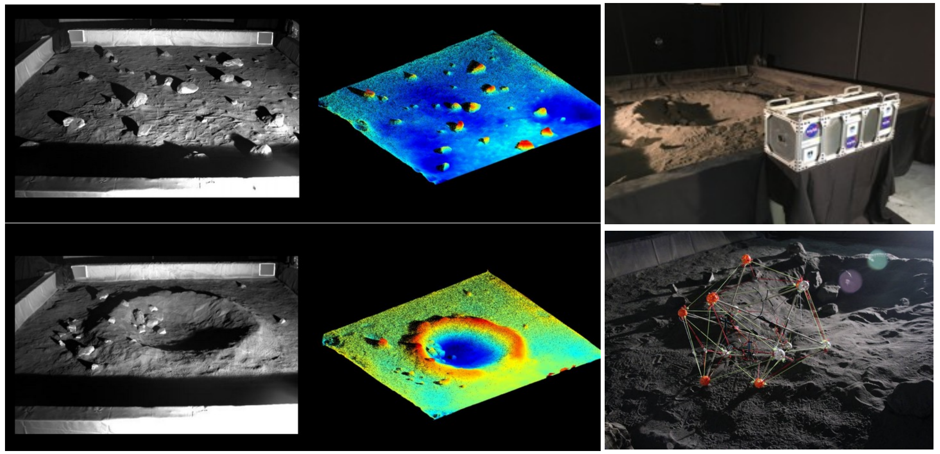
Lunar Terrain Vehicle (LTV)

Center Capabilities:

Silicon Valley

NASA Ames Research Center

Regolith Testbed for Development & Testing



KEY ATTRIBUTES / COMPETENCY

The current facility contains two testbeds: the first has the largest collection (approximately 8 tons) of JSC-1A lunar lowlands regolith simulant in a testbed that measures 4m x 4m, and the second has over 12 tons of Anorthosite highlands simulant. The facility can be configured to suit the needs of the desired testing and is equipped for dust mitigation and safety oversight.

Potential capability improvements (currently awaiting funding) include a lighting and video recording system and support structure.

CHALLENGE ADDRESSED (HLS & LTV)

The SSERVI Regolith Testbed could help numerous Artemis projects including the HLS and LTV. Hardware and environmental testing scenarios include, but are not limited to, surface system interface and mobility, dust exposure and mitigation, terrain relative navigation sensors, regolith handling and sampling, additive printing and sintering technology development, electrical couplers and interfaces, granular mechanics, surface physics, and robotics integration.

HERITAGE

Initiated by 2009 Centennial Challenge Regolith Mining Competition. Past users include:

- NASA VIPER Mission
- Ames Research Center, Intelligent Robotics Division
- Universal Studios
- SSERVI Teams

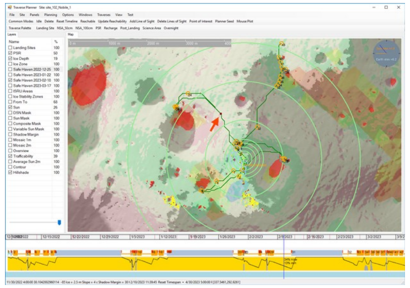
SUMMARY

The SSERVI-managed Regolith Testbed is available to the planetary science community, including CLPS and commercial developers. Thus far, the testbed has been used to conduct studies on optical sensing, drill testing, ISRU ID and extraction techniques, and remote robotic outreach activities. The testbed can accelerate innovation from idea generation thru iterative testing and can quickly drive design improvements for science and technology projects. In addition, the testbed can help understand the basic effects of continued long-term exposure to dust in a simulated analog test environment.

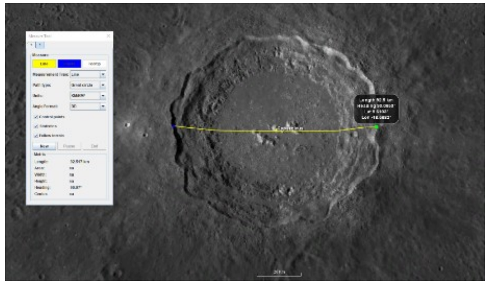
APPLICATIONS BEYOND

The Regolith Testbed is an excellent test environment for the next phases of the Artemis Program. Future uses could include: testing ISRU methods for for fuel, water and other resources; terrain-relative navigation sensor development, and testing robotic sensors using LIDAR, radar, and stereo vision to help robots maneuver safely in dusty environments. Robots are currently under development for regolith surface preparation to create landing pads for landers, and the testbed could benefit research involving the extraction of metals from regolith using molten regolith electrolysis, regolith as a manufacturing feedstock for additive printing, sintering, and manufacturing using regolith.

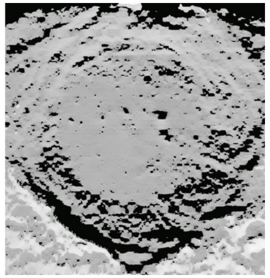
Tools for Traversing the Lunar Surface



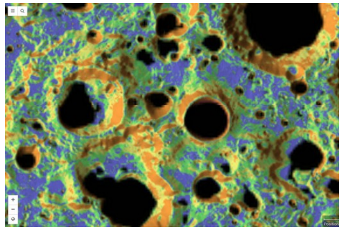
Sample multi-lunar-day traverse



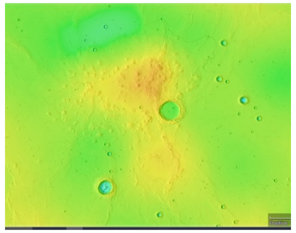
Measurement of Copernicus crater



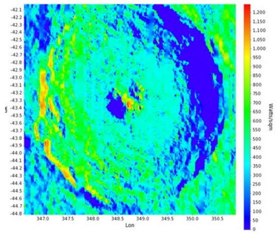
Surface Potential Analysis



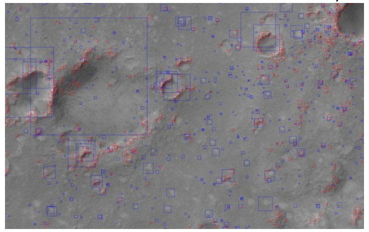
South Polar Slope Map with PSR Overlay



Blend of LASER Altimetry and Gravity Mapping



Lighting Analysis



Crater and Boulder Hazard Analysis

CHALLENGE ADDRESSED (HLS, LTV, other Artemis): The planning of robotic and human traverses requires integrating a complex array of engineering and scientific constraints and preferences. NASA Ames has three unique traverse tools for navigating the lunar surface.

SUMMARY: SSERVI manages the Moon Trek Portal which allows users to study the lunar surface as seen through the eyes of many different instruments aboard many different spacecraft, even from different nations. The user client is web-based, with no requirement for purchase or installation of software beyond a current web browser.

Celestial Mapping System (CMS) provides a toolkit of features for visualization and analysis that would enable lunar and cis-lunar domain/situational awareness, in-situ operations, planning, visualization and analysis of subsurface features.

Tools based on Lunar Reconnaissance Operations (LRO) data and developed for the VIPER lunar rover mission provide maps of surface lighting, temperature, line-of-sight to ground stations, and proximity to permanent shadow and other locations on the lunar surface.

KEY ATTRIBUTES / COMPETENCY

In addition to serving visualization of mapped data products, the Moon Trek portal provides analysis tools measuring distance, elevation profiles, solar angle, slope, crater and boulder hazards, lighting, and electrostatic surface potential, and more.

CMS offers flexibility to update to the latest imagery and terrain datasets as they are being acquired. The CMS measurement tools are more precise than those that are originally built as 2D and later extended to 3D.

The LRO data-based tools are mature evaluation tools currently feeding products into traverse planning for VIPER rover. They provide efficient generation of lighting and communications maps for polar regions.

HERITAGE

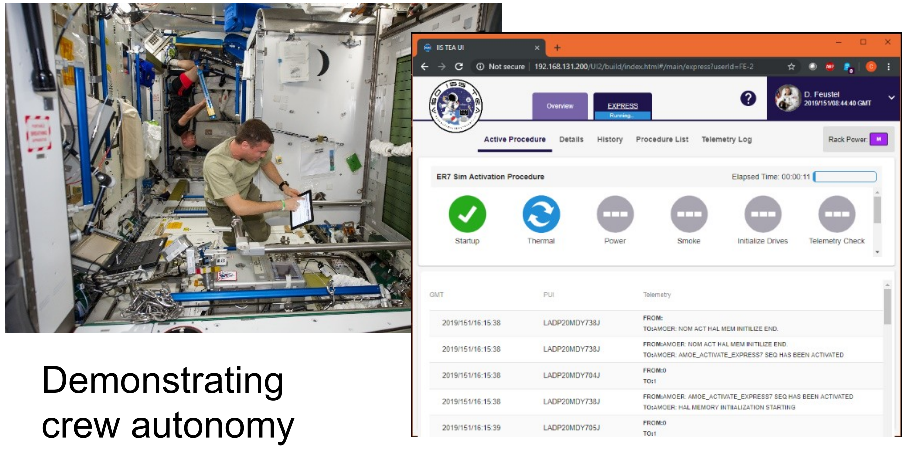
Moon Trek is the successor to our earlier Lunar Mapping and Modeling Portal (LMMP).

CMS stems from the NASA WorldWind application.

LRO data-based tools were developed for Resource Prospector (RP) and are now in use for VIPER lunar rover mission.

APPLICATIONS BEYOND: The Ames analysis tools and visualization capabilities for traversing the lunar surface will enable sustained operations on and exploration of the Moon and beyond. The capabilities will facilitate traverse planning, ISRU, and characterization of expanded areas of lunar operations. The tools are scalable to all spheroidal celestial bodies in our solar system hence, allowing for visualization and analysis on Martian and Venusian terrains, and rendering of subsurface structures on other worlds, such as Mars lava tubes, and Europa and Enceladus subsurface oceans.

Autonomous Mission Operations



Demonstrating crew autonomy onboard ISS

CHALLENGE ADDRESSED (HLS, Gateway, LTV)
Autonomous Mission Operations during Gateway and LTV missions are critical to improve flight controller and crew situational awareness and responsiveness during ascent/descent operations and during dormant periods.

KEY ATTRIBUTES / COMPETENCY
Ames has decades of expertise in autonomy enabling technology for spacecraft and UAVs. Includes multiple in-space missions, current HEOMD AES funding / Gateway engagement, and terrestrial applications (UAVs). Leverages existing autonomy technology funded by HEOMD / Gateway engagement to deliver critical capability to Gateway:

- Fault management solution baselined by Gateway program.
- Ongoing autonomy investment by AES and Gateway program.
- New investment by Gateway program to develop autonomous life support for Mars forward.

SUMMARY
Develop and demonstrate LTV Autonomous Mission Operations for use during lander missions, to improve flight controller and crew situational awareness and responsiveness. Technical approach uses NASA developed model-based automated planning and scheduling and plan execution technology.

This technology has been developed and demonstrated in simulations with NASA flight controllers and onboard the International Space Station (ISS). Elements of the technology have been integrated with flight software (e.g. CFS) and integrated with user interfaces (crew displays, flight controller fault displays) and will be further developed for autonomous ECLS.

Technical approach will use relevant engineering models (schematics, FMEAs, etc.) to enable Gateway autonomy for dormant operations, and during LTV missions to improve flight controller and crew situational awareness and responsiveness.

HERITAGE
Frank et al. 2015. Demonstrating autonomous mission operations onboard the international space station. Proc. AIAA Space Conference and Exposition.
J. Badger, J. Frank. Spacecraft Dormancy Operational Design for a Crewed Martian Reference Mission. Proc. of the AIAA Space Conference, 2018.
Aaseng et al.. Development and Testing of a Vehicle Management System for Autonomous Spacecraft Habitat Operations. Proc. of the AIAA Space Conference, 2018.

APPLICATIONS BEYOND
Autonomous operations is a critical mission capability as we shift our goal toward sustainable presence on the moon and then Mars

Crew Interfaces, Operations & Equipment

CHALLENGE ADDRESSED (HLS, Gateway, LTV)

Gateway and HLS program objectives (e.g., HLS-Obj-011) include provision of vehicle design and capabilities that enable effective and efficient crew performance throughout the mission. Critical to this objective are the interfaces and equipment that provide the crew with the capability to monitor and control vehicle systems and operations during all Artemis phases.

SUMMARY

Commercial provider(s) will need to validate and verify the crew interface software and hardware, as well as operations concepts they develop for Artemis lunar missions. This will require extensive access to NASA experience and expertise in the design and theory underlying human-system interface of heritage aerospace vehicles. It will also require extensive access to NASA experience and expertise for empirical validation of novel interfaces, equipment and operation concepts via human-in-the-loop (HITL) testing.

KEY ATTRIBUTES / COMPETENCY

- Extensive experience relevant to crew vehicle interface/display design and development for a variety human-piloted air and space vehicles—e.g., fixed-base aircraft flight-deck simulators, moving-base vibration simulators, Orion display design.
- Pioneering contributors to the development of modern virtual- and augmented-reality (VR and AR) display, spatialized audio, and haptic simulation technologies—e.g., VR Shuttle exterior visual inspection and AR air traffic control concepts.
- Extensive experience in development, analysis, and empirical validation of novel multi-modal (visual, auditory, and haptic) interfaces—e.g., Mars surface exploration.
- Extensive human-system performance/interaction research/testing experience and expertise, including study design and statistically-driven data analysis—e.g., hardware/ software development and human-in-the-loop testing that underpins crew vibration limits and countermeasures for Orion and successor Artemis vehicles.

HERITAGE

Researchers at ARC, beginning during the 1980s, initiated the first wave of personal simulators with relatively low cost head-mounted virtual reality, spatialized audio hardware/firmware, and computer-controlled haptic (force-feel) simulators.

APPLICATIONS BEYOND

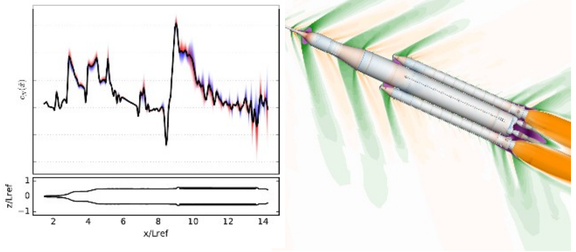
Experience and lessons learned from Artemis Phase 1 will lead to refinements of interface, operations, and equipment concepts for later lunar missions & eventual Mars missions.

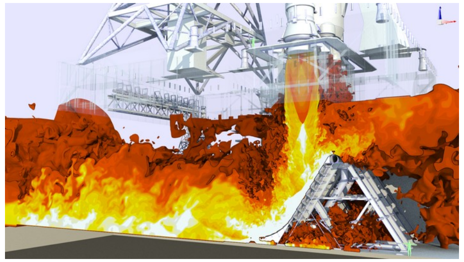
Advanced Modeling & Simulation Support

Lunar Terrain Vehicle

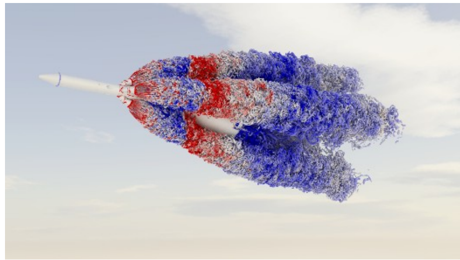
High-fidelity modeling and simulations to develop induced environments of space vehicles

Ascent Aero-database





Launch Environment Pad 39B



Orion Supersonic Abort Scenario

CHALLENGE ADDRESSED (HLS, Gateway, LTV)

Launch architectures supporting Gateway missions require induced environment assessment for certification. NASA's high-fidelity modeling and simulation capabilities, subject matter experts (SME) and computational tools, will accelerate the certification process.

SUMMARY

Existing modeling and simulation capabilities for SLS and Orion will be extended to accommodate the challenges with Artemis. Industry can leverage SME experience and tools for establishing the induced environments, such as launch environment, vibro-acoustic environment, ascent aero-database, stage separation aero-database, etc.

KEY ATTRIBUTES / COMPETENCY

- Integrated database development
- Ascent aerodynamics
- Stage/Booster separation
- Multi-species formulation with multi-phase analysis for water-based sound-suppression system, and ascent tank sloshing.
- Automated arbitrarily complex geometry for rapid turnaround time in case of short design cycles and/or mission critical deadlines
- High-order accurate simulations in space and time
- Uncertainty analysis for complex databases
- End-to-end analysis, reducing handoffs
- High-performance computing expertise and resources for large scale, rapid simulation

HERITAGE

Ames computational aerosciences modeling and simulation team supported the Space Shuttle and Constellation programs, and currently supports the SLS and Orion programs. Many tools, developed "in-house", have been used extensively in these programs.

APPLICATIONS BEYOND

Ensuring a safe pre-launch, engine ignition, lift-off, ascent, and stage separation are critical to avoiding launch disasters as well as potential delays. These capabilities will be required for the certification of the commercial services

Exploration Interfaces for EVA

KEY ATTRIBUTES / COMPETENCY

- Ames has capabilities to quickly prototype and field test exploration interfaces for EVAs.
- Ames has experience developing and deploying human-centered designed software for mission operations.
- Ames has a vast experience in:
  - science-driven development and evaluation
  - field analogs
  - evaluating concepts of operations, tools, and software for extreme environments.

CHALLENGE ADDRESSED (HLS, LTV)

For HLS and LTV, science-driven extravehicular activities (EVAs) will be a new paradigm for exploration. Concepts of operations are still being defined for surface EVAs which will have a greater number of components than microgravity EVAs.

HERITAGE

Ames has developed and evaluated prototype systems, including NEEMO and BASALT, field tested in using Earth analogs, with and without comm delays.

SUMMARY

Flexible exploration, resource constrained spacewalks, science & task management, and intermittent communication will require new concepts of operations that leverage integrated, modern software tools to support new EVAs. Ames is collaborating with JSC to develop future EVA Operation Systems.

APPLICATIONS BEYOND

Developing and evaluating surface EVAs will be essential for mission success towards sustainable Moon presence and eventual exploration of Mars.

Human Centered Software and System Design and Evaluation

Lunar Terrain Vehicle

KEY ATTRIBUTES / COMPETENCY

- Extensive expertise and experience in design and validation of advanced display/control interfaces, data management systems, and adaptive planning tools, for a variety of human-piloted air and space vehicles.
- Extensive expertise and experience in Human-In-The-Loop (HITL) testing of human-system design and architecture impacts on overall system performance, including experimental design, data collection/analysis, and the appropriate tailoring of simulator fidelity.
- Extensive expertise and experience in human-computer interface design & assessment in aerospace applications.
- Unique HITL facilities for testing under spaceflight conditions for iterative HSI design, including multi-axis large-motion (VMS), long-arm centrifuge with vibration capability for ascent/descend simulations (20-g Centrifuge), multi-axis vibration (Human Vibration Lab), & sleep/circadian testing (Fatigue Countermeasures Lab).

CHALLENGE ADDRESSED (HLS, Gateway, LTV)
HLS architecture and HW/SW design must be human-centric to provide for human health needs, to harness human capabilities for overall system resilience, and to minimize vulnerability to human limitations and errors. Artemis Phase 1 risk will be significantly reduced with robust HSI architecture and design that enables prompt and effective crew action under both nominal and off-nominal conditions.

HERITAGE
HITL validation on the 20g of reach standards under combined G-force and vibration in support of human exploration HSI requirements for and off-nominal launch operations (Orion, Commercial Crew Program)

HITL validation of display legibility under launch vibration

SUMMARY
NASA Ames personnel have decades of experience in the writing, validation, and verification of human system integration requirements, and in assessing effective crewed vehicle/habitat designs. ARC SMEs have expertise in the design and evaluation of Multimodal Displays and Controls (visual, auditory, haptic), Human Workload, Performance, Usability, & Error Analyses, Impacts of Spaceflight Environments (acceleration, vibration, tilt, noise, sleep loss & circadian misalignment, vestibular adaptation), and Vehicle Data Management & Onboard Adaptive Planning.

APPLICATIONS BEYOND
Experience and lessons learned from Artemis Phase 1 will lead to future lander architecture refinements of interface, operations, and data management concepts for later lunar missions and eventual Mars missions.