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Capabilities Deep Dive

September 25, 2019

Dr. David Korsmeyer, Assoc Center Director for R&T
Dr. Sally Cahill, Ames Capabilities POC

Agenda

- Introduction – Dr. David Korsmeyer
- Facilities for Testing and Analyses
- Technology
  - Onboard Technology
  - Operations Technology
  - Earth-hosted Technology
- Science
- Closing – Dr. David Korsmeyer

Purpose of the Briefing

- Today is an opportunity for Industry to better understand Ames' capabilities relevant to HLS.
  - Ames considers its capabilities to be both unique and world-class
- Through this forum, we hope you will gain an improved understanding of Ames' capabilities
  - Offline meetings are encouraged to further develop Appendix H support content and ideas
- Today's audience consists of potential Appendix H vendors
  - NASA participants have no knowledge of and cannot provide guidance to Appendix H Requirements or Industry Comments previously submitted
  - See FedBiz Ops for official contacts
    - Also for Ames, contact Sally Cahill, sally.a.cahill@nasa.gov, 650.604.5671.

Questions?

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- During the meeting you will have the opportunity to ask questions and ‘upvote’ previous questions asked by other participants so we can address these questions.

- Please submit your questions anonymously to Conference IO:

  https://arc.cnf.io/sessions/r84r/#!/dashboard

- All questions will get addressed either today or will be posted to the website shortly after the meeting

  https://www.nasa.gov/ames/AmesCapabilityDeepDive

- For more information about how to access NASA Ames resources/services and to connect with subject matter experts contact:

  Sally Cahill, sally.a.cahill@nasa.gov, 650.604.5671.

Appendix H: Center Points of Contact

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Attachment B: NASA Center Points-of-Contact

Next Space Technologies for Exploration Partnerships -2 (NextSTEP-2)

Appendix H: Human Landing System Integrated Lander

Broad Agency Announcement NNH19ZCQ001K_APPENDIX-H

The table below lists the Center Point-of-Contact for each NASA Center should an offeror choose to inquire about relevant facilities or expertise.

Center	Point-of-Contact
Ames Research Center	Chad Frost, 650-604-1798, chad@nasa.gov
Armstrong Flight Research Center	Charles Rogers, 661-276-7572, charles.rogers-1@nasa.gov
Glenn Research Center	Gary Ruff, 216-433-5697, gary.a.ruff@nasa.gov
Goddard Space Flight Center	Mark Lupisella, 301-286-2918, mark.l.lupisella@nasa.gov
Jet Propulsion Laboratory	Dave Eisenman, 818-354-4430, david.j.eisenman@jpl.nasa.gov
Johnson Space Center	Carlos Westhelle, 281-483-4816, carlos.h.westhelle@nasa.gov
Kennedy Space Center	Julius Edelmann, 321-861-7526, j.edelmann@nasa.gov
Langley Research Center	David Dress, 757-864-5126, david.a.dress@nasa.gov
Marshall Space Center	Jason Adam, 256-961-2317, jason.r.adam@nasa.gov
Stennis Space Center	Lauren Underwood, 228-688-2096, lauren.w.underwood@nasa.gov

NASA Centers, and Ames

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Core Competencies at Ames Today

A broad and unique research center

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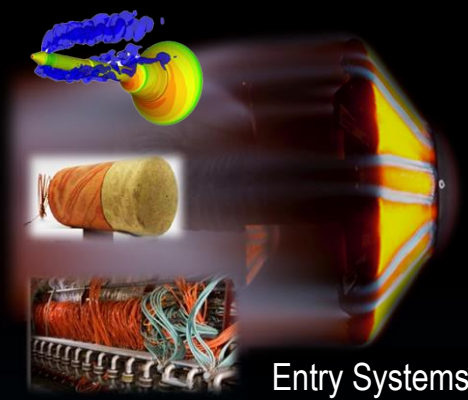
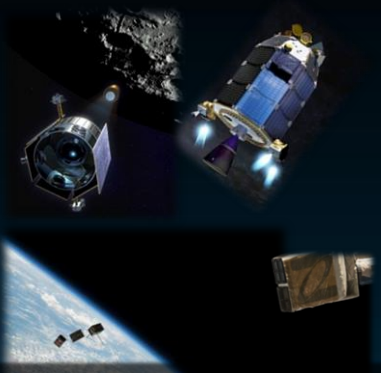
Air Traffic Management



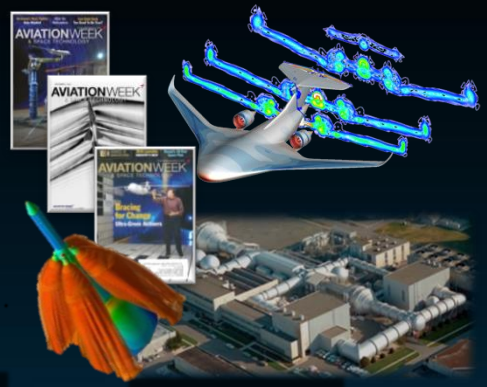
Entry Systems

Advanced Computing & IT Systems

Intelligent/ Adaptive Systems

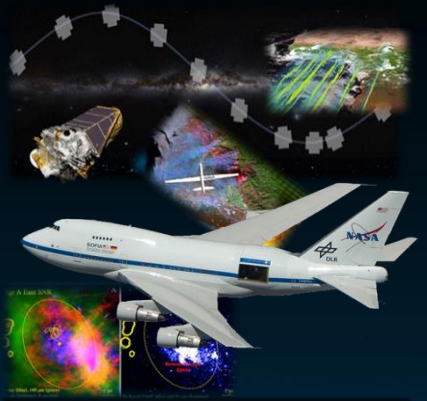


Cost-Effective Space Missions



Aerosciences

Astrobiology and Life Science



Space and Earth Sciences

Major Research Facilities

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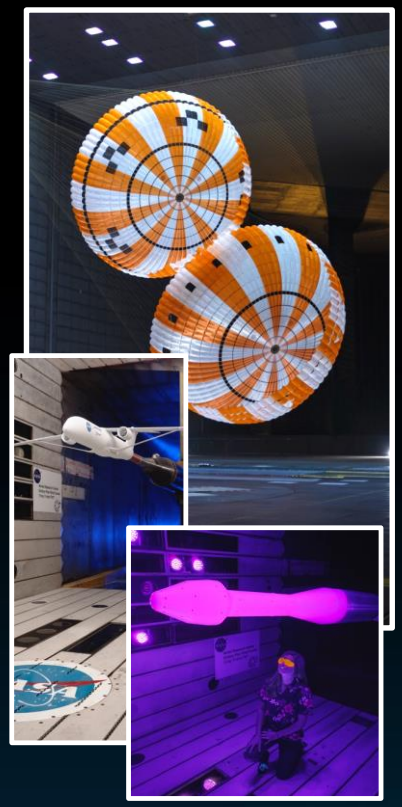
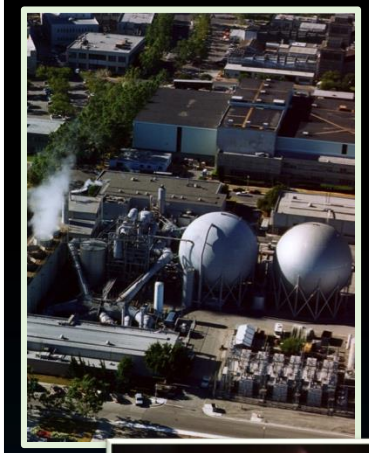
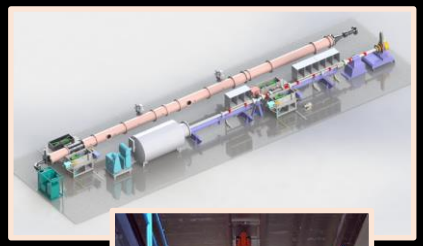
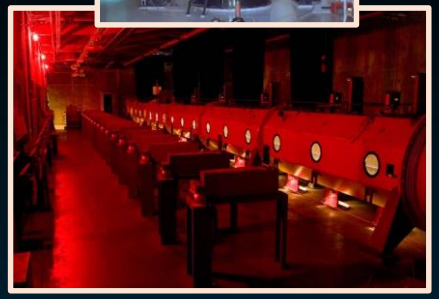


Wind Tunnels



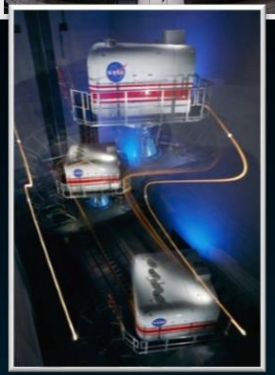
ARC Jet Complex





Range Complex



Simulators

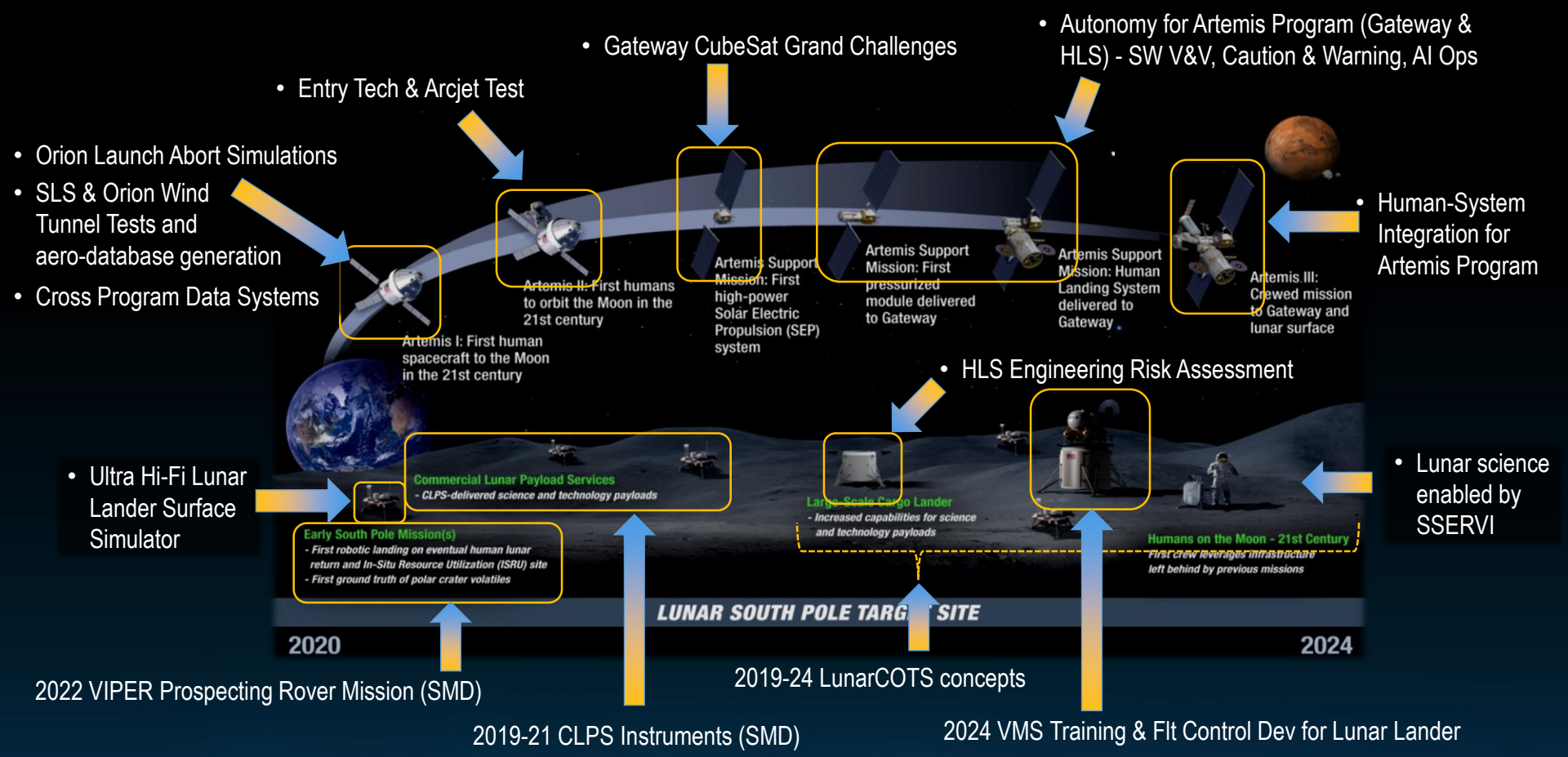


Advanced Supercomputing

Ames for Artemis

Phase 1: Lunar Surface by 2024

List of some Enabling Capabilities



Ames Support of Lunar Science

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Polar Landers and Rovers (VIPER)

- First **direct measurement of polar volatiles**, improving our understanding of their lateral and vertical distribution, as well as their physical state and chemical composition
- Information on the geology of the South-Pole Aitken basin, the largest impact in the solar system

Non-Polar Landers and Rovers (CLPS Instrumts)

- Ability to explore scientifically valuable terrains not explored by Apollo. Examples include:
- Land at a lunar swirl and make the first surface magnetic measurement
- Visit young volcanic features such as Ina to understand volcanic evolution
- PI-led instruments - Discovery-class science such as geophysical network and visiting lunar volcanic region

Artemis 1 – CubeSat Program

(7 CubeSats: BioSentinel, 3x CubeQuest, LunarFlashlight, 2x BAA)

- Over a dozen satellites will be launched as part of Artemis 1

Orbital Data (SSERVI)

- Cubesats delivered by CLPS providers, or comm/relay spacecraft could acquire new scientifically valuable datasets
- Global mineral mapping (including resource identification), global elemental maps, improved volatile mapping

In-Situ Resource Initial Research (SSERVI and VIPER)

- What is the composition and ability to use lunar ice for sustainment and fuel

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Ames Lunar Missions:
Past, Present, and Future

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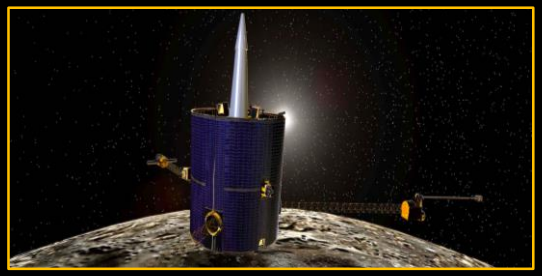
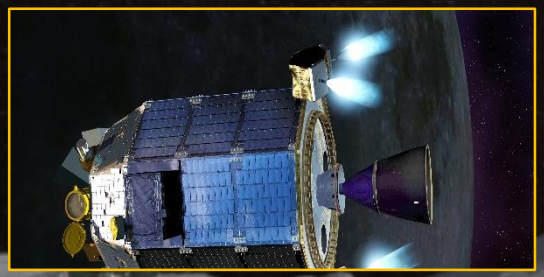


Lunar Prospector (Launched 1998)
- First global surface composition
- Polar volatiles & global magnetic maps

LCROSS (Launched 2009)
- Impacted lunar south pole
- Evidence for water ice in cold, shadowed regions



LADEE (Launched 2013)
- Lunar atmosphere and dust
- First deep space laser communication

VIPER (to be launched in 2022-23)
- Robotic rover at lunar pole
- In-situ resource characterization
- Commercial lander planned

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VIPER (Volatiles Investigation Polar Exploration Rover)

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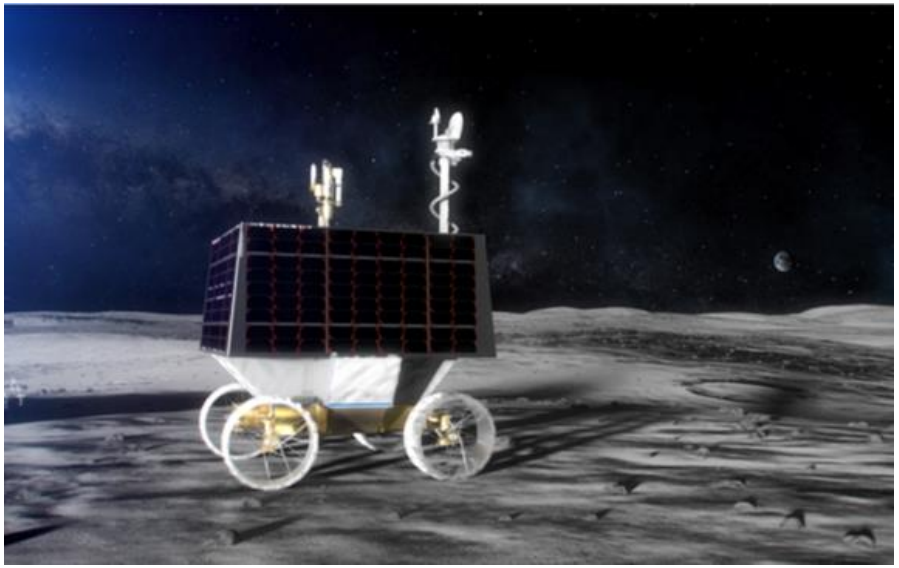

CHALLENGE ADDRESSED

Directly characterize the nature/distribution of volatiles at the lunar poles, potentially enabling great cost savings for future exploration missions (fuel), as well as enabling lunar surface habitation (Water, O2, Fuel)

SUMMARY

The VIPER Mission will reveal the lateral and vertical distribution and physical state / composition of lunar volatiles.

KEY ATTRIBUTES / COMPETENCY

VIPER will develop a solar-powered roving platform which can navigate through extended periods of darkness; this design will enable a multi-lunar day mission construct without the cost and complexity of Nuclear-based solutions

VIPER will build Lunar resource models, steering the future commercial marketplace. These resource models will be pivotal in enabling various different means for harvesting volatiles resources, at surficial, shallow and deep depths, all instrumental in creating a new lunar resource ecosystem

VIPER will be a pathfinder for lightweight, risk-tolerant mission execution, following on the heels of the successful LCROSS mission

HERITAGE

The mission team and approaches are extended from the former Resource Prospector mission planning activity. The rover, several instruments and mission plans were very mature, accelerating the time to get to VIPER launch readiness

APPLICATIONS BEYOND

VIPER mission development will define Agency technical understanding of mobility and operations development in an airless, polar region – fundamentally different than Mars mission design and planning

Ames' HLS relevant areas of interest

Facilities

- (Testing and Analyses capabilities)

Technologies

- (Onboard, Operations focused, Earth-hosted)

Science

- (Crew Health, Life support, Lunar Science)

Ames for Artemis
Facilities for Testing and Analyses

Vertical Motion Simulator (VMS)

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https://www.nasa.gov/vms-lunar

Vertical Motion Simulator (VMS)

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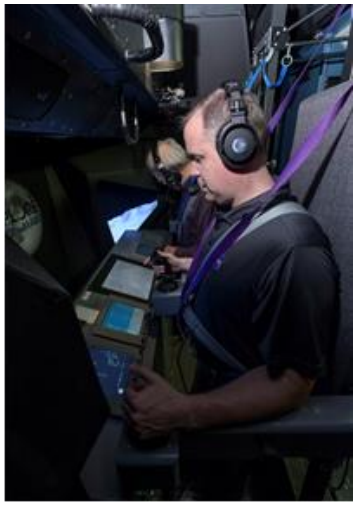


Interior and exterior view of the VMS during HLS simulation.

CHALLENGE ADDRESSED (HLS)

The manually controlled descent and landing on the lunar surface is probably the most critical and difficult phase of flight for the HLS. The VMS, with its large motion envelope, is the only existing ground based simulator capable of supporting the development, testing, and certification of the HLS to meet manual control handling qualities requirements.

SUMMARY

Significant improvements in ground-based simulation fidelity since the Apollo era, and the availability of flight-realistic motion make the VMS the most cost-effective solution for HLS development, testing/certification, and crew training. As safety risks are minimal, the VMS offers adaptability and flexibility in evaluating, testing and certifying HLS systems, and training crews on emergency and off-nominal situations.

KEY ATTRIBUTES / COMPETENCY

There are three broad areas where the VMS can add value and reduce risk to the Artemis Program:

• Development – May be used to obtain high-quality human-in-the-loop data required for development of flight controls, RCS sizing, and operational and test procedures.

• Testing & Certification – Offers engineering realism necessary for testing and certifying the HLS.

• Training – Provides cost-effective training on critical maneuvers including nominal and off-nominal situations with adequate fidelity to ensure positive crew training.

HERITAGE

Lunar Lander Handling Qualities Experiments - NASA developed a handling qualities standard for piloted spacecraft, first lunar lander study conducted in May 2007.

Space Shuttle Vehicle Landing and Rollout Engineering and Training - 10,000+ training runs performed; 85 shuttle engineering studies that led to 20+ flight rule changes.

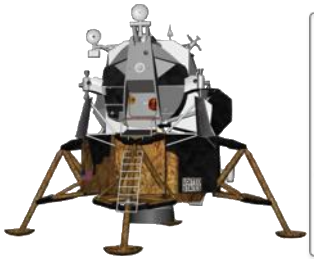
Joint Strike Fighter (JSF) Industry Pre and Post Award Evaluations - JSF program leveraged knowledge on vertical landing dynamics and control from prior VMS studies to design the X-32B and X-35B. Each manufacturer then used VMS to evaluate their designs and mitigate flight test risks.

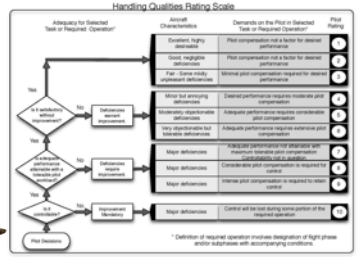
APPLICATIONS BEYOND

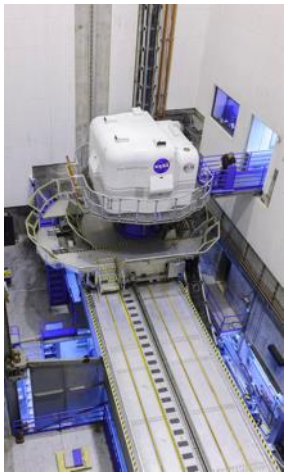
Technical approach can be extended for 2028 Lunar and future Mars applications

https://www.nasa.gov/vms-lunar

Vehicle Handling Qualities Evaluation







High fidelity piloted simulation addresses Level 1 vehicle handling qualities.

KEY ATTRIBUTES / COMPETENCY

- Extensive experience in crew vehicle interface/display design and development for a variety human-piloted air and space vehicles.
- Extensive experience in HITL ground testing of human-system interaction, vehicle handling qualities, including study design, data analysis, and appropriate fidelity simulator development.
- Extensive expertise in crew training and evaluation..
- Agency-unique facilities that enable a range of motion-based HITL and crew training paradigms including multi-axis large-motion (VMS), long-arm centrifuge with single-axis vibration capability (20-G Centrifuge), and multi-axis vibration (Human Vibration Lab).

CHALLENGE ADDRESSED (HLS)

HLS will require that crew to be able to manually pilot the lander during both descent to and ascent from the lunar surface under nominal and off-nominal conditions. Empirically validated analysis and modeling of vehicle and crew interfaces will be needed to ensure the design of robust controllable flight systems beginning from the first Artemis lander mission.

HERITAGE

Universally used Cooper-Harper rating for handling quality and NASA TLX for workload were invented at ARC. World-unique facilities such as the VMS have been used for decades in human-in-the-loop investigation of handling qualities and piloting skills for a wide variety of air- and space-craft. Beginning with Gemini and again for Orion, ARC has supported crew interface design V&V under spaceflight-representative vibration and G-loading.

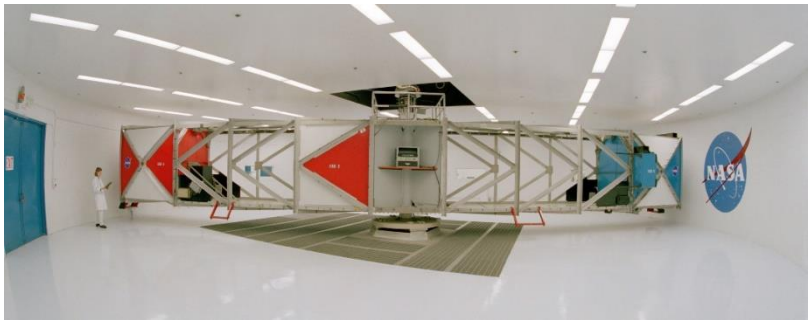
SUMMARY

Commercial provider(s) will need to validate the handling and ride qualities of the vehicle(s) they develop for Artemis. This will involve not only assessing how the vehicle responds to pilot inputs (i.e., handles), but also how crew interacts with system interfaces in the presence of vehicle's induced motion environment. In addition to modeling and analysis, such assessments will depend on human-in-the-loop (HITL) testing in high-fidelity motion simulators for verification and validation (V&V).

APPLICATIONS BEYOND

Lunar lander piloting and handling assessment for mission prototyping and crew training will continue throughout the lunar program and will need to be extended and enhanced for eventual Mars missions.

Vehicle Handling Qualities: Crew Interface Testing – The 20G Centrifuge



20G Centrifuge Rotunda

CHALLENGE ADDRESSED (HLS)

Manually controlled ascent and decent/landing with realistic g-loading is a critical phase of flight for the HLS. The 20G Centrifuge can simulate the propulsion-induced acceleration and vibration loads with a flight-like cabin environment (seats, instrumentation layout). Evaluation of crew ability to control spacecraft under combined g-loading and vibration can be assessed.

SUMMARY

The 20G centrifuge is the only facility in the US that can perform ascent and decent/landing Human-In-The-Loop testing that incorporate the effects of combined g-loading and vibration with existing rapid prototyping of candidate display and interface designs and con-ops. Spacecraft cockpit seating and instrument panel displays can be accurately modeled in the facility. Nominal and off-nominal manual control of lunar vehicle piloting can be tested in both the 20G Centrifuge and Vertical Motion Simulator (VMS) to provide a more comprehensive understanding of human performance for a candidate architecture/design in support of iterative human-centered design practices.

KEY ATTRIBUTES / COMPETENCY

- 20G Centrifuge is the only large radius human rated centrifuge operated by NASA
- Facility can provide up to 12.5 g of acceleration to human subjects and up to 20 g to other organisms or hardware. G loading can be steady state or programmed to follow a varying g profile.
- Realistic g-loading, vibration effects, seating, cockpit display(s) are uniquely available features.
- ARC has experience and expertise for both simulator operations and study design, data collection/analysis, and interpretation of findings.

HERITAGE

Early use in 1960's supporting Apollo program the effects of high g levels on plants and animals

Human studies include g-tolerance in various seating positions, visual perception and legibility studies, oculomotor control and reach studies, also Ares launch simulation with realistic seat vibration effects on test subjects visual and manual performance.

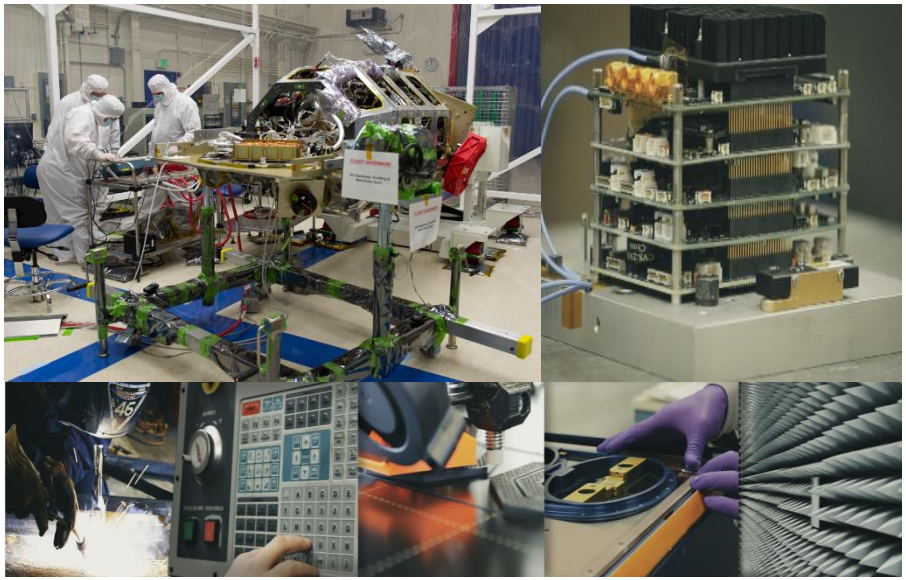
Launch simulation with g profiles of space shuttle and SpaceX Falcon 9 vehicles.

APPLICATIONS BEYOND

Testing and simulation approach can also be applied to future Mars decent and landing simulations.

https://www.nasa.gov/ames/research/space-biosciences/20-g-centrifuge

Manufacturing



CHALLENGE ADDRESSED (HLS & Gateway, Other Artemis)

Manufacturing of various hardware ranging from the research and development component level to complete systems certified for flight.

SUMMARY

The Ames Applied Manufacturing and Engineering Test Division provides hardware development, fabrication, assembly and test services to support all Ames manufacturing needs. Specializing in assisting researchers, scientists, engineers and others develop their concepts into prototypes and finished hardware for facility, laboratory or flight. We assist in the manufacturability of any and all projects and offer guidance to reduce manufacturing time and cost.

KEY ATTRIBUTES / COMPETENCY

NASA Ames provides expert fabrication technology for research hardware development, drawing review, consultation in fabrication and machining methods.

NASA Ames Manufacturing specializes in; additive manufacturing for rapid and precise prototyping, integration and assembly, adaptive test engineering, flight system development, environmental testing and much more.

Cradle to grave project management, consulting and estimating services for design, fabrication, assembly and testing. Specialize in assisting researchers, scientists, engineers and others develop their needs into concepts, prototypes and finalized hardware whether for spaceflight, laboratory use or for facilities.

Ames Craftsmen employ state-of-the-art manufacturing processes and are the most skilled technicians in the world able to evolve abstract ideas into tangible hardware for aeronautics, space flight and the advancement of science.

HERITAGE

Satellites, Rodent Habitats, Wind Tunnel Models/Supports & Hardware, Thermal Protection, Flight Hardware, SOFIA

APPLICATIONS BEYOND

Greatly increase the confidence of producing high quality hardware that meets or exceeds all requirements on schedule and budget.

https://inside.nasa.gov/ames/manufacturing-division

Environmental Testing

CHALLENGE ADDRESSED (HLS & Gateway, Other Artemis)

Environmental Testing of various hardware ranging from the R&D component level to complete systems certified for flight.

SUMMARY

The Ames Applied Manufacturing and Engineering Test Division provides hardware development, fabrication, assembly and test services to support all Ames manufacturing needs. Specializing in assisting researchers, scientists, engineers and others develop their concepts into prototypes and finished hardware for facility, laboratory or flight. We assist in improving the manufacturability of any and all projects and offer guidance to reduce manufacturing time and cost.

KEY ATTRIBUTES / COMPETENCY

Environmental Test Laboratory provides unique and extreme environmental testing, vibration and shock testing, thermal-vacuum testing, large and small-scale strain measurement, and instrumentation. Long history of satellite manufacturing development and innovation, trailblazing new approaches and sophisticated techniques in physical measurements, structural testing and modal analysis, specialized calibration, mass property measurement, advanced data acquisitions, and analysis.

Equipment:

Ling Vibration Table (5,000 lbf)

Impact Shock Machine (2,000 g)

Genisco Centrifuge (150 g)

Instron Fatigue Machine (10,000 lbf)

Tenney Thermal-Altitude Chamber (3'x3'x4') (65,000 ft)

Southwark-Emery Tensile Machine (60,000 lbf)

Abbess Thermal-Vacuum Chamber (2' x 2' x 3')

Dynavac Thermal-Vacuum Chamber (6' D x 10' H)

Thermal Cycling/Bakeout Chambers (3' x 3' x 3')

Temperature Baths (-40 ℃ to 100 ℃)

Load, Pressure, Acceleration, Temperature Acquisition

Center of Gravity and MOI Instrument (1,000 lbf)

OMT Tilt Table (2 Axis of Rotation)

Dynamic Signal Analyzer (32 Channels)

Strain Gage Installation & Measurement

General Instrumentation and Data Acquisition Systems

5 Ton Overhead Crane

Machining Tools

Portable ISO class 7 (10K) Cleanroom, 250 sq. ft.

Portable ISO class 7 (10K) Cleanroom, 80 sq. ft.

RFI/EMI Shielded Enclosure

HERITAGE

Genesat, Pharmasat, O/OREOS, Phonesat 1-4, TechEdSat 1-8, EDSN, Nodes, EcAMSat, CHOMPTT, LADEE, LCROSS, Pioneer Venus, Galileo

APPLICATIONS BEYOND

High confidence of producing high quality hardware that meets or exceeds all requirements on schedule and budget.

Regolith Testbed for Development & Testing

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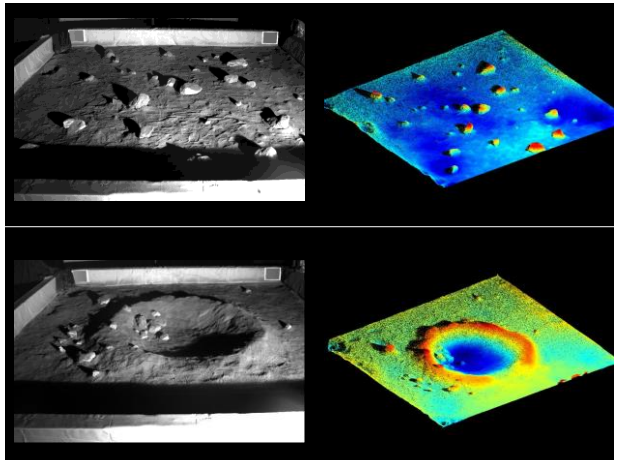

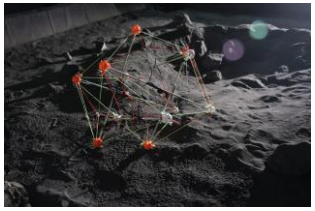

KEY ATTRIBUTES / COMPETENCY

The current facility contains the largest collection (approximately 8 tons) of JSC-1A lunar regolith simulant in a testbed that measures 4m by 4m. The facility also includes dust mitigation and safety oversight.

The regolith and testbed facility can be configured to suit the needs of the desired testing.

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

CHALLENGE ADDRESSED (HLS & CLPS)

The SSERVI Regolith Testbed could help numerous Artemis projects including the HLS and CLPS. 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:

- Optical sensing work and Polar Stereo Dataset
- Development and testing a drill-integrated neutron spectrometer

SUMMARY

SSERVI manages the Regolith Testbed and makes it available to the planetary science community, including commercial developers. Thus far, the testbed has been used to conduct studies on optical sensing and drill testing as well as 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 be utilized to help understand the basic effects of continued long-term exposure to a simulated analog test environment.

APPLICATIONS BEYOND

As with the near term testing, the Regolith Testbed can continue to provide an excellent test environment for the next phases of the Artemis Program. Future uses could include terrain relative navigation sensor development, testing robotic sensors utilizing LIDAR, radar, and stereo vision to help robots maneuver safely in dusty environments. Robots are also under development for the production and deployment of regolith surface preparation to create landing pads for landers. Testing methods for ISRU for fuel, water and other resources could also use the Testbed. These could involve the extraction of metals from regolith using molten regolith electrolysis, the use of regolith as a manufacturing feedstock for additive printing, as well as sintering and manufacturing using regolith.

Advanced Modeling & Simulation Support

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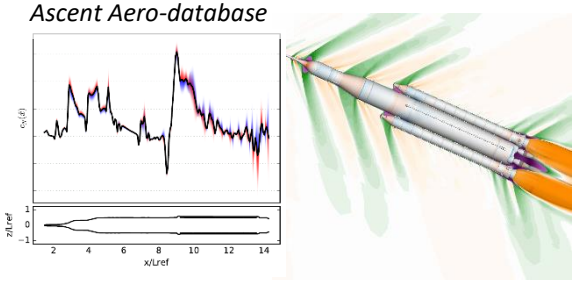
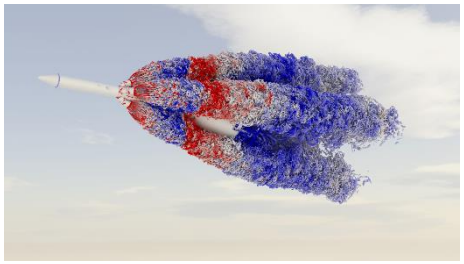
High-fidelity modeling and simulations to develop induced environments of space vehicles

Ascent Aero-database



Launch Environment Pad 39B



Orion Supersonic Abort Scenario

CHALLENGE ADDRESSED (HLS & Gateway, Artemis)

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

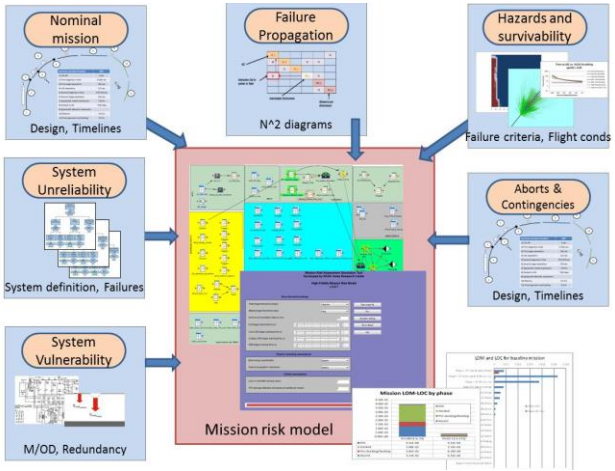
Ames computational aerosciences modeling and simulation team supported the Space Shuttle and Constellation programs, and currently supports the SLS and Orion programs. Many tools, developed "in-house", have been used extensively in these programs.

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

https://www.nas.nasa.gov

Engineering Risk Assessment (ERA)



ERA Tools are currently used throughout the life cycle of NASA spaceflight projects.

CHALLENGE ADDRESSED (HLS & Gateway)

Artemis requires quantitative risk assessment capabilities to

- Establish risk/reliability requirements for partners
- Support risk-informed design trades for architecture options
- Validate crew safety requirements

SUMMARY

Existing ERA models of lunar systems will be extended to represent the Artemis architecture. The updated model will provide risk-informed design trade study support throughout all program phases, quantitative feedback to define valid system requirements, and a means of verifying safety and reliability requirements. A safer, more effective campaign will be achieved.

KEY ATTRIBUTES / COMPETENCY

Engineering Risk Assessment is an Ames-developed capability that extends traditional PRA through explicit inclusion of physics-of-failure in a dynamic, simulation-based models.

Benefits of ERA Approach:

- Enables safer missions through more faithful analysis-based representation of the system risk
- Relates operational system state to its mission-critical functional capabilities
- Enables system-wide trade studies via rapid turn-around models
- Tracks multiple performance metrics, enabling one analysis to answer multiple questions in an integrated and consistent way
- Leverages initial Gateway and HLS data to inform the design requirements for 2028 and beyond
- Provides analysis-based validation for safety and reliability requirements

HERITAGE

The ERA Team lead the Lunar Surface System risk assessment under the Constellation program. ERA tools are used extensively for SLS and in support of CCP (Program and Partner applications).

APPLICATIONS BEYOND

Valid 2028 system requirements can be achieved, ultimately resulting in higher safety and mission success levels.

https://www.nas.nasa.gov/projects/era.html

Unitary Plan Wind Tunnel

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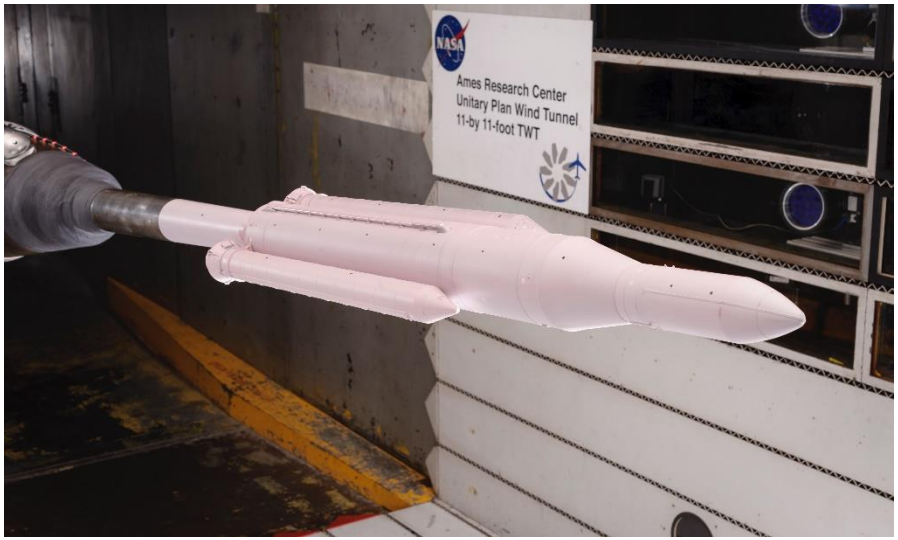

CHALLENGE ADDRESSED (Other Artemis)

The Unitary Plan Wind Tunnel (UPWT) is a key aerosciences capability that has supported the development of every NASA launch vehicle and will continue in this role with the Artemis program.

SUMMARY

The UPWT includes large transonic and supersonic wind tunnels that are critical to the development of launch vehicles and the launch abort systems associated with crewed capsules.

KEY ATTRIBUTES / COMPETENCY

The UPWT consists of two active tunnel legs and an Auxiliaries facility: the 11-By 11-Foot Transonic leg and the 9-By 7-Foot Supersonic leg. The supersonic leg uses an eleven-stage axial-flow compressor and aftercooler drive leg. A three-stage axial-flow compressor drives the 11-By 11-Foot leg. A common drive motor system can be coupled to either the three-stage or eleven-stage compressors. One tunnel can therefore be run while the other two are in the process of installing or removing test articles. The 11-By 11-Foot Transonic leg has a Mach number range from 0.20 to 1.40. The 9-By 7-Foot Supersonic leg has a Mach number range from 1.5 to 2.5. Both wind tunnels can vary the total pressure in the tunnel from low pressure to approximately two atmospheres to provide variable Reynolds numbers for test articles. The UPWT will continue to provide support to launch vehicle development in the areas of force & moment testing, aeroacoustics testing, and launch abort testing to validate designs.

HERITAGE

The Unitary Plan Wind Tunnel (UPWT) has supported the development of every NASA launch vehicle including Apollo, the Space Shuttle, and more recently Orion and the Space Launch System (SLS).

APPLICATIONS BEYOND

The UPWT will continue to provide support to launch vehicle development for all future configurations.

https://windtunnels.arc.nasa.gov

Entry Systems Commercial Support

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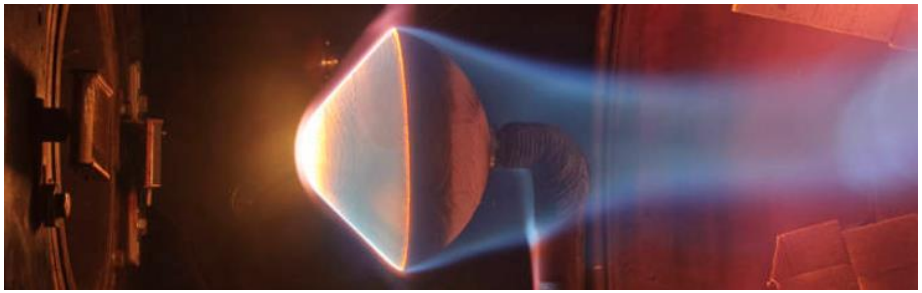


CHALLENGE ADDRESSED (HLS & Gateway)

If HLS and Gateway are augmented by commercial launch and resupply services, NASA expertise in entry systems will be required for SME support and certification as is the case with the Commercial Resupply Services (CRS) effort for ISS cargo return.

SUMMARY

In response to the NASA Next Space Technologies for Exploration Partnerships-2 Omnibus Broad Agency Announcement, Industry is requesting Subject Matter Expert (SME) input for conceptual heat shield / decelerator studies. Ames expertise in aerothermodynamics, thermal protection materials, arc jet testing, and entry systems development will be required for the success of commercial endeavors relevant to any commercial launch and resupply activities.

KEY ATTRIBUTES / COMPETENCY

- Arc Jet Testing
- Advanced CFD (aerothermodynamics and free flight simulations for dynamic stability)
- Nonequilibrium Shockwave Radiation (Testing and Modeling)
- Reusable and Ablative Thermal Protection Systems (TPS)
- TPS Integration (gaps, seams, fillers, and carrier structure bond)
- TPS Robustness - micrometeoroid orbital damage
- Computational Materials & TPS Modeling
- Entry Systems Technologies (mechanical deployables and 3D wovens)
- Entry, Descent, and Landing (EDL) Instrumentation

HERITAGE

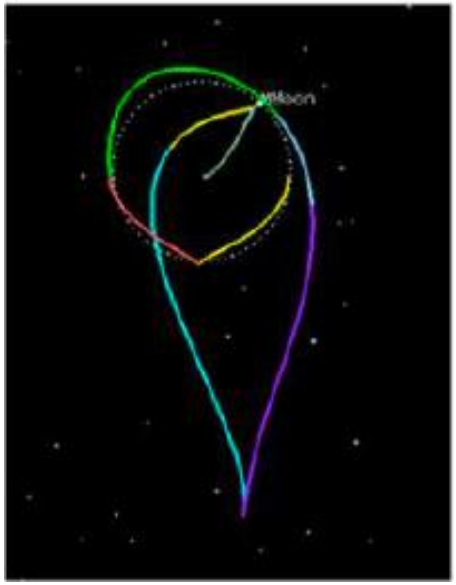
NASA Ames operates the sole Agency arc jet testing capability required for certification of all atmospheric entry endeavors. Ames is the inventor of the blunt body and lifting body concepts and has supported every NASA atmospheric entry mission from Project Mercury to today's Artemis.

APPLICATIONS BEYOND

Even once commercial services are certified, arc jet testing for flight lot material acceptance and aerothermal/thermal protection SME support during operations will be required.

https://www.nasa.gov/centers/ames/entry-systems-and-technology

Integrated Orbit/Trajectory Analysis



CHALLENGE ADDRESSED (HLS)

Identifying and analyzing alternative orbits and trajectories for Artemis Phase 1, Human Landing System.

SUMMARY

Evaluating the various orbits within the lunar sphere of influence will enable mission planners and architecture designers to develop plans to efficiently utilize Artemis assets, including Gateway and the Human Landing Systems. This capability has supported the development of the NRHO orbit and the Human Landing System configurations.

KEY ATTRIBUTES / COMPETENCY

NASA Ames has unique, recent experience designing and executing a broad array of lunar orbit and transfer trajectories

Analyzed transfer trajectories: direct, weak stability boundary, phasing loops, LOI->NRHO

Unique lunar orbit design and analysis for low lunar orbit stability, accounting for irregular lunar gravity

Analysis of the design space to achieve transfers from NRHO to low lunar orbit/landing

Low thrust trajectory design for TLI to lunar orbit and transfer trajectories between various lunar orbits

HERITAGE

LCROSS, LADEE, Constellation, Gateway NRHO, HLS trajectories

APPLICATIONS BEYOND

Continue to effectively utilize Gateway orbit location

Helps identify future trajectories for Artemis activities

Helps develop requirements for future science and exploration missions

https://www.nasa.gov/centers/ames/engineering/smallsat

Multi-Mission Operations Center

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CHALLENGE ADDRESSED (HLS and Gateway)
A large program like Lunar Gateway will have many partner organizations and multiple small projects that make up the whole. The Ames Multi-Mission Operations Center (MMOC) can provide low-cost mission operations support for Lunar Gateway feeder projects. (Slide update coming)

SUMMARY

The MMOC is composed of the facilities, networks, IT equipment, software, and support services needed by flight projects to effectively and efficiently perform all mission functions, including planning, scheduling, command, telemetry processing, and science analysis.

KEY ATTRIBUTES / COMPETENCY

- The Multi-Mission Operations Center (MMOC) is designed to be a low-cost, general purpose, highly flexible and configurable resource for multiple simultaneous spaceflight missions operating at Ames.
- It deploys high-performance capabilities in an extensible and adjustable environment so that missions can reap the advantages of using common general services along with support for unique requirements.
- The MMOC's ready-to-use services reduce start-up time, shorten procurement and provisioning and allow mission planning to focus more on science and less on infrastructure.
- The MMOC utilizes the Ames Mission Network, which is dedicated solely to mission traffic.
- The MMOC typically supports 5 – 10 simultaneously operating, separate spaceflight missions of widely varying size and complexity.

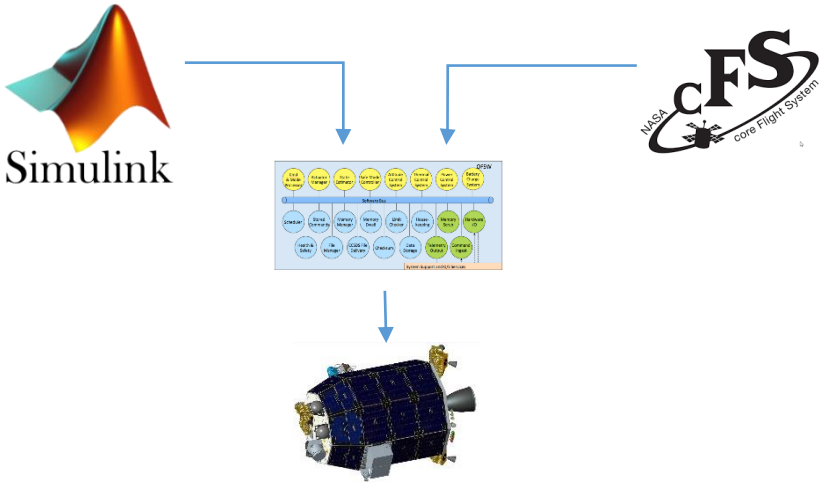
HERITAGE
Recent MMOC-Supported Missions:
GeneLab, IRIS, Kepler/K2, LADEE, LCROSS, SOFIA, Space Shuttle, STPSat-5 and ISS Payloads: Astrobee, BioCulture System, Cell Science, EMCS, Fruit Fly Lab, Human Exploration Telerobotics, Rodent Habitat, SPHERES

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

https://www.nasa.gov/centers/ames/engineering/facilities_mmoc.html

Ames for Artemis
Technologies:
On-board Technology

core Flight Software (cFS)



CHALLENGE ADDRESSED (HLS & Gateway, CLPS)

To meet the pace of retuning to the moon safely requires subsystems and venders to develop software around a common, proven technology. Modern software development workflows and engineering tools can be build around flight proven frameworks to reduce development and testing efforts and deliver high assurance software.

SUMMARY

Ames has developed cFS based flight software and build a workflow for utilizing tools for Model Based Design, Model Based Systems Engineering, Formal Methods, and Continuous Integration. The rapid prototype and deployment workflow was used on LADEE, and continuously improved for the upcoming missions BioSentinal and Starling

KEY ATTRIBUTES / COMPETENCY

cFS/cFE is a NASA developed middleware targeting space missions. It adheres to international communication standards and protocols and provides common functionality needed for space missions. The common architecture streamlines test, integration, and deployment from many subsystems. GSFC open sourced cFS making it available to industry and other users.

Model-based design and simulation-based test driven development allow rapid prototyping of flight software subsystems. When combined with an integrated simulation environment, developers and engineers can quickly test designs and algorithms and evaluate performance.

The tools and workflow developed at Ames allow rapid development and immediate feedback of spacecraft software design and performance. The tools include auto-generation of high reliable code that can be quickly deployed to flight hardware.

HERITAGE

- cFS used on 60+ missions
- cFS + Simulink designed flight software and simulation for Ames led LADEE mission
- Workflow and tools used and updated for upcoming BioSentinel and Starling missions

APPLICATIONS BEYOND

Model based design is advancing in the software and systems engineering domains. cFS is growing in user base and missions. New tools and approaches will further improve software quality and capabilities.

Autonomous Flight Software

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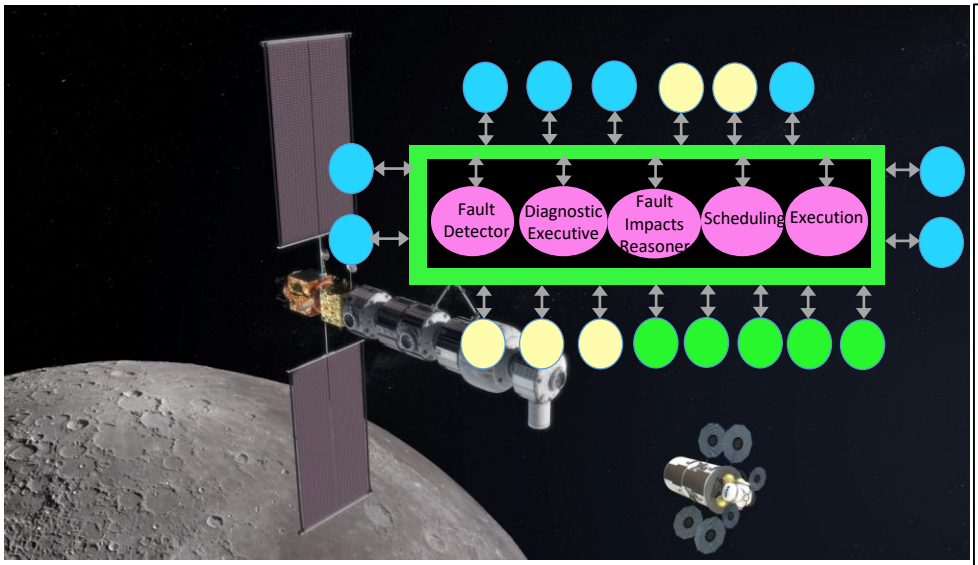


SUMMARY

Develop and demonstrate integration of autonomy applications with NASA-developed core Flight Software (cFS) for use by Gateway and HLS. Leverage LADEE and Biosentinel-heritage cFS application expertise, and LADEE and Gateway developed command and data dictionary management technology.

This technology has been developed and demonstrated on Orion simulations and Gateway simulations. It has been integrated with flight software (e.g. CFS) and integrated with user interfaces (Orion crew displays, flight controller fault displays) and scalability has been demonstrated on embedded processors (PPC 750).

Technical approach will use Gateway and HLS engineering models to develop and demonstrate autonomy applications for relevant scenarios on path-to-flight hardware.

CHALLENGE ADDRESSED (HLS & Gateway)

Autonomous Mission Operations capability such as automated planning, plan execution, and fault management are critical enabling capabilities for dormant Gateway operations, and are enhancing for many critical HLS mission phases (descent and landing, launch, surface operations), and must be integrated with flight software.

KEY ATTRIBUTES / COMPETENCY

Ames has expertise in integrating autonomy applications for spacecraft and UAVs. Includes multiple in-space missions (LADEE, Biosentinel), and current HEOMD AES funding / Gateway engagement. Leverage existing automation technology funded by HEOMD / Gateway engagement to deliver critical automation technology to Gateway and HLS.

HERITAGE

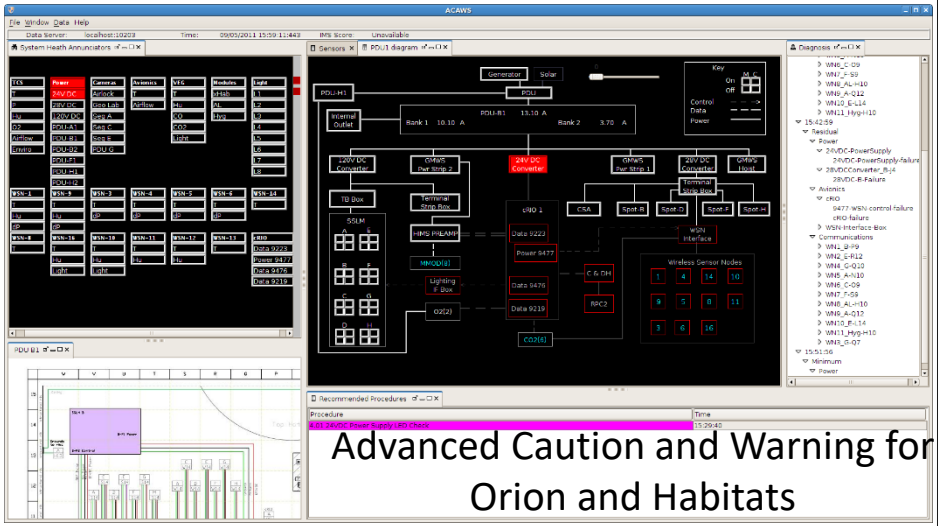
Aaseng et al. 2018. Performance analysis of an autonomous fault management system. In Proceedings of the AIAA Space Conference and Exposition.

G. Aaseng et al. Development and Testing of a Vehicle Management System for Autonomous Spacecraft Habitat Operations. Proceedings of the AIAA Space Conference, 2018

APPLICATIONS BEYOND

Advancing this technology now will position the agency to deliver for future Mars missions.

Autonomous Caution and Warning System



SUMMARY

Develop and demonstrate Gateway Autonomous Caution and Warning. Develop and demonstrate HLS Autonomous Caution and Warning for use during lander missions, to improve flight controller and crew situational awareness and responsiveness. Technical approach uses model-based fault management technology to perform fault detection, diagnosis, and fault impacts reasoning. Technology employs combination of commercial software and NASA developed components.

This technology has been developed and demonstrated on Exploration Flight Test One (EFT-1), Orion simulations, and Gateway simulations. It has been integrated with flight software (e.g. CFS) and integrated with user interfaces (Orion crew displays, flight controller fault displays) and scalability has been demonstrated on embedded processors (PPC 750).

Technical approach will use HLS engineering models (schematics, FMEAs, etc.) to develop and demonstrate Gateway and HLS fault detection, isolation and impacts on flight computer.

CHALLENGE ADDRESSED (HLS & Gateway)

Autonomous Caution and Warning: Caution and warning and fault response during HLS missions is critical to improve flight controller situational awareness and responsiveness during ascent/descent operations and during dormant periods.

KEY ATTRIBUTES / COMPETENCY

Ames has decades of expertise in automation for spacecraft and UAVs. Includes multiple in-space missions, HEOMD-funded Gateway engagement, and ARMD-funded terrestrial applications (UAVs). Leverage existing automation technology for Gateway engagement to deliver critical automation technology to Gateway and HLS.

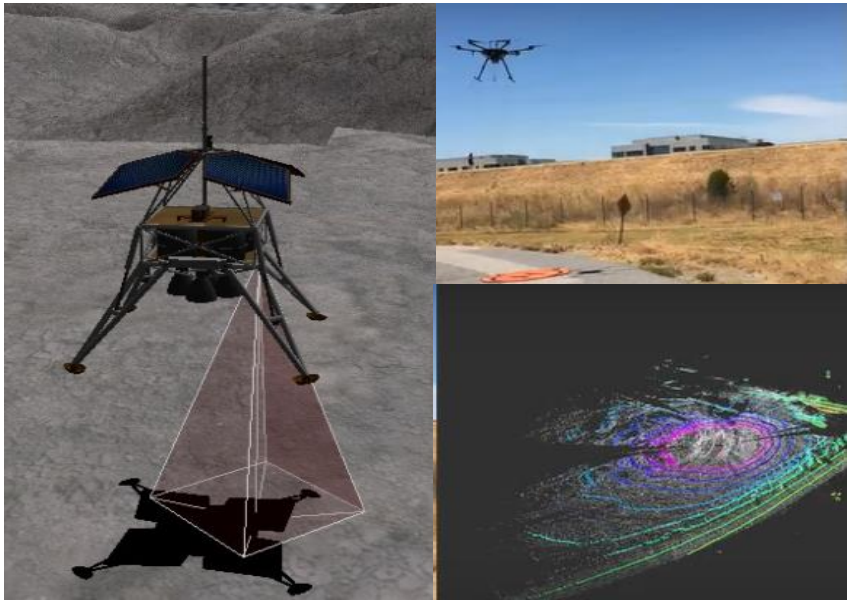
HERITAGE

Aaseng et al. 2018. Performance analysis of an autonomous fault management system. In Proceedings of the AIAA Space Conference and Exposition.
Schumann et al. 2019. Model-based System Health Management and Contingency Planning for Autonomous UAS.

APPLICATIONS BEYOND

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

Precision landing sensors and algorithms



CHALLENGE ADDRESSED (HLS)

Precision landing sensors and algorithms: Autonomous navigation and adaptive speed and attitude control using vision enhanced sensing is critical to enable precision landing.

KEY ATTRIBUTES / COMPETENCY

Integrated LiDAR/Stereo Camera for computer vision based hazard identification and lander planner; Adaptive control and estimation for precision speed and attitude control; Off-nominal with recovery; Off-nominal with fault isolation; Digital elevation maps; Real-time landing site selection with automated planning and execution.

SUMMARY

Develop and demonstrate autonomous precision landing sensors and algorithms integrated with fault detection/isolation and trajectory planning using computer vision aided sensing. Technical approach uses NASA developed LiDAR and stereo camera based navigation and adaptive control along with model-based automated planning and plan execution technology.

The technologies have been developed and demonstrated in realistic simulations and using several helicopter drones integrated with relevant sensors. Elements of the technology have been integrated with drone flight software and user interfaces.

Technical approach will use relevant engineering models and tested in piloted NASA Ames Vertical Motion Simulator facility as well as in a 55-lb class helicopter drone.

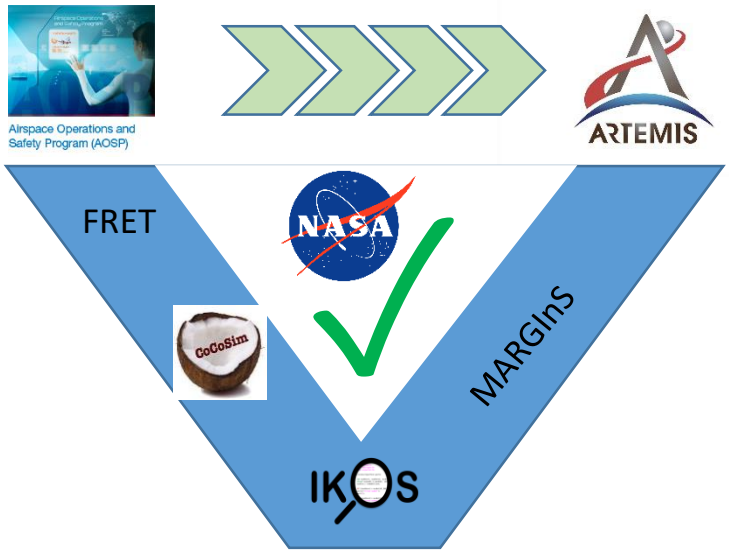
HERITAGE

Control and Simulation of an Autonomous Lunar Lander, Corey A. Ippolito and Jeremy Frank, NASA Ames Research Center, Moffett Field, CA 94035, AIAA 2009-5811.
An Autonomy Architecture for High-Density Operations of Small UAS in Low-Altitude Urban Environments, Corey A. Ippolito1, Kalmanje Krishnakumar2 NASA Ames Research Center, Moffett Field, CA, 94035, AIAA 2019-0689

APPLICATIONS BEYOND

Autonomous precision landing is a critical mission capability as we shift our goal toward sustainable presence on the moon and then Mars.

Automated Tools for Integrated Verification and Validation



CHALLENGE ADDRESSED (HLS & Gateway, CLPS, Other Artemis)

There is a need for automated V&V tools to quickly perform IV&V on vendor-provided software and provide feedback to them within the accelerate development timeline for Artemis systems.

SUMMARY

Over the past ten years, Ames have developed a suite of automated V&V tools that can address all phases of software development and help speed-up IV&V activities. The tools are targeting a model-based development process and have customizations for core Flight Software (cFS)-based software, which are the process and platform targeted for Artemis software development.

KEY ATTRIBUTES / COMPETENCY

Our suite of automated tools targets all phase of software development;

- Requirement creation/formalization/analysis for early V&V
- Exhaustive Simulink model V&V with modified condition/decision coverage (MC/DC) testing
- Scalable, precise static code analysis for C/C++ with customization for cFS-based software
- Advanced stress testing tools for hard to reproduce potential failure cases
- V&V evidence integration within assurance case toolset for fast review against NPR 7150.2 standard
- NLP-based tool to support traceability

HERITAGE

- Developed under ARMD and proven by aviation industry
- ACM distinguished paper award for paper titled "Assumption Generation for Software Component Verification", voted best paper of IEEE ASE 2002 conference

APPLICATIONS BEYOND

Technical approach can be extended for 2028 applications, e.g., Moon rovers (VIPER) and CubeSats in Moon orbit

Onboard Adaptive Planning Systems

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Crew Autonomous Scheduling Test aboard ISS -- 2017

CHALLENGE ADDRESSED (HLS & Gateway)

HLS and Gateway will require a new paradigm of autonomous operations, especially when humans are involved. The concept of operations must shift toward increasingly earth-independent activity requiring new approaches to critical mission elements such as crew and vehicle *activity planning and scheduling*.

SUMMARY

Dynamic planning are re-planning enabling crew self-scheduling during increasingly Earth-independent operations

KEY ATTRIBUTES / COMPETENCY

- Mature capability applicable to human, robotic, and human-robotic activity planning
- Operationally validated through multiple Mars surface missions and on ISS as well as through analogs
- Mission ready capability to support crew self-scheduling with light time delays.

HERITAGE

Mars Exploration Rovers, Phoenix Mars Lander, Mars Science Laboratory, Mars 2020; Multiple NEEMO expeditions including every one testing comm delays; ISS Mission Control Crew activity scheduling (Optimis) and 2017on-board CAST Study

APPLICATIONS BEYOND

Crew activity planning and self-scheduling will be a critical mission capability as we shift our goal toward sustainable presence on the moon and then Mars

https://humanfactors.arc.nasa.gov/techareas/tech_areas.php

Crew Interfaces, Operations & Equipment

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CHALLENGE ADDRESSED (HLS & Gateway)

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.

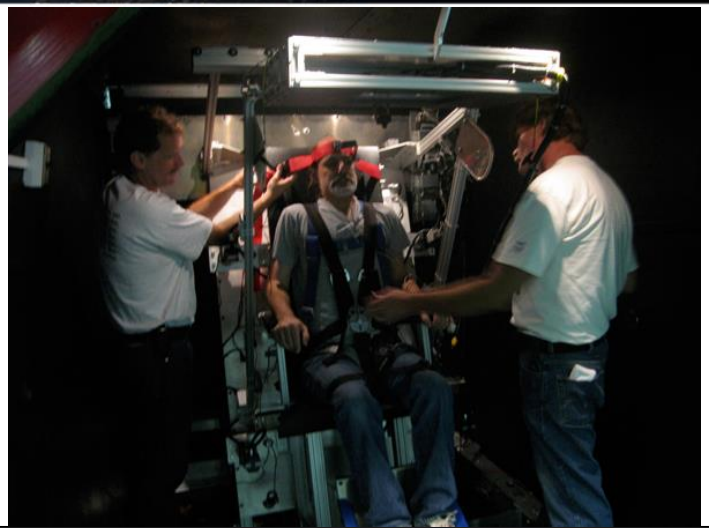
APPLICATIONS BEYOND

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.

https://humanfactors.arc.nasa.gov/techareas/tech_areas.php

Ames for Artemis
Technologies:
Operations Technology

Human Centered Software and System Design and Evaluation



CHALLENGE ADDRESSED (HLS)
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.

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.

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).

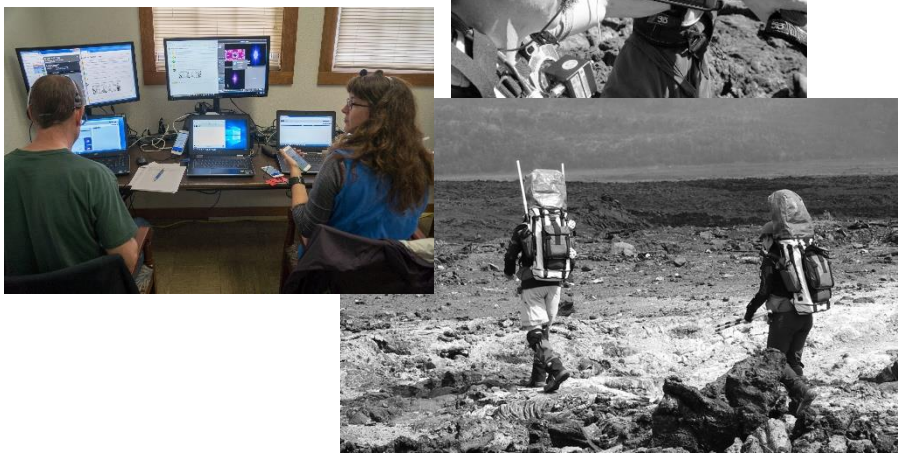
HERITAGE
HITL validation on the 20g of reach standards under combined G-force and vibration in support of human exploration HSI requirements for and off-nominal launch operations (Orion, Commercial Crew Program)

HITL validation of display legibility under launch vibration

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.

https://humanfactors.arc.nasa.gov/techareas/tech_areas.php

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, other Artemis)

For HLS and Artemis, 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.

Mission Operations and Training

Human Exploration Research Analog Study -- 2016

CHALLENGE ADDRESSED (HLS & Gateway)

HLS and Gateway will require new paradigms of autonomous operations whenever humans are involved. Communication blackouts, bandwidth constraints, and time delays will shift the concept of operations toward increasingly earth-independent activity requiring new approaches to crew training and for managing teaming.

SUMMARY

Increasingly intelligent and autonomous systems bring with them the need for new approaches to teaming and training for the humans that remain part of the operational system. Long duration earth-independent missions require onboard just-in-time training and performance support tools at the right level of fidelity.

KEY ATTRIBUTES / COMPETENCY

- Decades of experience in training and teaming for both space and aeronautics applications.
- Currently focused on human teaming with increasingly autonomous systems, e.g., with Unmanned Aerial Systems, autonomous ground vehicles, Urban Air Mobility, etc.
- Expertise and experience in training simulation and simulator fidelity, as well as with virtual/augmented reality, just-in-time and on-board training systems.
- High-TRL capabilities that are ready to be used in order to accelerate schedules and increase training effectiveness, as well as reduce vehicle design costs & crew training costs.

HERITAGE

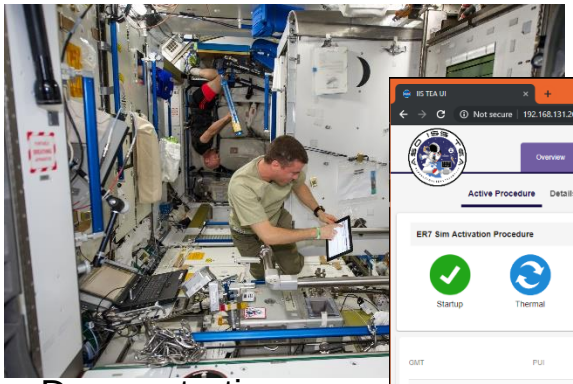
Crew Resource Management: Developed at Ames for flight-deck, adopted globally; *Adaptable Training and Decision Support (ATADS)*: Developed at Ames as a vision for spaceflight onboard training; *Task Load Index (TLX):* Developed at Ames and now iOS app – most widely used tool to assess user workload.

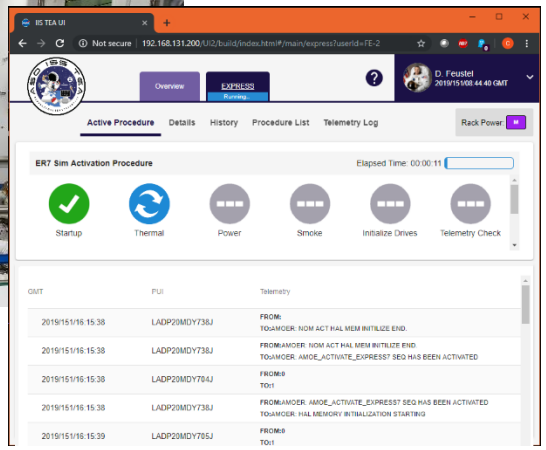
APPLICATIONS BEYOND

New paradigms for Training and Teaming will be a critical mission capability as we shift our goal toward sustainable presence on the moon and then Mars.

https://humanfactors.arc.nasa.gov/techareas/tech_areas.php

Autonomous Mission Operations





Demonstrating crew autonomy onboard ISS

SUMMARY

Develop and demonstrate Gateway autonomy during dormant phases. Develop and demonstrate HLS 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).

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

CHALLENGE ADDRESSED (HLS & Gateway)

Autonomous Mission Operations during Gateway and HLS missions are critical to improve flight controller situational awareness and responsiveness during ascent/descent operations and during dormant periods.

KEY ATTRIBUTES / COMPETENCY

Ames has decades of expertise in automation for spacecraft and UAVs. Includes multiple in-space missions, current HEOMD AES funding / Gateway engagement, and terrestrial applications (UAVs). Leverage existing automation technology funded by HEOMD / Gateway engagement to deliver critical automation technology to Gateway and HLS.

HERITAGE

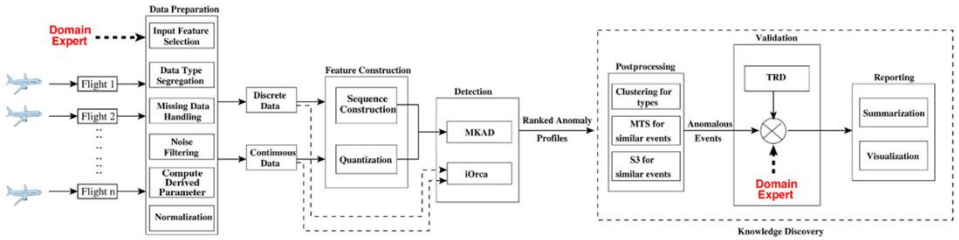
Frank et al. 2013. Autonomous Mission Operations. In Proceedings of the IEEE Aerospace Conference.
Frank et al. 2015. Demonstrating autonomous mission operations onboard the international space station. In Proceedings of the AIAA Space Conference and Exposition.

APPLICATIONS BEYOND

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

https://ti.arc.nasa.gov/tech/asr/groups/planning-and-scheduling/

Data-Driven Discovery of Anomaly Precursors



CHALLENGE ADDRESSED (HLS & Gateway)

A high-energy, safety-critical vehicle such as a rocket, lander, or habitat needs to be monitored for precursors to anomalies and failures.

Real-time rapid response, while minimizing false positives and false negatives, will be essential to successfully operate a Human Landing System (HLS).

SUMMARY

Historical rocket launch datasets hold a substantial amount and variety of spatio-temporal data.

Deploy a knowledge discovery process to identify anomaly precursors during rocket launches.

Select a suitable combination of algorithms for automated outlier detection.

KEY ATTRIBUTES /COMPETENCY

Deploy a systematic way of selecting a suitable combination of algorithms based on factors such as available data, types of anomalies, and the scale of the problem.

Data mining to discover precursor sequences of events hidden in historical datasets from rocket launch data.

Automated module for data preparation based on feature selection, data type segregation, missing data processing, noise filtering, and normalization.

Outlier detection using super-fast, one-class Support Vector Machines using a sampling strategy.

Anomaly detection method that works with continuous *and* discrete sequences.

HERITAGE

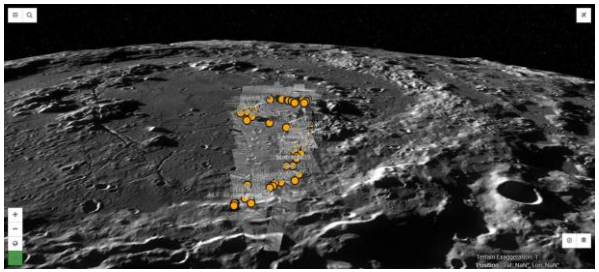
Matthews et al. 2013. Discovering Anomalous Aviation Safety Events Using Scalable Data Mining Algorithms. Journal Of Aerospace Information Systems 10(10).

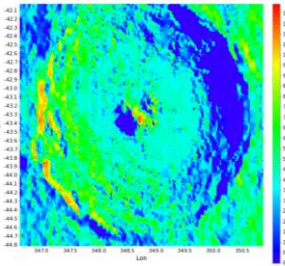
Iverson et al. 2012. General Purpose Data-Driven System Monitoring for Space Operations. Journal of Aerospace Computing Information and Communication 9(2).

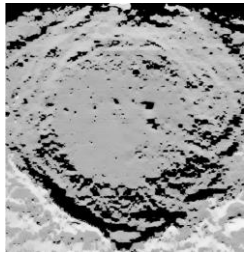
APPLICATIONS BEYOND

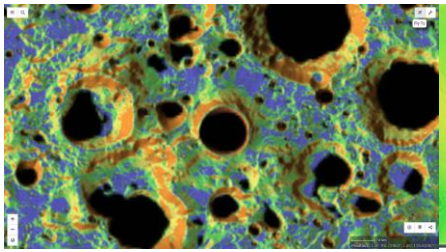
Data-driven discovery of anomaly precursors is a critical mission capability as we shift our goal toward sustainable presence on the moon and then Mars

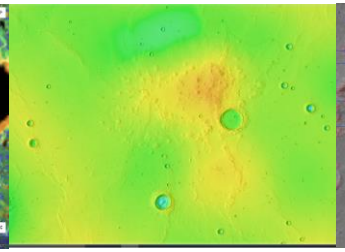
Tools for Visualizing and Analyzing Lunar Data

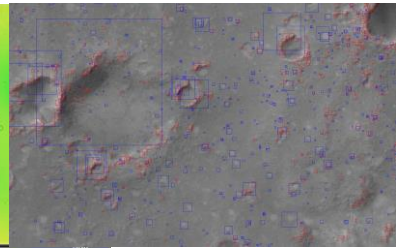

Schrodinger Basin Traverse Planning


Lighting Analysis


Surface Potential Analysis


South Polar Slope Map with PSR Overlay


Blend of LASER Altimetry and Gravity Mapping


Crater and Boulder Hazard Analysis

CHALLENGE ADDRESSED (HLS, CLPS, other Artemis): NASA's Moon Trek visualization and analysis portal could help numerous Artemis projects including the HLS and CLPS. Tools and capabilities provided by Moon Trek can significantly facilitate characterization of potential lunar landing sites and areas of operation. The portal can provide 2D, 3D, and VR visualizations of regions of interest.

SUMMARY: SSERVI manages the NASA Solar System Treks Project (SSTP) with development and operations done at JPL. The project produces a family of on-line data visualization and analysis portals supporting mission planning, planetary science, and outreach. The Moon Trek Portal integrates massive amounts of data presented in different projections, allowing 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.

KEY ATTRIBUTES / COMPETENCY

Infrastructure and design of the system's backend capabilities take full advantage of cloud-based resources, artificial intelligence, and machine learning in delivering advanced visualization and analysis capabilities. The system handles big-data datasets, efficiently delivering tiled views with resolution adjusted to the user's selected perspective.

The value of each of the thousands of co-registered, georeferenced data products served is greatly enhanced by their being presented in context with each other. Products displayed can also be downloaded for analysis with other tools. An API provides access to backend services for other clients.

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

HERITAGE

Moon Trek is the successor to our earlier Lunar Mapping and Modeling Portal (LMMP), developed as part of the Constellation program. Moon Trek features greatly enhanced capabilities over the previous LMMP platform. Other portals in the SSTP suite have supported the Dawn and Cassini missions. We are currently supporting the Mars HLS2 effort and the BepiColumbo mission with existing portals and and the OSIRIS-Rex, Hayabusa2, and MMX missions with portals in development.

APPLICATIONS BEYOND: The analysis tools and visualization capabilities of Moon Trek will be enablers of sustained operations on and exploration of the Moon. The capabilities of Moon Trek will facilitate traverse planning, ISRU, and characterization of expanded areas of lunar operations. As data is gathered from future missions, Moon Trek can greatly enhance the utility and value of that data by placing it in context of a vast array of other lunar data products. This allows for the easy comparison of data products and the blending of different data products from different missions aboard different spacecraft, revealing information that the individual data products alone cannot provide.

https://sservi.nasa.gov

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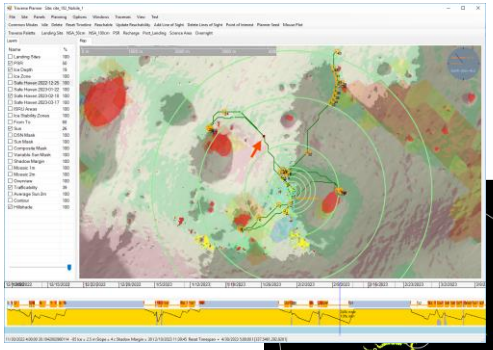
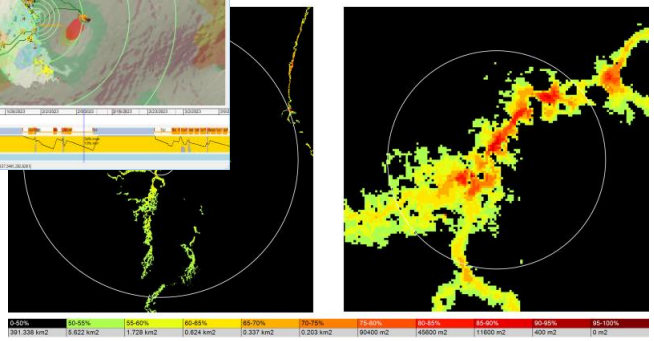
Landing Site and Traverse Analysis



Sample multi-lunar-day robotic traverse near Nobile (south polar region)



Surface area vs solar coverage at 2m array height, estimating power generation potential at landing sites; 9 and 1 km radius circles; near Shackleton

CHALLENGE ADDRESSED (HLS, CLPS, Other Artemis)

Landing site selection and the planning of robotic and human traverses requires integrating a complex array of engineering and scientific constraints and preferences. The lunar poles, in particular, involve unique challenges due to low angle and constantly-changing lighting and the current lack of relay satellites.

SUMMARY

NASA Ames currently supports Artemis landing site selection by generating maps of surface lighting, temperature, line-of-sight to ground stations and proximity to permanent shadow and other locations that could harbor ice and other volatiles. These products are also being used for site selection by the VIPER lunar rover mission

KEY ATTRIBUTES / COMPETENCY

Mature site selection / evaluation tools used now for site selection and traverse planning for VIPER rover

Mature tools currently feeding products into Artemis landing site selection process

Tools rest on foundation of LRO data products

- Efficient generation of lighting and communications maps for polar regions
- Generation of subsurface temperature maps which constrain locations of volatiles (partnership with PSI and UCLA)
- Pixel-level DEM generation from multiple NAC images (O. Alexandrov, R. Beyer)

HERITAGE

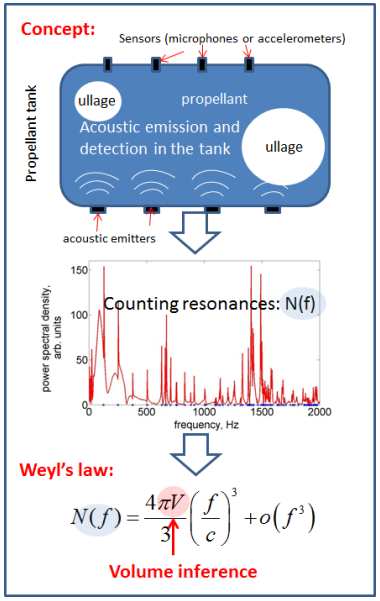
Tools developed for Resource Prospector (RP) and now in use for VIPER lunar rover mission. Key personnel (A. Colaprete, LCROSS & RP PI; R. Elphic, Lunar Prospector Science Team, LADEE Proj. Scientist) have been deeply involved in detection and evaluation of lunar polar volatiles.

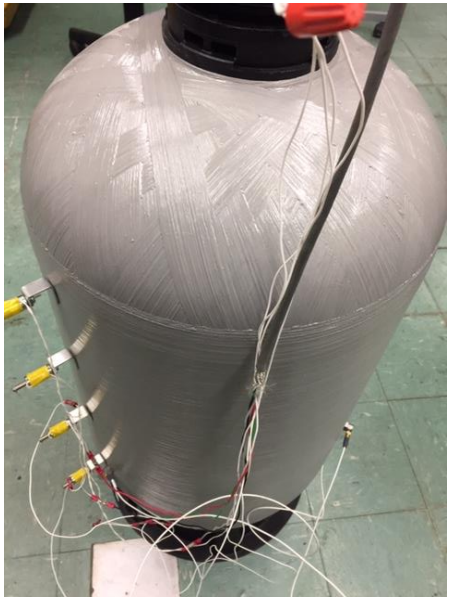
APPLICATIONS BEYOND

The amount, distribution and accessibility of lunar polar volatiles will drive the design of sustainable lunar architectures. These tools are in use now to help plan the first missions to answer these questions.

Ames for Artemis
Technologies:
Earth-hosted Technology

Composite Tank Mass-Gauging





KEY ATTRIBUTES / COMPETENCY

Leverage NASA Ames

1. Cryogenic Lab competency in cryogenic fluid managements
2. TI Applied Physics Group's multiple years experience in modeling cryogenic fuel tanks
3. TI Applied Physics Group's machine-learning capability for engineering physics applications

Both hardware and software for the mass-gauging will be developed in NASA Ames, by the Cryogenic Lab and Applied Physics group, respectively

CHALLENGE ADDRESSED (HLS & Gateway)

Accurate liquid mass gauging is crucial for propellant management, water subsystems management, ISRU units, and in-space coolants management. However, most established mass-gauging methods are inapplicable in zero gravity environments where the liquid assumes unknown shape configurations.

SUMMARY

Develop new liquid mass-gauging technology that uses a network of external actuators and sensors to measure tank volume from its spectral response. The overall approach will combine machine learning with physics based spectral theory.

HERITAGE

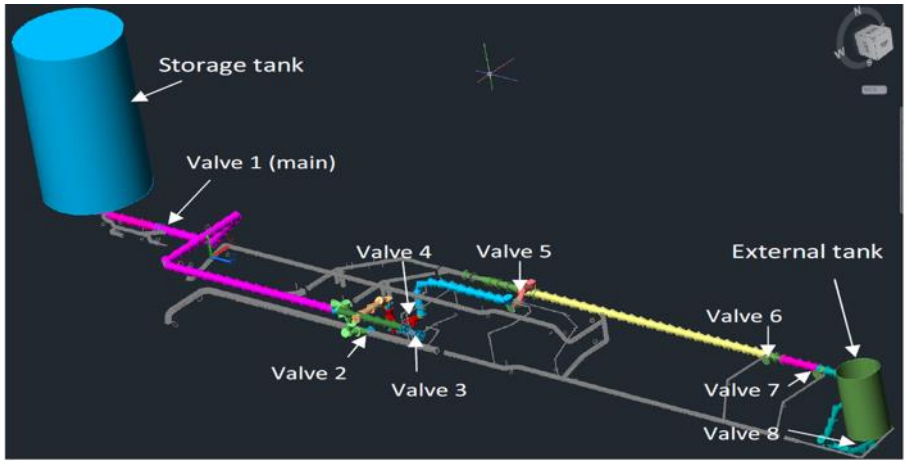
J. Feller, A. Kashani, M. Khasin, C. Muratov, V. Osipov and S. Sharma, *Spectral mass gauging of unsettled liquid with acoustic waves*, Advances in Cryogenic Engineering: Proceedings of the Cryogenic Engineering Conference (CEC) 2017, 9–13 July 2017, Madison, Wisconsin, USA

J.Feller, A. Kashani, M. Khasin, C.Muratov, V. Osipov, S. Sharma, *Spectral mass gauging of unsettled liquid with acoustic waves*, NASA/TM-2018-219876

APPLICATIONS BEYOND

Zero and reduced gravity propellant mass gauging is a key enabling capability for deep space exploration

Autonomous Cryogenic Loading



CHALLENGE ADDRESSED (HLS & Gateway)

Safe cryogenic fluid management is needed for rapid, safe, and efficient space transportation. Cryogenic propellant storage and transfer systems are complex and currently require significant expert human resources to manage safely.

SUMMARY

Autonomous control of cryogenic operations in space can leverage advanced Artificial Intelligence (AI) algorithms to mimic and improve on our best engineering practices. This effort seeks to develop this capability, by leveraging machine learning to establish the propellant transfer models needed to support autonomous decision making.

KEY ATTRIBUTES / COMPETENCY

Leverage NASA Ames machine-learning capability to autonomously select cryogenic propellant transfer models from a space of parameterized physics-based candidate models.

Development will be guided by available data from multiple sources, including sub-scale data to be collected in the Cryogenic Lab at ARC, the full-scale data collected by GRC and KSC NASA centers and data from academic research.

Build on TI Applied Physics Group multi-years' experience in modeling two-phase cryogenic fluids systems, which has culminated in the development of a computational platform for physics-based modeling of cryogenic loading operations. The platform is based on a variable set of cryogenic correlations for two-phase flow, the associated parametric space, and a multi-step approach to optimization of the model parameters.

HERITAGE

TI Applied Physics Group experience developed over multiple years in collaboration with ARC Cryogenics Lab, and the KSC cryogenic testbed. Leverage existing data and experiment capability at ARC, KSC, and GRC.

APPLICATIONS BEYOND: Viable scenarios of Moon-to-Mars Exploration are based on LOX-propulsion. Autonomy is critical to developing and sustaining efficient propellant loading for space operations.

https://ti.arc.nasa.gov/tech/dash/groups/physics/

Ames for Artemis
Science

Human Health and Performance

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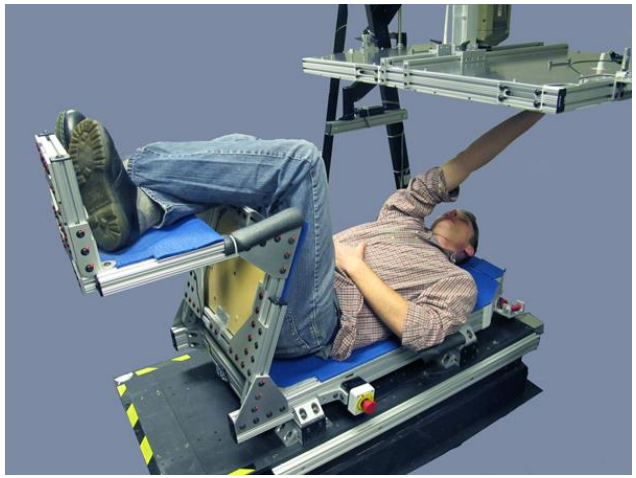
AMES RESEARCH CENTER



CHALLENGE ADDRESSED (HLS & Gateway)

HLS and Gateway systems must safeguard human health needs, harness human capabilities for optimized overall system performance, and anticipate/mitigate human limitations and errors. Artemis Phase 1 risk will be significantly reduced with robust HSI design that protects crew health, enables prompt and effective crew responses under both nominal and off-nominal conditions, and minimizes human error.

SUMMARY

NASA Ames personnel have decades of experience in human health and performance. ARC SMEs have expertise in the assessment of human visual, vestibular, auditory, haptic, autonomic, cognitive, and motor function and the adverse effects of spaceflight environments (acceleration, vibration, tilt, noise, sleep loss & circadian misalignment, vestibular perturbation and adaptation), and nutritional needs.

KEY ATTRIBUTES / COMPETENCY

- Extensive knowledge of human nutritional needs and of human performance capabilities and limitations associated with aerospace conditions, and of the associated NASA human-system standards and requirements (NASA-STD-3001).
- Extensive expertise and experience in the measurement and analysis of visual, auditory, vestibular, oculomotor, autonomic, cognitive, and manual control function under earth-based and spaceflight-relevant environments.
- Extensive expertise and experience in development and validation of novel human performance technologies.
- 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).

HERITAGE

HITL measurement human visual and manual reach performance under combined G-force and vibration

Patented technologies for measurement of human performance relevant to a range of aerospace tasks.

APPLICATIONS BEYOND

Experience and lessons learned from Artemis Phase 1 will lead to a better anticipation and understanding of the human health performance challenges facing later lunar missions and eventual Mars missions.

https://humanfactors.arc.nasa.gov/techareas/tech_areas.php

Bio-Sensors & Wearables

CHALLENGE ADDRESSED (HLS & Gateway)

Given that HLS and Gateway will involve longer duration missions beyond the Van Allen Belt, state-of-the-art biometric capabilities will be required assess crew readiness-to-perform.

SUMMARY

Real-time, in situ, assessment of physiological state to inform readiness to perform, focused on increasingly Earth-Independent mission operations.

Real-time, in situ, mitigation of adverse physiological states.

KEY ATTRIBUTES / COMPETENCY

- Ames has the only centrifuge-mounted, 5-degrees of motion, vibration assessment set-up in the country and the top researcher in the country in the area of fatigue measures and bio-sensors.
- Distinct and complementary set of competencies in this area relative to JSC, specifically in the assessment and mitigation of vibration, fatigue, and orthostatic intolerance.
- High-TRL capabilities that are ready to be used in order to accelerate schedule and reduce vehicle design costs & crew training costs.

HERITAGE

Unique expertise in applied, aerospace-focused, R&D in fatigue countermeasures, motion sickness, orthostatic intolerance, vibration countermeasures, and visuomotor assessment of brain state. Current customers include NASA, Space-X Boeing, Office of Naval Research, etc.

APPLICATIONS BEYOND

Real-time assessment of crew state will be a critical mission capability as we shift our goal toward sustainable presence on the moon and then Mars

https://humanfactors.arc.nasa.gov/techareas/tech_areas.php

Crew Health - Medical Data Architecture

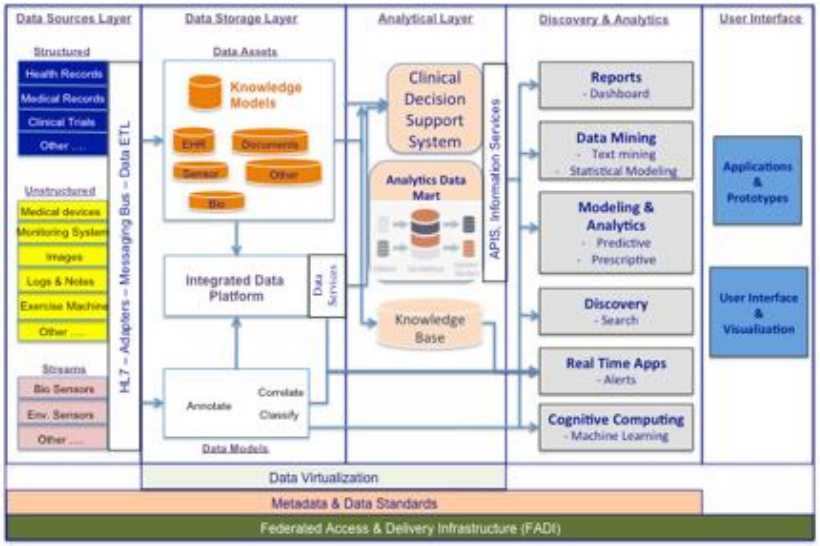


Diagram of the Medical Data Architecture for Human Exploration Missions

CHALLENGE ADDRESSED (HLS & Gateway)

Medical Data Architecture (MDA) addresses the risks that we do not have the capability to (1) comprehensively process medically-relevant information to support medical operations; and (2) to provide computed medical decision support during exploration missions.

SUMMARY

The medical data architecture informs medically relevant information management and flow for ground and flight medical operations needed for assessing medical operational con ops in the HLS in preparation for missions requiring greater crew autonomy in medical decision making.

KEY ATTRIBUTES / COMPETENCY

- Ames has developed a prototype medical data management platform and approach that accommodates advancements in technology, including medical data sources, infrastructure and software tools.
- Ames participated in the NASA Next Space Technologies for Exploration Partnerships (NextSTEP) Gateway Habitat evaluations, to evaluate habitat prototypes through system tests that map to relevant mission scenarios and test objectives.
- Ames has enabled ExMC to successfully generate Level 4 and 5 Medical and Crew Health and Performance System requirements that with the goal of delivery to the Gateway Program.
- Ames technology has integrated with technologies from collaborators external to HRP including: the Canadian Space Agency, Translational Research Institute and Advance Exploration Systems.
- Ames has expertise for the development and evaluation of crew health & performance assessment sensors/tools.

HERITAGE

Based on decades of experience with previous medical information sharing systems, with MDA prototypes going through extensive and methodical ground testing.

APPLICATIONS BEYOND

To meet the challenges of exploration missions requiring Level of Care V medical care, a self-contained medical system that enables autonomous crew health care.

https://www.nasa.gov/ames/research/space-biosciences

ECLSS (Life Support Technologies)

Advanced wastewater, solid waste management, and CO_2 capture and compression technologies developed at ARC.

CHALLENGE ADDRESSED (HLS & Gateway)

Gateway will require robust and reliable life support systems to manage air revitalization, water/wastewater, and solid wastes while it is crewed, and also repeatedly support unprecedented durations of dormancy. Systems will also need the flexibility to accommodate a multitude of future vehicles and crew sizes.

SUMMARY

Ames is identifying, developing and testing agile concepts to provide simple, reliable solutions for CO_2 management, water recovery and solid waste management for life support needs of Gateway and beyond. This includes microbial dormancy of water systems, and leading commercial development of waste flight demonstrations.

KEY ATTRIBUTES / COMPETENCY

- The Ames Bioengineering Branch has established expertise in life support systems analysis and development to reduce mission costs and ensure crew health and safety.
- Developed simple solid waste management techniques to dry and safe waste, and reduce volume. Systems developed at Ames are serving as a model for Ames-led commercial development of ISS demonstration for trash compaction processing system (TCPS). .
- Providing water system management methods that enable emergency water recovery from urine and microbial control techniques for extended system dormancy.
- Created reliable CO_2 capture and solid state compression technologies, and trace contaminant control capability.

HERITAGE

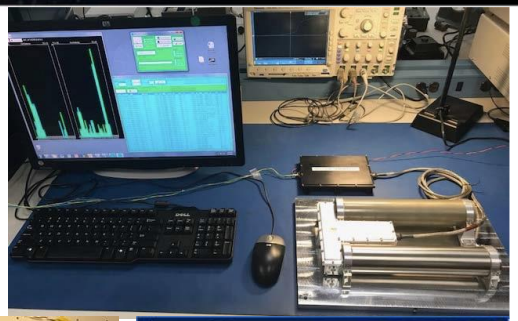
Ames has been a leader in developing innovative solutions for regenerative life support systems for over 35 years.

APPLICATIONS BEYOND

These systems will provide next generation air revitalization, water recovery, and waste management systems required for a sustainable presence on the Moon and Mars.

https://www.nasa.gov/ames/research/space-biosciences/bioengineering-branch

Lunar Exploration Science



CHALLENGE ADDRESSED (HLS, CLPS)

To advance science knowledge that directly impacts future lunar and deep-space exploration. Includes geophysical studies of the nature/distribution of volatiles at the lunar poles, and biological studies of the combined effects of low gravity and high radiation on living systems.

SUMMARY

Low-cost, low-mass and low-power science payloads that address key questions in lunar geology, including the distribution of volatiles in polar regions, and the effects of the deep space environment on living organisms.

KEY ATTRIBUTES / COMPETENCY

ARC leads Agency in designing & developing low-cost (lunar) payloads addressing geophysical and biological science objectives.

Infrared and neutron spectrometers developed for Lunar Prospector, LCROSS, LADEE and VIPER missions.

Spectrometers will characterize the nature & distribution of lunar volatiles in permanently shadowed regions, laying the foundation for commercial interests.

Biosciences payloads developed for numerous SmallSats and dozens of ISS experiments are providing the scientific foundation for understanding how living organisms respond to long-duration exposure to low-g and high radiation, serving as a proxy for deep space exploration.

Ames' expertise in autonomy will enable science to be done with minimal crew interactions, and allow science to be performed without human-tending.

HERITAGE

ARC scientists/engineers have extensive experience in: designing and developing low-cost payloads for LCROSS, LADEE and VIPER lunar missions, and in developing 60+ biosciences payloads for SmallSat and ISS applications.

APPLICATIONS BEYOND

Lunar environment represents a proxy for deep space radiation environment, and hence bioscience experiments conducted on lunar surface are important elements of a broader "gravity as a continuum" program of experiments.

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Conclusion

Purpose (Redux)

- Today was an opportunity for potential vendors to further understand ARC's capabilities in greater detail
  - ARC considers its capabilities to be both unique and world-class
- Through this forum, we hope that an improved understanding of ARC's capabilities was achieved
  - Offline meetings are encouraged to further develop Appendix H support content and ideas
- Today's audience consisted of potential Appendix H vendors and NASA ARC personnel
  - NASA participants have no knowledge of and cannot provide guidance to Appendix H Requirements or Industry Comments previously submitted
  - See FedBiz Ops for official contacts
    - Also for Ames, contact Sally Cahill, sally.a.cahill@nasa.gov, 650.604.5671.

Questions?

- During the meeting you had the opportunity to ask questions and ‘upvote’ previous questions asked by other participants.

- Question were shown anonymously to others in Conference IO:

  https://arc.cnf.io/sessions/r84r/#!/dashboard

- All questions will get addressed either today or will be posted to the website shortly after the meeting

  https://www.nasa.gov/ames/AmesCapabilityDeepDive

- For more information about how to access NASA Ames resources/services and to connect with subject matter experts contact:

  Sally Cahill, sally.a.cahill@nasa.gov, 650.604.5671.

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Thank You!

For questions:
Sally Cahill, sally.a.cahill@nasa.gov,
650.604.5671