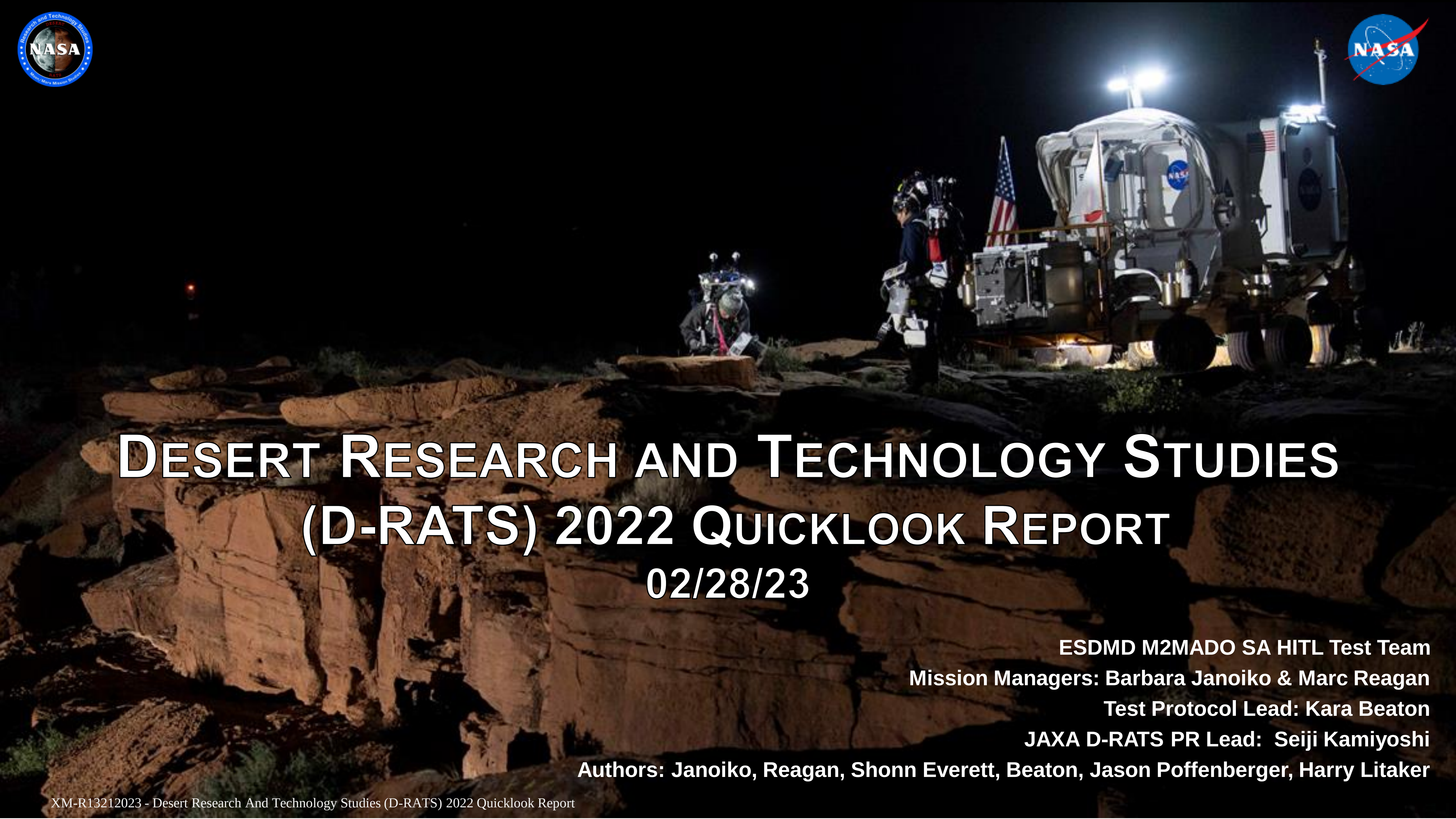

Desert Research and Technology Studies (D-RATS) 2022 Quicklook Report

02/28/23

ESDMD M2MADO SA HITL Test Team

Mission Managers: Barbara Janoiko & Marc Reagan

Test Protocol Lead: Kara Beaton

JAXA D-RATS PR Lead: Seiji Kamiyoshi

Authors: Janoiko, Reagan, Shonn Everett, Beaton, Jason Poffenberger, Harry Litaker

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Section 1

Executive Summary

Executive Summary (1 of 2)

This report summarizes the Desert Research and Technology Studies (D-RATS) 2022 analog tests

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

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 poles; and (2) Exploration sites that challenge communication with Earth
- **International Partner Involvement –** NASA is working with the Japan Aerospace Exploration Agency (JAXA) to scope mission & functional requirements for an Artemis Pressurized Rover (PR), which JAXA may provide
- **Charter –** HQ Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Architecture Development Office (M2MADO) Strategy and Architectures (SA) 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

- **Objectives –** Analog tests conducted in October 2022 by the D-RATS team addressed three high-level objectives:
  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
- **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

NASA's 6-wheeled pressurized rover (PR) testbed was updated to test drive-by-windows & drive-by-cameras driving modes

D-RATS 2022 is testing to establish mission-class, terrestrial, field-analog capability and initial operations recommendations to support Artemis strategy and architecture objectives

Executive Summary (2 of 2)

HIGH-LEVEL OBJECTIVES ACCOMPLISHED

- **Investigated Pressurized Rover ConOps & Capabilities for Artemis Exploration** (Objective 1)
  - Completed testing with 4 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, 3 NASA engineers)
  - Collected detailed objective & subjective data supporting 10 strategic questions related to Artemis PR operations
  - Field geologists present in field observed rover operations & EVAs
  - Science team in Houston 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 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 for more details)
- Summary and team detailed reports will be posted on the [D-RATS 2022 wiki]

Accomplished 3 high-level objectives: investigated PR ConOps & Capabilities for Artemis exploration, incorporated JAXA pressurized rover design elements in testing, and 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 Mission Control Center (MCC) in Houston**
  - Networked a remote 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 remote 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-LTV Lighting & Navigation Simulation tests

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

Remote 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 support tests
- **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.

Pressurized Rover Cabin 1B 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 MCC, and tool carrier support)
    - Crew Follows (PR leads, providing precision navigation to subsequent location of interest, plus all the above)

Data Collection Areas

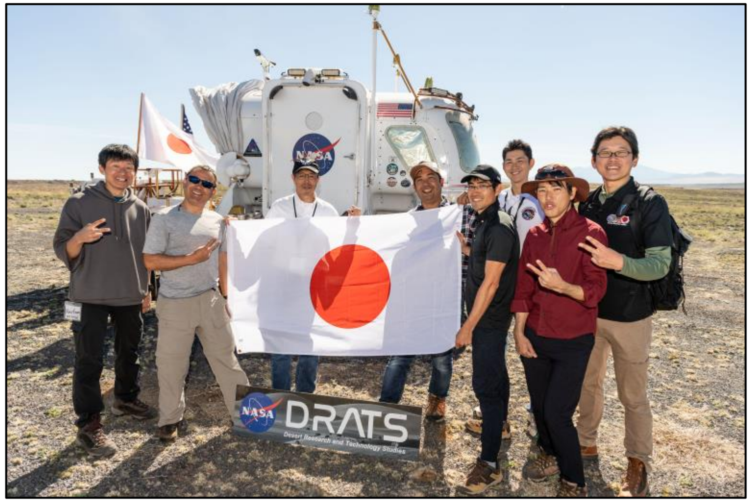
1. Driving with windows and with camera-projected displays
2. Exterior lights and cameras for driving and EVA support
3. Interior cabin layout
4. Habitation activities
5. Logistics stowage and management
6. Trash stowage and management
7. Exterior stowage and management of EVA tools and samples
8. Rover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

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 (SCICOM) with EV crew is both more efficient and achieves better science than funneling science conversations through 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 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 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 ConOps 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 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
  - 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’s Test Report** is available upon request from JAXA



JAXA team photo by rover

2.4 Objective-2 Summary (2 of 3) "Integrate with JAXA engineers & astronauts and incorporate JAXA PR design elements into testing"

- **Important note on Pressurized Rover Windows and Driving Cameras:**
  - Two "bookend" driving modes were evaluated this year: Driving with Cabin 1B windows and driving with JAXA-specified driving cameras projected onto internal cabin monitors
  - JAXA's PR concept is NOT "*no windows*" – but rather their goal is to understand the MINIMUM windows required (because windows = mass + other pressure vessel design challenges), how windows can best be augmented with camera views, and what specifications those cameras and associated internal displays should have (including FOV, screen resolution, etc.)

- **High-Level Pressurized Rover 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 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.

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"

- **Pressurized Rover Testing Caveats**
  - Only the extreme bookends on windows vs. cameras were tested this year.
    - Clearly, multiple huge windows lends superior mission performance over no windows, limited cameras, and flat screens to assimilate the camera views.
  - The camera mode tested at D-RATS-22 (external cameras feeding flatscreen monitors) is well below what today's high-end technology allows.

- **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.

2.5 Objective-3 Summary (1 of 3) "Re-establish rover analog field-testing skills & capabilities to investigate Artemis architecture ConOps"

- **Next generation 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 & MCC) and out-of-sim needs
  - Remote 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
- **MCC capabilities developed in Houston**
  - Voice communication
  - Video
  - GPS tracking

Re-developed 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 MCC team in Houston is the right answer for MCC support of an analog test; but the 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. Remainder we think we understand how to solve 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

- **Recommendations for Future D-RATS Field-Test Support**
  - Find a different MCC facility 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

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

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 MCC in support of science and operations

- **Recommendations for Future D-RATS ConOps 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

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)

- **Documentary teams from Felix & Paul Studios and National Geographic documented crew missions**
- **The day after D-RATS 22 operations concluded was a scheduled Media/Outreach Day:**
  - 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 we used and ask questions of team experts
  - Media and Legislator Outreach was scheduled for the second half of the day
    - Elected officials who attended were the Mayor of Flagstaff Paul Deasy, AZ State Sen. Theresa Hatathlie and staffers for Sen. Sinema and Re. O’Halleran
  - 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

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 test subjects were fitted with a wearable monitor, which the H-3PO team retrieved data from after each test.
  - The H-3PO test report will be posted on the D-RATS 2022 wiki

- **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-test dates to Lunar LiTES team and provided access to field facilities during tests
  - Included Lunar LiTES team in media outreach day
  - The Lunar LiTES test report will be posted on the D-RATS 2022 wiki

Two engineering crew 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.

2.8 PR/LTV Design Takeaways (1 of 2)

Target Audience: PR Project, LTV Project

- **Driving using Cameras only or Windows**
  - *Using the test-configuration we had* for camera-only 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 untested might have greatly enhanced crew situational awareness of terrain hazards, best traverse path selection, and science context, e.g.,

    1. 3D 360 cameras
    2. VR headsets with HUD info
    3. LiDAR
    4. 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

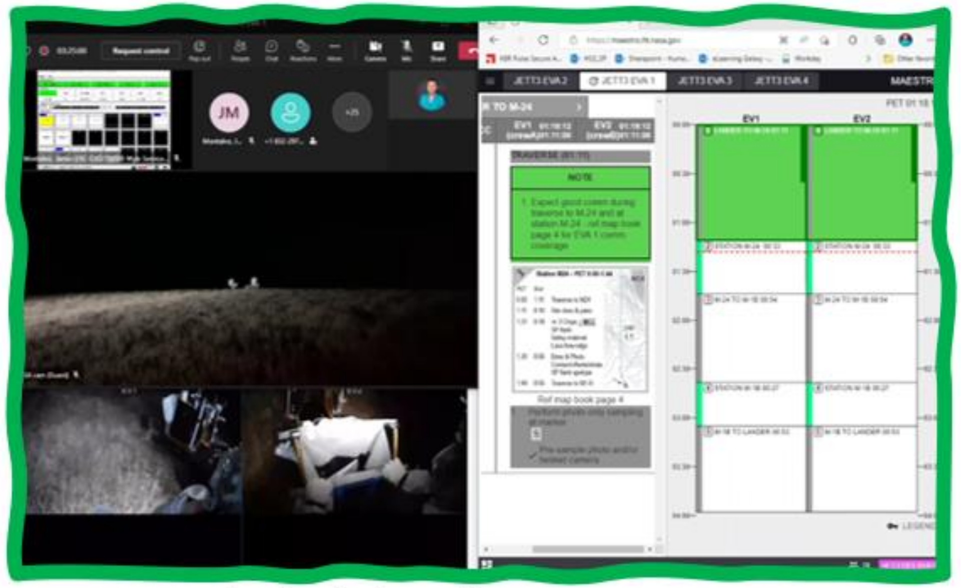
2.8 PR/LTV Design Takeaways (2 of 2)

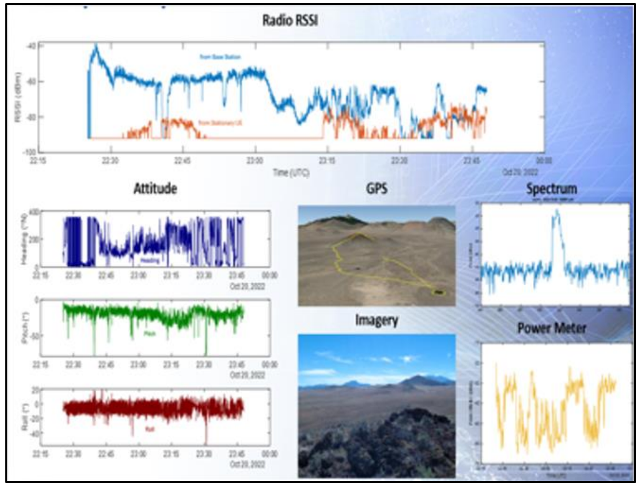
Target Audience: PR Project, LTV Project

- **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. These occur frequently in the real world but are absent in the current rockyard.

2.9 Full D-RATS Report and Team Reports

- This report summarized D-RATS analog tests performed near Flagstaff Arizona in October, 2022
- A detailed D-RATS 2022 report and appendices will be posted on the D-RATS 2022 wiki
- The following team reports will also be posted on the wiki and will be included as appendices in the full report:
  - D-RATS Science Lessons Learned
  - JAXA D-RATS ‘22 Quick Summary
  - H3PO EVA Heart Rate Data Analysis
  - Lunar LiTES Test Report





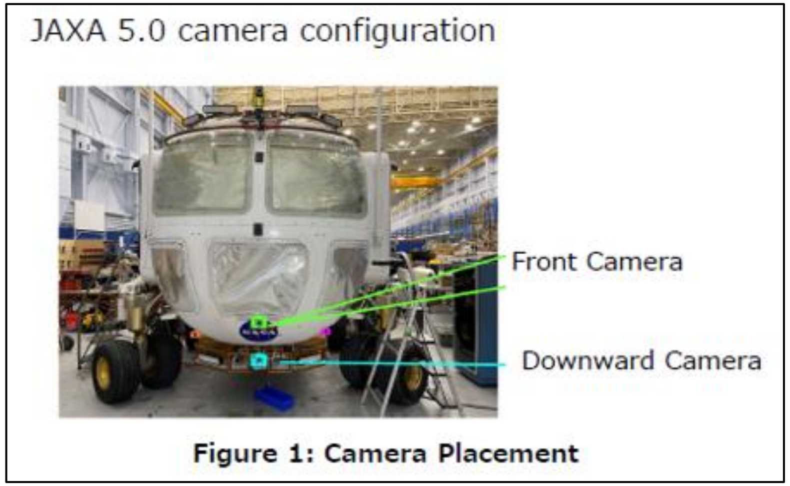


Figure 1: Camera Placement

2.10 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 (SA)

- **Stakeholders & Contributors:**

JSC
HQ
KSC
GSFC
ARC
GRC

Acronyms

AC	–	Air Conditioner
ADO	–	Architecture Development Office shorthand for M2MADO
BPLF	–	Black Point Lava Flow
CAPCOM	–	Capsule Communicator (communicates with flight crew)
Comm	–	Communications
ConOps	–	Concept of Operations
CY	–	Calendar Year
D-RATS	–	Desert Research And Technology Studies
EHP	–	Extravehicular Activity and 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
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
LiTES	–	Lunar LTE Studies
LTE	–	Long Term Evolution (in communications)
LTV	–	Lunar Terrain Vehicle (unpressurized)
M2M	–	Moon to Mars
M2MADO	–	Moon to Mars Architecture Development Office
MCC	–	Mission Control Center
MPH	–	Mobile Pressurized Habitat
NASA	–	National Aeronautics & Space Administration
Op Cons	–	Operations Concepts
Ops	–	Operations
PAO	–	Public Affairs Office
PR	–	Pressurized Rover
PWS	–	Portable Water Supply
SA	–	Strategy & Architectures
SA	–	Situational Awareness
SER	–	Science Evaluation Room
SCICOM	–	Science Communicator
SMD	–	Science Mission Directorate
SRR	–	System Requirements Review
USGS	–	United States Geologic Services
VR	–	Virtual Reality
xEVA	–	exploration EVA
xInfo	–	exploration Info