National Aeronautics and Space Administration

NASA Center Capabilities
Ames Research Center

Center Points of Contact:

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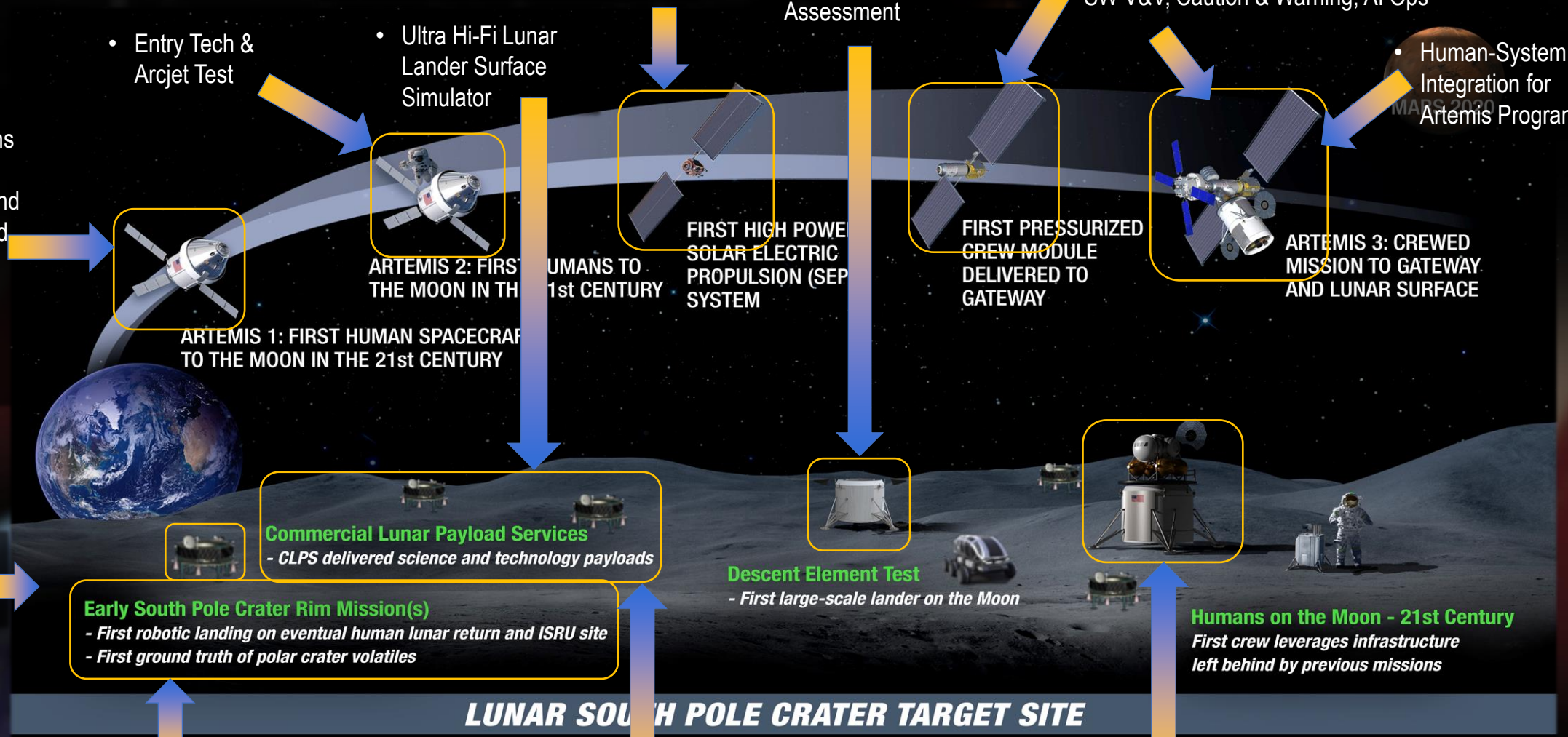
ARTEMIS

Ames for Artemis Phase 1: Lunar Surface by 2024

List of some Enabling Capabilities

- Orion Launch Abort Simulations
- SLS & Orion Wind Tunnel Tests and aero-database generation
- Cross Program Data Systems
- Entry Tech & Arcjet Test
- Gateway Science & CubeSats
- Ultra Hi-Fi Lunar Lander Surface Simulator
- HLS Engineering Risk Assessment
- Autonomy for Artemis Program (Gateway & HLS)
  - SW V&V, Caution & Warning, AI Ops
- Human-System Integration for Artemis Program



- Lunar science enabled by SSERVI

2022 VIPER Prospecting Rover Mission (SMD)

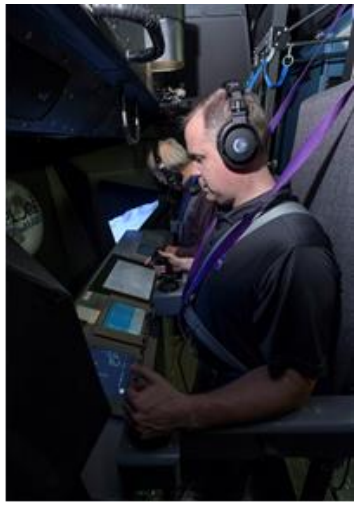
2019-24 CLPS Instruments (SMD)

2024 VMS Training & Flt Control Dev for Lunar Lander

Ames Research Center Capabilities

- Vertical Motion Simulator (VMS) for Lander Development, Testing, Certification, and Training

Flight simulator with large-amplitude, independent six degree-of-freedom motion capability that is uniquely suited to realistically recreating the flight dynamics of Human Lander Systems.
(https://aviationsystems.arc.nasa.gov/facilities/vms/index.shtml)



The VMS is a safe and cost-effective environment for:

HLS Development

- Rapid implementation and evaluation of candidate HLS designs
- Flight control, guidance, displays, and procedure development for HLS manual control per requirements for Crewed Space Systems (NASA HEOMD-003)
- Design and evaluation of potential in-flight crew training vehicles

HLS Testing and Certification

- Develop certification packages for human-in-the-loop usability as required by NASA HEOMD-003
- May be offered as GFE to industry partners for operational testing, evaluation, and certification

HLS Training and On-going Development

- The VMS is the most operationally realistic ground-based crew training platform available today
- Allows rapid exposure and training capability for a wide range of nominal and off-nominal situations
- May be used for continuous HLS development and crew training as in the Space Shuttle program

Ames Research Center Capabilities

- Autonomy Intelligent Systems Division (https://ti.arc.nasa.gov/)
  - Software Verification and Validation
    - Automated V&V for software to ensure quality and safety without lengthy test campaigns. Accelerating timeline and reducing oversight may lead to software being done in a rush and with less quality oversight. Automated V&V can help increase quality while respecting accelerated timeline
  - Caution and Warning
    - Caution and warning and fault response during crewed missions, and to improve flight controller situational awareness and responsiveness during dormant periods.
  - Automation of Operations
    - Autonomous operations to reduce flight controller and crew workload during crewed missions, and to reduce flight controller workload during dormant periods
  - Playbook (planning and scheduling for human and robotic activities)
    - Systems currently used to plan/schedule all crew activity on ISS as well as Mars Science Laboratory and Mars 2020 rover activity. Also used for first crew self-scheduling study on ISS in 2017-18.

Ames Research Center Capabilities

- Human Factors
  - Human Systems Integration Architecture
    - For increasingly Earth-independent contingency management
  - Vibration assessment impact on human visuo-motor performance
    - 3-axis of motion vibration chair mounted on human-rated centrifuge
  - Wearable bio-sensors
    - Wireless assessment of full-range of psychophysiological metrics
  - Formal training and teaming (crew resource management)
    - Just-in-time-training methods/technologies and crew resource management
- Integrated Mission Information Systems (also known as Cross Program Data Systems)
  - Low-cost, highly adaptable/expandable integrated information systems architecture for managing engineering and safety data across the mission life-cycle

Human Systems Integration Division (https://human-factors.arc.nasa.gov/)

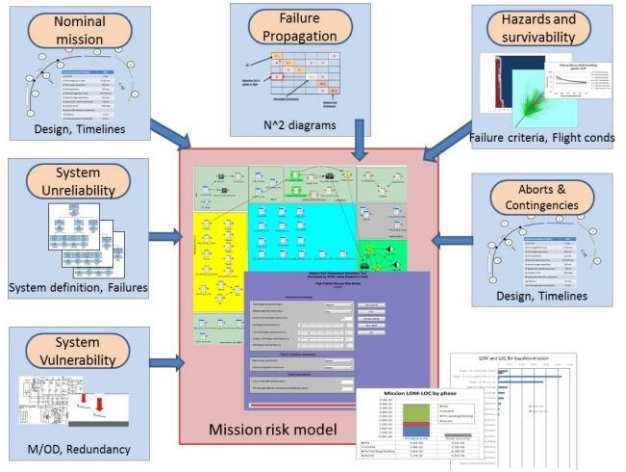
Ames Research Center Capabilities

- Engineering Risk Assessment (ERA) (https://www.nas.nasa.gov/projects/era.html)

ERA extends traditional probabilistic risk assessment techniques through the explicit inclusion of physics-of-failure and dynamic system modeling. The result is a set of rapid turn around tools/models which provide quantitative, risk metrics for uses such as:

- Ensuring crew safety through awareness of risk implications of design decisions throughout the project lifecycle
- Risk-informed decision making for investment choices
- Requirement scoping, validation, and verification

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



- Advanced Material Development & Arc Jet Testing:
  - The Ames Entry Systems & Technology Division is a leader in high temperature materials engineering. (https://www.nasa.gov/centers/ames/entry-systems-and-technology)
  - Thermal Protection Materials Branch design & analysis capabilities: (https://www.nasa.gov/content/thermal-protection-materials-branch)
    - High temperature ceramic materials development and characterization, e.g. nozzle throats
    - Advanced conformal, high-strength composites for thermal protection
    - In-situ instrumentation of complex composites for accurate health monitoring (thermal, aerodynamic, etc.)
  - Thermophysics Facilities Branch test capabilities: (https://www.nasa.gov/centers/ames/thermophysics-facilities-home)
    - Interaction Heating Facility (IHF) 60MW arc jet for high heat flux, long duration (> 1hr) testing of large models
    - Panel Test Facility (PTF) provides test capability for acreage heating on panels up to 16”x16” and angles of -5°to 8°

National Aeronautics and Space Administration

NASA Center Capabilities
Armstrong Flight Research Center

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ARTEMIS

What Does Armstrong Really Do?

- Armstrong has facilities and requisite expertise to conceive, design, analyze, fabricate, integrate, maintain, and conduct disciplinary research, flight research, and flight test on modified or unique research vehicles and systems

- Armstrong's strength is in integration of developmental systems – integration of systems into a vehicle (fundamental aero type work) or of vehicles into a system (unmanned aircraft system [UAS] in the National Airspace System [NAS])
  - Combination of engineering, operations, and safety skills inherent in workforce and flexible/lean processes to manage risk down to an acceptable level

- While majority of work is aircraft-based, the same skills are also applied to non-aircraft work (vehicle integrated propulsion research, ground test, **Orion Pad Abort [PA]-1 integration, Orion Ascent Abort [AA]-2 developmental flight instrumentation (DFI) development and integration, X-43,** lifting bodies, **Lunar Landing Research Vehicle,** etc.)

- Technical staff is experienced with various aircraft types, flight regimes, systems – not restricted to a certain class of aircraft
  - Same people to work subsonic, supersonic, hypersonic systems

Capabilities and Core Competencies

Engineering Research

- Airframe/power-plant maintenance, avionics technicians, experimental modification/fabrication, flight systems qualification, experimental test pilots, test operations planning
- Systems engineering and integration (SE&I), aerodynamics, propulsion, structures, flight controls, subsystems, instrumentation

Atmospheric Flight Research

- Partnership, program/project development
- Mission, research, flight test objectives development
- Airworthiness certification, ground/flight/range safety
- Technology, systems development/integration/test
- Mission control, range operations

Facility Capability

- Experimental and testbed aircraft
- Unmanned aircraft systems
- Earth science and infrared astronomy platforms
- Real-time engineering simulation

Range and Test Facilities

- Dryden Aeronautical Test Range (DATR)
- Research Aircraft Integration Facility (RAIF)
- Flight Loads Laboratory (FLL)
- Building 703 SOFIA/Airborne Science Operations

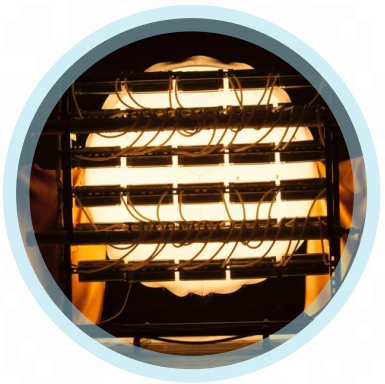
Facility Capability

Support Aircraft and Maintenance Organization (SAMO)

Support aeronautics research and science missions; provide versatile aircraft to meet requirements for pilot proficiency, safety chase, photography, video, and research flights in dual-capacity roles

Dryden Aeronautical Test Range (DATR) Capabilities

Safely monitor and control aeronautics research and science flight activities; provide real-time acquisition and reduction of flight research telemetry and radar data, video tracking, and effective voice communications to flight and ground crews (includes ISS/Soyuz VHF support)



Simulation Laboratory

Test simulation-supported software and hardware to develop, integrate, and validate highly complex aeronautics research aircraft and low Earth orbit vehicles

Flight Loads Laboratory (FLL)

Provide high temperature and structural testing – mechanical, thermal, structural dynamic, mass properties – of large-scale structures to simulate subsonic through hypersonic flight conditions

AFRC Program and Project Space Activities

Flight Opportunities Program (FOP)

FOP is a Flight Service Provider for testing NASA lunar technologies that require relevant-environment testing

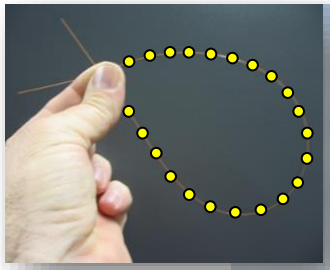
- STMD-Chartered program managed at AFRC
- Match promising space technologies to commercial flight platforms contracted through FOP
- Can expand this service offering through on-ramp of commercial flight providers

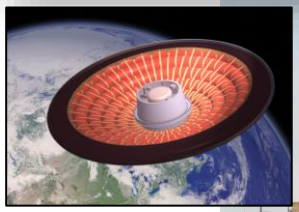
Lunar-Lander Trainer Study

- AFRC tasked in May 2008 to evaluate concepts for Free-Flying Lunar Lander Training Vehicles (LLTVs)
- Report delivered on 16 Oct 2008; study results included:
  - Training objectives and preliminary vehicle requirements
  - Scoring criteria against which to grade LLTV concepts
  - Peer-reviewed by 4 Apollo moonwalkers, 2 Shuttle commanders
  - Consensus of study was that a free-flying trainer is required

Fiber Optic Sensing System (FOSS)

- Support STMD/TDM Cryo-Fluid Management Portfolio Project - FOSS-based instrumentation for temperature and liquid level sensing; applies to ISRU Liquefaction effort
- FOSS will fly on Atlas V to measure temperatures on Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID), and strain and temperature on subsequent EDL missions
- AFRC/JPL activity to explore tactile sensor for rover wheel





Testing Lunar and Mars Approach and Landing Sensors at NASA Armstrong

NASA Armstrong F-18 Testing Mars Science Laboratory (MSL) Landing Radar

Test of Autonomous Landing and Hazard Avoidance Technology (ALHAT) LIDAR

Flight Opportunities Program Masten Xombie Testing Vision Landing System (VLS) for Perseverance Mars Rover

NASA National Campaign Tests of Urban Air Mobility Simulated Instrument Flight Rule Approach and Landings

Opportunities for Testing on Flight Opportunities Program Flight Providers

Masten Rocket VTVL Vehicles

World View and Raven Balloons (100K ft Altitude Capability)

UP Aerospace Sounding Rocket

National Aeronautics and Space Administration

NASA Center Capabilities
John H. Glenn Research Center

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ARTEMIS

2024 and Beyond: Glenn Lunar Technology

Integrated Electric Power Production and Distribution

- Kilopower (1-3kW) fission power demonstration
- Energy storage and conversion (batteries, fuel cells, solar)
- Advanced modular power management and distribution systems

Cryogenic Fluids Storage and Transfer

- Acquisition and transfer of fluids under reduced gravity
- Reduced boil-off and thermal management
- Propellant liquefaction for lander cryogenic propulsion systems

Solar Electric Propulsion (SEP)

- Extend and enhance the capabilities of new exploration and science missions

In-Situ Resource Utilization: "Living off the Land"

- Oxygen from Lunar regolith
- Water from permanently shadowed craters

Surface technologies: Landers, Rovers, and Habitats

- Development of innovative wheels for rovers
- Materials development supporting new lander propulsion systems

Advanced Communications Systems and Architectures

https://www1.grc.nasa.gov/facilities/

Plum Brook Station: Space Environmental Test Capability

Delivering one-of-a-kind environmental testing capability at one location

Space Environments Complex
The World's Largest Space Environmental Simulation Chamber

Largest space simulation vacuum chamber

Highest capacity Mechanical Vibration Facility (MVF)

Upper-stage In-Space Propulsion Facility (ISP)

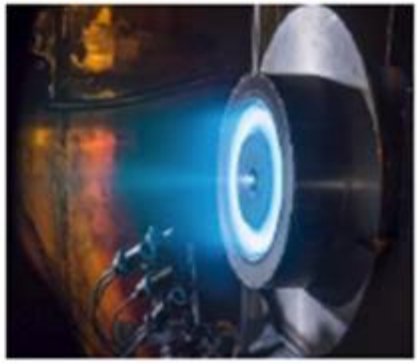
Most Powerful Reverberant Acoustic Test Facility (RATF)

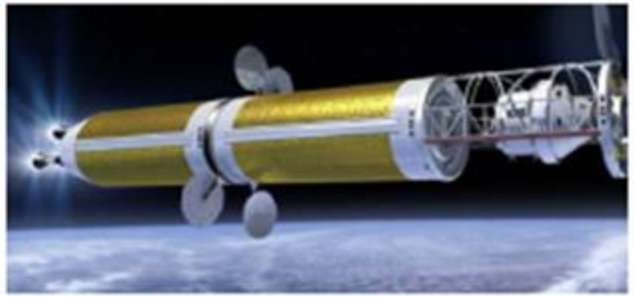
https://www1.grc.nasa.gov/facilities/spf/

https://www1.grc.nasa.gov/facilities/isp/

Glenn Research Center – Space Propulsion and Cryogenic Fluids Management

- **NASA Glenn delivers innovations in propulsion technology and propellant management critical to the Agency's mission to transport astronauts into deep space. Glenn provides expertise and facilities for research, design, analysis, technology, testing, and flight system development**
- **NASA Glenn core expertise includes:**
  - Propulsion systems (chemical, electric, and nuclear thermal) design, development, fabrication, and flight test
  - Glenn leads NASA's electric propulsion and power, from early-phase research through flight systems development, enabling commercial technology transfer
  - Cryogenic Propellants (liquid, gas, densified) including LOX/LH2, LOX/LCH4, LOX/RP-1, NTO/MMH, green. Expertise in design, development, handling, storage, demonstration, and flight test of fluid systems
  - In-Situ Resource Utilization (ISRU) technology and system development, where Glenn's internationally recognized expertise enables use of high leverage natural resources for space systems (both regolith and atmosphere derived)





https://www.nasa.gov/content/glenn-expertise-space-propulsion-and-cryogenic-fluids-management

Glenn Research Center - Power Systems

- **NASA Glenn is ushering in the next generation of technologies for power generation, energy conversion and storage by studying and developing solar power generation, batteries, fuel cells, and power management and distribution. NASA Glenn engineers have extensive expertise in the integration of each of the respective technologies into end-to-end systems, and have the facilities required for the testing, verification, and validation of those end-to-end systems**
  - Core expertise includes solar power generation, batteries, fuel cells, regenerative fuel cells, thermal energy conversion and heat rejection, radioisotopes, fission, power management and distribution, and integration.
  - Extensive capabilities in power management and distribution including autonomous power control (APC), power system fault management, power distribution reconfiguration, optimal battery management, and power system design, analysis, and modeling, and system integration.
  - Development of power generation capabilities include the development of solar cells, solar arrays, primary fuel cells, radioisotope power systems, fission power systems, and associated thermal systems.
  - Development of energy storage capabilities consist of research and development for batteries and regenerative fuel cells.
  - Development of advanced modular power systems (AMPS) for modular power distribution capabilities including the regulation of power generation and storage systems; delivering of both low- and high-voltage generated power to users; the providing of conditioned power to a wide variety of loads; and automatic controls to facilitate the protection and management of power systems.

https://www.nasa.gov/content/glenn-expertise-power-energy-storage-and-conversion

Glenn Research Center – Communications & Materials and Structures for Extreme Environments

- **NASA Glenn Communication and Intelligent Systems enables orders-of magnitude increases in mission data transfer and provides continuous, cost-effective, and secure high data-rate communications**
  - Directs and conducts research and engineering development in fields of advanced communications and intelligent systems technologies for applications in current and future aeronautics and space systems.
  - Core expertise includes advanced antennas, integrated radiofrequency and optical terminals, software-defined radios, cognitive radios, high-power amplifiers and networking for high-data-rate communications.
  - Exploitation of new radiofrequency spectrum and maximizing data throughput on existing spectrum allocations are continuous endeavors.
  - Development of intelligent controls, smart micro-and nano-sensors, and harsh environment electronics.
    - https://www.nasa.gov/content/glenn-expertise-communications-technology-and-development

- **NASA Glenn Materials and Structures Technologies improve aircraft engines, space propulsion systems and planetary surface operations while contributing to break-through technologies for practical Earth applications**
  - Includes the research, development, demonstration, and flight application of advanced materials, structural concepts, and mechanisms to enable high-performance, long-life aerospace systems subjected to the extreme environments encountered in propulsion and power, planetary entry, planetary surface operations, and the space environment.
  - Development of materials for extreme environments include a combination of high temperatures, complex gaseous atmospheres ranging from oxidizing to reducing, high pressures, large dynamic and impact loads, molten materials, cryogenic temperatures, electromagnetic fields, and space radiation.

https://www.nasa.gov/content/glenn-expertise-materials-and-structures-for-extreme-environments

National Aeronautics and Space Administration

NASA Center Capabilities
Goddard Space Flight Center

EVA Capabilities Center Points of Contact:

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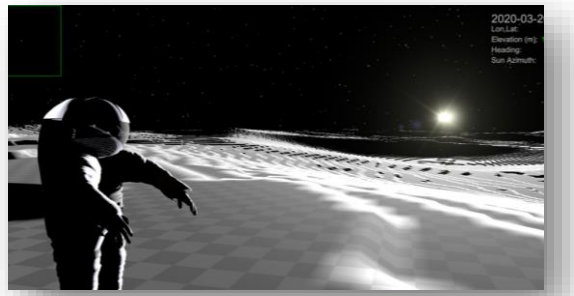
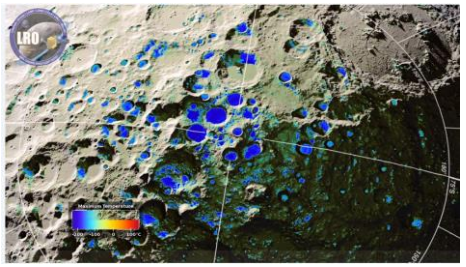
ARTEMIS

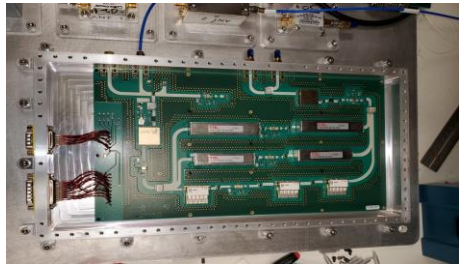
Science & Mission Support

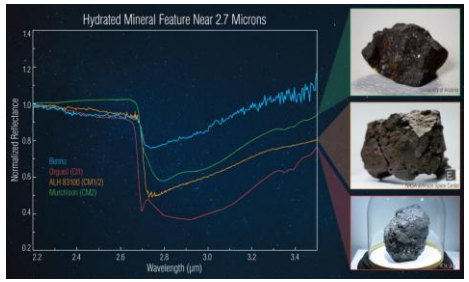
- **Development of operations support** for crew deployed science payloads, including instrument development, ConOps development, and base camp planning & design
- **Participation in classroom and field geoscience training for astronauts**, engineers, flight controllers, and managers
- **Leadership of field campaigns** in analog environments to:
  A. Provide training to astronauts and human space flight personnel
  B. Develop of operational concepts for the crewed surface exploration of the Moon and Mars
  C. Test crew deployed science payloads
  D. Develop understanding of dominant planetary surface processes
- **Supporting EVA hardware** development and development of real-time science support architecture, including handheld instruments & sensors, radiation sensors and other supporting instrumentation, as well as virtual and augmented reality systems
- **Remote sensing databases and data visualization** for lunar science including imaging, geology and data processing capabilities. Using LRO data to define landing sites and EVA traverse plans
- **Lunar surface science** for surface properties, environment, dust, plasma, exosphere, landing site selection & characterization, base camp planning, traverse planning
- **Moon to Mars Space Weather Office** provides space environment situational awareness and is improving characterization and modeling of events and risks
- **Base Camp Planning and Design**: Developing base camp designs, including Human System Integration



Understanding & Monitoring the Lunar & Space Environment







Operating in the harsh lunar and space environment

- Sophisticated models and laboratory studies enable an understanding of the dust, plasma, and radiation environment and how to deal with these challenges
- Advanced cryogenic systems with specialized materials selection and realistic test facilities enable operation in a highly variable thermal environment
- GSFC has expertise in monitoring of the space weather environment, modeling, and anomaly assessment, e.g. Moon to Mars Space Weather Office and Community Coordinated Modeling Center

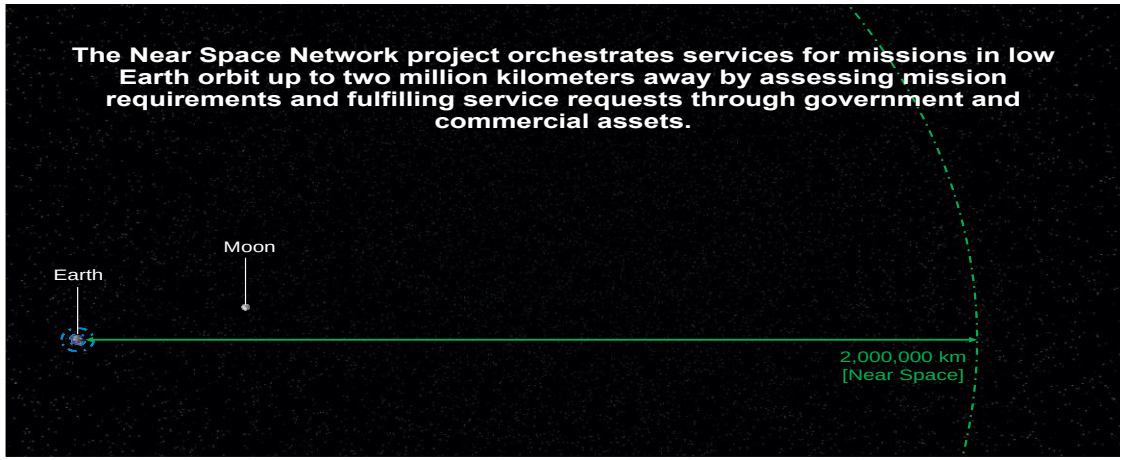
Sensor & Instrument Development

- Experienced technology development and flight build organizations for potential lunar & space instruments, including IR spectrometers, cameras, mass specs, XRF, particle and dust sensors, microwave, neutron gamma ray spectrometers, mapping lidars along with the thermal, power, packaging and communications needed to hold and operate them.
- High heritage miniaturized sensors to provide knowledge of the space environment, including dose risk to astronauts
- Miniature instruments for use by astronauts on the lunar surface and in space
- Expertise in small scale regolith and sample handling systems
- Instruments can operate successfully in the harsh lunar & space environment and serve to identify hazards for human exploration, identify resources for future utilization, and advance scientific understanding.
- In-situ and remote sensing of key space weather and environmental indicators (e.g. electrons, neutrons, protons, electric and magnetic fields)

Communications & Navigation

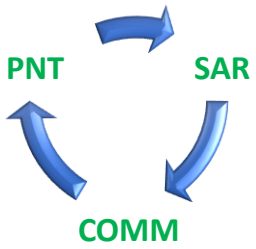
Communications & Navigation Services:

- **Near Space Network:** The Near Space Network project orchestrates services for missions in low Earth orbit up to two million kilometers away by assessing mission requirements and fulfilling service requests through government and commercial assets.
  - DTE and non-DTE services within the NSN service volume (encompasses Lunar), including Government and Commercial providers will be orchestrated and provided via NSN



EVA Applicable Comm and Nav Capabilities:

- **LunaSAR**: Search and Rescue capabilities for Lunar Surface – based on international SAR messaging standards and surface operations experience. Flexible architecture allows for beacon integration into vendor suit systems, enabling emergency location capability and astronaut health signaling supporting a wide ecosystem of commercial users
- **Surface Navigation**: LunaNet PNT service providing cis-Lunar GPS-like service to Lunar surface assets. PNT receivers can be integrated into suits or surface assets to utilize this service. Includes far-side capabilities. In concert with autoNGC, enables SAR positioning via the following:
  - Onboard, autonomous software cFS apps for navigation using data from an assortment of available sensors. Enables rapid, onboard autonomous decision and control for time-critical activities. Accurate navigation via real-time surface position knowledge updates, supports Search and Rescue.
- **GNSS Receivers**: Use of weak-signal GNSS from Earth for Lunar surface location services on Earth-facing Lunar locations, as will be demonstrated by LuGRE mission.
- **LunaNet Communications and Networking:** Seamless transport and delivery of data across diverse surface, orbiting relay and direct-to-earth assets. Data within the network are dynamically prioritized to provide critical information at the fingertips of the astronaut.



Engineering, Technology, Servicing, Instrument Development

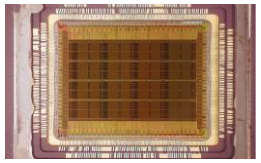
Shane Kimbrough with RELL

>25 yrs Expertise in Robotics, Servicing, and Tool Development

- Mission planning, simulation, and execution of >40 in-flight servicing tasks
- Rapid and successful development of >190 astronaut and robotic tools in support of Hubble Space Telescope, Alpha Magnetic Spectrometer EVA servicing mission, NASA's Return-to-Flight tool suite, ISS robotic servicing technology demonstrations and OSAM-1
- Expertise in adapting, ruggedizing and qualifying COTS hardware and scientific instrumentation for the space environment such as the GSFC provided ISS Robotic External Leak Locator (RELL) that has successfully located external fluid leaks on ISS
- Extensive experience and proven methods to establish modular hardware interfaces for robotic and crew servicing that extend operational lifetimes
- Current work includes developing a common crew handling package for astronaut deployed instruments

Coating and Optics Capabilities

- Coatings for reflective/anti-reflective visors for space helmets and window coatings for lander
- Low-cost ultra-thin polymer coatings for dust mitigation

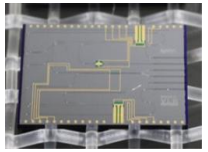


EEE Parts

- Selection, procurement, risk analysis of EEE parts for building space flight hardware.
- Innovative evaluation strategies for determining suitability of parts for space flight applications.

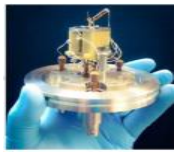
Radiation Effects & Analysis

- Radiation Effects and Analysis Group assesses effects of the natural space radiation environment
- Presently supporting the development of radiation tolerant display technology.



Miniaturized sensor technologies

- Photonic Integrated Circuit
- Freeform optics

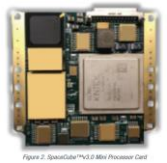


Astronaut-deployed and hand-held instruments

- Lunar experiment survey system for handheld instruments and for emplaced packages
- Regolith, topography, water, compounds, surface & exosphere processes

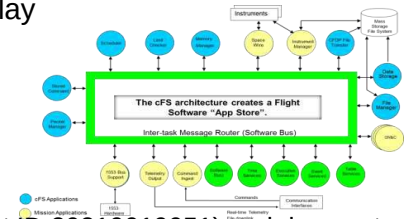
Fiber Optics and Photonics

- Design, manufacturing, testing, failure analysis, and integration of fiber optics & optoelectronics.
- Received Patent in 2018 for new method of processing RF information.



SpaceCube

- Intelligent multi-purpose avionics system that incorporates several miniaturized electronic cards for mix-and-match 1U (10 cm × 10 cm) cards.

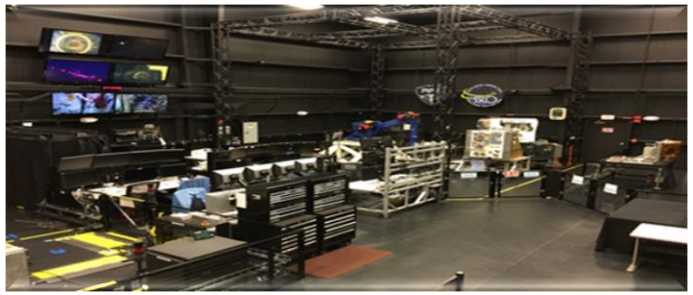


Core Flight Software

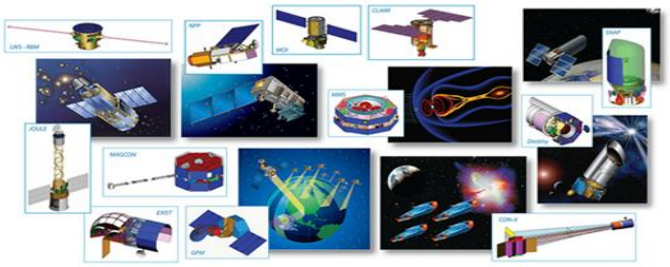
- Open source, human-rated reusable flight software. Being used on many missions, including Gateway and outside of NASA.
- *NASA Software of the Year for 2020*

Facilities

- **State-of-the art facilities for qualifying spaceflight & servicing** hardware, software & ground testing for robotic and astronaut tools with assets that simulate mission operations.
- **Space Science Mission Operations** provides operations for planetary, heliophysics, and astrophysics missions
- **Instrument Detector Development Lab**: Highly advanced semiconductor fabrication activity that enables development for MEMS and nanotechnology, Detector micro-electronic packaging and characterization.
- **Clean Room & Engineering Integration**: One of the largest cleanrooms in the world; Dedicated cleanroom facilities for manufacturing and testing; Integration and Testing complex provides end-to-end engineering.
- **Independent Verification and Validation Center** provides systems and software engineering functions to improve safety and reliability of missions
- **Wallops Flight Facility** provides safe, rapid and cost-effective access to space for technology demonstrations
- **Mission Design Lab, Instrument Design Lab, Architecture Design Lab** for rapid design and advanced concept development using multiple platforms (e.g. CLPS)



Compact Thermal Camera



National Aeronautics and Space Administration

NASA Center Capabilities
Jet Propulsion Laboratory, California Institute of Technology

Center Point of Contact:

Name: David Eisenman

Title: JPL POC to HEOMD Advanced Exploration Systems Division

Email: David.J.Eisenman@jpl.nasa.gov

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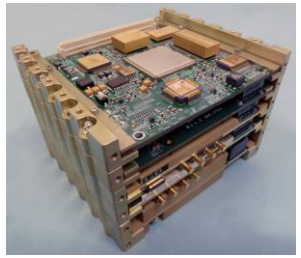
www.nasa.gov

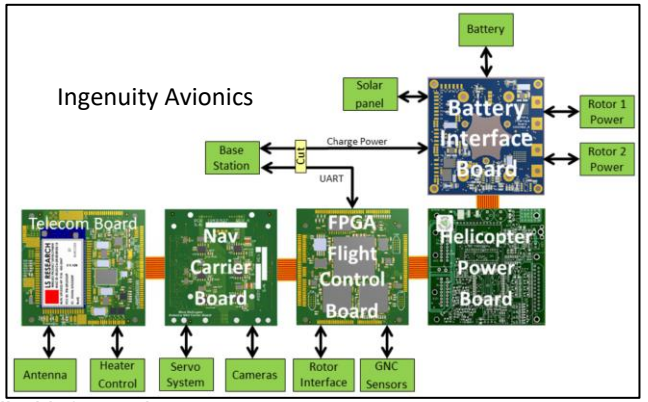
JPL Micro/Nano Capabilities Applicable to EVA Systems

- The JPL **Micro Devices Laboratory (MDL)** enables or enhances NASA missions and instruments by continuously improving microfabrication tools developed by the semiconductor industry to develop critical microelectronic components and technologies that are otherwise unavailable, from invention to space flight.
  - Since 1989, MDL has provided end-to-end capabilities in support of design, fabrication, and characterization of advanced components and sensors.
  - https://microdevices.jpl.nasa.gov/
- JPL has extensive experience in development of **Avionics and Comm Radios for Small System** for multiple Deep Space CubeSats and smaller systems such as the Mars Ingenuity Helicopter and small planetary rovers.
  - https://ieeexplore.ieee.org/document/7943885
  - https://www.sciencedirect.com/science/article/pii/S0094576520300333
  - https://www.jpl.nasa.gov/cubesat/pdf/Brochure_IrisV2.1_201611-URS_Approved_CL16-5469.pdf
  - https://www.jpl.nasa.gov/cubesat/missions/iris.php
- JPL has developed **F Prime, an Open Source Flight Software Framework for Small Systems** for multiple Deep Space CubeSats, and the Mars Ingenuity Helicopter.
  - https://github.com/readme/featured/nasa-ingenuity-helicopter
  - https://nasa.github.io/fprime/



Iris V2 CubeSat Deep-Space Transponder

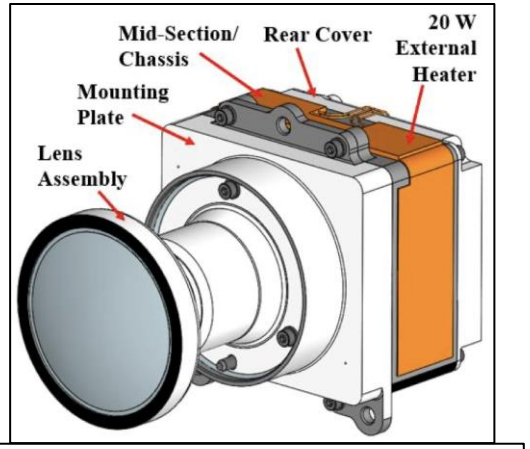
Ingenuity Mars Helicopter (1.8 kg)



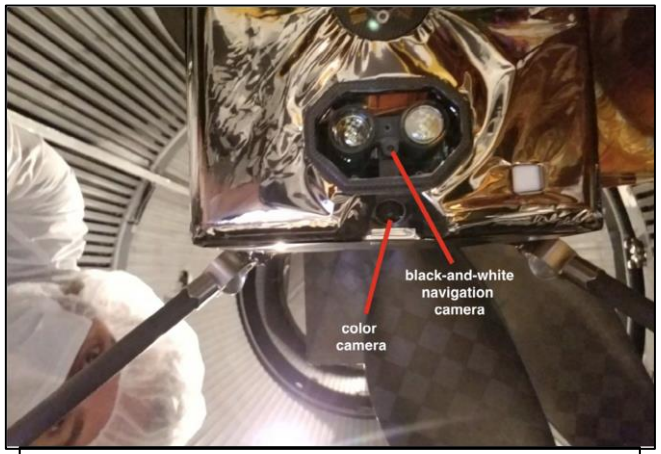
JPL Imaging Cameras for EVA Surface Exploration

- Engineering Cameras to support Surface EVA excursions and related activities such as sample collection.
  - https://mars.nasa.gov/mars2020/spacecraft/rover/cameras/#Engineering-Cameras
  - https://link.springer.com/article/10.1007/s11214-020-00765-9
- JPL is developing an enhanced engineering camera (EECAM) for Lunar surface operations based on the Perseverance rover EECAM design, and Day/Night Lunar Surface Navigation Capability.

Perseverance Flight EECAM's

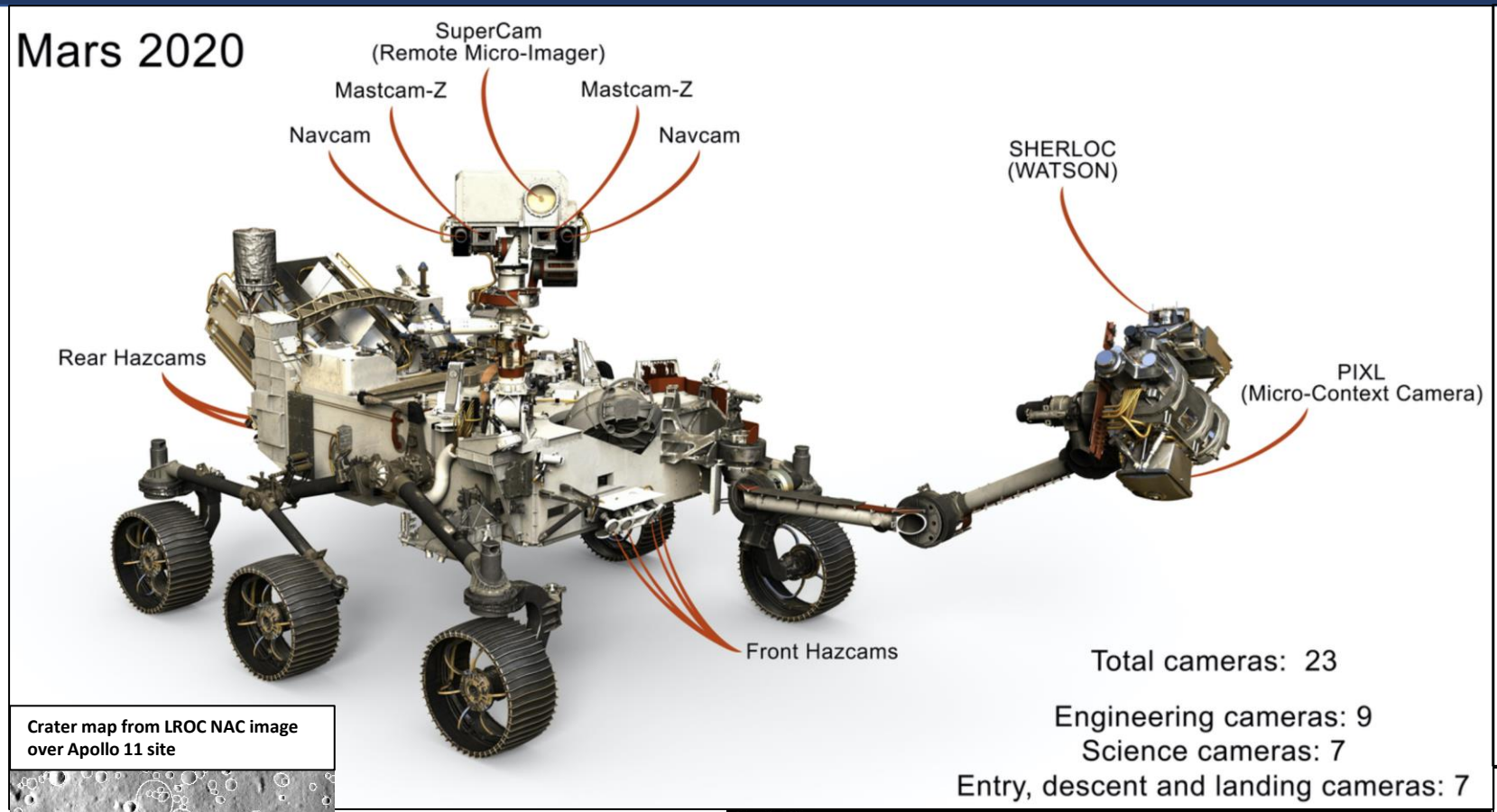


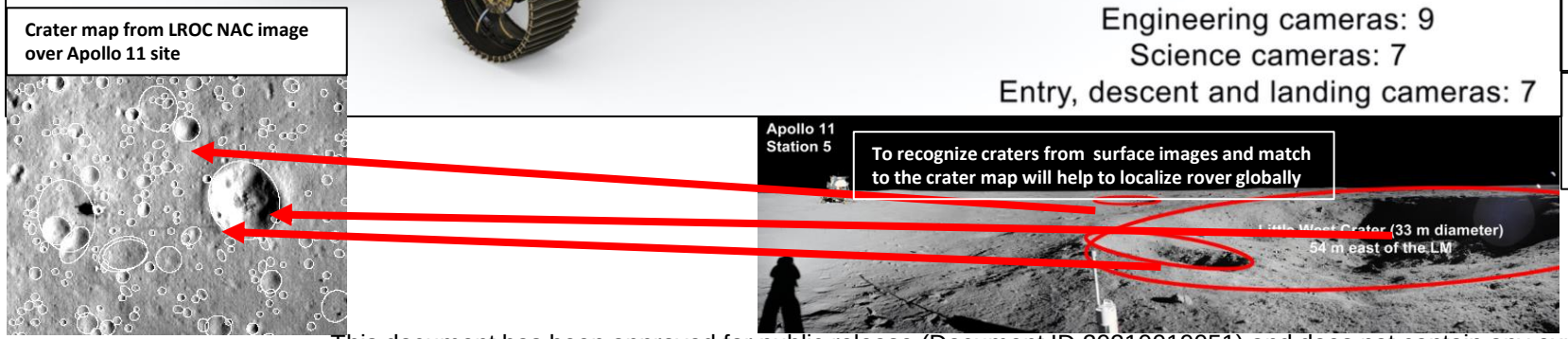
EECAM Design with Heater



Ingenuity Helicopter Cameras

JPL Planetary Surface Navigation Capability Applicable to EVA Systems





- JPL has extensive capability to navigate and track planetary surface missions safely over hazardous terrain.
- This capability involves an integrated and distributed system, with components on the rover (e.g., comm and surface imaging, sun sensors, star trackers, gyros, accelerometers, etc.), a lander (if applicable), orbiters, surface maps and DEMs made from orbital and rover imaging, autonomy software on the rover and an Earth-based mission control center.
- This same capability is applied to locate & document science targets, and precisely place instruments and collect samples.

https://moon.nasa.gov/exploration/diy-exploration/

JPL Environmental Monitoring Capability for Human Space Exploration Missions

Atmosphere Monitoring

- *Electronic Nose (ENose)* – chemical sensor to detect, identify, and quantify leaks and spills of selected volatile organic compounds
- *Vehicle Cabin Atmosphere Monitor (VCAM*) – ISS Express rack sized GCMS to measure major atmospheric constituents, and identify and quantify the presence of trace amounts of known and unexpected chemical
- *Spacecraft Atmosphere Monitor (S.A.M.)* – miniature GCMS; ISS tech demo
- *Laser Air Monitor (LAM)* – miniature , low power laser spectrometer to continuously monitor major atmospheric constituents for Orion with industry partner
- *Portable Life Support System (PLSS) CO_2 Sensor* - miniature laser spectrometer to accurately measure CO_2 and water vapor in the oxygen line; impervious to liquid water

Fire Monitoring

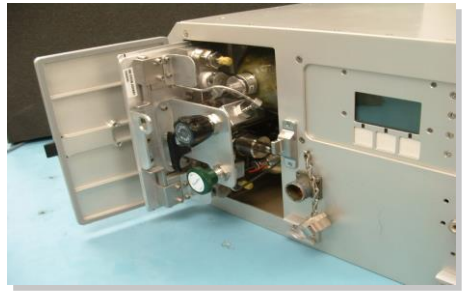
- *Combustion Product Monitor (CPM)* - Miniature, low power laser spectrometer to continuously detect and measure fire gases (HCl, HF, HCN, CO, CO_2, O_2); Safire tech demo

Water Monitoring

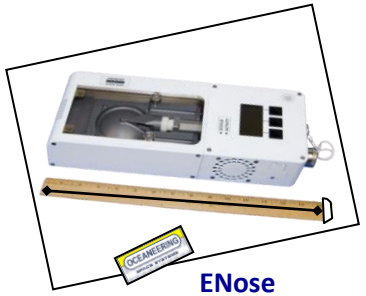
- *Organic Water Monitor (OWM)* – measures organic content of potable water; developing technology for future ISS tech demo partnered with JSC
- *mini Total Organic Carbon Analyzer (miniTOCA)* – miniaturizes the current ISS TOCA; developing TLS technology for future ISS tech demo partnered with JSC
- *Spacecraft Water Impurity Monitor (SWIM)* – front end to S.A.M. to volatilize water and measure with a high precision mini GCMS

Microbial Monitoring and Mitigation

- *Comprehensive vehicle & surface microbial surveys & assessments*
- *Water Sample concentrator*; ISS tech demo with industry partner
- *Biofilm mitigations technology development*



VCAM

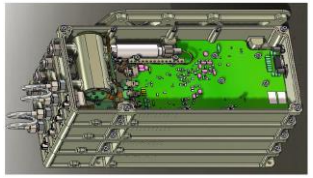


ENose

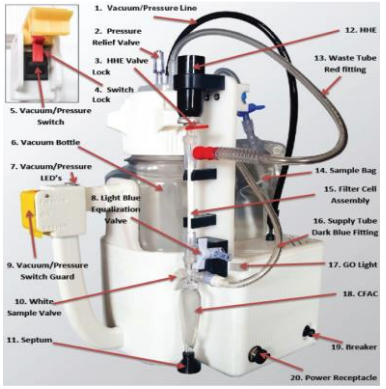
S.A.M.

CPM

PLSS CO_2 Sensor



LAM



ISS Water Sample Concentrator

JPL Pilot Mask Sensors Applicable to EVA Systems

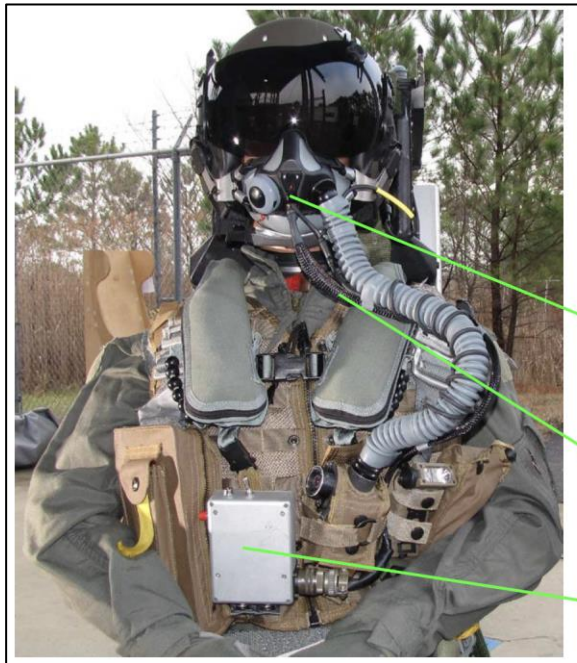
- JPL is developing miniature in-mask carbon dioxide, water vapor, and oxygen sensors to address occurrence of physiological episodes across the U.S. Navy aircraft fleet causing pilot blackouts.
  - Also working to transition these sensors, which have been test flown on NASA jet aircraft and a Navy test dummy in an environmental chamber, to a higher maturity level that can be implemented by Navy fleetwide and provided in high volumes by a commercial manufacturer.

Internal wiring routes around microphone and connects to:
(1) laser
(2) detector
(3) pressure-temp (PT) sensor
(4) thermistor.

The PT sensor is to the right near mask lip, mounted to instrument housing.

The thermistor is thermal epoxied to the housing. It does not protrude into exhalation valve opening.

JPL tunable laser diode sensor inside mask



Exhaust valve where JPL sensor head is mounted

Cable between JPL Electronics and JPL sensor head

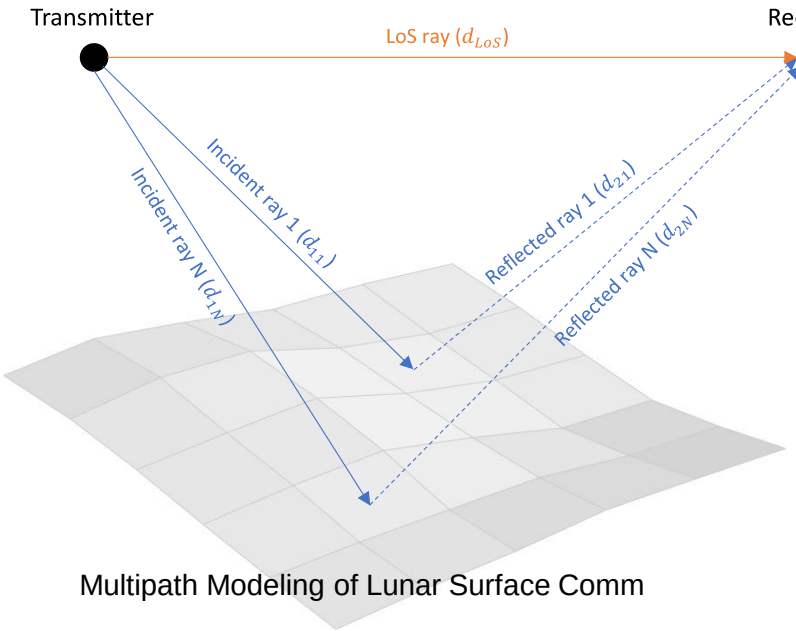
JPL Electronics

NAVAIR test dummy fitted with JPL tunable laser diode sensor and electronics

JPL Deep Space Communications and Tracking

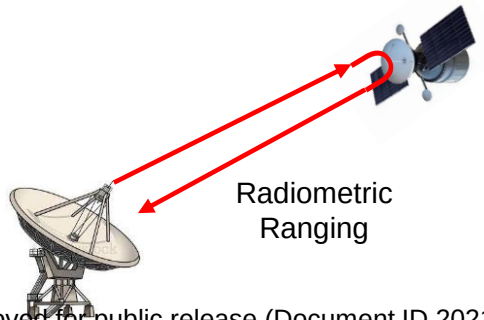
- **State-of-the-art capabilities in Deep Space communications and tracking**
  - Decades of experience in providing communications and navigation services to Lunar and Deep Space missions
  - Flight system development for Deep Space missions, e.g. Universal Space Transponder
  - End-to-end communication system architectures and trades for Lunar and Deep Space missions

- **Unique capabilities for Deep Space and Lunar missions**
  - High-sensitivity, power-constrained, and reliable communications
  - High-precision tracking techniques
    - 2-way and 3-way Doppler
    - Radiometric ranging, including re-generative PN and telemetry ranging
    - Delta Differential One-way Ranging (ΔDOR)
  - Advanced system analysis, modeling, and simulation techniques
    - Multipath analysis/simulations for Lunar surface environment
    - Ground station and spacecraft coverage analysis
    - Statistical link analysis with weather effects
    - Delay (Disruptive) Tolerant Network (DTN), flight and ground
    - Interleaving and ARQ design that mitigates fading



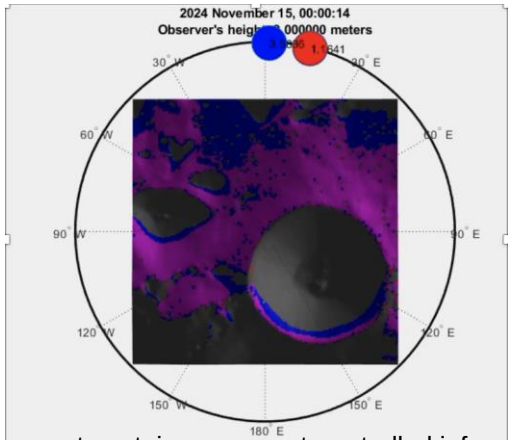
Multipath Modeling of Lunar Surface Comm

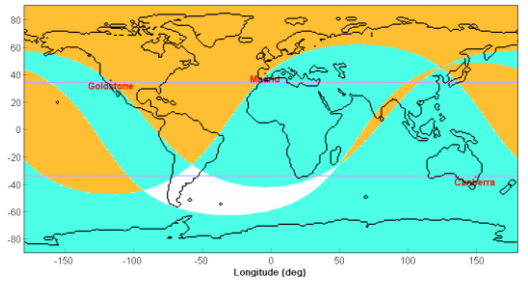
Universal Space Transponder



Radiometric Ranging

Sun/Earth Visibility at Lunar South Pole





Ground Station Coverage of Lunar spacecraft

Other JPL Technological Capabilities Potentially Applicable to EVA Systems

Batteries for extreme low temperatures:

- Cold capable batteries (up to -60˚C) simplify thermal design and reduces overall heater power draw
- JPL is working with multiple commercial battery vendors to incorporate JPL low temperature electrolytes into standard battery product lines

MER Battery

Sample Handling Technologies:

- 100 kg return mass constraint and contamination concerns related to both crew safety and scientific integrity will require drilling, coring, and caching capability, along with redundantly sealed thermally controlled containers
- JPL has significant experience in designing and building end-to-end sampling systems that integrate instruments, actuators/mechanisms, and robotics

MSL SASPaH

Additive Manufacturing (AM) for Space Applications:

- AM enables new part designs that are impossible with traditional subtractive manufacturing while at the same time saving cost and schedule
- JPL has extensive experience in and specialized facilities for space-qualified AM parts

Gradient alloy rocket nozzle

National Aeronautics and Space Administration

NASA Center Capabilities: Johnson Space Center and White Sands Test Facility

Center Points of Contact:

Primary POC: Ron Diftler

myron.a.diftler@nasa.gov

Secondary POC: Sam Gunderson

samuel.b.gunderson@nasa.gov

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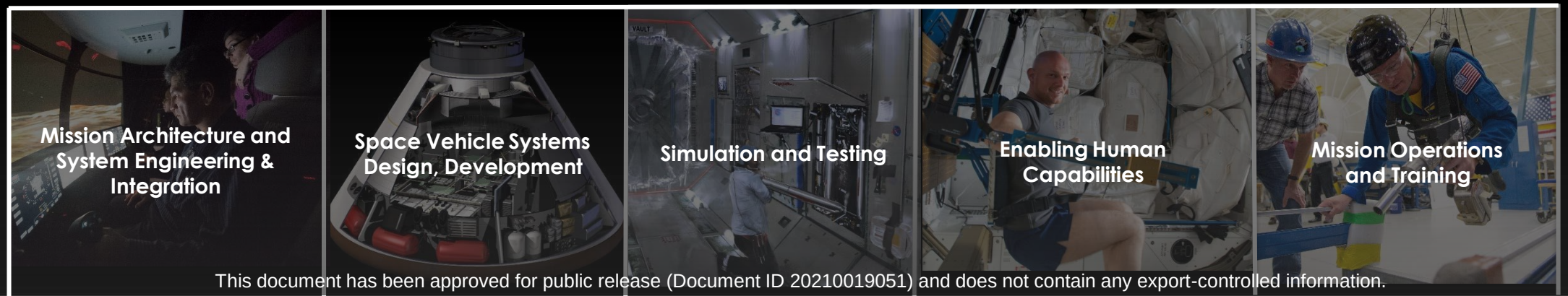
JSC Comprehensive Capabilities for Human Spaceflight

Experienced in mission-level multi-program systems engineering and integration of human and vehicle systems. Capabilities span mission architecture, vehicle systems and design, simulation and testing, enabling human capabilities, and mission operations and training to integrate unique solutions for human spaceflight.

Mission Architecture
- End-to-end mission performance assessments
- Beyond LEO Architecture Parametric Sizing Tool
- Mission planning expertise
- Mission modeling
- Vehicle sizing

JSC Capabilities Details
- https://www.nasa.gov/johnson/exploration/technology/jsc-capabilities

Systems Engineering and Integration
- Strong, effective vehicle-level and systems SE&I
- Uniquely qualified to tailor standards/processes to achieve appropriate rigor in prototypes, development hardware or spaceflight applications
  - Standards application and requirements development
  - DDT&E at spacecraft, system and component level
  - Certification & human rating
- Demonstrated experience delivering of flight items leveraging specific domain capabilities for customers
  - Large scale, fully tested, verified and qualified systems
  - Spaceflight certified components
  - Inline analysis and simulation products, including IV&V



JSC Space Vehicle Systems - Design & Development

Expertise in the design and development of crewed and uncrewed space vehicle systems, including aeroscience and flight mechanics; power and propulsion; software, robotics, and simulation; structures; avionics; crew health and performance; and thermal.

Lunar Design Aspects

- Lunar crew module and systems
- Flight operations
- Human systems integration display development
- Autonomy/Class A Core Flight Software
- Probabilistic Risk Assessment
- Optimized exploration-class medical capabilities
- Integrated avionics and software backbone compatibility
- Dust characterizations and mitigation
- Light weight hatch and docking system DDT&E
- ECLSS/thermal optimization
- Crew emergency response equipment
- Robust, thermal runaway resistant battery design
- Glass/Windows database

JSC Simulation and Testing

Development of high-fidelity, real-time, human/hardware-in-the loop engineering simulations/models/tests. Software development expertise for flight/ground systems, embedded and integrated software, and quality engineering/assurance.

System Testing

- Battery screening/abuse testing
- Power quality & storable cryogenic testing
- Electronics design & comm testing
- Antenna modeling & test
- 6 DOF Dynamic Docking Systems Testing
- Mechanical and electrical part testing, failure analysis
- Hypervelocity impact testing (MMOD) for shielding
- Composite Overwrapped Pressure Vessel Testing

Hazardous Testing

- NASA-STD-6001 Flight Acceptance Standard Tests (FAST):
  - Upward Flammability, Materials Odor & Offgas Toxicity, Heated Promoted Combustion, LOX/GOX Mech Impact, Hypergolic Material Compatibility
- Rocket Propulsion Test & Eval: In-Space Propulsion Systems, Hypergolic Propellants, LOX/Methane, Small SRM's
- Decontamination & Refurbishment of Flight Components
- O2 Compatibility Assessments, Component/Material Testing & Hazards Evaluation
- Propellant & Aerospace Fluids Testing & Energetic Hazards Evaluation
- Pressure Vessel Destructive Testing, Analysis, Qual & NDE
- Training Courses:
  - COPV Damage Detection, Blast & Frag, Hypergol Systems, H2 Handling, FAST Familiarization, Totally Encapsulating Suit Boot Camp, Fire Hazards in O2 Systems, O2 Systems Ops & Maintenance

Human-in-the-Loop Simulations

- Human Vacuum/Thermal Chamber Testing
- Active Response Gravity Offset System (Argos)
- Manual Control of Vehicles
- Mock-up Development
- Underwater & Surface Systems Analog
- Human Exploration Research Analog (HERA)
- Planetary exploration training for the crew

Simulation

- Rarefied Gas Dynamics (RGD)
- Integrated Power, Avionics, and Software test bed
- Systems Engineering Simulator

Environmental Testing

- Random vibe w/ high G & high force
- Radiant Heat Test Facility
- EMI test chambers
- Acoustics Environment Analysis
- Operational Environment Lighting Analysis
- Lunar Environment chamber with soil

Enabling Human Capabilities

Experienced in integrating human systems into mission architecture and EVA systems. Capabilities include expertise in human health and performance, EVA, and exploration sciences.

Human Health and Performance

- Provides subject matter expertise on vehicle certification requirements interpretation and provides verification methods assistance for all human rating space flight requirements:
  - HSI Plans and Processes
  - Human System Requirements and Verification plans
  - Human Factors Engineering
  - Crew Task Analysis
  - Crew Worksite Analysis
  - Human Error Analysis
- Review and applicability of human system standards, tailoring of verification plans, technical guidance and test facilities spanning a wide set of expertise:
  - Vehicle Acceleration and Velocity Models Analysis (Occupant Protection)
  - Manual Control of Vehicles
  - Toxicology and Contamination Control Plans
  - Radiation Monitoring, Protection and Exposure Analysis
  - Decompression Sickness Mitigations
  - Lunar Dust Exposure Management and Mitigations
  - Acoustics Environment Analysis
  - Operational Environment Lighting Analysis
  - Human Centered Design and Space Habitability Architecture
  - Environmental Monitoring (surfaces, air, water)
  - Crew Health and Nutrition Systems

Extravehicular Activity (EVA)

- External Interface definition, requirements, and integration (hatches, ladders, handrails, worksite interfaces, lighting)
- Internal interface definition and support (power, water, communication)
- Evaluation of preliminary module concepts (physical or VR), including support for engineering and crewed evaluations and simulations
  - Refinement of operations concepts for use of module to perform EVA and EVA servicing
  - Support for analog testing (Neutral Buoyancy Lab, Active Response Gravity Offset System, VR sims)
- Assurance and certification of EVA hardware
- Safety and reliability controls for EVA operations

Exploration Science

- Science Mission Planning
- Lunar sample handling, containment, contamination control, physical and chemical properties, and dust
- Sample curation (cold curation building capacity)
- Lunar science expertise (sample science, remote sensing, planetary science, analytical instruments)
- Human science expertise
- Landing site characterization
  - Geotechnical properties characterization
  - Traverse planning
- Image analysis expertise (photogrammetry)
- Planetary exploration training for crew

Mission Operations & Training

JSC provides mission planning, training, and mission execution for all of NASAs human space flight missions. JSC has extensive experience coordinating and integrating both international and commercial partners.

Mission planning, Training, and Mission Execution

- Operations concept definition
- Requirements integration
- Operations product development
- flight design& mission analysis
- Curriculum development
- Flight controller Training
- Instructor Training
- Astronaut Training
- Real-time Operations

Design For Operations – Incorporating human space flight experience into the design process helps provide an efficient, operable EVA design.

- power/data channelization
- flight software integration
- bus loss & load sheds
- loss of attitude control
- Manual Operations
- Overrides
- "Fly As Is" Assessments
- ops workaround solutions

Mission & Training Facilities – Mission control and training facilities are the hub for human space flight operations.

Mission Control
- Control & Customer Support Room
- Network access

Space Vehicle Mockup Facility
- High Bay for Full Size Mockups
- Crew Training
- Development & Testing

Astronaut Training Facility
- High Fidelity Space Craft Simulators
- Integrated Systems Training

Neutral Buoyancy Laboratory
- One of the worlds largest pools
- Crew Training
- Hardware verification

Rapid Prototype Lab (RPL) - Development of vehicle displays and astronaut interface prototypes for quick deployment. This capability is imbedded into the crew office providing direct crew feedback and experience into the crew interface development process.

National Aeronautics and Space Administration

NASA Center Capabilities
Kennedy Space Center (KSC)

Center Point of Contact:

Primary POC

Julius “J” Edelmann

j.edelmann@nasa.gov

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Kennedy Space Center

NASA's Kennedy Space Center (KSC) - Offers world class expertise and capabilities in support of:

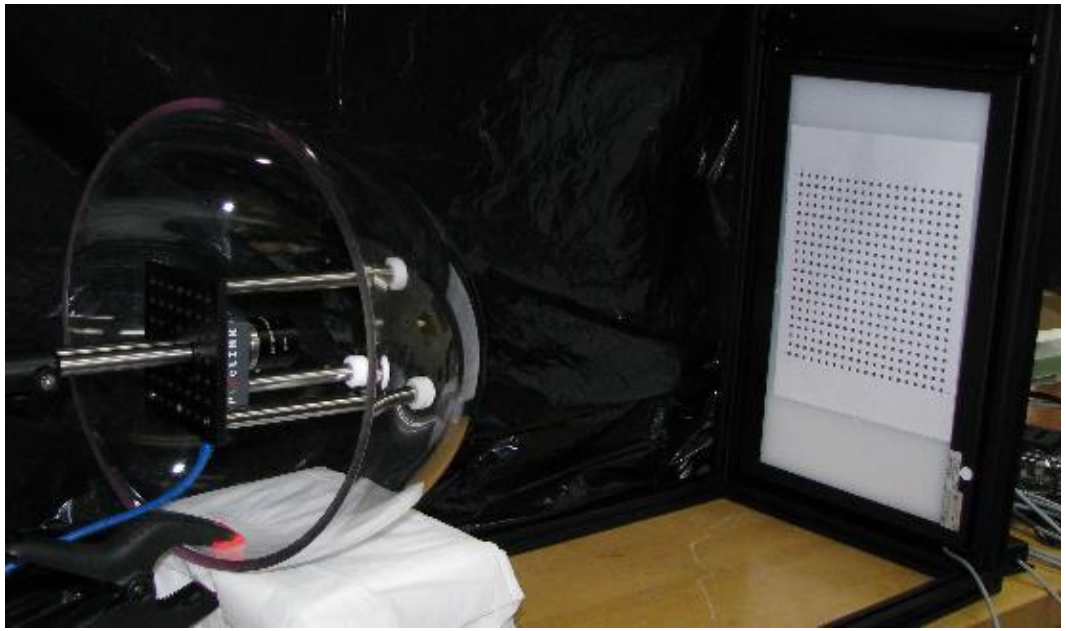
- Commercial companies performing development, testing, risk mitigation, manufacturing, and processing of Exploration EVA suits and systems in support of the HLS and Artemis Programs.

Testing tools and prototype EVA suit under dusty conditions in our 25 ft by 25 ft (15 ft height) negatively pressurized Regolith Bin with 120 tons of Black Point-1 (BP-1) simulant.

https://kscpartnerships.ksc.nasa.gov/LandingSystemsGO

Visor and Window Metrology

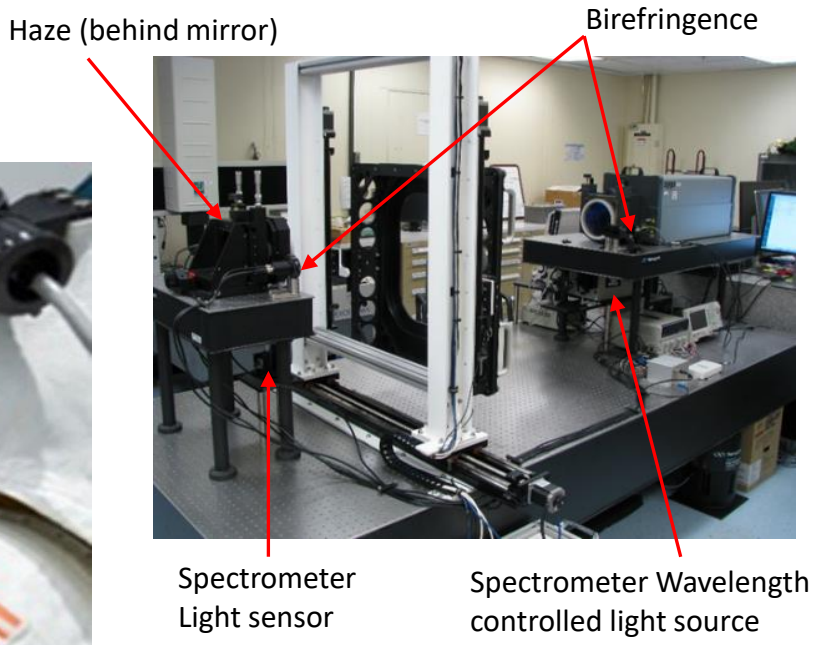
- Visor Metrology (Artemis, Center Innovation Funds (CIF) project)
- Window Metrology (Orion, ISS, Boeing, SpaceX, CIF, NESC)
- Window defect sensors (Orbiter, Orion)



Optical system measuring astronaut visor distortion

Astronaut two-visor helmet

Window Metrology



Additional customized instrumentation has been added to measure transmission, color shift, reflection, haze, parallelism, and birefringence (polarization evolution) in space flight windows

Granular Mechanics, Regolith Operations, and ISRU

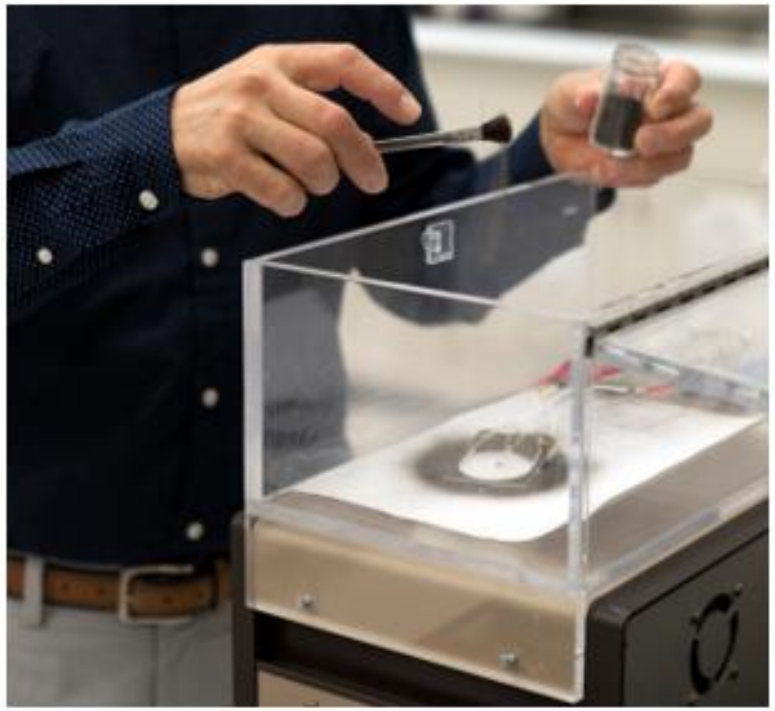
- EVA Suit and Tool Testing
- Dust-tolerant mechanisms
- Plume-surface interaction
- Regolith characterization
- Robotics for surface systems
- Excavation technologies
- Construction and 3D printing with regolith
- Trash to gas
- ISRU technologies for living off the land

3D additive manufacturing with Regolith

Dust-tolerant connector

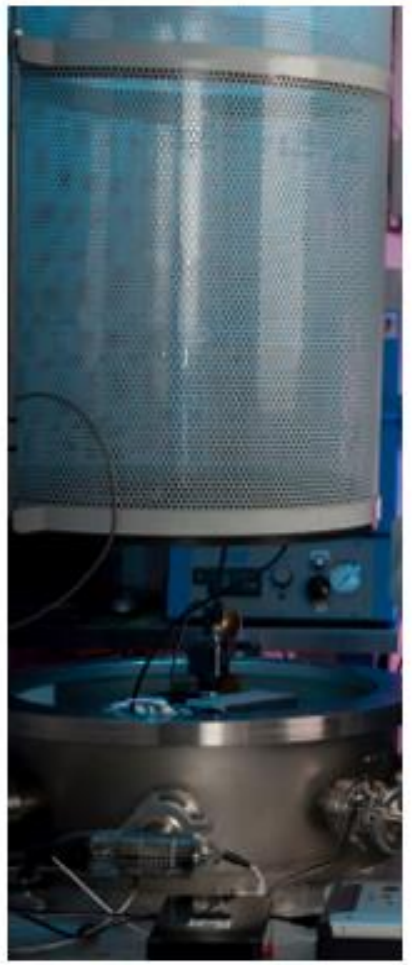
Electrostatics and Dust Mitigation

- Electrodynamic Dust Shield (EDS) that repels dust from surfaces and multiple materials (including glass, fabrics, visors, and flight hardware) using dynamic electric fields
- Technologies to protect flight hardware and launch equipment from electrostatic discharges



Testing of a transparent EDS which uses dynamic electric fields to remove dust from surfaces

Testing of the EDS on fabric (before and after)



Bell jar vacuum chamber used for testing of the EDS before and after flights

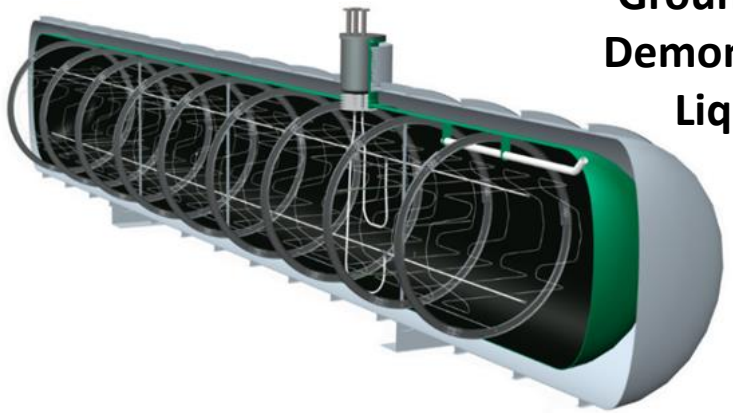
xEVA Informatics Backpacks & Analog/Field Communications

- Backpacks developed in several iterations over the past two decades to support EVA, mission operations, and science communities
- Next gen will be used to support Artemis analog missions, operations development (@ JSC rock yard), and crew training
- Contains primary tech capabilities of xEMU suits (voice, video, position/heading, computing, xINFO lighting, bioinformatics, meshing radio) in a lightweight package allowing for rapid deployment in testing/field/analog mission environments without the overhead & mobility restrictions of pressurized suit
- Provides platform for future capability development (AR/VR, real-time science instrument data transmission, data analytics, etc.) in a lightweight, cost-effective package
- Team has expertise in development & implementation mission communication, lunar architecture studies, technical integration of flight elements in analog test environments, and simulated mission network architectures

Cryogenics Technology

- Thermal insulation systems and novel materials
- Energy-efficient technologies for space launch and exploration
- Advanced propellant transfer systems
- Multilayer Insulation (MLI) performance testing
- Zero boil off and propellant densification and liquefaction
- Energy-efficient storage and control of cryofuels
- Portable propellant loading systems
- Technologies for autonomous cryogenic loading operations

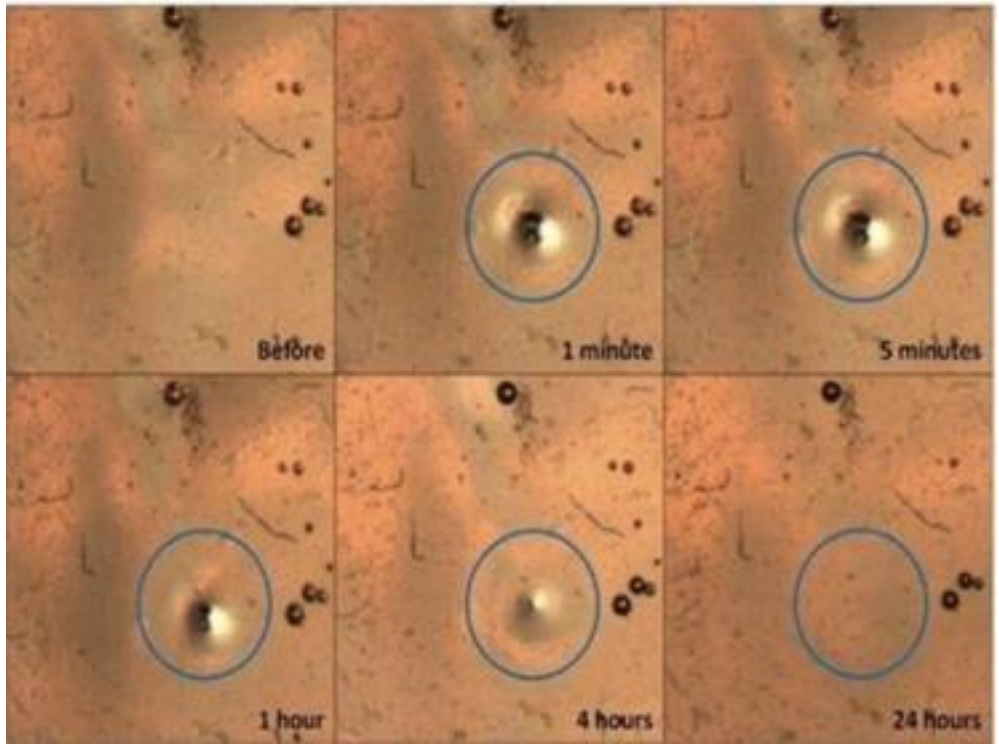
Ground Operations Demonstration Unit Liquid Hydrogen (GODU-LH2)



Brayton cycle helium refrigerator coupled to heat exchanger inside 33,000 gallon LH2 tank
Demonstrated zero boiloff, propellant densification (down to 12 K), and liquefaction.

Materials Science Technologies and Composites Damage Detection

- Electrostatic charge build-up resistant materials and coatings
- Self-healing systems
- Corrosion-hardened materials
- Damage detection technologies for flexible and composite materials



Picture of Self-Healing Low-Melt Polyimides

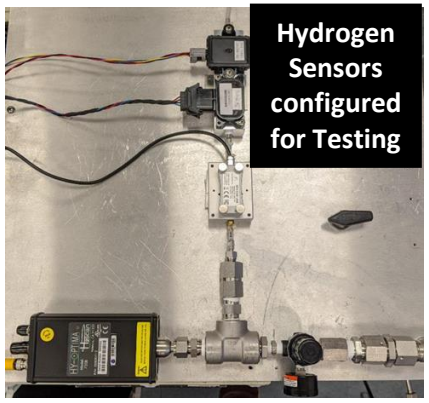
Engineering & Testing Capabilities

Expertise in launch vehicles and payload processing provides risk mitigation solutions for future space missions.

- Hypergolic and cryogenic propellants Subject Matter Expertise
- Ground test and vehicle emulator operations
- Testing and laboratory capabilities support
- Vehicle flight analysis
- Modeling and simulation
- Software development
- Lunar instruments development
- Materials and processes


Optical Window Testing

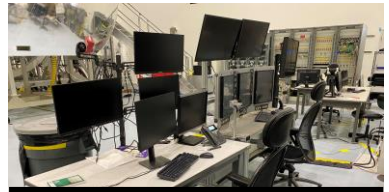

Contamination Inspection


Hydrogen Sensors configured for Testing

Hypergols Operations


Lunar Instruments


Launch Equipment Test Facility


Orion/Gateway Emulator

KSC Laboratories

- Advanced Imaging and Analysis Laboratory (AIAL)
- Animal Care Laboratory
- Applied Chemistry Laboratory (ACL)
- Applied Meteorology Unit (AMU)
- Applied Physics Laboratory (APL)
- Biomedical Engineering Research Laboratory
- Chemical Sampling and Analysis Laboratory
- Chemistry and Life Sciences Laboratory
- Precision Cleaning & Component Refurbishment
- Chemical Analysis (Propellants and Fuels)
- Cryogenics Test Laboratory (CTL)
- Design Visualization
- Electrical Development Laboratory (EDL)
- Electromagnetic Laboratory (EML)
- Electrostatics & Surface Physics Laboratory (ESPL)
- Environmental Microbiology Laboratory
- Fiber Optics and Communications Laboratory
- Granular Mechanics and Regolith Operations Laboratory (GMRO)
- Health Physics Radiological Laboratory
- Launch Equipment Test Facility (LETF)
- Materials Analysis Laboratory (MAL)
- Mechanical and Environmental Testing Laboratory (METL)
- Metrology Laboratory
- Microgravity Simulation Support Facility (MSSF)
- Non-Destructive Evaluation Laboratory (NDE)
- Precision Measurement/Alignment Lab (PMA)
- Prototype Development Laboratory (PDL)
- ISS Offline Payload Laboratories
- Standards and Calibration Lab
- Vibration Test Laboratory (VTL)

Infrastructure and Logistics Capabilities

Facilities and Infrastructure

- Launch operations and communications
- Clean rooms
- Firing rooms
- Hazardous payload processing facilities including the Payload Hazardous Servicing Facility (PHSF) and Multi-Payload Processing Facility (MPPF)
- Non-hazardous payload processing facilities including the Space Station Processing Facility (SSPF)
- Assembly, manufacturing, integration, and operations support facilities
- Launch and Landing Facility (LLF)*

*Managed by Space Florida

Logistics and Transportation Services

The technical expertise in logistics services includes maintenance planning, supply support, handling, transportation, technical documentation, and test equipment for operations and maintenance of ground and flight hardware.

- Storage, handling and servicing/de-servicing expertise
- Transportation services by rail, air, road and sea transportation methods including lifting and handling
- Large warehouse space, some environmentally controlled

National Aeronautics and Space Administration

NASA Center Capabilities
Langley Research Center

Center Points of Contact:

Primary POC
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Secondary POC
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Director – Space Technology and Exploration Directorate
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ARTEMIS

Structures, Materials and Mechanisms

New materials, foundational technologies, and structural concepts to design, manufacture, validate, and sustain advanced aerospace vehicles and systems

Capabilities

- Topology optimization of process modeling for manufacturing
- Design, develop, and test structural articles
- Material characterization
- Material life prediction
- MMOD and regolith impact damage assessment
- Extreme thermal cycling on composite structures
- Damage mechanics of composite and metallic materials
- Digital twin
- Space environments
- Radiation shielding and design
- Material life prediction

System Development Expertise

- Design and analysis of lightweight / composite structures
- Prototype vehicle components to validate mass savings
- Subscale manufacturing of demonstration units
- Radiation shielding and vehicle analysis
- Lunar environment effects experiment design
- Inflatable habitats and airlocks; Inflation systems development

Lunar Dust Mitigation Technologies

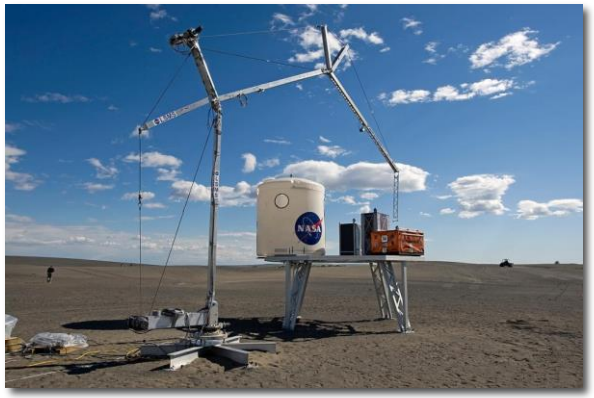
- Materials Development
- Multifunctional materials
- Composite materials
- Surface engineering

Durability, Damage Tolerance, and Reliability

- Advanced NDE technologies for unique materials and geometries
- In space NDE systems
- Novel certifications approaches using uncertainty quantification
- Lightweight/smart vehicle health monitoring systems for autonomous diagnosis and prognosis

Technology Example: Lightweight Surface Manipulation System (LSMS)

- A light weight, scalable and versatile, long-reach manipulator that combines high structural efficiency and robustness, with the enhanced dexterity and multi-functionality of a deployable robotic arm



LSMS testing at Moses Lake, Washington

Deorbit, Descent and Landing (DDL)

Design, Analysis, and Testing

- Landing systems (active/passive)
- Advanced ISRU construction methods
- Entry and launch vehicle flight dynamics
- Thermal/structural analysis and optimization
- Retro-propulsion/reaction control system
- Flight mechanics in all lunar applications
- System analysis (mass models, propulsion, technology requirements)
- Triple-Pulse LIDAR development lab
- Coherent LIDAR lab
- Advanced LIDAR development lab
- Laser material spectroscopy lab

Simulation (Both EDL and DDL)

- POST2 Flight mechanics software
- Flight reconstruction
- LAURA2 and FUN3D high speed CFD solvers

Sensor Technologies

- Navigation Doppler LIDAR (NDL)
- Flash LIDAR
- Laser ranging
- LIDAR test range
- Velocity and hazard avoidance
- Autonomous guidance, navigation, and control
- Stereo Imaging (active and passive electro-optical systems development and instrument design)

Artist rendition of LTV using 3-D Imaging flash LiDAR terrain mapping

Design for Mission Operation

Transformative solutions for Adaptive and Autonomous Systems, Human-machine teaming, intelligent flight systems, and new vehicle and operational concepts

Autonomous Guidance, Navigation, and Reconnaissance

Capabilities

- Software/hardware in-the-loop
- Physics-based simulation of lunar environment and infrastructure

Flight System Expertise: Design validation by integrated simulation

- Evaluation of human interface modalities for robotic lunar systems
- Evaluation autonomous system performance

Technologies

- 3-D Imaging flash LiDAR terrain mapping
- Sensor fusion/perception for avoiding obstacles and hazards, estimating position and orientation

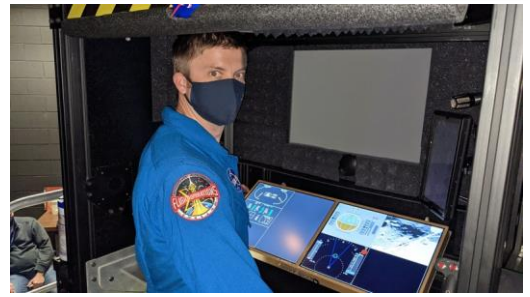
Human Systems Integration (HSI)

Capabilities

- World-class design, development of operator/vehicle interface

HSI Flight System Expertise

- Development, verification of con-ops, requirements, success criteria
- Task analysis, function allocation
- Risk and hazard identification
- Crew training development
- Design validation of human interface modalities, autonomous systems using rapid simulation and evaluation

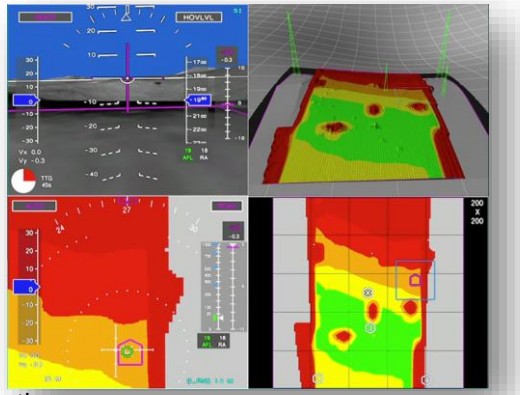


Development, Application, and Evaluation of Lunar Flight Deck Technologies and Surface Operations

Technology Example: Synthetic and Enhanced Vision System Technologies

- Complement and supplement natural vision
- Provide unobstructed camera and sensor views
- Enhance understanding of landing zone; support trajectory and energy management
- Minimize mission and vehicle constraints from lighting / window views

Provide flight crews visibility superior to window in all conditions of lighting and obscuration



Test Facilities - Sustainability

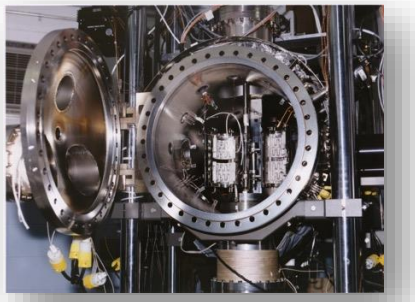
Durability, Damage Tolerance, and Reliability

- Materials Research Laboratory
- Digital Image Correlation
- Electron Microscopy (PFIB)
- Confocal Microscopy (FRASTA)
- In-situ inspection (UT, X-Ray, thermography
- Materials Processing (Arc Melter and Crystal Puller
- Flight Hardware integration and environmental facility

Thermal vacuum chamber

From −320°F to 2500°F

Mechanical and environmental testing



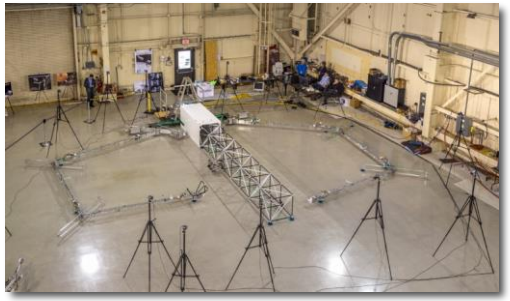
Ultra-high vacuum fatigue load frame chamber

Large-Scale Flight Structures Test Facilities

- Landing and Impact Research Facility (LandIR)
- Combined Loads Testing (CoLTS)
- Spacecraft Structures and Dynamics Lab

LandIR Facility

CoLTS



Spacecraft Structures and Dynamics Lab

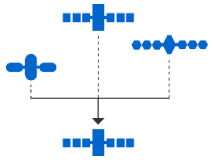
Systems Analysis & Concepts

Our Mission: We enable NASA leadership to effect meaningful change through well-informed decision-making by performing concept development, analysis, and integration of complex aerospace systems.

Strategic Analysis

Concept Design, Analysis, and Assessment of

- Campaigns
- Integrated Architectures
- Mission/Flights
- Vehicles



Decision Analysis

Technology Assessment & Gap Analysis

Framework structures, strategy development, market analysis, **portfolio formulation** and evaluation decision support

Multi-mission/flight planning over extended periods of time to accomplish missions

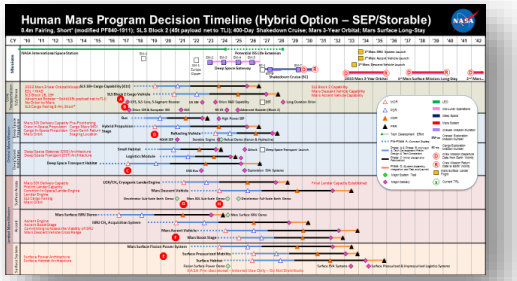
Highly integrated architectures developed to support a campaign or multiple missions/flights

End-to-end missions/flights for atmospheric and space missions; strong air and space trajectory analysis capablity

Air and space **vehicle design**, sizing, and configuration

Portfolio characterization and **prioritization facilitation**, process development, data visualization

Characterization of **technology and capability needs** vs. state-of-the-art



National Aeronautics and Space Administration

NASA Center Capabilities
Marshall Space Flight Center

Center Points of Contact:

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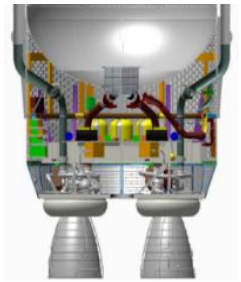
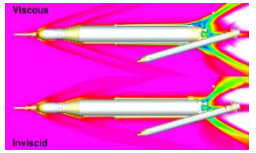
ARTEMIS

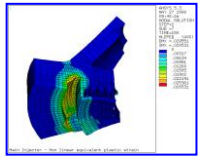
Chemical Propulsion (MSFC)

In addition to extensive heritage in LO_2/LH_2 propulsion from Shuttle, expertise includes:

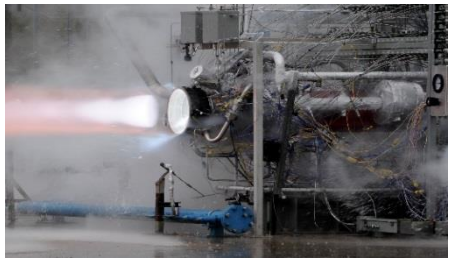
- LO_2/Methane propulsion systems and components
  - Designed and hot fired first 25-lbf LO_2/Methane thruster in-house (2005)
  - Developed standard parametrics for LO_2/Methane injector design now used by multiple engine vendors
  - Designed, developed and tested 1k and 4k LO_2/Methane thrust chamber assemblies with regenerative cooled chambers
- Pioneers in the use of advanced manufacturing techniques for propulsion applications
  - Developed & hot fire tested an in-house additively manufactured 30k thrust engine
  - Developed, hot fire tested & transferred to industry the technology to additively manufacture copper combustion chambers
  - Developing advanced manufacturing techniques for nozzles to dramatically shorten the manufacturing time, subscale hardware in test today
- Storable Propulsion Systems and components
  - Experience with pressure-fed and pump-fed storable systems.
  - Leveraging DoD divert and attitude control thruster and high-pressure helium technologies for potential applications to lunar and Mars missions
- In-house design, development, and test expertise for stages/spacecraft systems
  - Propulsion feed system, pressurization, propellant management including integration of cryogenic fluid management (CFM) technologies, tanks
  - Component technology development for these systems including lines, ducts, valves, CFM technologies, etc.
- Design, development, technology maturation including all of the detailed analytical capabilities for all types of propulsion systems
  - Component expertise includes turbomachinery, combustion devices, lines, valves, ducts, and thrust vector control
  - Detailed analytical capabilities include stress, thermal, loads, rotordynamics, structural dynamics, computational fluid dynamics, acoustics and vibroacoustics, steady-state performance, and transient modeling



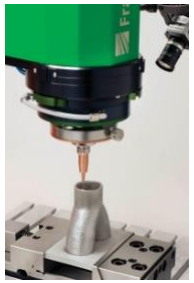




Materials & Processes (MSFC)

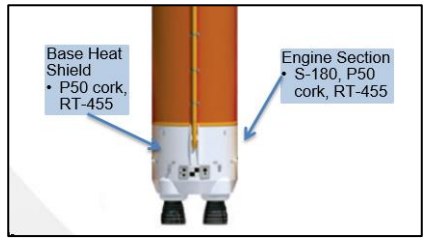
Full-Scale Advanced Manufacturing

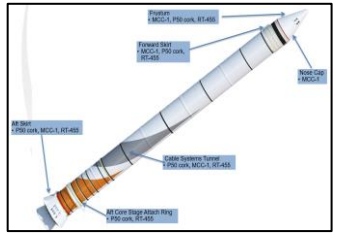
Process development through prototype and flight



- Low-Cost, Flexible Tooling Solutions
- Metal Joining
  - Solid state and fusion welding expertise
- Thermal Protection Systems (TPS)
  - Process development and full-scale application

- Composites
  - Coupon level to full-scale, integrated structures
- Additive Manufacturing (AM)
  - International leader in laser powder bed fusion AM processes, part manufacturing, NDE, and flight certification



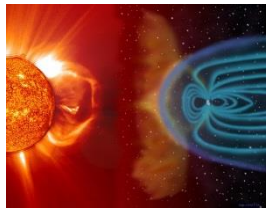


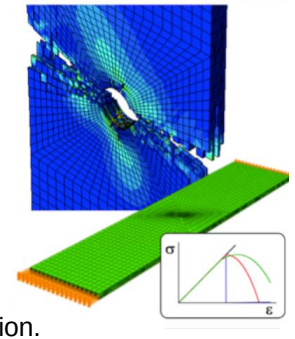
M&P Engineering Services

Proven and effective flight expertise and solutions

- Technical Expert Consulting
  - Material selection, fracture control, alternative approaches, forming, forging, diagnostics, contamination control, and more

- Material Properties Database (MAPTIS)
  - Metallic, non-metallic, and AM properties
- Space Environmental Effects
  - Unique space environment testing capabilities
- Mechanical and Tribology Testing
  - Extensive range of test force, rates, and environments; liquid hydrogen experts
- Non-Destructive Evaluation (NDE)
  - Full-range NDE services and development

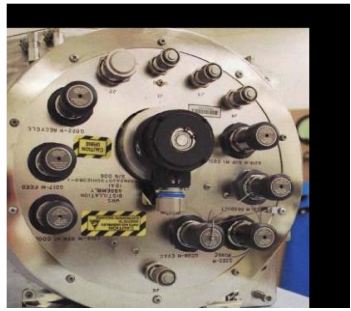


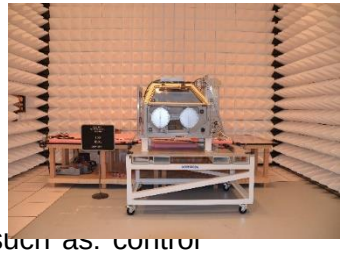


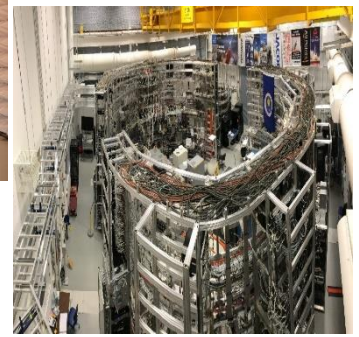
Systems Engineering (MSFC)

Design, Development, and Fabrication of Spacecraft Systems

- Lunar Landers system/subsystem analysis, design and integration for human and robotic missions
  - Collaborated with APL on Mighty Eagle demonstration lander in support of precursor lander mission development
  - Designed electromechanical controller for Human Lunar Lander Program Descent Vehicle Risk Reduction
- Extensive, internationally recognized capability to design, develop, test, and evaluate the Environmental Control and Life Support Systems
  - Ground development of ECLSS systems and 20 years of flight hardware development and sustaining for ISS ECLSS
  - Use of additive manufactured techniques to fabricate flight hardware for ISS ECLSS
- DDT&E control electronics, power supply modules, embedded software for space science experiments and instruments on satellites, ISS life support systems and payloads
- Designed new and ruggedized existing COTS imagery systems for multiple launch vehicles and space-based scientific projects.
- Designed RF Comm Link/Antenna Analysis & Testing For Lander Technologies, SLS, HLS, Gateway and a CLPS provider

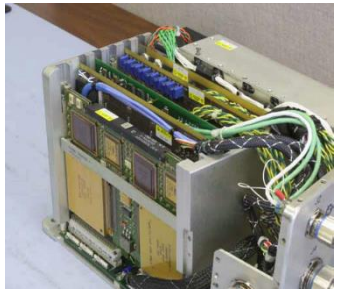






Specialized Engineering Services

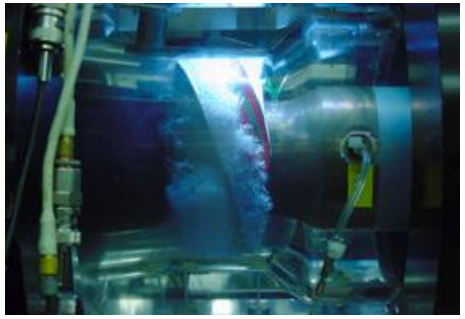
- Specialize in Mechanical Design, Analysis (thermal, dynamics, stress), and Mechanical Fabrication
- Specification, design, development, test, and characterization of electrical and electronic components, subsystems, and subsystems, such as: control electronics, power supply modules, GN&C hardware (inertial navigation units, star trackers, gyros, etc.),
- E3 Requirements Development and Tailoring, E3 and Power Quality Design, Analysis, Modeling and Testing, Electrical Grounding and Bonding and Lightning Protection (E3 Lead for ISS, Gateway Level 2, Gateway Hab Office, SLS, Commercial Crew)
- Fabrication and test of printed circuit board assemblies, cable/harness assemblies, and integrated avionics components
- CMMI L3 developed human-rated, real-time embedded software, integration, V&V, and simulation and hardware in-the-loop (HIL) framework
- Design and develop specialized science instrumentation and payloads such as neutron spectrometers which have flown aboard high altitude balloons, cubesats, and the ISS Provide monitoring/analysis of data for in flight operations.
- Autonomous and crewed spacecraft and science mission operations concept development, planning, training, and executing, including DSN, data processing and data distribution infrastructure leveraging more than 40 years of operations capability.



Test Facilities (MSFC)

- **Propulsion Test**
  - Sub-scale injectors and elements, thrusters, gas generators, turbopumps
  - Oxygen and hydrogen cold flow
  - Cryostructural
  - On-orbit vacuum environment
  - Solar thermal propulsion
  - Solid motor propellant & materials
  - Hot gas material characterization
  - Engine Systems (LH2, CH4, RP-1)

- **Experimental Fluid Dynamics Test**
  - Air & water flow
  - Full flow air blow down for turbopump turbine inlet testing of subscale solid motor casing & nozzle designs
  - Probe calibration testing
  - Subscale nozzle internal contours and back pressure data via blow down testing
  - Pump impeller & inducer sub- and full-scale performance mapping via visual water flow testing
  - Air blow down testing



- **Structural Strength Test**
  - Hazardous structural test
  - Cryostructural test
  - Tensile & compressive loads test
  - Combined Environments
  - Load environments to simulate launch, on orbit, and landing conditions for development, qualification, acceptance & research

- **Structural Dynamics Test**
  - Experimental modal analysis to verify and correlate FEM.
  - Vibration, acoustic, and pyrotechnic shock
  - Microgravity vibration emission testing

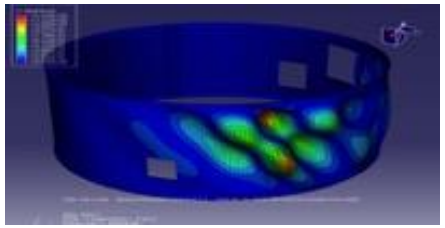
- **Environmental Test**
  - Thermal vacuum and thermal cycle/humidity
  - Altitude
  - Launch ascent/descent
  - Vacuum bake out
  - Optical certification bake out
  - Arc Jet/Hot Gas

Large-Scale Design of Vehicle Systems (MSFC)

Systems Engineering & Integration

- **Technical Management**
  - Risk and knowledge management
  - Perform metrics and margin management
  - Lifecycle review planning
  - Certification of flight readiness strategy
  - Trade study identification and tracking
- **System Design and Definition**
  - Integrates and manages overall system design
  - Establishes design requirements and facilitates compliance
- **Test and Verification**
  - Leads verification and validation planning and integration
- **Systems Analysis**
  - Leads and performs system-level modeling and analysis
  - Mass margin management
  - Ascent debris assessment
  - Assistance with systems hazard and failure evaluations
  - Human factors engineering

Structural Design & Analysis



- **Structural Dynamics, Loads & Stress Analysis**
  - Structural analysis & Fracture mechanics
  - Vibroacoustic environment definition
  - Integrated coupled loads analysis
- **Structural & Mechanical Design & Modeling**
  - Vehicle component design and integration
  - Pyrotechnic systems analysis
  - Meteoroid debris analysis
- **Composite Structures**
- **Aerosciences**
  - Aerodynamics
  - Acoustic environments
  - Rocket exhaust plume characterization
  - Aerothermodynamics
  - Venting
- **Thermal Design, Analysis & Control**
  - Thermal/fluid analysis
  - Launch vehicle TPS
  - Spacecraft thermal analysis

Flight Mechanics & Analysis

- **Control Systems Design & Analysis**
  - Requirements definition
  - Development
  - Verification
  - Launch vehicle and spacecraft
- **Guidance & Trajectories**
  - Guidance laws
  - Trajectory designs
  - Mission analysis
- **Navigation Systems**
- **Guidance, Nav & Control Testing**
- **Modeling & Simulation**
- **Integrated Systems Health Management and Automation**
- **Natural & Induced Environments**
  - Terrestrial
  - Planetary

National Aeronautics and Space Administration

NASA Center Capabilities
Stennis Space Center

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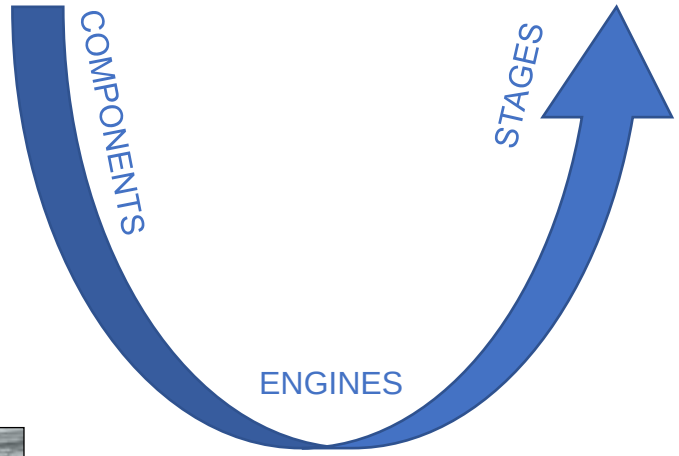
ARTEMIS

Propulsion Test Support from Components to Stages

SSC manages NASA's largest propulsion test site, providing:

- Test capabilities ranging from components to stages
- Development and acceptance testing for NASA, other Government and commercial programs
- Technical oversight and test program execution
- Engineering expertise and operations



B-1/B-2 Test Stand
Max Thrust (Klbf)
11,000 (designed)
Altitude (Kft)
Ambient
Propellants
LOX/LH2

E-3 Test Facility Cells 1-2
Max Thrust (Klbf)
60
Altitude (Kft)
Ambient
Propellants
LOX/H202/RP/LCH4/
IPA/JP-8/Hybrid

A-1 Test Stand
Max Thrust (Klbf)
1,500 (designed)
650 (current)
Altitude
Ambient
Propellants
LOX/LH2

E-1 Test Facility Cells 1-3
Max Thrust (Klbf)
1,200
Altitude (Kft)
Ambient
Propellants
LOX/LH2/RP/Hybrid
(Methane Planned)

A-3 Test Stand
Max Thrust (Klbf)
1,000 (designed)
300+ (altitude)
Altitude
100 Kft (designed)
Propellants
LOX/LH2

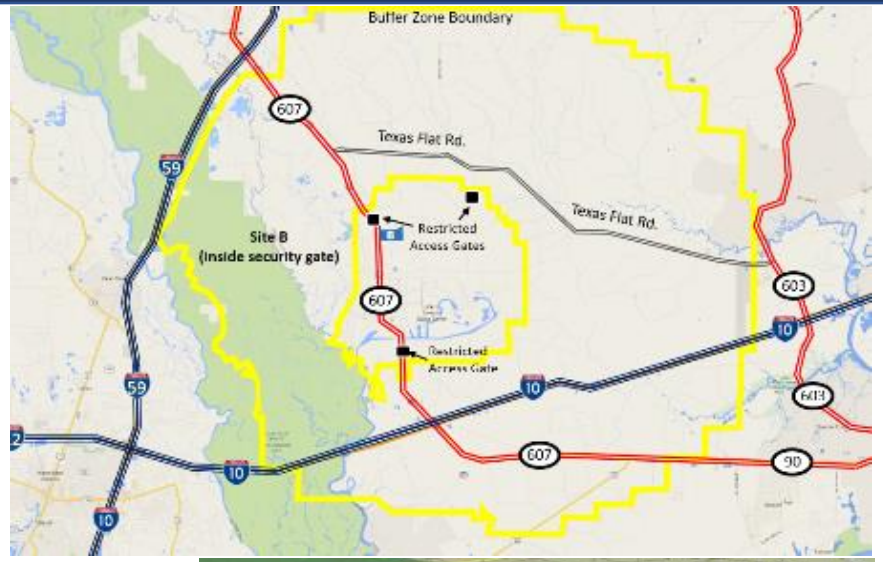
A-2 Test Stand
Max Thrust (Klbf)
1,500 (designed)
650 (current)
Altitude
Ambient
and 60 Kft
Propellants
LOX/LH2

- Testing from subscale to stages (1klbf to 7Mlbf thrust)
- Multiple fuel types including methane, hydrogen and RP
- Extensive experience working with commercial partners

Untethered Lander Flight Testing

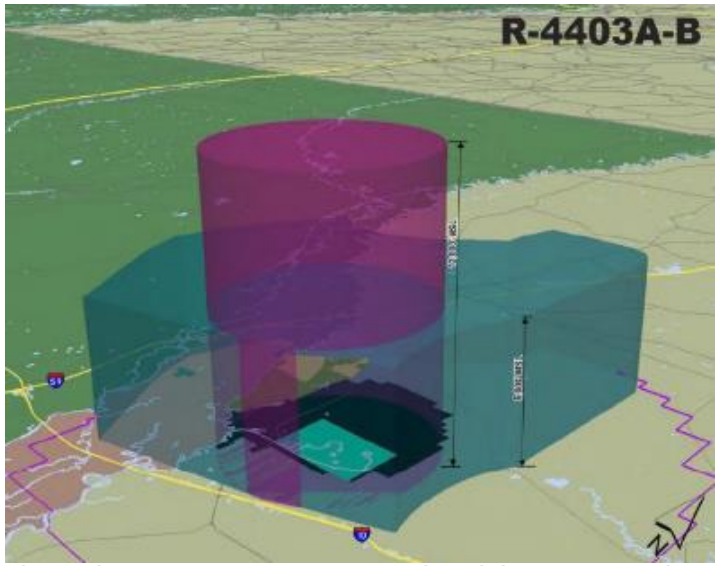
100+ Square Miles of Restricted Airspace

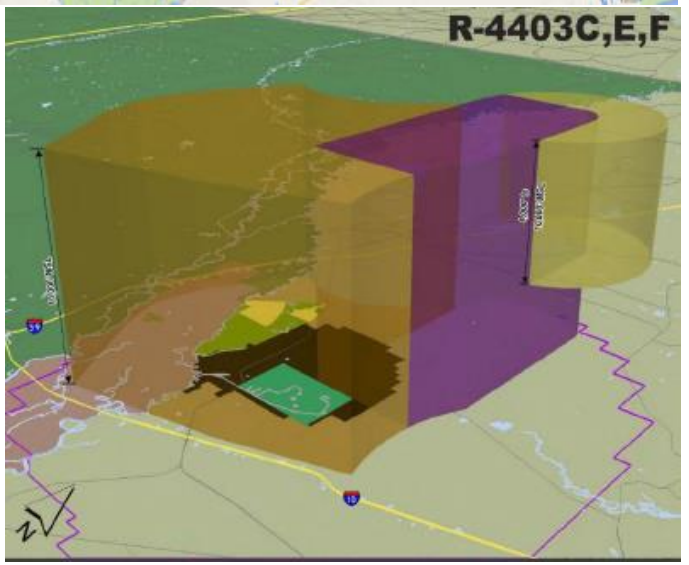
- SSC restricted airspace that can be utilized by the DOD, NASA and Commercial Industry
- Multiple range activities can occur to enable autonomous operations between airborne and land-based platforms
- Maximum altitude is 10,000 feet in portions of the airspace



Legend

- R-4403A
- R-4403B
- R-4403C
- R-4403E
- R-4403F
- Government-owned Area
- SSC Buffer Zone





SSC Autonomous Systems Lab (ASL)

Autonomous Systems Engineering

Integrated Systems Health Management

Predictive- and Condition-Based Maintenance

Embedded Hardware and Software Design

User Interface Design

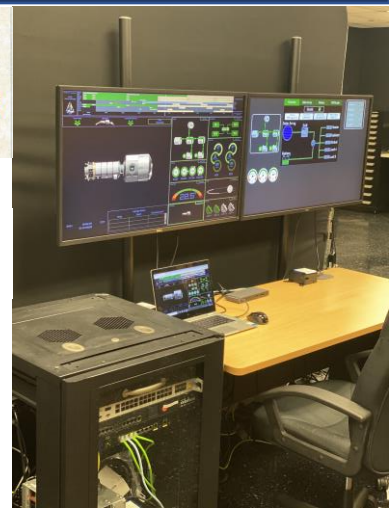
Fully Equipped Laboratory

CMMI Level 3 Certification Underway

2021 IEEE Aerospace Conference
Best Paper in Track Award
Track 11: Diagnostics, Prognostics and Health Management (PHM)
for excellence in technical innovation and presentation

Stennis Space Center Gaining Recognition for Cutting-Edge Autonomous Systems Work

https://www.nasa.gov/centers/stennis/news/releases/2021/SSC-Gaining-Recognition-for-Cutting-Edge-Autonomous-Systems-Work

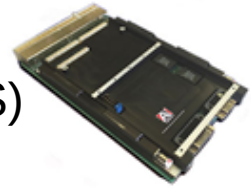


NASA Platform for Autonomous Systems (NPAS) enables…

Rapid, cost-effective development of scalable, intelligent, safety-critical autonomous systems

Digital twins that employ reasoning and decision-making based on human thought processes resulting in predictable (safe) system behaviors

Applications on multiple spaceflight computing platforms such as the RAD750 (SP0-S) using VxWorks and ARM processors



Integration with core Flight System (cFS) flight software

Distributed, hierarchical applications required for complex dynamic systems

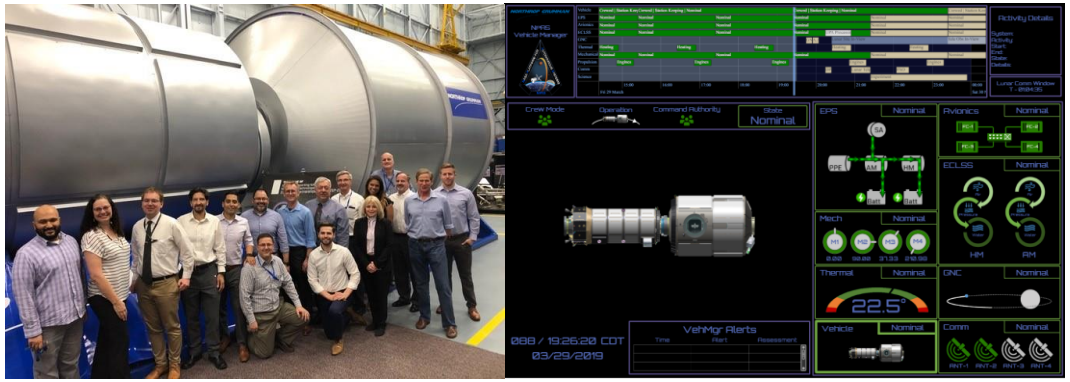
Recent ASL Accomplishments

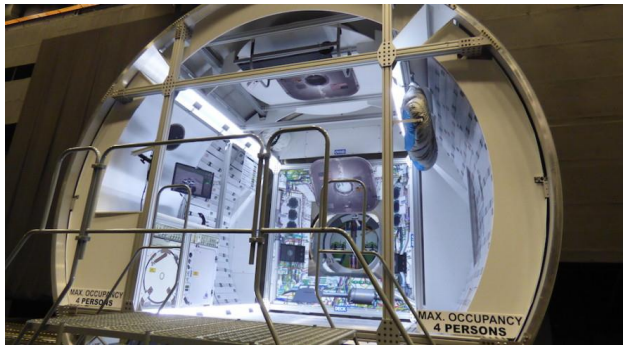
NASA's 1st autonomous system to be certified for Class C Safety Critical operations at SSC HPGF.

In 5 months the ASL developed a complete, custom autonomous system, integrated it into existing Northrop Grumman hardware and software, and supported NextSTEP-2 demonstrations. **Northrop Grumman was awarded a sole-source contract to provide the Gateway HALO module.**

NORTHROP GRUMMAN

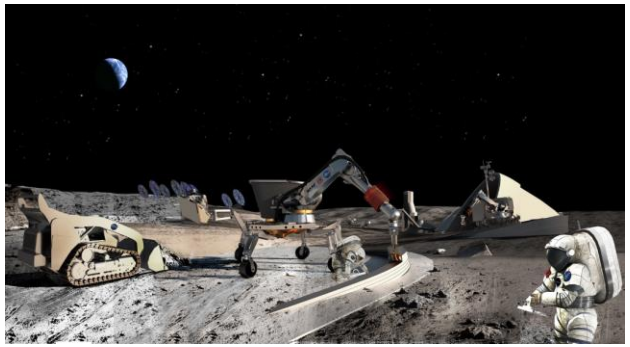
Developed **predictive and condition-based maintenance** algorithms/tools for cryogenic pumps. 2021 IEEE Aerospace Conference **best paper award** for predictive maintenance & ISHM.





Partnered with Lockheed Martin to reduce risks for **autonomous operation of Gateway, Orion, and other elements of Artemis.**

LOCKHEED MARTIN



FY22 – begin development of the Lunar Surface Innovation Initiative Build & Excavation Autonomous System with Transport (BEAST), a multi-center project **to enable sustainable autonomous lunar ISRU**.