gate in which ratings above this gate are indicative of workload that is not satisfactory without a reduction in spare capacity
- When using the Bedford scale, each subject must be briefed as to the task they are rating, the period over which to make the rating, and the other tasks for which they need to judge their spare capacity
- These items need to be consistent across subjects for each task
- The Bedford scale is not linear, and the underlying distribution is not predicted to be normal, thus calculation of a mean and median or the uses of parametric statistics are not appropriate
- This verification requires that every subject's raw score is a 1, 2, 3, 4, 5, or 6 on the Bedford scale
- The Bedford scale allows for half ratings (e.g., 1.5), which is also allowed here, if the rating is below a 6 (a rating of 6.5 or higher is not acceptable for verification of a workload requirement)



Bedford workload rating scale

3.6.2.11.1 Baseline Handling Qualities Test

To assist subjects in understanding how to use this SAE1441 scale, the test team conducted a simple baseline test before each crew mission

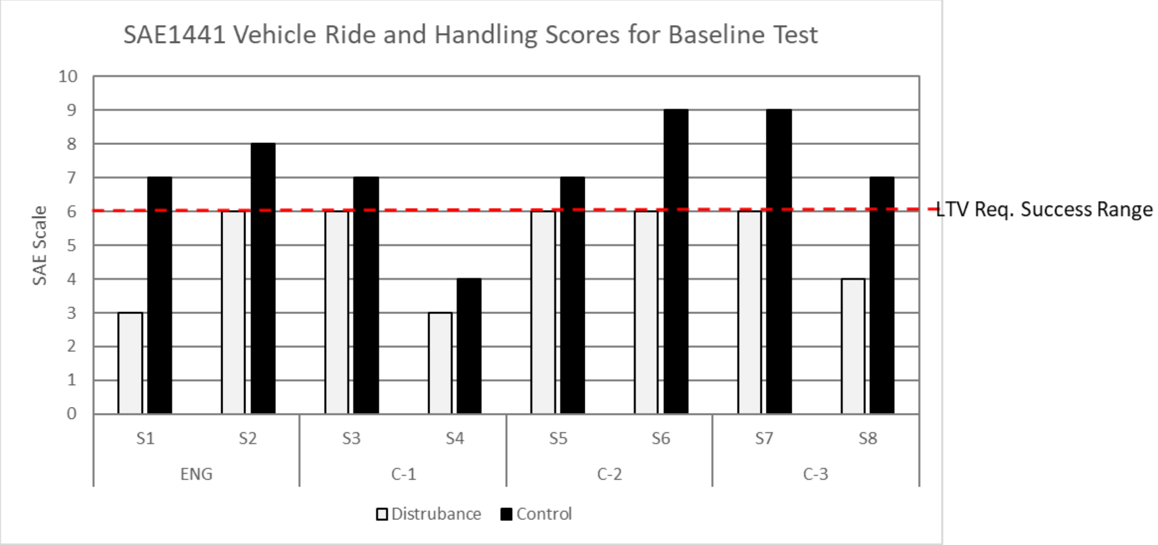
- **Baseline Handling Qualities Test**
  - Using a pair of Toyota Tacoma 4x4 pickup trucks (figure upper right) with a 125-meter straight line course down an approximate 12-degree slope, the subjects were asked to put the vehicles into 4-wheel low and proceed out the rocky slope with medium to large rocks, at approximately 8 km (5 mph) (figure lower right)
  - Investigators told the subjects to take note of the driving control response of the vehicle and how that affected their ability to drive
  - When the subjects made it to the bottom of the predetermined slope, they were told to turn the truck around on a section of flat terrain and proceed back up the same 12-degree slope
  - The test took approximately 15 minutes for subjects to finish
  - With the course completed, the subjects were asked to score the driving performance of the trucks based on the SAE1441 scale
  - This gave the subjects a chance to use the scale in a real-world environment before entering their mission and to ask any questions of the test team on the use of the scale

Toyota Tacoma 4x4 pickups used for the baseline test

Toyota Tacoma 4x4 pickups used for the baseline test

3.6.2.11.1 Baseline Handling Qualities Test (cont)

- Eight test subjects accomplished baseline testing (figure and table at right)
- Out of the eight subjects, five of those individuals rated the disturbance as 6 or moderate, while two subjects rated the disturbance as 3 or and one as 4 or annoying
- For the control scores, four out of eight subjects rated their handling performance as 7 or acceptable, while two rated it as 9 or very good and one as 4 or poor
- Using the criteria from the LTV requirement where success is 80% of the ratings collected are in the desirable range for both dimensions, baseline results indicated five subjects had ratings in the desirable range, while three failed the vehicle's handling performance, showing only a 63% success with the handling performance for these vehicles on this specific test course
- For disturbance experienced by the subjects, they could definitely feel the steering wheel go all over the place when running over rocks and ruts of the slope
- Subjects noted that speed and direction was key to assisting in minimizing turning
- One subject stated about the disturbance: "*It was not plush, but I was happy with* [the vehicle's handling performance]"
- Some subjects mentioned the rocks affected control as well, while other indicated the steering control was respectable



Individual baseline handling performance scores

Team	Subject	Disturbance		Control		SAE Pass/Fail
		Adjectives	Score	Adjectives	Score	
ENG	S1	strong	3	acceptable	7	Fail
	S2	moderate	6	good	8	Pass
C-1	S3	moderate	6	acceptable	7	Pass
	S4	strong	3	poor	4	Fail
C-2	S5	moderate	6	acceptable	7	Pass
	S6	moderate	6	very good	9	Pass
C-3	S7	moderate	6	very good	9	Pass
	S8	annoying	4	acceptable	7	Fail

Individual SAE Handling Performance Scores from Baseline Testing

3.6.2.11.2 GEN 1B Testing

For the GEN 1B rover missions, subjects were given two window configurations and two crabbing modes to score for handling performance

- <u>**Driving Configurations**</u>
  - **Drive-by-Camera**
    The first driving configuration was the drive-by-camera concept where the windows were covered, and crewmembers drove by camera views displayed on interior monitors (figure top right)
  - **Drive-by-Windows**
    The second window configuration was drive-by-windows, where the existing GEN 1B windows were exposed and crewmembers drove by looking through the physical windows (figure bottom right)

Windowless drive-by-camera configuration

Drive-by-Windows configuration

3.6.2.11.2 GEN 1B Testing (cont.)

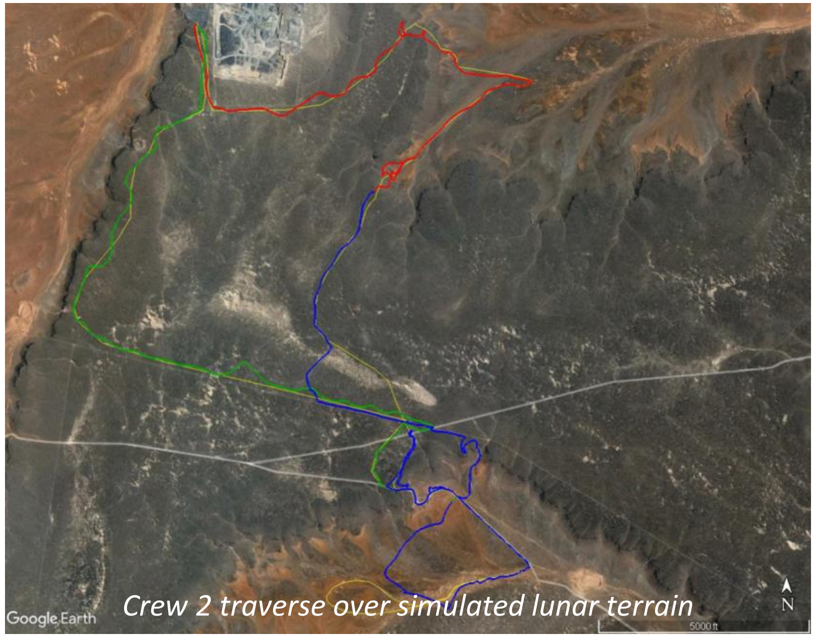
- **GEN 1B Crabbing Modes**
  Within each window configuration, the subjects had two crabbing modes, where all six wheels on the vehicle could be rotated to a desired angle for sideways driving or "crabbing", so named because it resembles the sideways movement of crabs
  - **360-Degree-Maximum Crab Mode**
    For this test, the default mode was the original crabbing mode of the vehicle where the wheels could rotate at any angle desired by the driver, up to 360 degrees (a photo of the rover being teleoperated with a 45-degree crab angle is shown at the right)
  - **18-Degree-Maximum Crab Mode**
    The second mode was a crabbing mode requested by JAXA, where the wheels were limited to a maximum crab driving angle of 18 degrees

Analog PR driving at a 45-degree crab angle during teleoperation

3.6.2.11.2 GEN 1B Testing (cont.)

- **Overall Driving Conditions and Data**
  - The terrain the subjects experienced was rocky and rough, with slopes varying from flat to 20-degrees (figure top right)
  - Each mission took 2.5 days over this simulate lunar terrain with long durations of driving (figure lower left)
  - The table at bottom right has vehicle and task stats for distance traveled, average speed, power used, and driving time for each team

Rover analog testbed climbing ~20-degree, rocky hill



Crew 2 traverse over simulated lunar terrain

Vehicle and Task Stats for Distance, Average Speed, Power and Time

Team	Total Distance Traveled (in km)	Average Speed (in kph)		Power Used (in Kilowatt Hours)	Driving Time (hh:mm:ss)		Notes
		Windowless	Windows		Windowless	Windows	
ENG	15.38	2.13	2.61	47.28	2:44:00	2:33:00	
Crew 1	11.41	1.13	1.52	30.29	5:51:00	2:16:00	Crew lost half a day due to weather
Crew 2	22.39	3.11	2.37	57.57	6:17:00	1:06:00	
Crew 3	19.03	2.1	1.4	38.5	3:51:00	1:25:00	Crew lost half a day due to illness

3.6.2.11.3 Handling Qualities & Workload in Drive-by-Camera Configuration

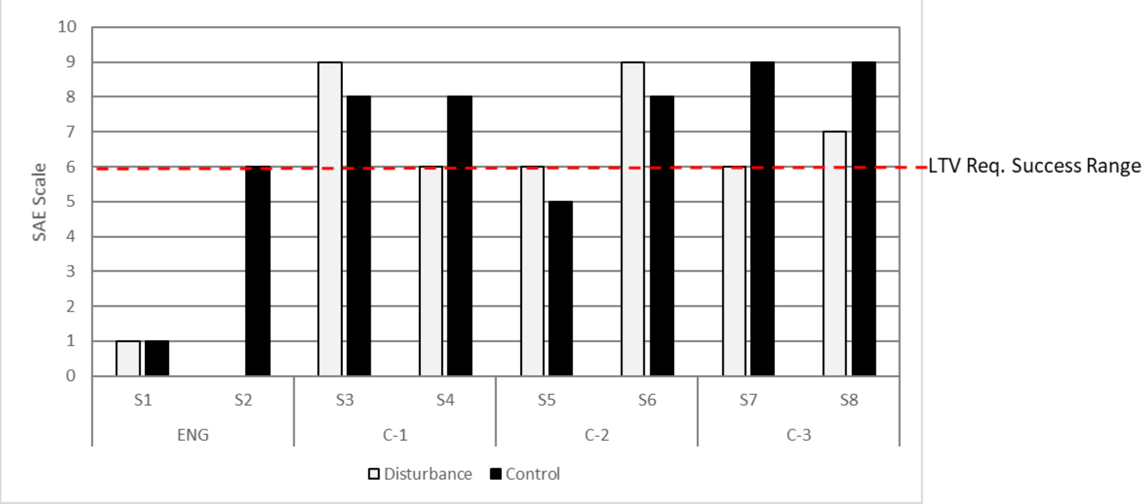
This section presents the data and results of the Drive-by-Camera tests for all crews

Drive-by-Camera Configuration

- The windowless, drive-by-camera configuration consisted of two dedicated driving cameras at the front of the vehicle and six external rover cameras located around the vehicle with four 69 cm (27 inch) 4k high-definition monitors for the crew to use (see section 3.4.8 for locations)
- The figure on the right shows test crew driving at night with the windows covered and driving displays installed in the drive-by-camera test configuration
  - Note, the dual blue-green colored perspective lines overlaid on the driving screens represent the innermost and outermost edges of the dual wheels on each side of the analog rover
- The SAE1441 vehicle ride & handling performance scores for driving in drive-by-camera mode for the 360-degree-maximum crab mode and max 18-degree-maximum crab mode tests are shown on the next slide
  - Note: due to missing data for the engineering team dry runs, in addition to having outlier data, only data from the six crewmembers was used for the analyses (however, the engineering crew data was retained for completeness)

Crew driving in the tested Drive-by-Windows configuration

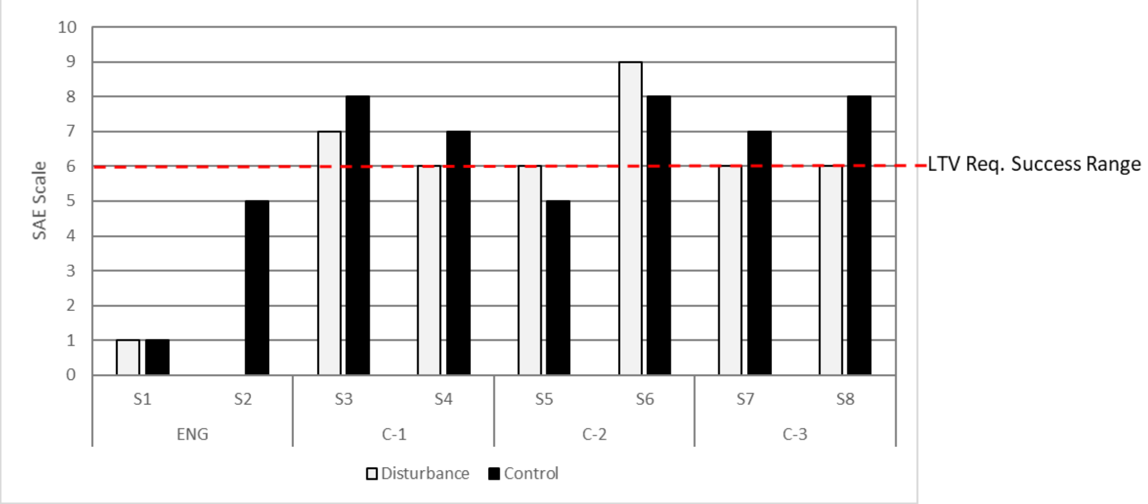
3.6.2.11.3 Handling Qualities & Workload in Drive-by-Camera Configuration



SAE1441 vehicle ride & handling performance scores for driving in drive-by-camera mode with the 360-degree-max crab mode enabled

Individual SAE Handling Performance Scores for Drive-by-Camera Configuration in 360-degree-max Crab Mode

Team	Subject	Default Mode				SAE Pass/Fail
		Disturbance		Control		
		Adjectives	Score	Adjectives	Score	
ENG	S1	Not Acceptable	1	Not Acceptable	1	Fail
	S2	No Data	0	Fair	6	Fail
C-1	S3	Trace	9	Good	8	Pass
	S4	Moderate	6	Good	8	Pass
C-2	S5	Moderate	6	Borderline	5	Fail
	S6	Trace	9	Good	8	Pass
C-3	S7	Moderate	6	Very Good	9	Pass
	8	Some	7	Very Good	9	Pass



SAE1441 vehicle ride & handling performance scores for driving in drive-by-camera mode with 18-degree-max crab mode enabled

Individual SAE Handling Performance Scores for Drive-by-Camera Configuration in 18-degree-max Crab Mode

Team	Subject	JAXA Mode				SAE Pass/Fail
		Disturbance		Control		
		Adjectives	Score	Adjectives	Score	
ENG	S1	Not Acceptable	1	Not Acceptable	1	Fail
	S2	No Data	0	Borderline	5	Fail
C-1	S3	Some	7	Good	8	Pass
	S4	Moderate	6	Acceptable	7	Pass
C-2	S5	Moderate	6	Borderline	5	Fail
	S6	Trace	9	Good	8	Pass
C-3	S7	Moderate	6	Acceptable	7	Pass
	S8	Moderate	6	Good	8	Pass

3.6.2.11.3 Handling Qualities & Workload in Drive-by-Camera Configuration

Assessment of Drive-by-Camera Configuration

- In default mode (360-degree-max crab angle), the subjects noticed the vehicle handling stability may be compromised due to variable forward input originating from the surface roughness; however, careful driving through rough terrain (i.e., bumps and dips) caused only minimal disturbance
- These observations in disturbance also held true for 18-degree-max crab mode
- Regardless of crabbing mode, subjects indicated while on flat terrain the controllability of the vehicle was good with quick respond from the vehicle
- In high-speed driving, the vehicle handling performance could be unstable at times as the rear wheels are controlled at the same time as the front wheels
- This caused some limitations in control and made turning a bit difficult with a joystick controller
- The subjects indicated that in 18-degree-maximum crab mode, the control was a bit more jerky and less desirable with the limited crab angle
- However, cruise control was deemed very effective and impressed the subjects by the responsive controllability while in that mode
- Also observed by the subjects was the fact that even though there were multiple camera views in the vehicle, it was inadequate to cover all required field-of-view (FOV) areas in terms of view angles and camera resolution
- Nevertheless, by requirement given for success, only 63% of subjects agreed their handling performance of the vehicle was desirable for this configuration
- As an observational note, it was perceived by the subjects the speed of the vehicle on the display screens through the camera views seemed higher than the actual speed
- The design of a system has a significant impact on crew workload and productivity
- Integration of the human into the system is a fundamental tenet of human-rating
- Understanding how the system design affects crew workload is part of the integration process.
- Additionally, if the resultant workload during a mission is too high, crew fatigue can affect safety
- In conjunction with the vehicle handling qualities, a workload rating was also collected
- Only one subject indicted they had enough spare capacity in this configuration to do all the additional tasks required, while two indicated insufficient spare capacity for easy attention to additional tasks, three indicated reduced space capacity, one indicated little spare capacity and one subject indicated very little spare capacity but was able to maintain a level of effort on the primary task
- Crab mode did not seem to play a role in the workload scores according to subject comments; however, the windowless configuration played a significant role
- Subjects indicated it was difficult to manage interpretations of situational awareness from multiple displays and required the driver to change views and zoom the cameras in/ out which could not be performed by one person while driving
- Swapping between two computers to update the GPS and camera views for wayfinding and science was, at times was overwhelming
- The crew divided responsibilities to easy the workload of the driver
- However, even with this division of tasking, the crew was near max workload
- Interestingly, subjects did note that the workload was easier in the widow configuration since the primary source was looking out a window and supplemented by cameras
- Conversely, the overall median workload for the windowless configuration was a rating of 5 meaning the crew had reduced spare capacity where additional tasks could not be given the desired amount of attention
- This is an important finding as most NASA requirements indicated a workload of 3 or less is desired

3.6.2.11.4 Handling Qualities and Workload in Drive-by-Windows Configuration

This section presents the data and results of the Drive-by-Windows tests for all crews

Drive-by-Camera Configuration

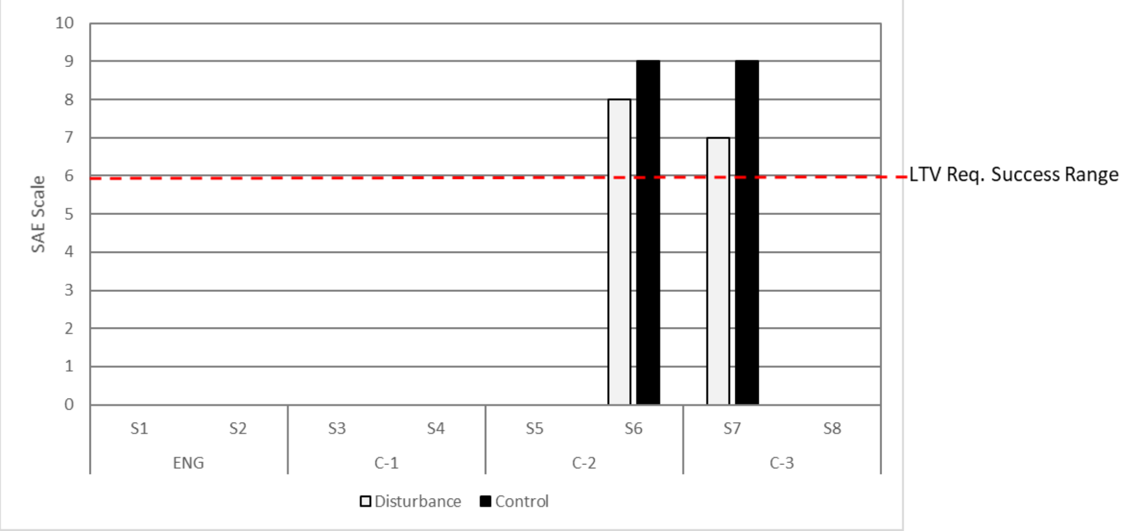
- The window configuration consists of seven windows for a total window area of 3.68 square meters (39.6 square feet) (see figure top right)
- Three years of data exists on this window design with some handling quality data
- Field testing in 2022 presented several limitations for data collection in this configuration
  - During the window configuration phase, the Engineering test team had little opportunity to drive with the physical windows; thus, no data was recorded
  - Additionally, due to weather, Crew 1 did not get the opportunity to drive in this configuration, but did experience driving with physical windows for two hours during the first part of Crew 2’s mission without any data recorded
  - Finally, due to an illness, both Crew 2’s and Crew 3’s data was only partially recorded

Engineering crew driving in the tested Drive-by-Windows configuration

3.6.2.11.4 Handling Qualities and Workload in Drive-by-Windows Configuration

Assessment of Drive-by-Windows Configuration

- In default mode (360-degree-maximum crab mode), subjects noted the disturbance of the rover's joystick style hand controller felt uncomfortable in with some terrain features, especially with numerous rocks
  - To address this issue, subjects were able to adjust the vehicle's speed and max rate
- This also held true for disturbance in 18-degree-max crab mode
- Control in default mode (360-degree-max crab mode) was easier than the test subjects expected
  - They like the ability of the vehicle to complete a point turn, noting this function was critical in certain areas and/or terrain
- In 18-degree-max crab mode, the overall control of the vehicle was as expected; however, the 18-degree restriction made it difficult to perform quick turns, which gave the subjects much less controllability over the vehicle
- With these limitations in mind, the data collected met the desirable range and indicated the handling performance of the vehicle successfully passed in both the default and 18-deg-max crabbing modes, as well as nominal driving operations over simulated lunar terrain at night for the two data points collected (see figures and tables on this and next slide)
- However, due to the limitations of the data collection, only 25% of the subjects showed this success; thus, by requirement more testing will be needed before a definitive answered can be given

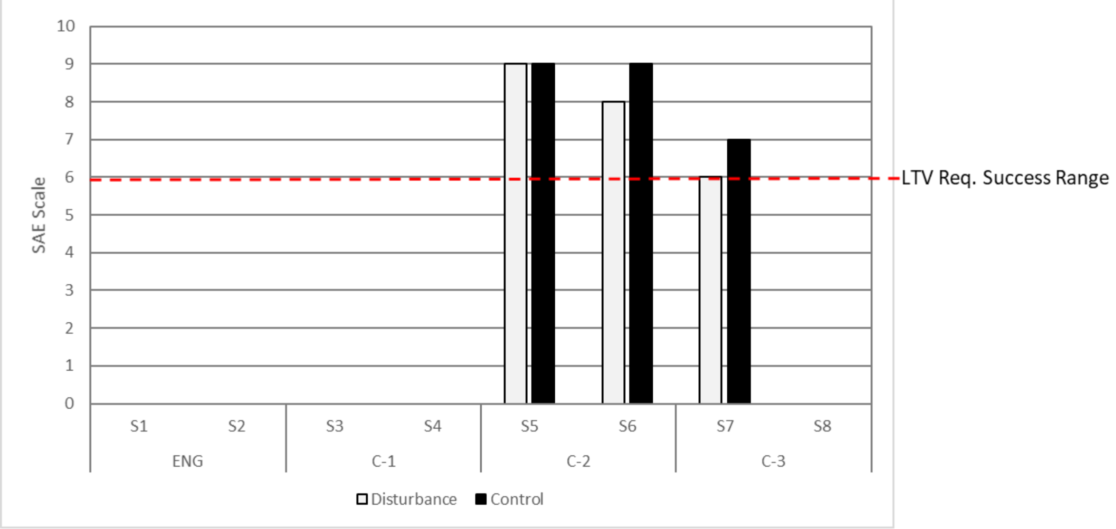


SAE1441 vehicle ride & handling performance scores for driving in drive-by-windows mode with 360-degree-max crab mode enabled

Individual SAE Handling Performance Scores for Drive-by-Windows Configuration in 360-degree-max Crab Mode

Team	Subject	Default Mode				SAE Pass/Fail
		Disturbance		Control		
		Adjectives	Score	Adjectives	Score	
ENG	S1	No Data	No Data	No Data	No Data	
	S2	No Data	No Data	No Data	No Data	
C-1	S3	No Data	No Data	No Data	No Data	
	S4	No Data	No Data	No Data	No Data	
C-2	S5	No Data	No Data	No Data	No Data	
	S6	A Little	8	Very Good	9	Pass
C-3	S7	Some	7	Very Good	9	Pass
	S8	No Data	No Data	No Data	No Data	

3.6.2.11.4 Handling Qualities and Workload in Drive-by-Windows Configuration



SAE1441 vehicle ride & handling performance scores for driving in drive-by-windows mode with 18-degree-max crab mode enabled

Individual SAE Handling Performance Scores for 18-Degree-Max Crab Mode

Team	Subject	JAXA Mode				SAE Pass/Fail
		Disturbance		Control		
		Adjectives	Score	Adjectives	Score	
ENG	S1	No Data	No Data	No Data	No Data	
	S2	No Data	No Data	No Data	No Data	
C-1	S3	No Data	No Data	No Data	No Data	
	S4	No Data	No Data	No Data	No Data	
C-2	S5	Trace	9	Very Good	9	Pass
	S6	A Little	8	Very Good	9	Pass
C-3	S7	Moderate	6	Acceptable	7	
	S8	No Data	No Data	No Data	No Data	

- The workload while driving in this configuration, regardless of crabbing mode, indicated half of the subjects rated their workload, while the other half did not record their scores
- The majority scored their workload as low and stated in this window configuration driving the rover was much like a conventional car
- However, subject observations noted that depending on terrain, their workload could vary from insignificant to insufficient space capacity for easy attention to additional tasks
- For example, for an insignificant workload, the terrain would be flat with minimal large rocks
- Whereas an insufficient workload, the terrain would be sloped with many hazards and large rocks
- Conversely, the overall median workload score for window driving was considered a rating of 2 meaning the workload was perceived as low.

Section 3.7

Public Outreach / Education Activities (D-RATS Objective 4)

Work with the Public Affairs Office (PAO) to perform D-RATS public outreach activities

3.7 Public Outreach / Education Activities (D-RATS Objective 4)

- **D-RATS management and team worked with representatives from NASA HQ, the PAO, OSTEM, and legislative affairs to accomplish the following public outreach and educational activities**
  - **Provided access to Felix & Paul Studios and National Geographic to film Artemis training**
  - **Coordinated and supported Outreach/ Education Events**
  - **Provided Social Media Updates** – provide content for NASA Expeditions account throughout September JSC Rock Yard dry runs/training and October field test
  - **Hosted VIP/Media/Outreach/Education Day**
    - Led event in-person from field site
    - Worked with local USGS counterparts to advertise in the local Flagstaff area
    - VIPs invited to participate all day
    - Hosted multiple information stations – split up visitors into smaller groups and rotate through stations every 10 minutes

- **Team POCs:**
  - HQ/Erin Mahoney;
  - PAO/Nilufar Ramji; Vanessa Lloyd
  - HQ outreach Strategist / Patricia Moore
  - Legislative Affairs/Elizabeth Ahrens

3.7.1 Field Trip & Media Day

October 24: Field Trip and Media Day

Morning:

- More than 190 middle school, high school, and university students attended to learn about Desert RATS and take photos inside the rover

Afternoon:

- 22 Media outlets attended and conducted interviews with mission managers and with rover operators during rover rides. Major outlets included:
  - NBC, Fox, CNN, NPR, PBS, ITV
  - Japanese media: NHK News Japan, Tokyo Broadcasting, Asahi Shimbun, Yomiuri Shimbun, Kyodo News, Nippon News

Additional Community Engagement

- Talk and Q&A at Lowell Observatory, Flagstaff
- Visit to Navajo Nation school, Dzil Libei Elementary

Flagstaff Mayor Paul Deasy attended both the Lowell Observatory event and Field Trip/Media Day. Arizona State senator Theresa Hatathlie and staffers for Sen. Sinema and Rep. O'Halleran also attended Field Trip/Media Day.

ESDMD Outreach Strategist Patricia Moore discussed NASA's Moon to Mars exploration strategy and Desert RATS at the Lowell Observatory.

3.7.2 Digital and Media Coverage

NASA Web Products

- Pre-mission Web Article
- Meet the Team Web Article
- Media Advisory
- Post-mission Web Article

NASA Social Media Highlights

- Pre-mission Web Article (NASA Artemis): Facebook; Twitter
- Pre-mission Web Article (NASA SLS): Twitter
- Meet the Team Web Article (NASA Johnson): Facebook, Twitter
- Meet the Team Web Article (NASA Artemis): Facebook, Twitter
- Media Advisory (NASA Artemis): Facebook; Twitter
- Jessica Meir posts: Tweet 1, Tweet 2
- Highlights Reel (NASA Artemis and NASA Johnson): Instagram
- Total Engagement*: ~38,300 likes; 850 shares/RTs

Media Coverage*

- Outlets: PBS, Fox Business, Fox Weather, Popular Mechanics (1), Popular Mechanics (2), National Geographic, New Scientist, KNAU News Talk (Arizona Public Radio/NPR), NBC 12 News (1), NBC 12 News (2), Fox 10 Phoenix (1), Fox 10 Phoenix (2), Space.com, ITV, Arizona Patch, Asiana Times, AZ Daily Sun, Interesting Engineering, Navajo-Hopi Observer, NY Post, , The Irish Sun
- Total number: 22

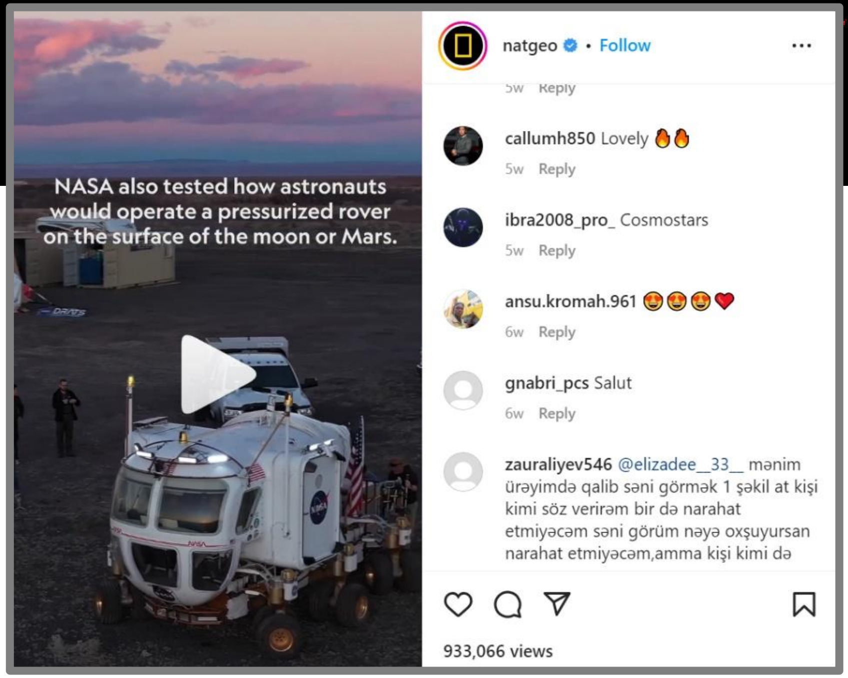
Coverage from Doc Crews

- Felix and Paul (forthcoming)
- National Geographic
  - Article
  - Social Media: Instagram, Twitter, LinkedIn
    - ~933K views; 53,300 likes

Media Day

- Hosted a media and outreach day for students, reporters, and elected officials
- Congressional Attendance
  - State Senator Theresa Hatathlie, Flagstaff Mayor Paul Deasy, and representatives from Congressman Tom O'Halleran and Senator Kyrsten Sinema's staff
- Media
  - Members of the media (representing 22 outlets) gathered to hear remarks from Flagstaff Mayor Paul Deasy and D-RATS mission managers, conduct interviews, and capture imagery of the rover
- Student Outreach
  - More than 190 middle school and college students spoke with D-RATS team members to learn about the mission and explore the inside of the rover

*Note that engagement and media coverage numbers are estimates based on manual tracking and don't represent an exhaustive list



Section 3.8

Addendum

3.8 Addendum

3.8.1 Conflicts of Interest

- None of the investigators or stakeholders receive any research support from non-public sponsors of research
- They do not perform any validation research of a drug or device
- They do not receive any gifts or income from individuals associated with these research studies
- They do not use their positions, or proprietary or confidential information obtained in performing their duties, in any marketing, investing, or commercial ventures

3.8.2 Funding

- Funding for the project and testing was provided by NASA's ESDMD ADO Strategy and Architectures division

3.8.3 Test Readiness Review & Institutional Review Board Approvals

- A test readiness review (TRR) was conducted by the DRATS HITL team and completed for all components of the test
- A complete hazard analysis was written and approved prior to the TRR and included all necessary hazards associated with human interaction with test articles
- The TRR approval letter is included in Appendix E
- This test protocol is not considered human subject research and therefore does not need to report any findings to the IRB (the letter of exemption is included in Appendix E)

3.8.4 Test Data Privacy & Confidentiality

- The privacy of the research subject and the confidentiality of any research data about the subject associated with this study will be maintained in accordance with (1) NASA Policy directive (NPD) 7100.8 "Protection of Human Research Subjects"; (2) NASA Procedural Requirements (NPR) 7100.1, "Protection of Human Research Subjects"; and (3) to the extent allowed by Federal law

Section 3.9

References

3.9 References

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Appendix A

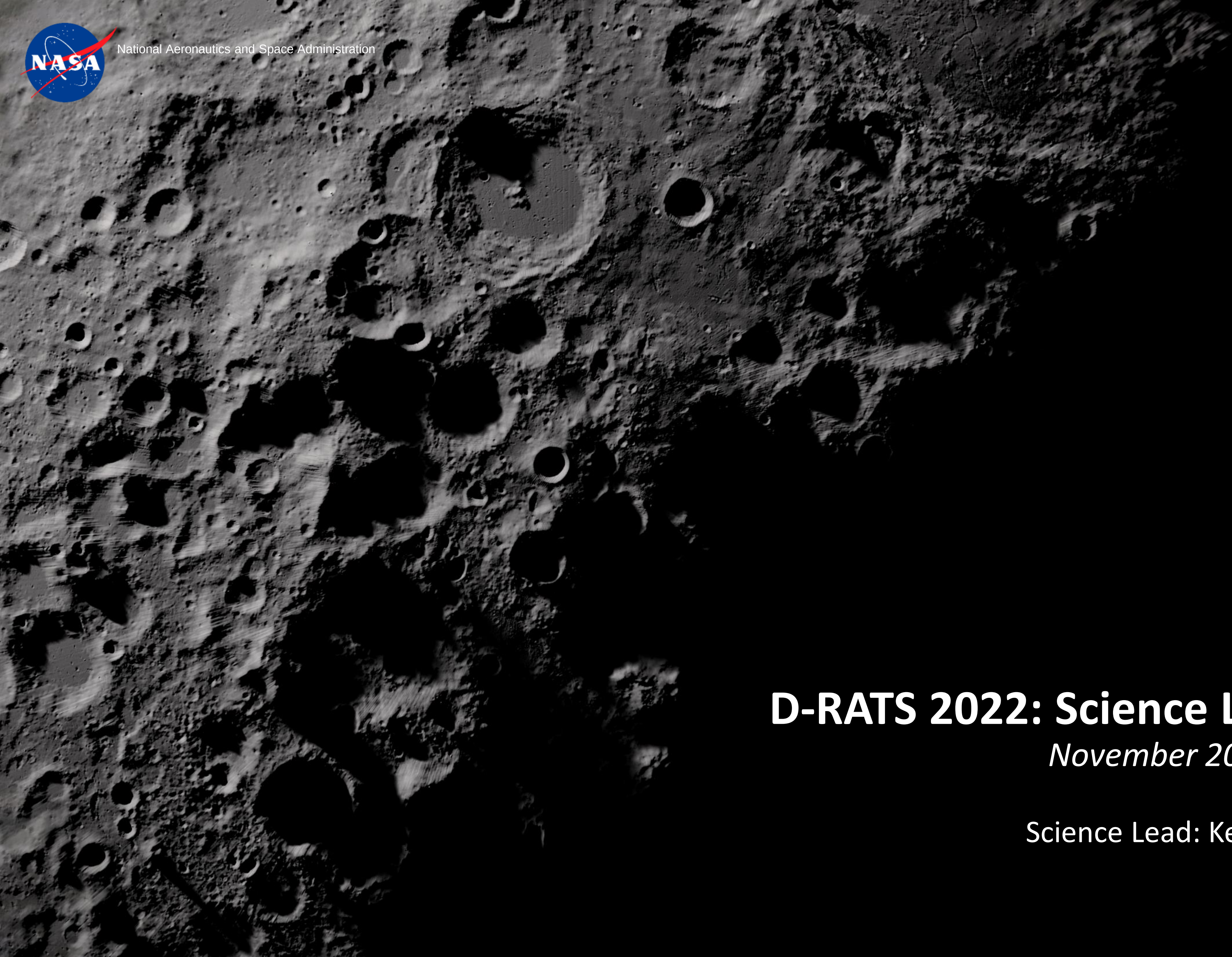
Acronyms

Acronyms

AC – Air Conditioner
ADO – shorthand for M2MADO
AMCC – Analog Mission Control Center
BPLF – Black Point Lava Flow
CAPCOM – Capsule Communicator
CLPS – Commercial Lunar Payload Services
Comm – Communications
ConOps – Concept of Operations
CY – Calendar Year
D-RATS – Desert Research And Technology Studies
DDT&E – Design, Development, Test & Evaluation
DITL – Day-in-the-life
EHP – Extravehicular Activity & Human Surface Mobility Program
ESDMD – Exploration Systems Development Mission Directorate
EV – Extra Vehicular (refers to crew: EV1, EV2, etc.)
EVA – Extra-Vehicular Activity
EVAS – Extra-Vehicular Activity System
FCT – Flight Control Team
FOD – Flight Operations Directorate
FOV – Field Of View
FR – Flight Rule
FY – Fiscal Year
GPS – Global Positioning System
H-3PO – Human Physiology Performance Protection & Operations
HD – High-Definition
HH&P – Human Health & Performance
HITL – Human in the Loop
HLS – Human Landing System
HSEI – Human Exploration & Operations Mission Directorate Systems Engineering & Integration
HQ – Headquarters
IP – International Partner
IVA – Intra-Vehicular Activity
JAXA – Japan Aerospace Exploration Agency
JSC – Johnson Space Center
LAT – Lunar Architecture Team
LiTES – Lunar LTE Studies
LTE – Long Term Evolution (in communications)
LTV – Lunar Terrain Vehicle (unpressurized)
M2MADO – Moon to Mars Architecture Development Office
MCC – Mission Control Center
MPH – Mobile Pressurized Habitat
NASA – National Aeronautics & Space Administration
Nav – Navigation
Op Cons – Operations Concepts
Ops – Operations
PAO – Public Affairs Office
PR – Pressurized Rover
PWS – Portable Water Supply
QGR – Questions Gaps & Risks
RSSI – Received Signal Strength Indicator
SAO – Strategy & Architectures Office
SA – Situational Awareness
SER – Science Evaluation Room
SCaN – Space Communication and Navigation
SCICOM – Science Communicator
SMD – Science Mission Directorate
SQ – Strategic Question
SRR – System Requirements Review
USGS – United States Geologic Services
VR – Virtual Reality
WCS – Waste Collection System
xEVA – exploration EVA
xInfo – exploration Info

Appendix B

Science Lessons Learned



D-RATS 2022: Science Lessons Learned

November 2022

Science Lead: Kelsey Young

Lessons Learned: Categories

- Rover Enabling Capabilities for Science
  - Cameras
  - Lighting
  - Teleoperations of the PR
- Analog Mission Preparation
- Training
  - Crew Training
  - Science Support Personnel Training
- Field Support
- MCC Support
- Thoughts on Future D-RATS/PR Test Objectives

PR Enabling Capabilities for Science

- Cameras
  - Driving and IVA Situational Awareness
    - **When the crew was driving in camera-only mode (windowless), science return was substantially limited.** Fewer observations were made, opportunistic descriptions and discoveries were limited, and large outcrops and important geologic contacts were missed by the crews.
  - EVA Situational Awareness
    - With current PR camera configuration, cameras could not see EV crew when they were within 3-5m of the rover. **PR camera configuration should enable viewing of both crew when they are right next to the rover, on all sides.**
  - **Critical to have the ability for both the crew and MCC to be able to see and control all cameras.**
    - MCC also needs to be able to *see* all camera views (including driving cameras). For example, the belly cam view can inform regolith property (size, texture, angularity, etc.) observations that can be assessed by MCC. This could enable more time for context observations that may be difficult/impossible to capture in other camera views available to MCC
    - Access to all camera views enhances MCC science observation capabilities, thereby removing the burden of the crew on making IVA observations when navigation demands their full attention.

PR Enabling Capabilities for Science

- Lighting
  - Lighting Configuration
    - Rover lighting control during EVA is important for science. Rover lights were helpful for navigation and broad situational awareness but could also swamp science targets with too much illumination. **Control on lighting illumination volume, temperature, and position would enhance EVA science return.**
    - Outstanding Questions: Should the lights be maneuverable to highlight/focus on targets of interest? How is that reconciled with wanting uniform lighting while driving? Should the lighting track some camera views?
  - Sun Lighting
    - At an EVA location that was positioned up-sun, **the crew blocked the Sun using the rover to highlight detailed science targets exposed on a hillside.** This enabled the crew to observe a larger area of an exposed slope and layering in rocks/sediments.
- Teleoperating rover during EVA
  - **When crew followed the rover to an EVA station, it saved time by eliminating navigation confusion but also minimized the number of opportunistic science observations made and overall science conversations when traversing between stations.**

Analog Mission Preparation

- Traverse Planning
  - Need final, high-level mission constraints earlier (e.g., traverse distances, rover parked or with crew during EVA, etc.)
  - Science team needs review time for ops products (i.e. cuff checklists) prior to test and an opportunity to comment/edit
- Science Products
  - Suggest having geologic maps and general base maps in the rover to help crew connect observations between stations
- Precursor Data
  - Data used for planning was not always the same as that available during the test. Make sure these data sets are consistent in future tests.
  - How do we handle vegetation and other “we know this because we’ve been there before but it’s a cheat” issues?
    - Ex. The field science team knew stations would be dominated by vegetation and not a good use of test time, but they didn't want to 'cheat' by revealing that

Training: Crew and Science Support Personnel

- Crew Training
  - Improve: Establish protocols for rover-led station traverse during EVA to improve science observations. Examples: walk adjacent to (not behind) the rover, have the rover complete its move to the station before the crew meets up with the rover, etc.
  - Improve: Provide a map book and clear station objectives to crew for help orienting and providing observations during EVAs
  - Improve: A list of common geology terms should be provided as part of training
  - Improve: Add more time for hand sample practice during classroom and field training
- MCC Support Personnel Training
  - Cross-train MCC Support Personnel for communication, rover teleoperation, and camera ops to ensure coverage of all roles (whenever possible)
- Field Support Personnel Training
  - Field personnel would benefit from training in communication and rover capabilities (if they are not already familiar with this) and definition of their roles/responsibilities

Field Support

- Field Support
  - Sustain: 2 science team observers worked great with the 2 EVs
  - Sustain: EVA ops (i.e., Grier, Jackie) paired with science resulted in productive conversations and informal cross-training that was beneficial to all. The same was true for pairing EVA with Science in mission preparation and MCC operations.
  - Improve: Science observers in field need radios with S/G (cell service spotty)
  - Improve: Based on future objectives, determine whether it is possible for science observers to be closer to EVs during EVAs for better observations. Observers were located near the Sun and in close proximity to other field personnel. It was difficult to see station details that the EVs were discussing and conversations from other field personnel made it challenging to hear crew in order to note their observations. Field verification of station details occurred after EVs departed a station.
  - Improve: Sun placement was inconsistent and could not be trusted for navigation/orientation; more consistency is needed for lighting tests and if using as a navigation aid; consider whether the Sun is needed/necessary for future tests

MCC Support

- Sustain: Having SCICOM speak directly to the crew greatly enhanced the scientific return during both IVA and EVA science
- Sustain: Diversity of personnel involved in MCC operations enabled more relevant personnel to understand analog testing and science integration into operations
- Sustain: Daily tags both pre- and post- traverse between the MCC and field leadership teams were critical in ensuring MCC team knew priorities and daily schedule, especially as both of those were often changing on a daily basis
  - Improve: The science field team was not involved in these tag ups but should be in the future; making this tag-up a formal meeting could help resolve who should participate
- Sustain: CAPCOM/Science proximity in the room helped relay science information faster/more accurately; both verbal and written (Teams chat) communication were effective
- Improve: Need more MCC personnel common across each crew traverse
- The number of science personnel (3) worked well for the scope and objectives of this year's test; 2 people was not enough to cover all the science tasks; the number of science personnel should scale with future tests/objectives

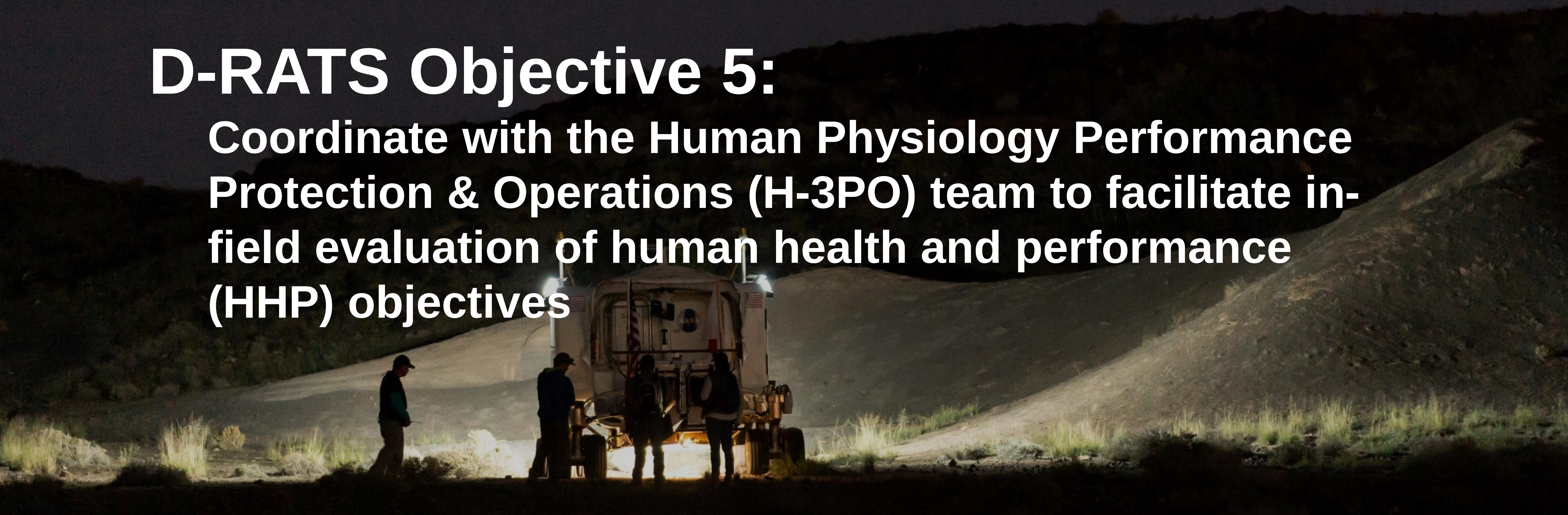
Thoughts on Future D-RATS/PR Testing

- Incorporate science payloads into operations
  - Rover-mounted payloads
  - EVA-operated payloads
- Possible use of automated traverse execution/machine learning algorithms?
- There could be value in repeating traverses in order to test different sets of objectives
- IV observation time the day after traverse is not ideal because the crew may not recall details about IV and EVA observations that occurred on the previous day.
- Increase science support team access to PR instrumentation (e.g., camera views, camera teleoperation, etc.) in order to equip the team to make observations in real-time

Appendix C – Coordination with H-3PO

D-RATS Objective 5:

Coordinate with the Human Physiology Performance Protection & Operations (H-3PO) team to facilitate in-field evaluation of human health and performance (HHP) objectives



Objective 5: Coordinate with H-3PO team to facilitate in-field evaluation of HHP objectives

- **HHP H-3PO objectives**
  a. Characterization of EVA task types, durations, frequencies, and associated physical workload and functional movements required to perform these tasks
  b. Stretch: Incorporate cognitive workload and performance measures (pre-, during-, and post-EVA if possible) to assess fatigue effects

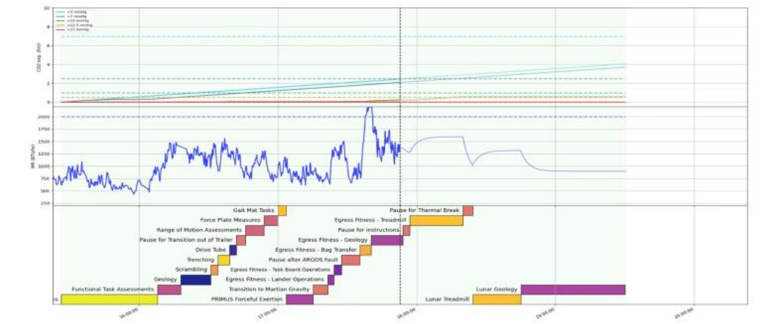
- **Team POCs**
  – JSC SK, H-3PO Lab: Patrick Estep, Monica Hew, Bradley Hoffmann, Grant Harman

- **Background**
  – The Crew State and Risk Model (CSRM), in development by H-3PO, is a modular framework of individual models that is intended to provide prediction and real-time monitoring of crew physical and cognitive state and associated risk implications as a function of tasks and procedures during execution of EVAs. H-3PO is primarily seeking data to validate this model, and to potentially support development of EVA simulation content in a virtual reality environment.

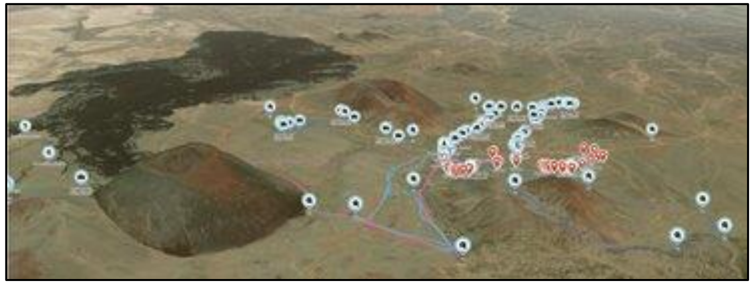
- **Measures**
  – **GPS:** Location, translation distance, max range, time spent at sites
  – **Heart rate monitor (HRM):** Heart rate, heart rate variability, ECG, *metabolic rate (modeled)*
  – **Timeline tracking tool (Maestro):** Time spent on each step/procedure
  – **Stretch:** Cognitive workload and performance measures (Bedford, TLX, Cognition, etc.)

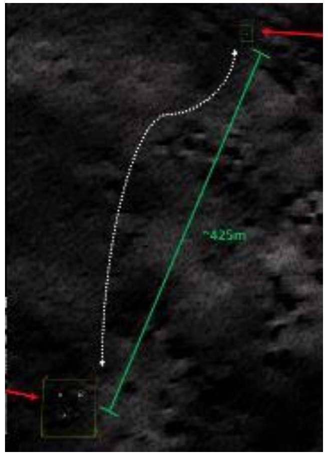
- **Result**
  – The proposed data measures, in a high-fidelity EVA-relevant geological exploration environment, will be used to develop, train, and validate the CSRM.

- **Traceability**
  – CHP.EVA.CONOPS: EVA ConOps for Health & Performance



Concept of CSRM display using ARGOS data uploaded to CHP-DB. This displays both real-time data (light) and predictions (dark) of inspiredCO2 (top), metabolic rate (mid), and timeline (bottom).





H3PO EVA Heart Rate Data Analysis

Monica Hew, Bradley Hoffmann, Grant Harman, and Zach Wusk

Human Physiology, Performance, Protection & Operation Lab (H-3PO)
SK-3

SK3 – H3PO EVA Heart Rate Data Analysis

- **Objectives: Multi-Year SSEO EVA Field Test Roadmap Objective: Characterize EVA task types, durations, frequencies, and associated physical/cognitive workload and functional movements required to perform these tasks.**
  - Support EVA human performance **modeling database**, e.g., EVA Informatics & Decision Support), CSRM (Crew State Risk Mel).
  - Various mission series: D-RATS (Desert Research and Technology Studies), JETT (Joint EVA & HSM Test Team), etc.
  - See future objectives slide
- **Accomplishments**
  - **Demonstrated human performance data collection and integration with cross-discipline field test team**
    - ✓ Focus on physical workload assessment (cognitive workload weren't collected in full in field due to ops issues)
    - ✓ A pilot study focus on establishing framework/foundations for future EVA field tests data collection and analysis
  - Data Collection – SSEO team trained remote DRAT engineering team teammate to collect data in field
    - ✓ **Heart Rate** (Polar/Garmin watch), **GPS** (Garmin watch or Suit GPS), **Timeline** (Video analysis)
    - Secondary metric: cognitive workload scale data collected (limited data available)
  - Data Analysis – **Establishing framework for Physical Workload Assessment**
    - ✓ Correlate heart rate data with discrete EVA task activities, GPS data, and mission configuration
- **High Level Lessons Learned**
  - SK call tree structure (google voice hotline support) allow efficient and continuous 24/7 remote support for field test
  - Heart rate (chest and wrist sensors) and GPS (wrist worn) data collection looks good on first pass.
  - SK provided additional backups in case sensor went down.
  - Daily pre-briefs were helpful.
- **Recommendations for Future Testing**
  - Challenges of supporting remotely only – lack of situation awareness, and ability to resolve problem real-time
    - Helpful to have daily quick text update on status of EV swap etc.
  - Data access was difficult to track down since the GPS and video data retrieval takes a long time to be release
    - May try to add more live links or share drive access

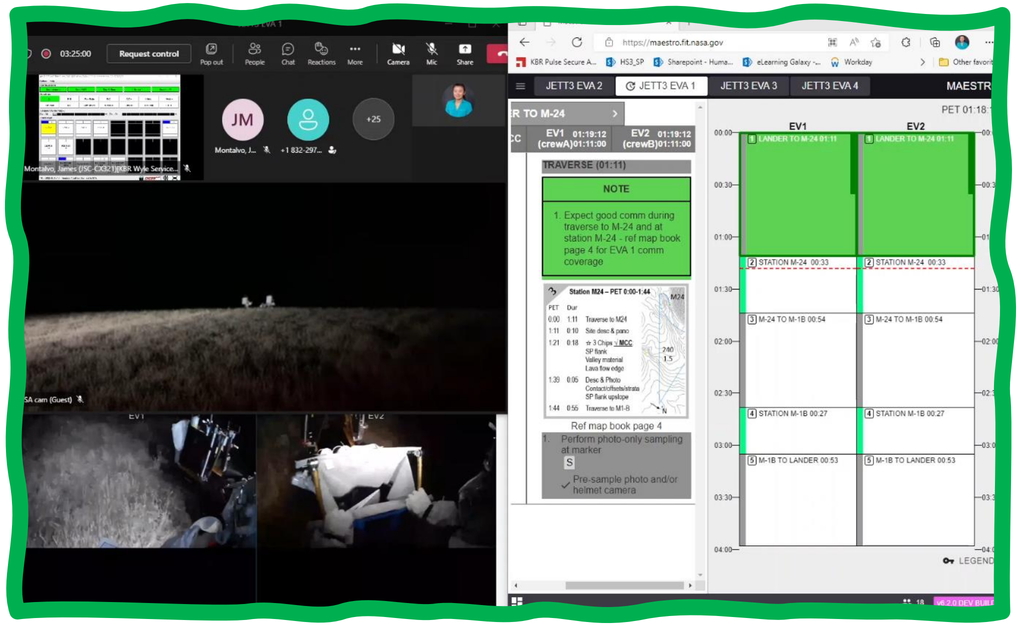
Human performance data collected shows feasibility to aid in operations task planning

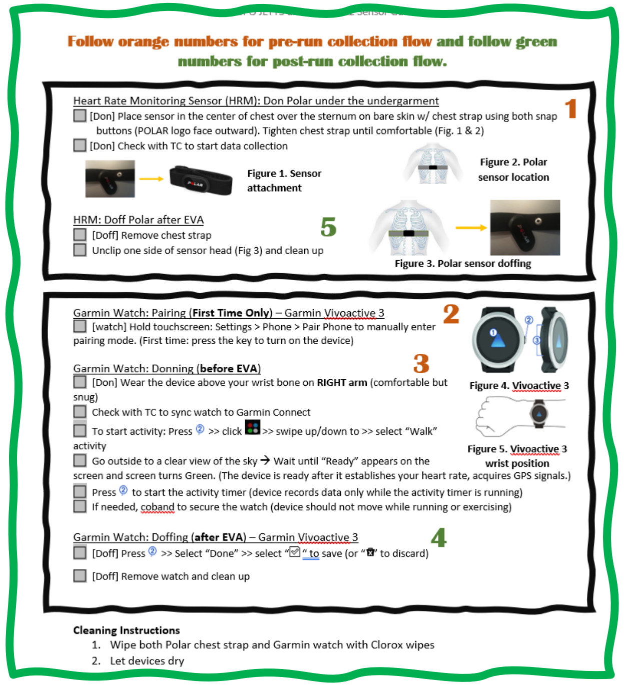
SK3 – H3PO Heart Rate Data Analysis

SK Operations:

- **Supported x1 Rock Yard Engineering Run, x2 remote Field Engineering Run, and x2 remote EVA field data collections**
- **Challenges in supporting remotely: training, visual SA, equipment issues and video delays.**
  - Setup google voice system for routing 24/7 on-call logistical support among teammates
  - Sensor guide
  - Video analysis and task categorization
- **Cognition data collection were limited to post EVA due to ops planning.**

Google Voice





Follow orange numbers for pre-run collection flow and follow green numbers for post-run collection flow.

Heart Rate Monitoring Sensor (HRM): Don Polar under the undergarment **1**
- [ ] [Don] Place sensor in the center of chest over the sternum on bare skin w/ chest strap using both snap buttons (POLAR logo face outward). Tighten chest strap until comfortable (Fig. 1 & 2)
- [ ] [Don] Check with TC to start data collection

Figure 1. Sensor attachment

Figure 2. Polar sensor location

HRM: Doff Polar after EVA **5**
- [ ] [Doff] Remove chest strap
- [ ] Unclip one side of sensor head (Fig 3) and clean up

Figure 3. Polar sensor doffing

Garmin Watch: Pairing (**First Time Only**) – Garmin Vivoactive 3 **2**
- [ ] [watch] Hold touchscreen: Settings > Phone > Pair Phone to manually enter pairing mode. (First time: press the key to turn on the device)

Garmin Watch: Donning (**before EVA**) **3**
- [ ] [Don] Wear the device above your wrist bone on **RIGHT arm** (comfortable but snug)
- [ ] Check with TC to sync watch to Garmin Connect
- [ ] To start activity: Press >> click >> swipe up/down to >> select "Walk" activity
- [ ] Go outside to a clear view of the sky → Wait until "Ready" appears on the screen and screen turns Green. (The device is ready after it establishes your heart rate, acquires GPS signals.)
- [ ] Press to start the activity timer (device records data only while the activity timer is running)
- [ ] If needed, coband to secure the watch (device should not move while running or exercising)

Figure 4. Vivoactive 3

Figure 5. Vivoactive 3 wrist position

Garmin Watch: Doffing (**after EVA**) – Garmin Vivoactive 3 **4**
- [ ] [Doff] Press >> Select "Done" >> select " " to save (or " " to discard)
- [ ] [Doff] Remove watch and clean up

Cleaning Instructions
1. Wipe both Polar chest strap and Garmin watch with Clorox wipes
2. Let devices dry

SK3 – H3PO Heart Rate Data Analysis

- **Analysis Assumptions (1/2)**
- **Maximum heart rate:** $HR_{max} = 208 - 0.7 \times age$ **[Tanaka *et al. 2001*]**
- **Heart Rate Zone assumption:**

POLAR. SPORT ZONES

TARGET ZONE & INTENSITY % OF HRMAX			PHYSIOLOGICAL BENEFIT / TRAINING EFFECT	DURATION
5	MAXIMUM	90-100%	√ MAXIMUM PERFORMANCE CAPACITY - Tones the neuromuscular system - Increases maximum sprint race speed	less than 5 minutes
4	HARD	80-89%	√ LACTATE THRESHOLD - Increases anaerobic tolerance - Improves high speed endurance	2 -10 minutes
3	MODERATE	70-79%	√ AEROBIC FITNESS - Enhances aerobic power - Improves blood circulation	10 - 40 minutes
2	LIGHT	60-69%	√ TARGETS FAT-BURNING - Increases metabolism & basic endurance - Strengthens body for higher intensity work	40 -80 minutes
1	VERY LIGHT	50-59%	√ BASIC ENDURANCE - Helps speed up recovery after heavy exercises - Improve overall health & metabolism	20 - 40 minutes

$$\%HR = \frac{HR}{HR_{max}} x\ 100\%$$

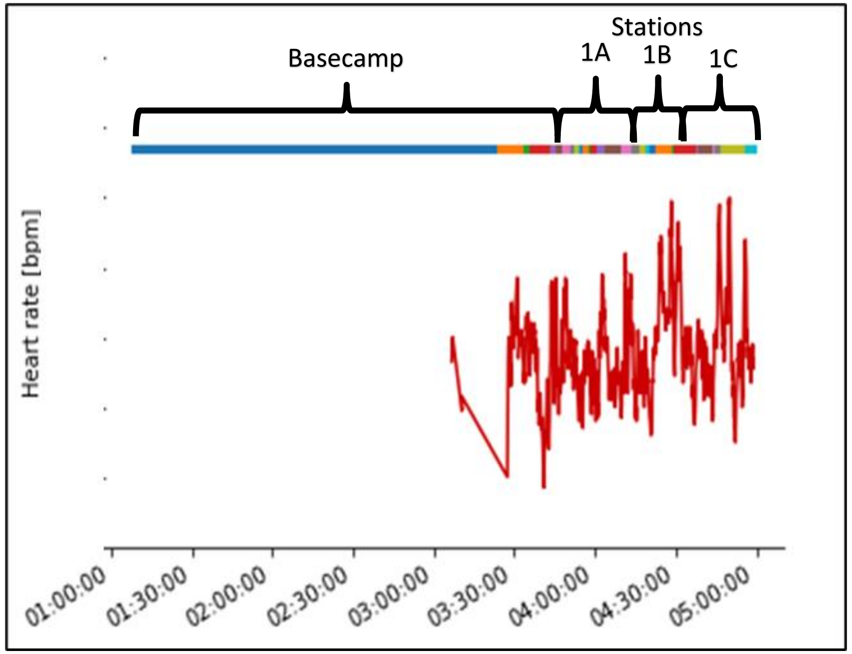
Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001 Jan;37(1):153-6. doi: 10.1016/s0735-1097(00)01054-8. PMID: 11153730.

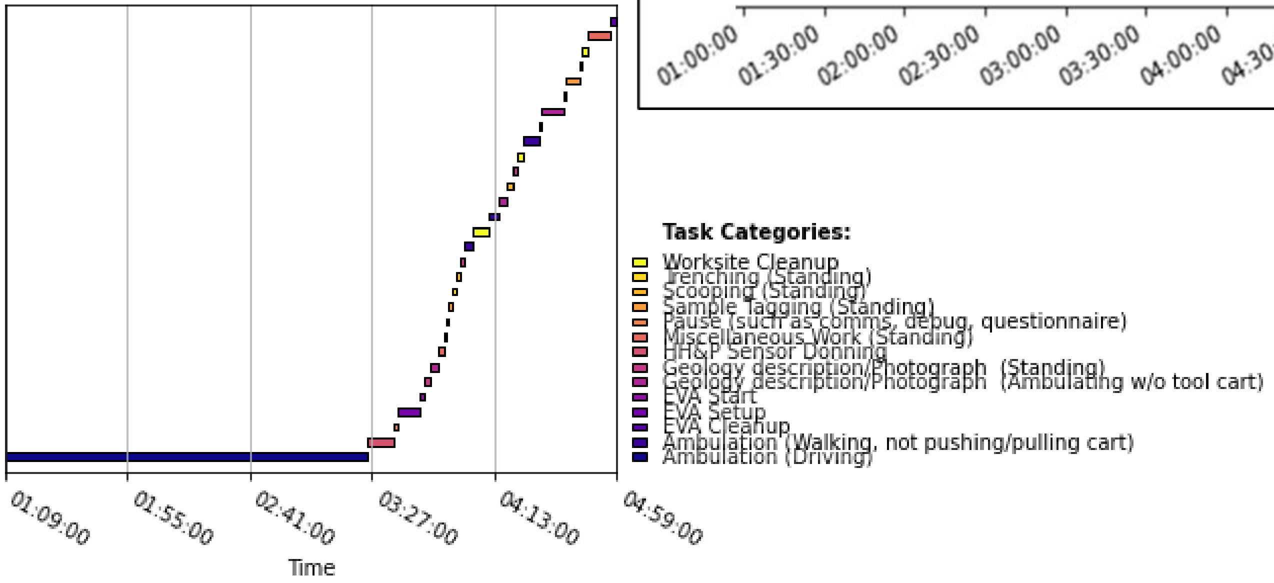
SK3 – H3PO Heart Rate Data Analysis

Heart Rate Data – Example EV in an EVA

category	Avg [% Max]	Max [% Max]	Duration [h:mm:ss]	Avg Speed [mps]
EVA Start	54	66	0:02:00	0.25
HH&P Sensor Donning	55	66	0:10:00	0.17
EVA Setup	49	66	0:08:00	0.17
Trenching (Standing)	52	56	0:02:00	0.06
Worksite Cleanup	55	78	0:10:00	0.39
Ambulation (Driving)	53	57	2:16:00	0.13
Geology description/Photograph (Standing)	55	75	0:09:00	0.17
Ambulation (Walking, not pushing/pulling cart)	61	79	0:13:00	0.48
Scooping (Standing)	50	57	0:04:00	0.11
Geology description/Photograph (Ambulating w/o tool cart)	55	75	0:15:00	0.36
Pause (such as comms, debug, questionnaire)	56	61	0:02:00	0.08
Miscellaneous Work (Standing)	57	79	0:11:00	0.20
Sample Tagging (Standing)	51	57	0:06:00	0.11
EVA Cleanup	53	56	0:02:00	0.13

Avg HR: (55% Max)
Max HR: (80 %Max)





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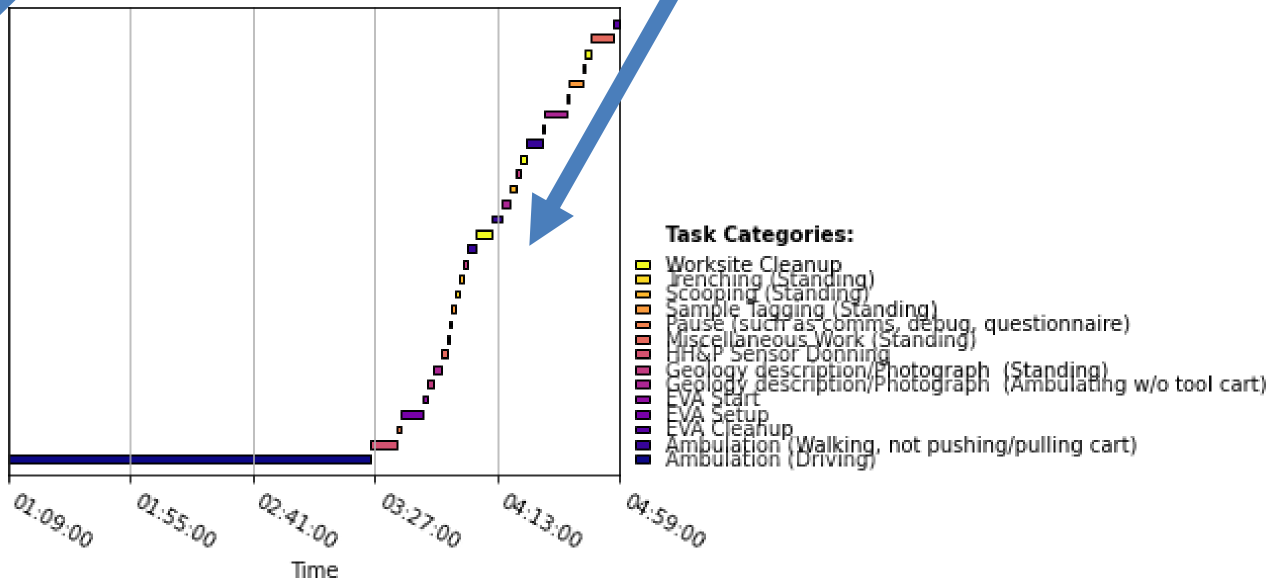
Reality of EVA field test:

- **Chopped timeline:** task duration are very brief
- **No designated/continuous task blocks:** difficult to decipher the physiological data before equilibrium states are reached. (physiologically choppy timeline)
- Lots of task has **"spillover"** from previous tasks: making it difficult to isolate/classify the driver events for HR in a chopped timeline.

Recommendation: Set aside engineering run or 1 EVA to do task-based blocks that allows physical activities to reach steady state (ambulation, geology, etc.). Use such run data to benchmark other realistic EVA runs.
Recommendations: reduce number of tasks/category to reduce granularity
Recommendation: add 2-minute window before and after for averaging



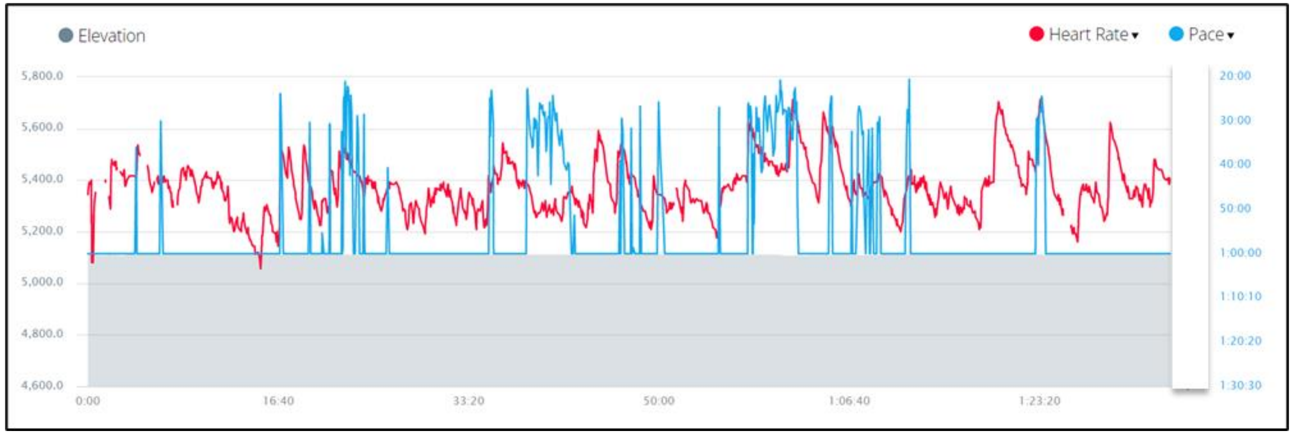
SK3 – H3PO Heart Rate Data Analysis

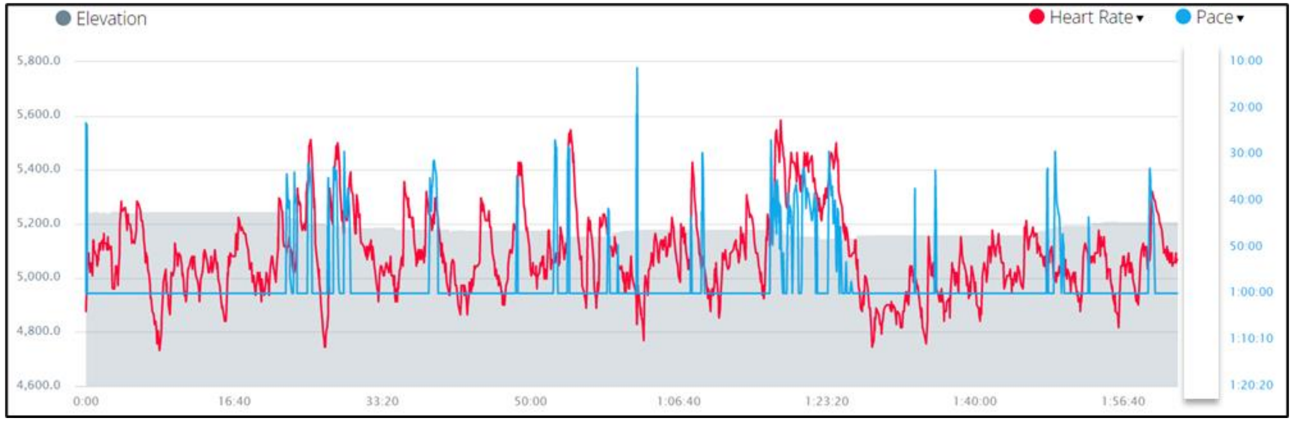
Human Performance Data – Example EV in example EVAs

HR zone charts show consistent physical workload profile between two similar EVAs for the same EV.

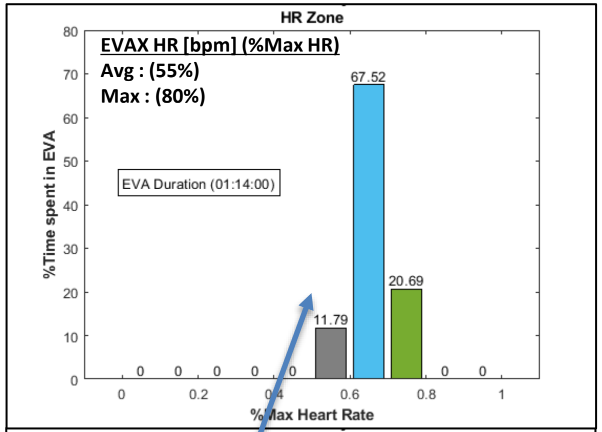
→ Capability in characterizing EVA physical workload

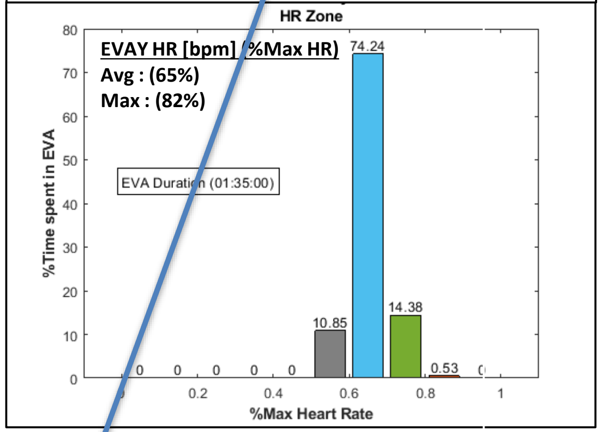
Elevation (ft)





Time (hh:mm:ss)





Workload Scale reflect consistent slightly right-shifted workload distribution in HR zone

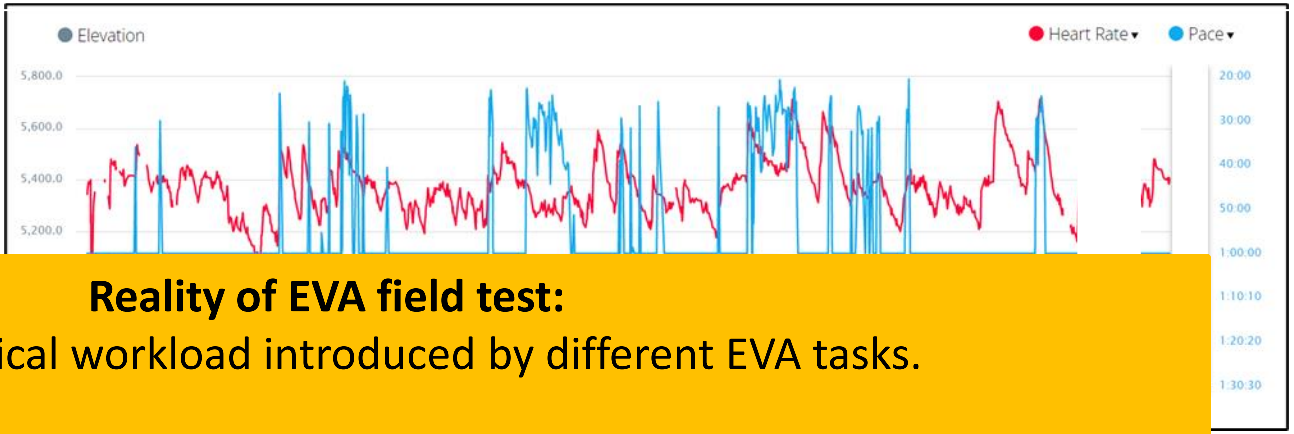
	Heart Rate (bpm) (%Max HR)	Speed (kmh)	Distance (km)	Duration (hr)	% Time spent in HR zone (median [Max])	Workload Scale (after EVA)
EVA X	Avg : (55%) Max : (80%)	Avg = 0.80 Mx = 4.99	1.30	1:34	Light Zone [Max]	4
EVA Y	Avg : (65%) Max : (82%)	Avg = 0.64 Mx = 8.53	1.40	2:02	Light Zone [Max]	3

Hear Rate (HR) Zone Legend

Very Light (50-59%)	Light (60-69%)	Moderate (70-79%)	HARD (80-89%)	MAX (90-100%)

SK3 – H3PO Heart Rate Data Analysis

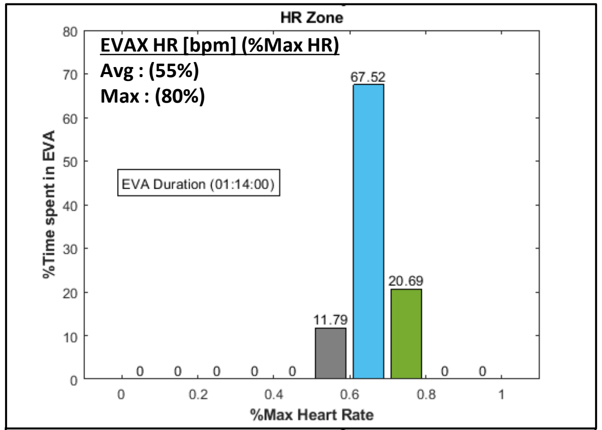
Human Performance Data – Example EV in example EVAs

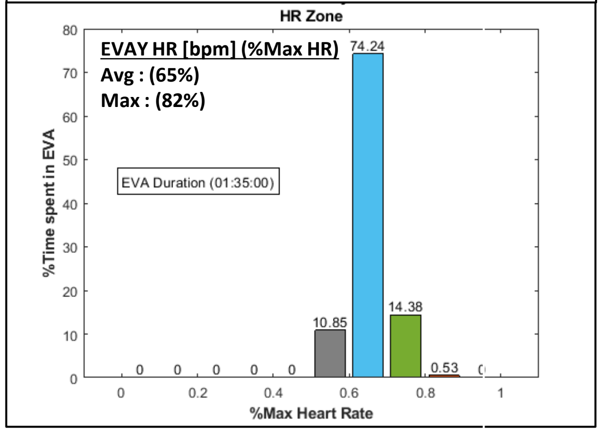


Reality of EVA field test:

- HR data can reflect physical workload introduced by different EVA tasks.
- HR workload zone distribution chart is a great way to see physical workload level. (Relying solely on average/max might not reveal the complete story if non-gaussian)

Time (hh:mm:ss)





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Hear Rate (HR) Zone Legend

Very Light (50-59%)	Light (60-69%)	Moderate (70-79%)	HARD (80-89%)	MAX (90-100%)

Future Work: Take away & Recommendation

– **Cognitive data collection** needs to be integrated into ops plan to balance simulation emersion.
– **Physiological task categorization definition:**
    - Discuss w/ FOD & Science teams to find meaningful definition for stakeholders (especially for CSRM, PerSIDs use)
    - Involve in EVA field test timeline planning: need more continuous task blocks to characterize physical workload better
– **Physical versus cognitive tasks affect heart rate differently:** both can be a big factor, especially when compounded. EVA field test timeline needs to be designed deliberately to answer these questions.
– One pager for future SK HHP implementation/collaboration in work for Atlas suit.
– **Refine field support/Ops and formalize data analysis framework** to turn this type of data fast around next time.
– See Future Objective list for additional lower priority items.

Lessons Learned – Sustained (what went well)

- SK call tree structure:
  - (google voice hotline support) allow efficient and continuous 24/7 remote support for field test, and seamless transition between several SK support staff over the mission.
- Data collection went well remotely despite some challenges
- SK provided additional backups in case sensor goes down.
- Maestro usage or more detailed EVA timeline will be helpful for HHP.

Lessons Learned – Recommendations [1/2]

- Challenges of supporting remotely only – lack of situation awareness, and ability to resolve problem real-time
  - Difficult to access EV CAM recordings post mission. (SA CAMs in field is super helpful. Having a better solution than current cell phone SA CAM will be super great for SA and HRP analysis.)
  - Teams video recording highlighting DICES cannot really see the field cam on the recordings.
  - Cannot download teams recording (might be best to have someone at MCC-H as host on teams' invitation)
  - Playbook only provides limited timeline information regarding EVA segment
- Data access:
  - Teams recording, GPS. Might be useful to establish a data drop location so that we don't have to bug test team members one-on-one. Streamline multiple group data will be helpful.
  - Team daily summary outlook for the remote and all test team

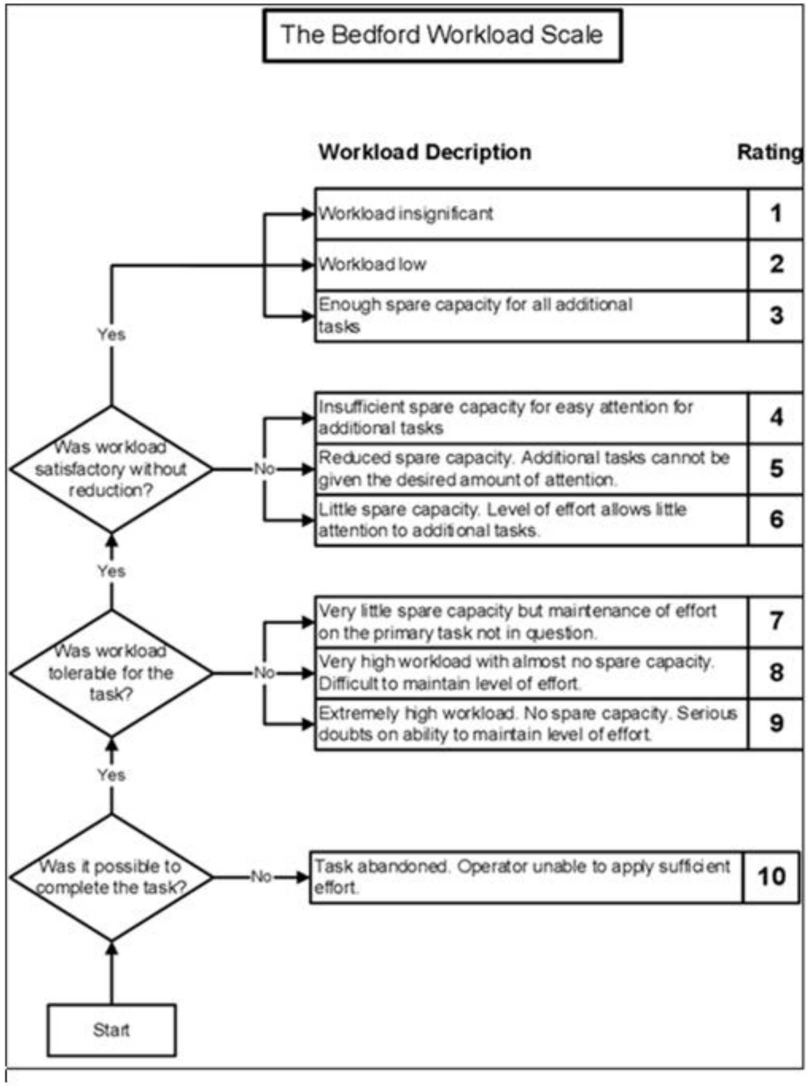
Lessons Learned – Recommendations [2/2]

- SA team specific:
  - Multiple apps reloading attempts needed in poor network environment might be needed for the data to go through cloud.
  - Helpful to have daily quick text update on status of EV swap etc. between the field team rep and remote support team
  - **Workload scales: Recommend dedicated time point to collect cognitive and physical workload for subjects in the timeline.**
  - Garmin on outside of glove as PET/backup timer is helpful for analog testing
  - Data Analysis Framework:
    - Timestamp consolidation across sensors and video data source.
    - Script and code automation
    - Revisit task definition discussion
    - Acquire subject age or VO2 max heart rate data since final data will only use % heart rate

Future Objectives

- **Recovery time & Fatigue:** recovery time from each of these physiological cart, how fast do they take to return to lower workload, spillover effect
- Cognitive Workload : Bedford/Borg CR10 scale cognitive scales
  - Classify EVA cognitive task activities via the videos, timeline and GPS data.
- Synergistic analysis of EVA physical and cognitive workload data:
  - For discrete EVA tasks
  - Physical vs cognitive task affects HR differently, but both can be a big factor especially compounded
- Terrain effect: contribution of slope and elevation on workload
- Cart and Tool effects on workload
- Wrist worn vs chest worn HR detection comparison

Bedford Workload Scale



Appendix D

D-RATS Past & Present

D-RATS Lite 2021: Overview

- **Sponsor: HQ Human Exploration and Operations Mission Directorate Systems Engineering & Integration (HSEI) Strategy and Architectures Office (SAO)**
  - Chartered SAO HITL Test Team to address high-priority HSEI HITL questions, gaps, and risks related to lighting and navigation capabilities and preparation for future Artemis analog tests

- **Location: East of SP Crater in the San Francisco Volcanic Field, ~30 miles north of Flagstaff, AZ**

- **Test Dates: October 18-24, 2021**

- **Rationale: It had been 10 years since the last D-RATS field-test in 2011**
  - Capabilities, skills, and partnerships needed to be (re-)developed
  - New mode of operations to simulate low natural lighting conditions at night

- **Results: D-RATS Lite 2021 re-established terrestrial field analog capabilities**
  - Established communications between the field (simulated Lunar surface), Flight Control Team (FCT) in Mission Control Center (MCC) at JSC, and other remote observers
  - Simulated low angle natural lighting conditions inherent to the Lunar south pole
  - Conducted representative Lunar surface operations to test capabilities and begin to understand Artemis EVA challenges and operations plans (e.g. navigation, traverse planning and execution, timeline development, representative in-station tasks, EVA tools, EVA workload and human performance)

D-RATS Lite 2021 was testing to re-establish terrestrial field analog capabilities and initial operations recommendations to support Artemis strategy and architecture objectives

D-RATS Partnerships (1997-2012, 2021)

Analog mission conducted by a combined group of inter-NASA center engineers and scientists, collaborating with representatives from other government agencies, industry, academia, and international partners, for the purpose of conducting integrated remote field analog mission simulations in relevant terrestrial environments

JSC, HQ, GSFC, MSFC, JPL, KSC, ARC, GRC, LaRC

14 field-tests from 1997-2011,
1 test at JSC in 2012,
1 capability field-test in 2021

D-RATS 2022 Partnerships

- **Customer:** HQ Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Development Office (M2MADO) Strategy and Architectures Office (SAO)
- NASA
  - **JSC**
    - Exploration Integration and Science Directorate
      - Exploration Mission Planning Office (XM)
      - Astromaterials Research and Exploration Science Division (XI)
    - Engineering Directorate
      - Software, Robotics and Simulation Division (ER)
      - Crew and Thermal Systems Division – Tools, Equipment, and Habitability Systems Branch (EC7)
      - Avionic Systems Division – Wireless and Communication Systems Branch (EV8)
    - EVA Human Surface Mobility Program (EVA HSM / EHP)
      - Systems Engineering and Integration (DI)
      - Pressurized Rover Pre-Project (DR)
    - Flight Operations Directorate
      - Astronaut Office (CB)
      - Flight Director Office (CA8)
      - EVA, Robotics and Crew Systems Operations Division - EVA Operations Branch (CX3)
    - Human Health and Performance (HHP) Directorate
      - Biomedical Research and Environmental Sciences Division – Human Physiology, Performance, Protection, & Operations Laboratory (SK3)
      - Human Systems Engineering & Integration Division – Habitability & Human Factors Branch (SF3)
      - Space Medicine Operations Division – Space & Occupational Medicine Branch (SD3)
    - Information Resources Directorate
      - Customer Engagement and Multimedia Services Office (IC)
    - Safety & Mission Assurance Directorate
      - Safety & Test Operations Division (NS)
  - **KSC**
    - Information Technology and Communications Services (KSC-ITC)
  - **GSFC**
    - Planetary Studies (6980)
  - **ARC**
    - Human Systems Integration Division – Human Computer Interaction Group (TH)
  - **GRC**
    - Space Communications Project Office – Lunar LTE Studies (Lunar LiTES)

- **International Partners**
  - JAXA
- **Other Government Agencies**
  - United States Geological Survey (USGS) Astrogeology Science Center
- **Academia**
  - Northern Arizona University (NAU)
- **PAO, Media, Educational Outreach**
  - Felix & Paul Studios
  - National Geographic
  - Local Community
- **Local Community**
  - Babbitt Ranch

JSC HQ KSC GSFC ARC GRC

Appendix E

Approvals

Test Readiness Review Approval

Test Readiness Review Board

1. Test Title: D-RATS 2022 Test Readiness Review	2. Page 1 Of 1

3. TRRB Date	4. File Number	5. Procedure Number	6. TPS Number
09/8/2022		Per Field Schedule	N/A

Approvals (Approvals as Required)

The Test Readiness Review Board approves conduct of this test upon completion of the listed open items prior to start of test.

7. TRRB Chairman: Burt Laws (XA)-Signed by JEP via telecon	8. Test Requester / Branch Representative: Barbara Janoiko (XM)-Signed by JEP via telecon
9. Quality Engineer: N/R	10. Test Crew Member / Representative: James "Vegas" Kelly (CB)-Signed by JEP via telecon
11. Medical Officer: Dr. Bob Sanders (SD)-Signed by JEP via telecon	12. Test Branch / Facility Manager: Lauren Edgar (USGS)-Signed by JEP via telecon
13. Test Safety Officer: Todd Bailey (NS)-Signed by JEP via telecon	14. Test Director: Barbara Janoiko (XM)-Signed by JEP via telecon
15. Test Article Expert: Omar Bekdash (ER)-Signed by JEP via telecon	16. TRR Coordinator: Jason E. Poffenberger (XM)-Signed by JEP

No.	17. Open Items	Assignee	Closed
1	All approving signatures review of rev A of D-RATS HA	Janoiko	9/30/22
2	Send PR HA and Fire Incident report to CB/ confirm closure is met by onsite TRR	Bekdash	9/12/22
1	See HA rev B and email concurrences		
2	See email confirmation, incident report, and onsite TRRB approval		

18. Open Items Closure Approvals

Test Director	TRRB Chairman
Barbara Janoiko (XM)-Signed by JEP via telecon	Burt Laws (XA)-Email concurrence

Form EA-005 (September 11, 2002)

Janoiko, Barbara A. (JSC-XM111)

From: Laws, Burt A. (JSC-XE111)
Sent: Friday, September 30, 2022 3:02 PM
To: Janoiko, Barbara A. (JSC-XM111)
Cc: Poffenberger, Jason E. (JSC-XM)[THE AEROSPACE CORPORATION]
Subject: Re: D-RATS Field TRR Closure

Barbara,
I concur with the closure responses and approve the TRR concur sheet. Let me know if you need anything additional from me. Thanks for your leadership and all your efforts toward DRATS 2022. I look forward to hearing about the field test successes/results after you return.
Thanks,
Burt

From: "Janoiko, Barbara A. (JSC-XM111)" <barbara.a.janoiko@nasa.gov>
Date: Friday, September 30, 2022 at 2:27 PM
To: BURT LAWS <burt.a.laws@nasa.gov>
Cc: "Poffenberger, Jason E. (JSC-XM)[THE AEROSPACE CORPORATION]" <jason.e.poffenberger@nasa.gov>
Subject: D-RATS Field TRR Closure

Hi Burt,

I put all of our TRR documents in a OneDrive folder that you should be able to access:
DRATS 2022 Field TRR

Action 1 can close if you concur with the updated Rev B of the HA (all other signatories concurred). Attached are two versions, one showing tracked changes and one showing all changes accepted.

TRR concur sheet can close if you concur with closure responses.

Please let me know if you have any questions!

Thanks,
Barbara

Not Human Subject Research Letter of Exemption

NASA Institutional Review Board (IRB)
2400 NASA Parkway
Houston, TX 77058
https://eirb.jsc.nasa.gov/
https://irb.nasa.gov/

NOT HUMAN SUBJECTS RESEARCH
29Jun2022

TO: Omar Bekdash
Wyle
omar.s.bekdash@nasa.gov

FROM: Marisa Covington, Ph.D., CIP
Chair, NASA Institutional Review Board

TITLE: DRATS Analog Testing

On 29Jun2022, the NASA IRB reviewed the following submission:

Study eIRB Number	STUDY00000512
Type of Review:	Human Subjects Research Determination
IRB Disposition:	Not Human Subjects Research
Date of Determination:	29Jun2022
FWA Number:	00019876

As written, the NASA IRB determined that the proposed activity is not research involving human subjects. IRB review and approval are not required.

Please include the following sentence in your Multinational Consent Form under "About This Research Consent Form":

> **"NOTE FOR US CREW ONLY: The NASA IRB has determined the proposed project is not considered human subjects research per U.S. 14CFR1230. As such, 14CFR1230 regulations have not been applied and the project is not under the purview of the NASA IRB."**

The PI is responsible for following all ethical and legal guidelines as well as ensuring that all NASA procedures and policies are met during the lifetime of this project (Test Readiness Review, clearance by NASA Safety, etc.).

This determination applies only to the activities described in the NASA IRB submission and does not apply should any changes be made. If you plan to modify this activity in any way, you must submit a study modification to the NASA IRB for a determination. You can create a modification by clicking **Create Modification / CR** within the study.

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Sincerely,

Marisa Covington, Ph.D., CIP
Chair, NASA IRB

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