Johnson Space Center

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National Aeronautics and Space Administration

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JSC/WSTF Products, Services, and Capabilities for CLDP

National Aeronautics and Space Administration

JSC primary facilities are located in Houston, Texas. Additionally, JSC manages the WSTF near Las Cruces, New Mexico.

JSC and WSTF possess extensive capabilities and expertise critical to CLDP and is extremely well positioned as a valuable partner, hardware provider, and service provider for industry performers submitting proposals for CLDP.

In this package, you will find:

- High Value/High Impact JSC Engineering Products available to CLD Providers.
- High Value/High Impact Human Heath and Performance Services available for CLD Providers.
- General JSC/WSTF Capabilities and Services relatable to CLD Providers.

JSC Engineering Products for CLDP

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While JSC/WSTF have many available capabilities and services, there are items JSC is particularly well positioned to provide based on current development investments and/or that has been designed, developed and flight proven via ISS or Orion.

1) Fire Emergency Equipment
   a) Portable Fire Extinguisher – a lightweight portable fire extinguisher for a worst-case open cabin fire
   b) Contingency Breathing Apparatus with Fire Cartridges – provides respiratory protection to crew in response to a fire event through post-fire cleanup
   c) Anomaly Gas Analyzer – an air constituents monitor for post fire and off-nominal landing scenarios
2) Toilet System – a microgravity and lunar gravity waste management system.
3) Exercise CMS/VIS System - critical to maintain crew's physiological condition while in microgravity, and to protect the vehicle from exercise loads while ensuring a safe and stable platform for exercise
4) Vehicle Systems Manager (includes Core Flight SW) – software control paradigm for autonomous operations and reduced ground operator support
5) Cold Stowage – used to support temperature sensitive (or controlled) science, including integration and ground logistics
6) Modular Battery System – provides multi-power source for commonality and reduce mass

JSC Engineering: Value-Proposition for CLDP

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NASA

High value and high impact capabilities will reduce DDTE technical, schedule risk.

EA Recommend	Value Rationale	DDTE Risk	Benefit Drivers for Collaboration
Fire Emergency Equipment (PFE, AGA, CBA)	Rapid mitigation of onboard CLD emergency combustion event (e.g. cabin fire) while crewed	M/H	Leverage design for space applications (HW & Lessons)
Toilet System(s)	Reliable and well-characterized devices that maintains/promotes crew wellness with future extensibility	H	Leverage Govt DDTE lessons and improvements from HLS and MCO
Exercise Sys (CMS/VIS)	Reliable and well-characterized device that maintains/promotes crew wellness	M	Extensive Govt experience on device AND its vibe isolation.
Vehicle Systems Manager (VSM)	Optimal control paradigm for resources and fault management, with scalable architecture that maximizes functionality and safety for the CLD	M/H	Govt design supporting standardization and interoperability
Cold Stowage Systems	Control of temperature-sensitive experimental payloads over specific thermal ranges for utilization	M	Leverage 20+ years of actual use over 100s of experiments.
Modular IVA/EVA Battery	Safe storage and delivery of electrical power, with scalability/operability enhancement, reduce mass & cost	M	Apply multi-program Govt skills delivering reliable power

H=High, M=Medium, L=Low (e.g. M/H => medium high)
EVA/IVA = Extra-vehicular, Intra-vehicular activity
CLD = Commercial LEO Destination

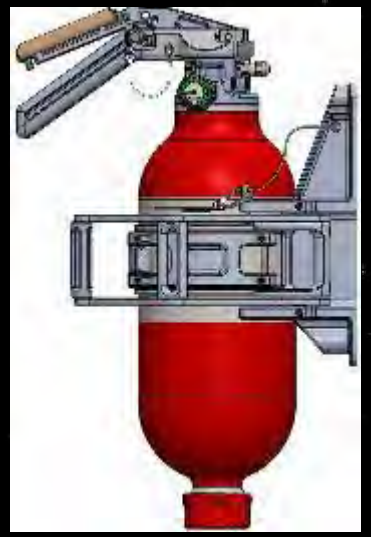
HLS = Human Landing System
MCO = Mars Campaign Office

Above levels of Dev. risk will be reduced upon accessing engineering's institutional knowledge, expertise, labs, tools, and associated skills base.

Portable Fire Extinguisher (PFE)

- The Orion program requires a lightweight portable fire extinguisher for a worst-case open cabin fire scenario: 5200mAh battery in laptop fire.
- The Orion PFE is a water-based fire extinguisher designed to extinguish open-cabin fires only (no hidden fires).
- The Orion PFE is for contingency use only.
  - Tank is ASME Certified Titanium Pressure Vessel.
  - Service Fluid: Nitrogen and water separated by a bladder
  - Fire Suppressant: 3lbs Water (Nitrogen is not discharged)
  - Water Requirement: JSC-SPEC-C-20D, Grade A
  - Nitrogen Requirement: Grade B Nitrogen per MPCV 70156

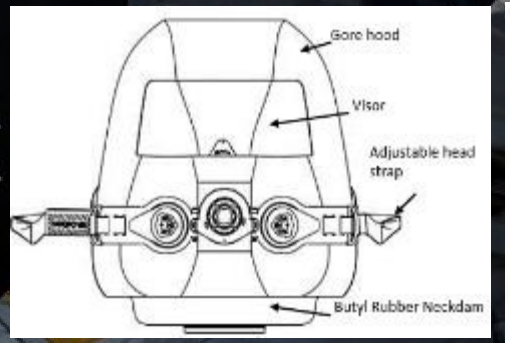
Technical Parameters	
Fill Pressure:	300 PSIG Water Spray
Expellant:	H2O Water Spray
Stowage:	Hard mounted on Orion ECLSS Wall (bracket is 10”L x 8”W x 10”D & 5.1 pounds) and Accessible in 5 Seconds (assuming crew at PFE)
Size:	18” Long x 6” Diameter
Mass:	13 Pounds Wet Mass [Tank with water] Bracket is additionally 5.2 lbs
Discharge Time:	25+ Seconds
Charged Life:	1 Year
Use Life:	5 Missions (Bladder has 5 year life)
Part Number:	SEH33125710 [PFE Assembly: SEH33125712 Bracket Assembly: SEH33125725]
Time to Build and Certify	ATP + 2-5 Years



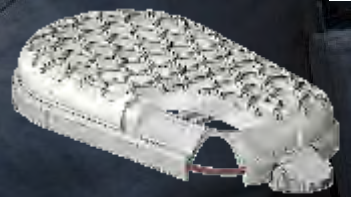
Contingency Breathing Apparatus (Emergency Mask with Fire Cartridges)

- The Contingency Breathing Apparatus (CBA) Assembly is designed to provide respiratory protection, with appropriate cartridges installed, to the Orion crew in response to a fire and post-fire event for a minimum of 8 hours of protection (with cartridge change-out). The CBA Assembly system contains the Emergency Mask (ISS) and the Orion Fire Cartridges (ISS FCs with added Prefilters).
- The Emergency Mask is one size fits most. EM (original) fit majority of crew population, EM-Small is an option for smaller female crew. It seals at the neck and has a nosecup.
- CBA Assembly does not:
  - provide an oxygen source
  - contain an interface for food or drink packages
  - contain any verbal communication enhancements
- The Fire Cartridge (FC) provides respiratory protection to the crew by oxidizing Carbon Monoxide (CO) and adsorbing other combustion products from a fire environment to below the 24-hour Spacecraft Maximum Allowable Concentrations (SMAC) values.
- Each FC set will have an operational life of 90 minutes, with Prefilter change-out.
- Prefilter is designed to provide the Fire Cartridge additional protection from water and smoke particulate.
  - Prevents water spray from prematurely clogging P100 filter, maximizing the use-life of the Fire Cartridges.

Technical Parameters	
Emergency Mask Mass:	1.5 lbs
Emergency Mask Dimensions:	0.33 ft^3 (0.01m^3)
Fire Cartridge Mass:	1 lb (packaged)
Fire Cartridge Dimensions:	4” x 4” x 7” (112 in^3)
Emergency Mask with 2 Fire Cartridge Mass:	3.5 lbs (1.6 kg)
Emergency Mask with 2 Fire Cartridge Vol:	0.43 ft^3 (0.012 m^3)
Time to Build and Certify	ATP + 2-5 Years
Part Numbers	CBA Top Assy: SEH40100484-301 ISS Emergency Mask: SEG40100366-601 ISS Fire Cartridge: SEG11101216-303



Emergency Mask without Cartridges (Front)



Anomaly Gas Analyzer (AGA)

The purpose of AGA is to serve as an air monitor for post fire and off-nominal landing scenarios.

- Combustion Products (CO, HCN, HCl, HF)
- Cabin Environments (CO_2, O_2, Total P)
- Ammonia (NH_3)

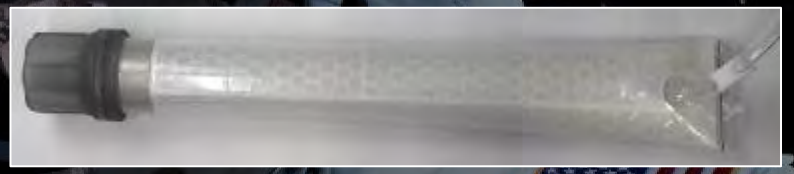
- Portable Hand Held Unit
- Battery Powered
- No Communication with ISS or Vehicle
  - Cabin Environments (CO_2, O_2, Total P)
  - Ammonia (NH_3)
- No Power Interface with ISS or Vehicle
- Contingency Use Only (For Orion)
- Multiple Units on ISS, Single Unit on Orion
- Part Numbers are:
  - ISS AGA Part #: SEZ33125556-302
  - ISS Pump Part #: SEG33125912-301
  - ISS Probe Part #: SEG33125913-301
  - Orion AGA Part #: SEZ33125556-301

Technical Parameters	
Power Source:	Canon BP-975 Battery
AGA Mounting:	Handheld or Specific to Orion
Size (Does not Include Protrusions):	11.5” x 6.9” x 4.5” & 8.6” x 4.5” x 3.2” Pump
Mass:	13.9 lbs
Time to Build and Certify	ATP +2-5 Years

Toilet System

- NASA is currently developing a Toilet under the Human Landing System (HLS) program that just completed PDR. CDR is planned for May 2026 with delivery to HLS in early 2028.
- Toilet can be used in microgravity and lunar gravity
- Urine is stored or disposed of (not recycled) and is stabilized using Oxone.
- Contingency hardware can be used in the case of a toilet failure or in cases that the toilet cannot be accessed
  - Collapsible Contingency Urinal (CCU) for urine collection
    - Currently certified for use on Orion, tech demo on ISS, planned for HLS
    - Urine can be vented or stored depending on mission needs
    - Male and female CCUs are available with appropriate interfaces
  - Artemis Bag for fecal collection is in development with the same schedule as the GFE Toilet mentioned above
- Current NASA investments will provide a micro-g CLD solution for CLD Initial Operational Capability. A further advancement to a regenerative ECLSS-forward solution is also of substantial interest to NASA JSC for 203X and beyond

Toilet Assembly



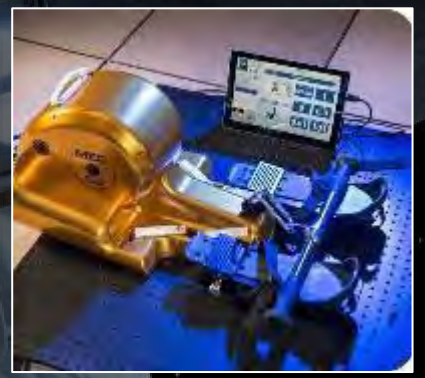
Collapsible Contingency Urinal (CCU)

Exercise Countermeasure System (CMS) Devices

- **JSC team has 25+ years of experience in designing, building, integrating, testing, and sustaining exercise devices in microgravity**
- Second Generation Treadmill (T2) | 15 years of use on ISS
- Advanced Resistive Exercise Device (ARED) | 15 years of use on ISS
- Cycle Ergometer with Vibration Isolation and Stabilization (CEVIS) | 25 years of use on ISS
  - 25+ years of experience integrating and sustaining Danish Aerospace Company (DAC) built ergometer with NASA designed VIS into ISS vehicle
- Miniature Exercise Device (MED2) | Tech demo performed on ISS
  - Enables aerobic rowing and up to 200 lbs resistance with a single cable
  - Device can be enhanced (i.e. increased resistance, cycling capability) to meet LEO Destination requirements
- Orion Flywheel | First flight on Artemis-II
  - Enables aerobic rowing and limited resistive exercise
- **JSC will leverage decades of expertise to rapidly develop a novel exercise device, modify COTS capabilities, or provide integration expertise, to meet LEO Destination requirements**
  - **Build off the Lessons Learned**

ARED

MED2



FLYWHEEL

CEVIS

Vibration Isolation and Stabilization (VIS) System

- Loads and vibrations generated by exercise are the result of the combined mass and C.G. motion (frequency, magnitude, direction) of the crewmember and exercise device. The low frequencies of exercise typically overlaps with the resonant frequencies of the vehicle.
- If exercise device/activity is not isolated, the impacts of these loads and vibrations:
  - Disturb payloads needing a microgravity environment
  - Can structurally damage the vehicle by exciting its natural frequencies
  - Can impact GN&C
- If exercise is not stabilized, the crewmember may not be able to safely and effectively exercise
- VIS design and Degrees of Freedom (DOF) are particular to exercise device modalities and CLD vehicle constraints

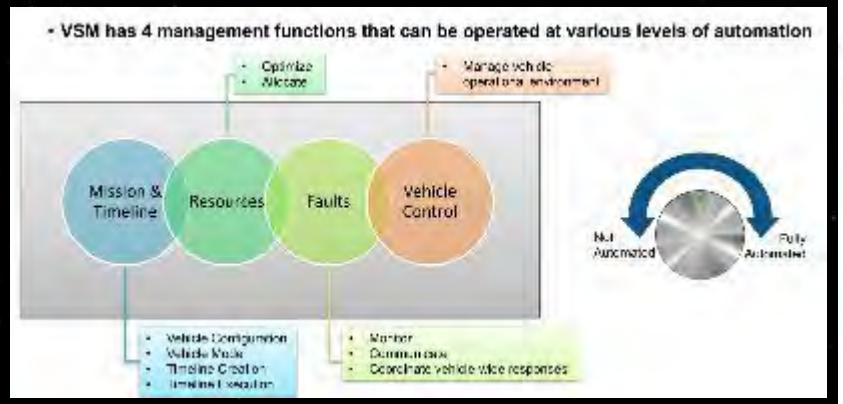
- **JSC Engineering has 25+ years of experience designing, building, integrating, and sustaining both active and passive VIS systems for exercise devices**
  - **TVIS, T2, CEVIS, ARED, E4D VIS**
    - **Each system's VIS was designed specifically for that hardware**
  - **JSC can design and build a custom VIS for a Commercial LEO destination**

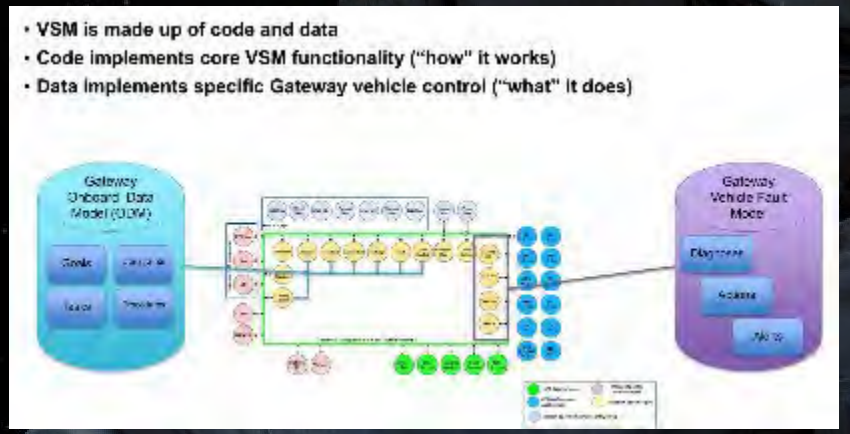
Vehicle Systems Manager (VSM)

Vehicle Systems Manager (VSM) is a software control paradigm that supports autonomous operations and reduced ground operator support – with functionalities as shown in the Table

- VSM uses a scalable and selectable set of Core Flight Software (CFS) applications that support several autonomous spacecraft functions
- VSM is data-driven and so can be applied to various spacecraft systems; it enables rapid updates based on operational needs and lessons learned
- VSM can be distributed across various systems, or run as a set of hierarchical system managers, thus handling complex autonomous tasks
- VSM runs on a dedicated flight processor and includes failure tolerant design for safety-critical onboard operations
- Includes operational and tooling framework for ground configuration, data development, and operations displays and tools
- The Gateway Program is currently using this VSM architecture

Technical Functionalities	
Mission Management	Goal-based tasks planned on a timeline; task execution includes constraint-guarded commands and procedure execution
Fault Management	Model-based real-time reasoning engine that assesses component and functional health to diagnose failures and impacts
Resource Management	Monitors and constrains use of limited resources (power/thermal, bandwidth, discrete hardware)
Vehicle Control and Operations	Battery charging, comms configuration
Human Interactions	Alert Management, Consequence Guidance, Decision Aiding, Command Arbitration
Ground-based Data Development Tools	Database tooling, Timeline Validation, Procedure Design





Cold Stowage Hardware Overview

Active Hardware

- Glacier is a freezer/refrigerator that support samples from -95°C to +4°C for launch/return and -160°C to +4°C on ISS.
- Polar is a freezer/refrigerator that support samples from -95°C to +10°C for launch/return and on ISS.
- Iceberg is a freezer/refrigerator that supports samples from -95°C to +4°C on ISS.
- Merlin is an incubator/refrigerator/freezer that supports samples from +4°C to +40°C for launch/return and from -10°C to +48°C on ISS.

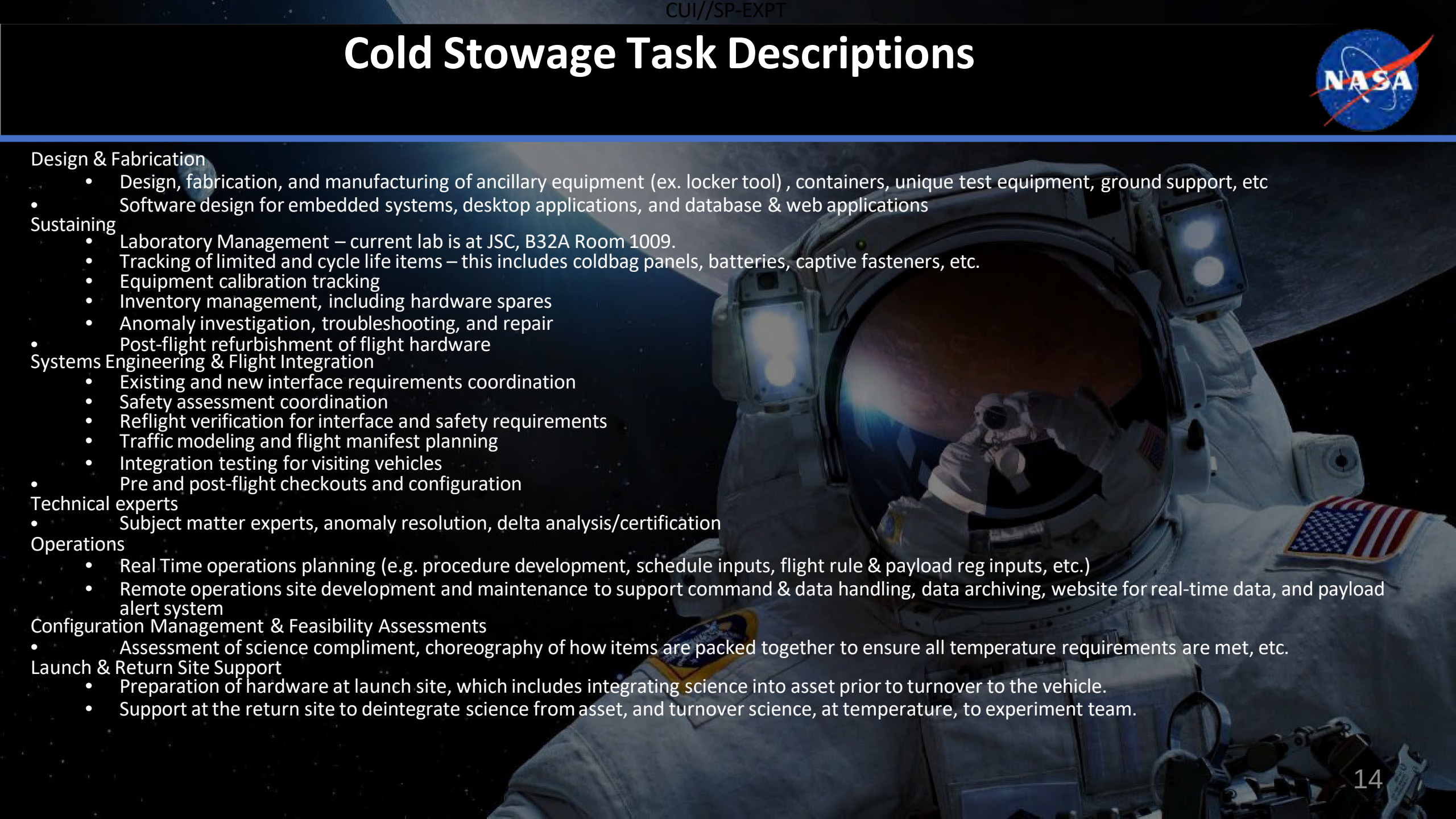
Passive Hardware

- Double Coldbags are insulated stowage bags used to transport samples to and from ISS on visiting vehicles
- Vacuum insulated panels are limited life and require replacement.
- Ice Bricks provide cooling or incubation to samples stored inside Double Coldbags/Mini Coldbags
- Ice Brick temperatures include -32°C, -26°C, +4°C, +10°C, +12°C, +16°C, +22°C, +25°C, +27°C, +34°C and +37°C

Ground Support Equipment

- Batteries for powered lockers – batteries are limited life items and require replacement.
- Portable refrigerators, incubators, and freezers.
- Rechargeables batteries for use with portable GSE.

Cold Stowage Task Descriptions



Design & Fabrication
- Design, fabrication, and manufacturing of ancillary equipment (ex. locker tool) , containers, unique test equipment, ground support, etc
- Software design for embedded systems, desktop applications, and database & web applications

Sustaining
- Laboratory Management – current lab is at JSC, B32A Room 1009.
- Tracking of limited and cycle life items – this includes coldbag panels, batteries, captive fasteners, etc.
- Equipment calibration tracking
- Inventory management, including hardware spares
- Anomaly investigation, troubleshooting, and repair
- Post-flight refurbishment of flight hardware

Systems Engineering & Flight Integration
- Existing and new interface requirements coordination
- Safety assessment coordination
- Reflight verification for interface and safety requirements
- Traffic modeling and flight manifest planning
- Integration testing for visiting vehicles
- Pre and post-flight checkouts and configuration

Technical experts
- Subject matter experts, anomaly resolution, delta analysis/certification

Operations
- Real Time operations planning (e.g. procedure development, schedule inputs, flight rule & payload reg inputs, etc.)
- Remote operations site development and maintenance to support command & data handling, data archiving, website for real-time data, and payload alert system

Configuration Management & Feasibility Assessments
- Assessment of science compliment, choreography of how items are packed together to ensure all temperature requirements are met, etc.

Launch & Return Site Support
- Preparation of hardware at launch site, which includes integrating science into asset prior to turnover to the vehicle.
- Support at the return site to deintegrate science from asset, and turnover science, at temperature, to experiment team.

Modular IVA/EVA Battery

- Provide modular, safe storage and delivery of 95Wh electrical power at 28V.
  - Provides a common interface to that can then be used by many items
  - Can be reconfigurable for various voltage requirements from 4 to 32V per module
  - Modules can be configured in series or parallel for additional voltage ranges and or current carrying capacity
  - Continuous operation over full voltage range without active cooling
  - Available in energy (95Wh at 0.5A) or light power (86Wh at 11A) formats per module
  - Possibly only battery that will be designed to be safe for use at all planned spacecraft environments with smaller compartments and elevated O^2 levels
  - Passive propagation resistant design eliminates fire/flame release during internal short circuit
  - Screened electrochemical cells maximize operational reliability
  - Externally-replaceable fuse enables near-real time fault recovery
  - Voltage and temperature telemetry enables safe charging with modular, air-cooled 28V or 120V charger or charge card
- Scalable to other (higher or lower) voltages and/or capacities (Wh) (1P-8S, 8P-1S, 4P-2S, 2P- 4S)
- Deliver Class R bond connectivity, rack-mounted or cabled

Technical Parameters	
Chemistry:	Lithium-Ion, 1P-8S, 18650 cell format
Energy, Voltage:	95Wh at 0.5A // 86Wh at 11A, up to 24-32.8Vdc per module
Stowage:	Soft stowed or rigidly secured in a soft-stowed assembly
Size:	7.68 x 0.90 x 3.99 in (19.5 x 2.29 x 10.1 cm)
Mass:	1.63 lbm (0.74 kg)
Volume:	27.6 in3 (0.45 L)
Usage Life:	5-15 Years pending storage and usage conditions
Part Number:	SEN130104886-30x (energy), SEN1304886-303 (power)
Approx Time to Delivery	ATP + 2-5 Years

1kWh from 12 Modules

95Wh from 1 Module

JSC Human Health and Performance Services for CLDP

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While JSC/WSTF have many available capabilities and services, there are items JSC is particularly well positioned to provide based on decades of human spaceflight experience related to Human Health and Performance.

1) Crewed Mission Habitat Analogs – used to emulate exploration-like habitat or spacecrafts
2) Behavioral Health and Performance – this includes behavioral medicine, psychological support, fatigue management, crew selection and training as well as support for spaceflight analog missions.
3) Radiation Monitoring, Protection and Exposure Analysis – capabilities to support human spaceflight operations in LEO
4) Human Research Payload Management & Processing – management and integration of human research experiments across all flight and analog platforms.

Crewed Mission Habitat Analogs

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- Analog environments are used to emulate an exploration-like habitat or spacecraft that provides the conditions of isolation, confinement and remote operations for up to four crewmembers.
- The Flight Analogs team develops mission scenarios and conditions analogous to those anticipated for missions, enabling a realistic and immersive flight-like environment. A tailored flight analog allows crew to experience day-to-day operations and the pace of being on-orbit.
- Planned mission durations may range from 7 days up to 45 days.
- Analog features include:
  - Mission Control Center (MCC) for real-time interaction with HERA crew members
  - 24/7 mission video surveillance with audio, recorded during mission
  - Simulation of Acquisition of Signal/Loss of Signal of varying duration
  - Individual crew sleeping quarters for 4 crew members
  - Crew training for analog mission preparation
  - Windows-based laptops and iPads for each crewmember
  - Virtual reality simulation for simulated EVA tasks
  - Medical Workstation (Remote medical procedures and examinations)
  - Exercise equipment (aerobic and resistive) to simulate daily operational activities
  - Simulated Environmental Control and Life Support System (ECLSS)
  - Payload operations to test hardware and procedures
  - 3D printer to support vehicle maintenance and operational tasks
  - Shower/sink with hot and cold running water for crew hygiene

Behavioral Health and Performance (BHP)

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- The BHP Operations group provides several services for optimizing mission success for each crewmember, including family members. The BHP's specific areas of responsibility include behavioral medicine, psychological support, fatigue management, crew selection and training as well as support for spaceflight analog missions.

- Areas of BHP support include the following:
  - Conducting astronaut applicant screening and crew selection processes
  - Providing individually-determined psychological support services for crewmembers and their families to maintain their behavioral well-being throughout all phases of the mission
  - Monitoring remotely the behavioral and cognitive health of LEO crewmembers via Private Psychological Conference and computer-based, cognitive assessment tools
  - Providing Fatigue Management Services for crewmembers assigned to missions and providing consultation to Crew Surgeons on issues related to spaceflight crews' work-rest schedule and fatigue management during pre-flight training and in-flight
  - Conducting leadership and team care training for crewmembers prior to flight assignment

Radiation Monitoring, Protection and Exposure Analysis

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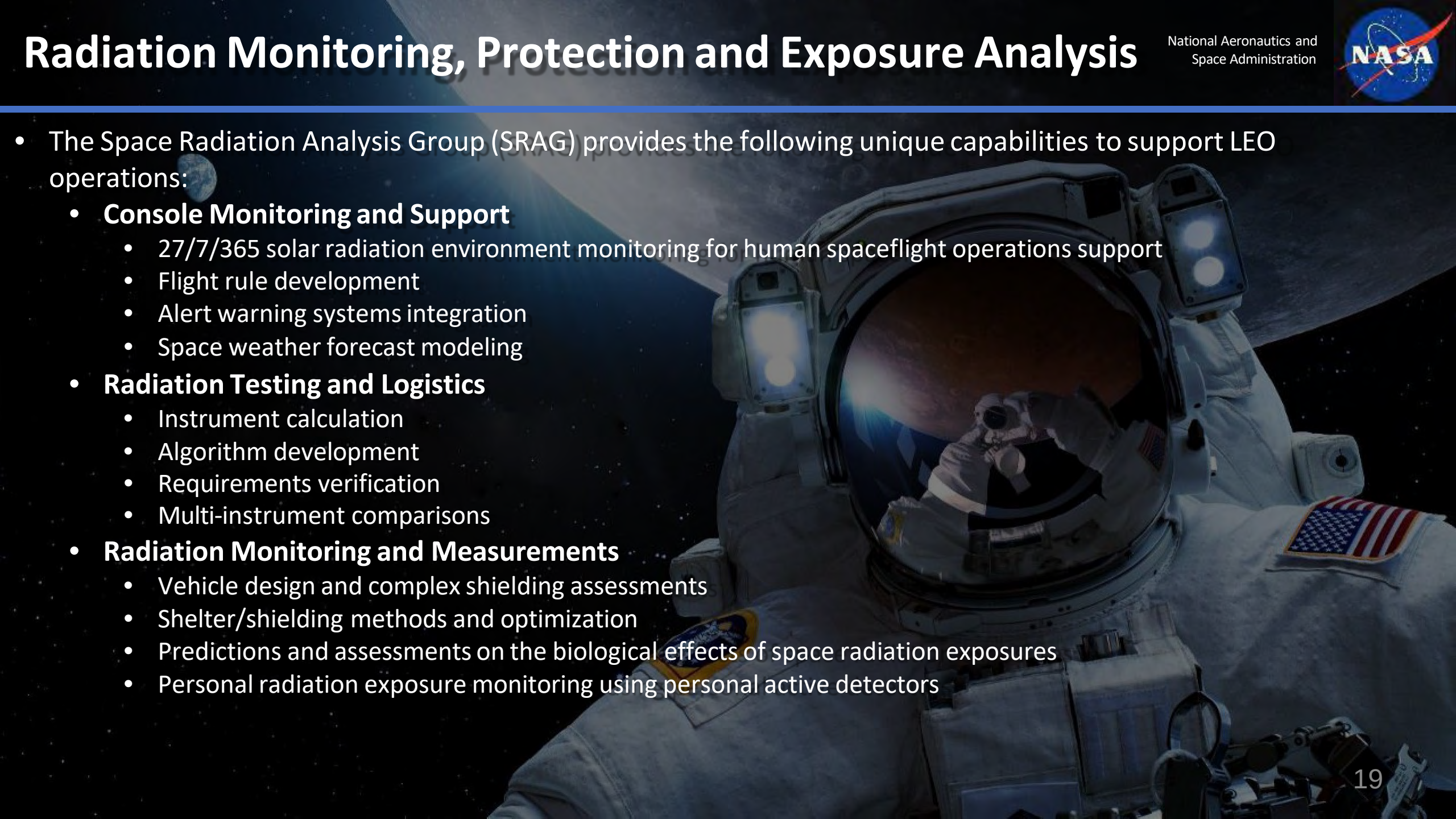

- The Space Radiation Analysis Group (SRAG) provides the following unique capabilities to support LEO operations:
  - **Console Monitoring and Support**
    - 27/7/365 solar radiation environment monitoring for human spaceflight operations support
    - Flight rule development
    - Alert warning systems integration
    - Space weather forecast modeling
  - **Radiation Testing and Logistics**
    - Instrument calculation
    - Algorithm development
    - Requirements verification
    - Multi-instrument comparisons
  - **Radiation Monitoring and Measurements**
    - Vehicle design and complex shielding assessments
    - Shelter/shielding methods and optimization
    - Predictions and assessments on the biological effects of space radiation exposures
    - Personal radiation exposure monitoring using personal active detectors

Human Research Payload Management & Processing

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- The **Research Integration and Operation** group manages and integrates human research experiments conducted across all flight and analog platforms. This includes:
  - Feasibility assessments for flight and analogs
  - Integrated medical and human research experiment requirements pre-, in-, and postflight for scheduling, sample sharing, and use of assets for data and sample collection

- The **Institutional Review Board (IRB)** provides consulting for human research studies and mission complements for spaceflight.

JSC/WSTF Capabilities and Services for CLDP

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General JSC/WSTF capabilities and services relevant to CLDP include:

- Human Subsystems - JSC puts the human in human spaceflight, leading the development, testing, integration, and certification of human subsystems critical for crew health and enhancing spacecraft operation and safety with unparalleled expertise in life support systems, crew interfaces, food systems, exercise systems, medical care, and behavioral support.
- Space Systems - JSC excels in space systems that support human performance and efficiency in space, including EVA systems, robotics, and habitability systems.
- Spacecraft Subsystem Design and Development - JSC possesses comprehensive capabilities in design, development, testing, and evaluation across a wide range of spacecraft subsystems, including guidance, navigation, and control (GN&C), propulsion, power (including batteries, solar arrays, and modular architectures), thermal systems, communication, flight software, and rendezvous, proximity ops and docking (RPOD).
- Systems Engineering & Integration - With expertise and capabilities in design, development, testing, and evaluation, JSC can offer design, manufacturing, simulation and modeling, and analysis for high-level vehicle performance.
- Spaceflight Environmental and Systems Testing - Leveraging specialized facilities and extensive expertise, JSC offers a full spectrum of testing services. This includes thermal vacuum testing, vibration testing, material compatibility assessments, and propulsion system testing. The White Sands Test Facility (WSTF) also provides specialized facilities that support the testing of hazardous materials, evaluation of spaceflight components, and qualification of in-space propulsion systems.
- Mission Planning and Execution - JSC is the hub for human spaceflight. We ensure the highest standards of safety and performance for our missions, preparing astronauts and ground crews for every situation.

JSC/WSTF Capabilities and Services for CLDP

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NASA

Human Subsystems

- Life Support - JSC excels in testing and evaluation, integration, prototype development, flight hardware certification and consultation for critical elements such as carbon dioxide removal, oxygen generation, water recovery, temperature regulation and waste management, essential for sustaining life during extended missions in the inhospitable environment of space.
- Crew Interfaces - For human spaceflight, how humans interact with vehicles and interfaces is a high priority. JSC's crew interface capabilities encompass a wide range of expertise and facilities focused on enhancing spacecraft design, operation, and safety.
- Food & Nutrition - JSC experts provide food and nutrition systems that maintain the health and optimal performance of crewmembers during spaceflight and upon return to Earth.
- Exercise Countermeasures - JSC provides research, engineering, development, integration, and testing of hardware and software technologies for exercise systems applications in support of human spaceflight.
- Medical & Pharmacology - JSC provides specialized primary medical care for astronauts and biomedical engineering support for all human spaceflight mission operations including protocols, contingency plans, crew health standards, and training.
- Behavioral Health & Performance - JSC's behavioral health experts are an integral part of advancing human spaceflight by understanding the psychological and behavioral response of humans to extreme environments.

JSC/WSTF Capabilities and Services for CLDP

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Space Systems

- Crewed Spacecraft - JSC is the hub of the United States' crewed spaceflight efforts and is renowned for its leadership in developing and operating crewed spacecraft. JSC is responsible for the design, testing, and management of spacecraft systems that ensure the safety and success of human spaceflight missions. Additionally, JSC has vast experience in working with commercial providers to meet NASA needs with a commercially developed design in Commercial Resupply Services and Commercial Crew Program.
- EVA Systems - JSC features world class facilities and competencies to support the design, development, testing and verification, and implementation of Extravehicular Activity (EVA) systems. JSC personnel have a vast knowledge of the technical challenges associated with space suit technology, ranging from mobility, sizing, and life support, to ventilation, hydration, and waste management.
- Orbital Space Stations - From the SVMF for training and operational assessments, to advanced robotics testing and human engineering expertise, JSC has diverse capabilities critical for the design, development, testing, integration, deployment and operation of orbital space stations.
- Rapid Flight Demonstrations - JSC's rapid flight demonstrations play a crucial role in advancing aerospace technologies by enabling fast, cost-effective testing of new systems. These demonstrations focus on quickly validating designs, concepts, and innovations in real-world conditions, reducing development time and fostering technological breakthroughs.
- Robotics - JSC provides research, engineering, development, integration and testing of robotic hardware and software technologies for robotic systems applications in support of human spaceflight. Advanced robotic systems technology efforts include both remotely controlled robots for space and terrestrial application and intelligent robotics for high value functionality.

JSC/WSTF Capabilities and Services for CLDP

National Aeronautics and Space Administration

Spacecraft Subsystem Design and Development

- Communications - JSC offers expertise and unique facilities in which multi-element spacecraft communications subsystems are interfaced with relay satellites and ground elements for end-to-end testing in a controlled radio frequency environment. JSC also provides for design, development, and testing of spacecraft communication systems, including evaluation of electromagnetic radiation properties of antennas and other radiating objects.
- Flight Computing & Avionics - JSC has facilities and expertise that specialize in the unique aspects of the design, development, testing and evaluation of avionics systems and architectures for human space flight. From critical commanding and data handling architectures to comprehensive component level testing and analysis, JSC stands as a beacon of expertise in the realm of aerospace technology.
- Guidance, Navigation, & Control - JSC provides design and evaluation of mission concepts, vehicle flight performance capabilities and requirements, and guidance, navigation, and control requirements and verification.
- Materials & Structures - JSC has world-class capabilities and unique expertise in structures design and development, analysis, testing and materials evaluation, damage and assessments. JSC has extensive experience in the design and development of space vehicle mating attachment systems and light weight hatches, windows, inflatable structures and traditional structures.
- Mechanical & Pyrotechnic - JSC has a long heritage of providing safe, reliable pyrotechnic solutions and mechanisms for aerospace applications. JSC is a worldwide leader in the development and testing of human-rated mechanisms, especially docking systems.
- Power - JSC provides test facilities and skilled personnel for many of the fluid and energy conversion systems required for human exploration and development in space, including power generation and storage, fluid storage and distribution, and electromechanical and hydraulic actuation.
- Propulsion - JSC has led the development and certification of many of NASA's human spacecraft propulsion systems and is actively engaged in the development and demonstration of advanced propulsion system technologies.
- Rendezvous, Proximity Operations, & Docking - JSC performs systems requirement definition, analyses, design and testing necessary to support the development of rendezvous, proximity operations and docking system designs and to verify the compatibility of the designs with functional and performance requirements.
- Software & Autonomy - JSC is a leader in software and autonomous subsystems for human spaceflight, offering an array of capabilities in high-fidelity, real-time, human-in-the-loop engineering simulations. Our expertise encompasses software development for flight and ground systems, real-time, mission-critical embedded software, software integration, and hardware-in-the-loop testing.
- Thermal Management - JSC stands at the forefront with our advanced thermal management design, development and testing capabilities. From cold stowage systems to active and passive thermal control system designs, JSC experts provide design, analytical simulation and modeling, standards and specifications development, validation and integrated testing.
- Thermal Protection Systems – JSC offers comprehensive expertise in spacecraft thermal protection systems, encompassing design, analysis, manufacturing, testing, and software tools for ensuring the structural integrity and thermal safety of spacecraft during re-entry.

JSC/WSTF Capabilities and Services for CLDP

National Aeronautics and Space Administration

Spaceflight Environmental and Systems Testing

- Acoustics - JSC has a wide range of capabilities in audio system design, analysis, testing, and evaluation and is a recognized leader in the field of spacecraft acoustics.
- EMI/EMC - JSC houses essential facilities and expertise to facilitate EMI/EMC engineering development, simulation, evaluation, and certification testing for crew, flight, and ground support equipment.
- Lighting - JSC provides internal and external lighting requirements verification, lamp and system lighting design, modeling and precise test and measurement of lighting and camera systems, as well as the simulation of orbital lighting environments, ensuring safety and functionality of ISS, Commercial Crew/Cargo, and Orion.
- Microbiology - From technology development to integrated testing of human-system interfaces, human performance, system concepts, and mission operations, JSC provides unique microbiology expertise to ensure environmental standards and crew health and safety are achieved for human spaceflight.
- Orbital Debris - JSC experts ensure the safety and sustainability of activities in Earth's orbit by characterizing the orbital debris environment, testing for impact effects, and developing shielding technology.
- Ovens & Freezers - JSC provides capabilities to handle unique needs for temperature extremes. The Cold Stowage team offers controlled environments to meet precise temperature requirements during ascent, on-orbit operations, and return of payloads and science experiments, enabling unique ISS science and research. Additionally, JSC provides access to advanced thermal chambers, including autoclaves and ovens.
- Pressure - Typical uses of our vacuum chambers have included development, engineering evaluation, and qualification testing of spacecraft components, subassemblies, and vehicles; preflight thermal-vacuum conditioning of flight hardware; development and calibration of instruments for use in the large chambers or in-flight; spacecraft seal studies; photographic film emulsion studies; and optical surface contamination studies.
- Radiation - JSC's physics, simulation and radiobiology tools allow experts to perform vehicle design and complex shielding assessments in different environments, develop shelter/shielding methods and optimization as well as predict and assess the biological effects of space radiation exposures.
- Thermal Vacuum - JSC thermal-vacuum test facilities provide thermal-vacuum chamber test operations for both crewed and uncrewed test environments. The facilities offer a wide range of performance capability, which can be matched to the individual test requirements of smaller test articles or large test article components and subsystems.
- Toxicology - JSC's uniquely skilled team serves as the NASA-wide resource for space toxicology by assessing chemical toxicity to establish spacecraft maximum allowable concentrations (SMACs), spacecraft water exposure guidelines (SWEGs), assigning toxicity hazard levels to all compounds that could enter the habitable area of a spacecraft, performing offgas testing of flight hardware and whole modules, and monitoring and analyzing air quality in human space vehicles.
- Vibration & Shock - JSC's Structures Test Facility can provide structural vibration and shock testing of spaceflight hardware to ensure structural integrity and functionality of spacecraft components to guarantee mission success.

JSC/WSTF Capabilities and Services for CLDP

National Aeronautics and Space Administration

Systems Engineering & Integration

- Integrated Vehicle Performance - With expertise and capabilities in mission design, detailed end-to-end trajectory optimization, high performance computing and data analytics, mission management product analysis, metrics production, and mission trades, JSC is shaping the future of space exploration missions.
- Manufacturing, Assembly & Integration - JSC offers advanced facilities and expertise ready to support almost every aspect of spacecraft development. Staffed by expert technicians and engineers, our facilities include cutting-edge clean rooms, fully equipped high bays, onsite manufacturing, and spacecraft testing facilities that provide the ideal environment for spacecraft assembly and seamless integration.
- High-fidelity modeling, simulation, and mission design tools - JSC develops and maintains a suite of sophisticated software tools critical for mission assurance and rapid development.

JSC/WSTF Capabilities and Services for CLDP

National Aeronautics and Space Administration

Mission Planning & Execution

- Spaceflight Operations - JSC serves as the central hub for NASA's human spaceflight operations, encompassing astronaut training, mission control, International Space Station (ISS) operations, Commercial Crew and Cargo operations, operations considerations for spacecraft development, and ongoing support for new exploration space missions.
- Crew & Operations Training - JSC is the proud home of the nation's elite astronaut corps and provides NASA's human spaceflight training. Our state-of-the-art facilities and expert training staff are unrivaled in their ability to provide comprehensive training for astronauts and ground crews alike, ensuring the highest standards of safety and performance for every human spaceflight mission.
- Mission Planning & Design - JSC has several groups that provide capabilities and expertise in mission planning, spaceflight architectures and analysis.
- Analogs & Mockups - NASA Johnson Space Center (JSC) offers a range of facilities to support mission development, crew training, equipment testing, and real-time mission troubleshooting.
- Program Management & Execution - JSC program leadership teams have enabled the successful execution of our Nation's human spaceflight programs, including the Apollo Program, the Space Shuttle Program, and the International Space Station Program. Now we are embarking on a new era of exploration further into the solar system with the Orion Program, Gateway Program, Extravehicular Activity and Human Surface Mobility Program and roles in the Commercial Crew Program and Human Landing System Program.
- Safety & Decision Support - JSC experts develop and administer flight and ground safety programs, focusing on protecting personnel, equipment, spacecraft and missions. Experts in safety and mission assurance conduct mishap and close call investigations, employ risk management strategies, perform risk management, assess hazards and failure modes, and provide reliability and quality assurance processes and assessments. JSC can also provide NASA Standards Workmanship Training.

JSC/WSTF Capabilities and Services

National Aeronautics and Space Administration

Full list of JSC/WSTF Capabilities and Services are organized in a tiered structure of
6 Themes > 55 Domains > 406 Capability Sets

Details of the 406 Capability Sets are found at the
JSC Front Door - Capabilities & Services website:

https://www.nasa.gov/johnson/frontdoor/capabilities/

JSC/WSTF Capabilities and Services
6 Themes and 55 Domains

National Aeronautics and Space Administration

Mission Planning & Execution
- Spaceflight Operations
- Aircraft Operations
- Crew & Operations Training
- Planning, Architecture & Analysis
- Analogs & Mockups
- Program Management & Execution
- Safety & Decision Support

Spacecraft Subsystems
- Communication
- Entry, Descent, & Landing Subsystems
- Flight Computing & Avionics
- Guidance, Navigation, & Control
- Materials & Structures
- Mechanical & Pyrotechnic
- Power
- Propulsion
- Rendezvous, Prox Ops, & Docking
- Software & Autonomy
- Thermal Management
- Thermal Protection

Human Subsystems
- Life Support Subsystems
- Crew Interfaces
- Food & Nutrition
- Exercise Countermeasures
- Medical & Pharmacology
- Behavioral Health & Performance

Spaceflight Environments & Testing
- Acoustics
- Aerosciences
- Dust
- EMI/EMC
- Lighting
- Microbiology
- Orbital Debris
- Ovens & Freezers
- Pressure
- Radiation
- Thermal Vacuum
- Toxicology
- Vibration & Shock

Exploration Research & Science
- Human Research Labs
- Human Factors & Performance
- Astromaterials Curation & Research
- Imagery Acquisition & Analysis

Space Systems, Systems Engineering & Integration
- Crew Spacecraft
- EVA Systems
- Landers
- In-Situ Resource Utilization
- Orbital Space Stations
- Rapid Flight Demonstration
- Robotics
- Rovers
- Surface Habitats
- Surface Infrastructure
- Integrated Vehicle Performance
- Manufacturing, Assembly & Integration
- Simulation & Modeling

Marshall Space Flight Center

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Do Business with Marshall

Marshall Capabilities

Environmental Control and Life Support System (ECLSS) Overview

Marshall Space Flight Center is pioneering ECLSS for a new era in human exploration with expertise in all aspects of air, water, and waste management systems, supported and enhanced by ECLSS flight hardware development, manufacturing, and testing expertise.

Potential areas MSFC can provide the most value for CLDP include:

- ECLSS Integration
  - MSFC has unique experience and capabilities to help identify problems and implement solutions early on in development
  - Conceptual design, manufacturing and testing at component, subsystem and ECLSS system
- Flight Hardware Design, Manufacturing, Assembly, Qualification, and Testing
  - In-House MSFC Flight Hardware design, manufacturing, assembly, qualification and testing – see examples on right
  - Integrated ground testing of ECLSS subsystems can identify integration and performance issues on the ground to ensure a robust flight system
- Development of an ECLSS architecture that can evolve into loop closure
  - Loop closure supports long duration exploration missions
- Development of Low Technology Readiness Level (TRL) ECLSS Hardware
  - Conceptual design, manufacturing and testing at component, subsystem and integrated ECLSS levels
- Subject Matter Expertise to help all ECLSS development areas

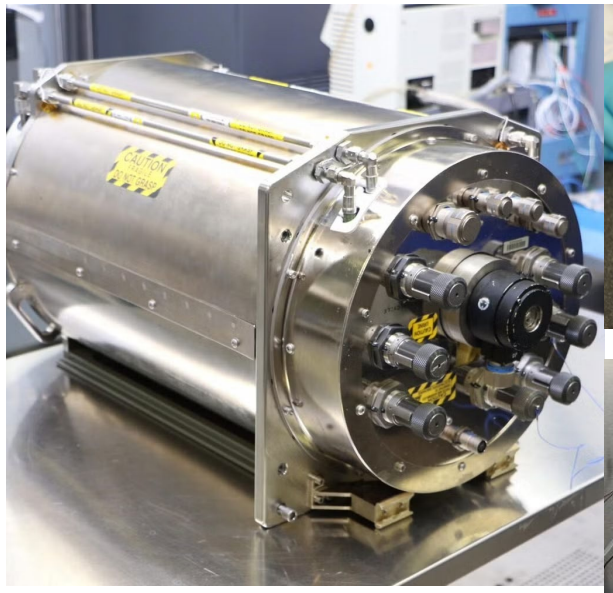
ECLSS @ MSFC

1. ISS Urine Processor Assembly (UPA): Designed, built and delivered ISS UPA. Continuing sustaining engineering for UPA including on-orbit troubleshooting, spares production and failure investigation.
2. ISS Four Bed Carbon Dioxide Removal (4BCO2) System: Designed, built and delivered ISS 4BCO2 removal system as a demonstration for exploration ECLSS. Continuing sustaining engineering for 4BCO2 including on-orbit troubleshooting, spares production and failure investigation.
3. ECLSS test capability including reduced atmospheric pressure and elevated Oxygen concentration:
   - Capability to test ECLSS subsystems and components as well as integrated testing with other ECLSS subsystems and components for integration issues
4. Long history of developing low Technology Readiness Level ECLSS systems into higher TRL and flight systems
5. Miscellaneous ECLSS Hardware developed and in development for ISS/Gateway:
   - Alternate H2 Sensor for Oxygen Generator
   - Alternate conductivity sensor for Universal Waste Management System (UWMS) aka toilet
   - Urine Transfer Pump for Gateway
   - Potable Water Dispenser for Gateway
   - Pre-treatment Pump development for Universal Waste Management System (UWMS) aka toilet

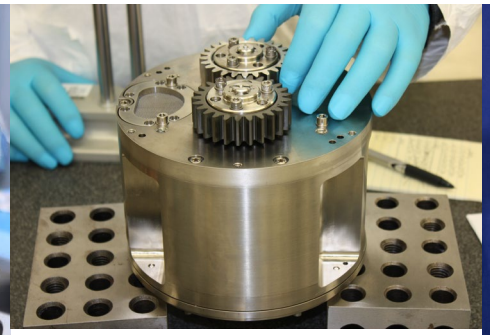
ECLSS Development, Qualification and Certification Testing

- MSFC Onsite Environmental Testing (e.g., Vibration, Leak, Thermal Cycle, Electromagnetic Interference (EMI)/ Electromagnetic Compatibility (EMC), etc.)
- MSFC Unique Chamber Test Facility for testing components, subsystems and systems with variable atmospheric pressure capability (8.2-14.7 psia)

Variable Atmosphere Test Facility for ECLSS



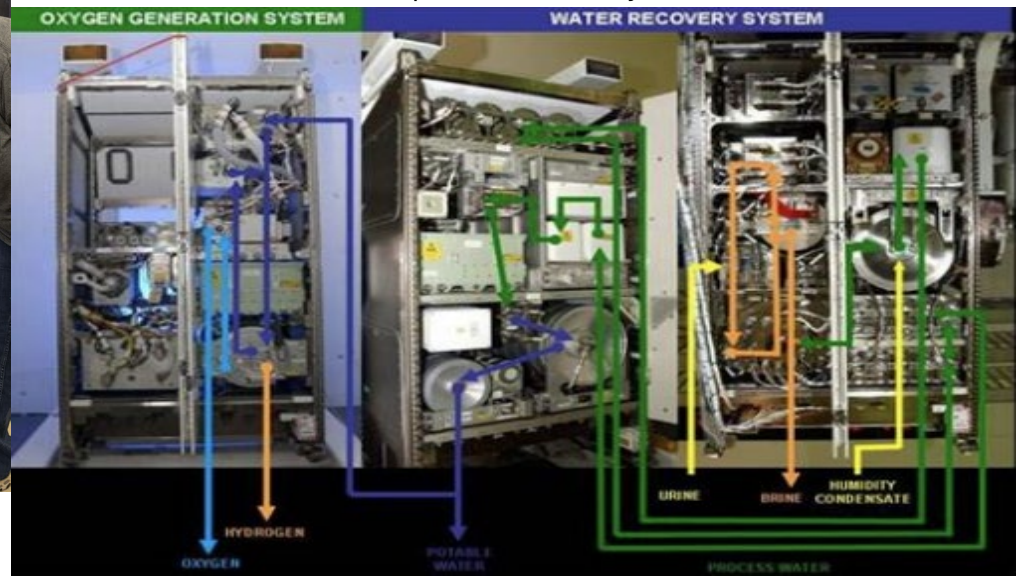
Urine Processor Assembly (UPA)/Distillation Assembly (DA)



UPA DA Compressor

Biofilms Testbed

Four Bed Carbon Dioxide Removal Assembly (4BCO2)



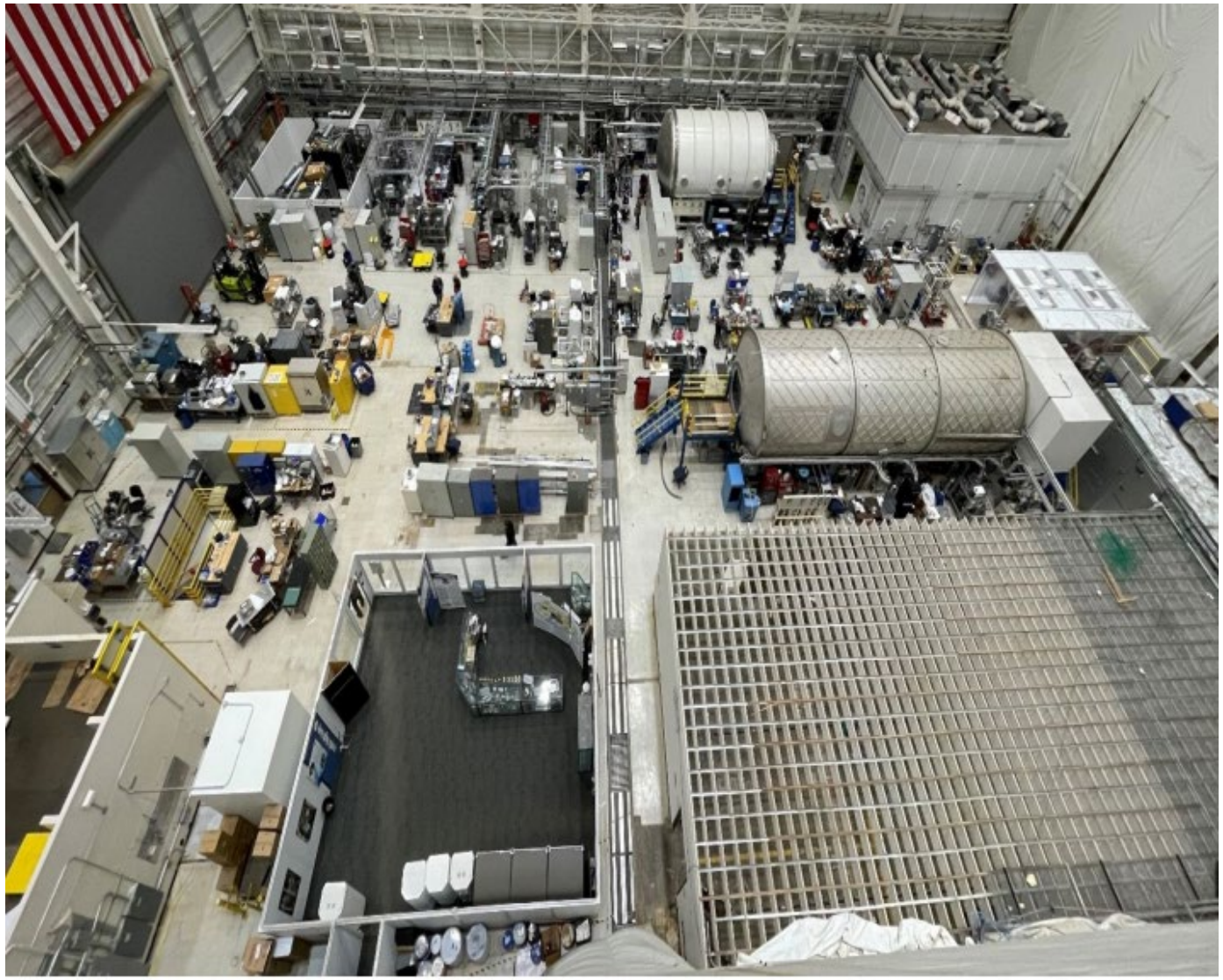
International Space Station ECLSS Racks

ECLSS Facility Capabilities

MSFC operates state-of-the-art facilities for the design, development, integration, and testing of human-rated ECLSS hardware within our ECLSS High Bay. The ECLSS facilities can be utilized for collaborative ECLSS ground test hardware or insight/oversight for the development and testing for commercial destination ECLSS systems.

ECLSS Facility Capabilities

- 24,000 ft^2 High Bay (120 ft x 200 ft), controlled environment
- Two 90-ton cranes with two 45-ton hooks each.
- High Purity Air (up to 150 psig), gaseous Nitrogen, and ultra-pure (18M-ohm) water
- 120V, 208V 3F, 480V 3F power sources
- Electrostatic Discharge Workbenches
- Environmental chambers for integrated ECLSS testing
- On site machine shop for rapid prototyping new concepts
- Chemistry Laboratory
- Machine Shop



ECLSS high bay.

Payload/Instrument Development, Integration, and Test

The Marshall Space Flight Center maintains expertise in the Development, Integration, and Test of instruments, racks, payloads, and subsystems, including the development of science instruments. The MSFC team offers subject matter experts for integration, testing, engineering development and on-orbit operations of payloads, satellites, landers, and ISS facilities (gloveboxes, furnaces, and multi-payload locker racks).

- Design, planning, and implementation of ground test programs for qualification and certification of flight projects
- Proof and leak testing of flight and ground hardware and test systems
- Launch site and post-launch integration/de-integration and testing

Space Systems Integration and Test Facility (SSITF)

- 10,000-square-foot temperature and humidity controlled high bay
- 20-ton overhead crane
- Forklifts, hydraulic lift carts, and work platforms
- Gas distribution panels
- 110 V and 208 V 3F power, including a 100 kVA 80 kW un-interruptible power supply
- Facility grounding system; ESD workbenches
- Payload Rack Checkout Unit (PRCU)
- Machine Shop

Life Sciences Glovebox

ExPRESS

Microgravity Sciences Glovebox

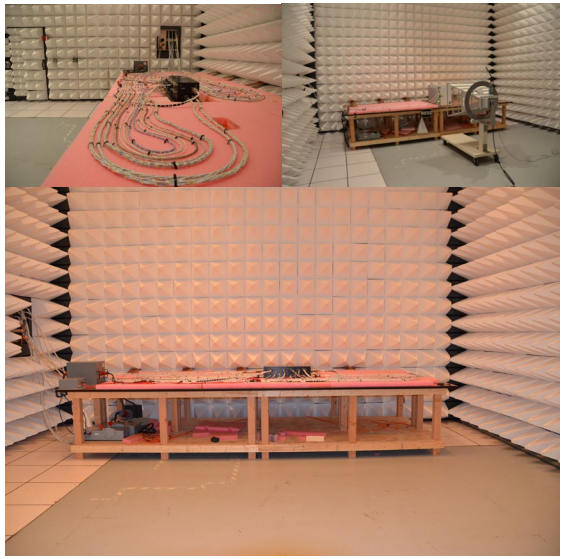
MCTF Vacuum Chamber and Mass Spectrometer

Mechanical Components Test Facility (MCTF)

- High-pressure test cell capable of supporting up to 5,000 psig
- 0.5-ton crane
- Wide range of pressure and flow instrumentation
- Leak-detection equipment to perform vacuum and pressure decay leak tests and fluid flow testing

Avionics: Electromagnetic Environmental Effects and Radio Frequency Capabilities

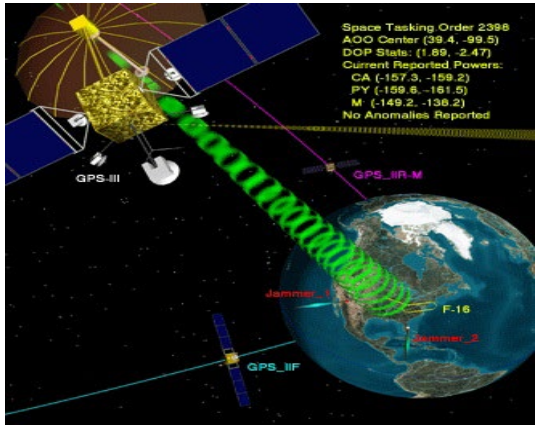
The MSFC **Electromagnetic Environmental Effects (E3)** team provides expertise in electromagnetic capability, lightning protection, electrical grounding, and electrical bonding. In addition to expertise, the E3 team also has facilities for testing to E3 requirements including capabilities to test for Lightning Indirect Effects, Electromagnetic Interference, Electrostatic Discharge (ESD), and Power Quality that could support commercial destinations.



MSFC EMI/EMC Test Facility (METF)

METF Facility Characteristics

- 2 welded steel anechoic enclosures
- 28'L x 20'W x 12'H
- 28'L x 24'W x 20'H
- Instrumentation Room for Ground Support Equipment
- Customizable Feedthrough Plates
- Fiber Optic Video Feeds
- AC Power: 120/208 VAC
- DC Power: 0 – 150 VDC /
- 0 – 100 A



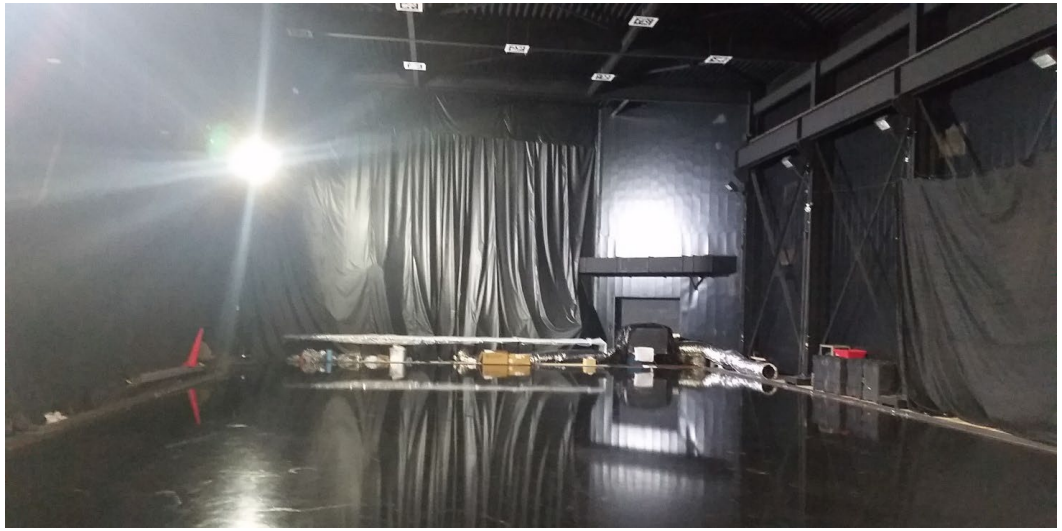
The MSFC **Radio Frequency (RF)** team provides expertise in the design, development, test, operation, and maintenance of communications, range safety, and tracking systems for new and existing launch vehicles and spacecraft. The RF Lab capabilities include measuring RF power, input sensitivity, modulation characteristics, bandwidth, and simulating GPS RF satellite signals, vehicle antenna patterns, and dynamic link analyses for the development and analysis of RF communication systems and component subsystems.

Avionics: Guidance, Navigation, and Control (GN&C) Hardware

The MSFC GN&C team provides expertise in evaluation, selection, and test of GN&C hardware including IMUs, sun sensors, star trackers, and specialized systems for automated rendezvous and capture. This expertise is supported by one-of-a-kind test facilities such as the Inertial Navigation Sensors and Test Lab, Navigation Components Lab, and the Flat Floor Robotics Laboratory (FFRL) which provides the capability of performing both open and closed loop testing in either digital or hardware-in-the-loop modes and a lab space to develop, integrate, and calibrate GN&C hardware.

GN&C Hardware Labs

Marshall's GN&C hardware labs provide testing capability for various GNC system components, including Inertial Measurement Units (IMUs), gyroscopes, accelerometers, star trackers, sun sensors, magnetometers, control moment gyros reaction wheels, and other various components. These labs contain various rate tables for gyroscope, accelerometer, and IMU development and testing, a small portable 6-axis tilt table, a Helmholtz coil for evaluating and testing of magnetometers, two armored test vaults for lifetime testing of reaction wheels and control moment gyroscopes, and other equipment.



Flat Floor Robotics Lab (FFRL)

The Flat Floor Robotics Lab (FFRL) contains a 44 x 86' precision air bearing epoxy floor for simulating near-zero gravity in three axes, an 8-axis dynamic overhead test robot, and the dynamic solar simulator. The dynamic solar simulator includes lights that simulate sunlight, which can be moved as a group on a two degree-of-freedom overhead carriage across the lab, or as individual lamps for specific lighting testing within the lab.

Avionics: Power and Electrical Integration

The Marshall Space Flight Center maintains subject matter expertise for Power & Electrical Integration including Power Electronics, Electrical Power Systems and Components, and Electrical Integration.

Power Electronics:

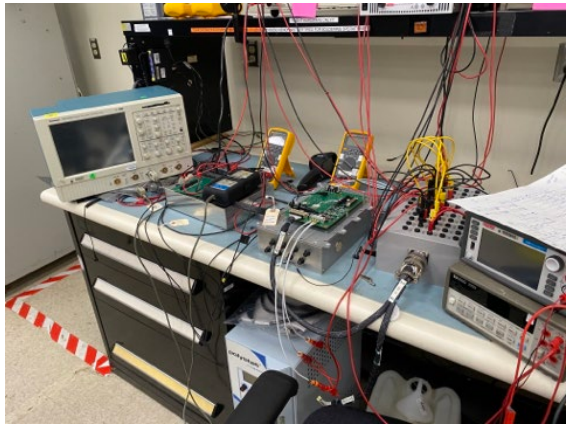
The MSFC team provides design, development, assembly, testing, and evaluation for human-rated power electronics hardware (with power levels ranging from milliwatts to kilowatts) that converts, regulates, and/or isolates power supplied to various flight or ground equipment. This expertise includes the areas of power conditioning, conversion, regulation, distribution, and management of circuits as well as power quality analysis. MSFC also maintains nearly 3500 sqft of lab space between 3 power electronics labs for hardware development and testing.

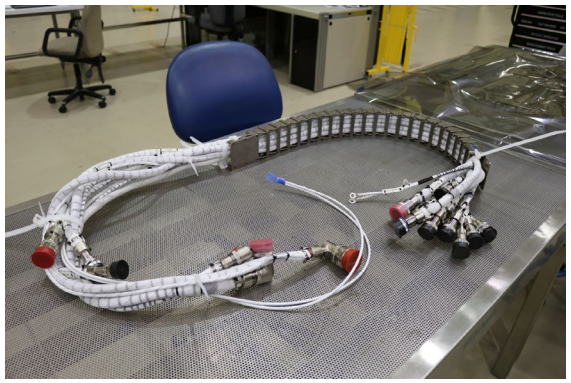
Electrical Power Systems and Components:

In addition to expertise, MSFC facility capabilities include a large test facility (nearly 8000 sqft) for Power Systems and Components development and testing including multiple thermal chambers ranging in size from 6 to 100ft^3 with cold temp operation to -70C, 3 Arbin test systems, and a Large Area Pulsed Solar Simulator used to characterize solar panels up to 12 ft^2, with illumination of 140 mW/cm^2 (1 Sun) at Air-Mass-Zero. These facilities are used for development and testing of power system architectures, components, batteries, regenerative fuel cells, and solar arrays.

Electrical Integration:

MSFC maintains expertise in electrical integration products including system schematics, cable interconnect diagrams, and cable harness including various analyses such as voltage drop and circuit protection. This expertise is supported by 2 lab areas (over 3000 sqft total) of test equipment and bench tops to build and test a variety of harness configurations and integration component tests.





Avionics: Electrical, Electronic, and Electromechanical (EEE) Parts

Marshall's EEE Parts Team provides parts screening and analytical services for a variety of components, vehicles, and spacecrafts including external customers. The EEE parts team expertise includes PIND, radiography, and Destructive Physical Analysis (DPA) for determining the cause of EEE parts and assembly failures. In addition to EEE engineering and analysis, MSFC's EEE parts team has subject matter expertise in electronic packaging and fabrication. These capabilities include electro-mechanical design, modeling & analysis, printed circuit board layout, fabrication and assembly of space flight hardware, ground support equipment, and rapid prototype units.

Electronic Fabrication Shop:

Electrical fabrication capabilities include metal fabrication, automated & hand soldering (J-STD-001 & Space), Cable/harness fabrication & test (NASA-STD-8739.4, IPC/WHMA-A-620), polymeric applications for conformal coating & staking (NASA-STD-8739.1), potting, part marking, lead forming, out-gassing, and avionics box level wiring & integration.

EEE Parts Failure Analysis and Screening Lab:

The EEE Parts Failure Analysis and Screening Lab provides expertise in obsolescence and failure analysis using a variety of methodologies including Nano-focus real-time x-ray and 3D x-ray tomography, x-ray fluorescence spectrometry, FTIR, ESEM w/EDS, leak testing (He & Kr), PIND testing, bond strength testing, metallography, and 3D microscopy.

Printed Electronics Lab:

MSFC's Printed Electronics Lab enables the research, evaluation, and development of the next generation of electronics with an emphasis in additive electronics and developing technologies to deploy in space for manufacturing and repair of electronics. This lab is key to maturing the technologies that will allow for fabrication and maintaining of electronics during long-term human-rated missions in space.

Avionics: Electrical Design, Imaging, and Sensors Capabilities

The Marshall Space Flight Center maintains world-renowned expertise in Electronic Design, Imaging, and Sensors consisting of both a Data & Signal Conditioning team and an Imaging and Sensors team.

Data & Signal Conditioning:

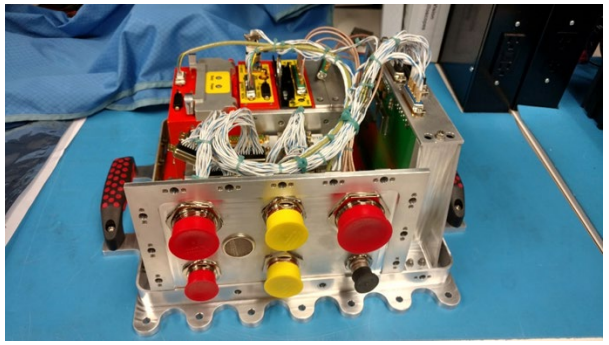
The Data and Signal Conditioning team provides the capabilities to design and develop flight computers, data and signal conditioning systems, instrumentation, and controller design and analysis for ground and space applications. Their subject matter expertise includes performing research, design, development, implementation, and testing of analog and digital electronic circuits, control devices, servomechanisms, and embedded control such as Field Programmable Gate Array (FPGA) logic design for space flight and ground hardware.

Imaging and Sensors:

The Imaging and Sensors team are widely known experts in the design, implementation, and testing of imaging, camera, and video systems for research and implementation of both spaceflight and ground **hardware including internal and external cameras and imaging for SLS and CLPS Landers**. This team maintains expertise in flight sensor instruments for advanced measurements and the development of imaging, camera, and video systems and components including optics, recorders, and frame grabbers.

MSFC designed and developed Internal and External Cameras for SLS flight

Ruggedized cameras developed and mounted to exterior of SLS rocket capturing live recording of booster separation and jettison.



EFILMERS ECCU

Flight Software and Simulation

The Flight Software and Simulation capabilities at Marshall Space Flight Center provides comprehensive engineering expertise for the development of flight and ground software and simulation, including software development facilities, avionics and software ground systems test facilities, and operation facilities. The MSFC division is a Capability Maturity Model Integration (CMMI) Maturity-Level 3 appraised organization with heritage in large and system space and vehicle systems that can be leveraged by commercial destinations.

Flight Software

MSFC has extensive experience in the development and verification of human-rated flight software for the Space Launch System (SLS) rocket including leading the entire effort through the entire software lifecycle, including requirements, design, test, verification, day-of-launch operations, and configuration management.

In addition, MSFC has developed flight software for the Mars Ascent Vehicle (MAV), 4-Bed Carbon Dioxide Scrubber (4BCO2), Urine Processor Assembly (UPA), and many other large and small projects.

Simulation

Commercial partners can leverage MSFC's development of the Advanced Real-Time Environment for Modeling Integration and Simulation (ARTEMIS) simulation software and the Managed Automation Environment for Simulation Test and Real-time Operation (MAESTRO) software.

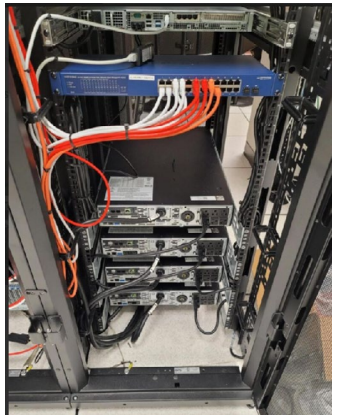
- ARTEMIS is the real-time simulation environment used to integrate the avionics components with flight software for formal certification testing of the integrated avionics and flight software suite.
- MAESTRO is an automation, configuration, and orchestration framework for running ARTEMIS simulations and viewing the results.

Example visualization of 4BCO2 sorbent bed data.

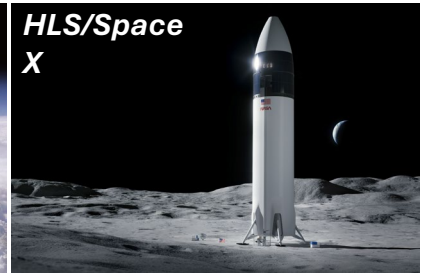
Hardware-in-the-Loop Test Facilities

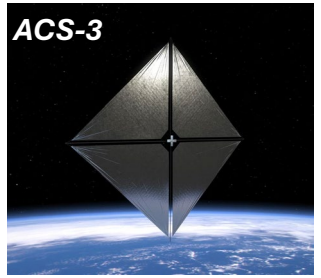
IATF System Integration Lab (SIL) and System Integration Test Facility (SITF)

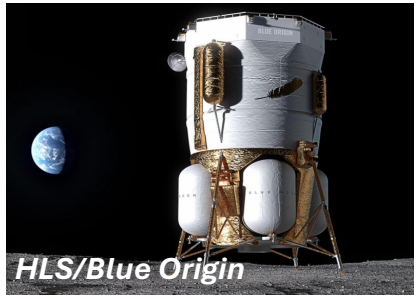
The Integrated Avionics Test Facility (IATF) and Avionics and Software Test Facility (ASTF) at Marshall Space Flight Center provide hardware-in-the-loop verification for the SLS program, Mars Ascent Vehicle (MAV) project, and can be configured for CLDP avionics verifications. The IATF and ASTF consist of a Systems Integration Laboratory (SIL) and Systems Integration Test Facility (SITF), Software Development Facility (SDF), and emulators designed for supporting the integration and test of the SLS avionics and software components. This heritage experience and capabilities can be leveraged by commercial destinations for avionics systems and software verification through representative hardware-in-the-loop labs at MSFC.



Guidance, Navigation, Control and Mission Analysis







Controls Design

- Ascent and in-space Flight Control
- POGO analysis
- Separation systems
- Attitude determination & control
- Smart Video Guidance Sensor (SVGS) technology

Mission Design

- Ascent Trajectories
- Vehicle Performance
- Aborts Analysis
- In-space Trajectories
- Payload Performance

Navigation

- Inertial Navigation
- Sensor and GPS Integration
- State Estimation
- Hardware Testing
- Orbit Determination
- GPS-denied nav tech

Guidance

- Throttle Commands
- Vehicle Steering
- Optimal Control
- Guidance Laws
- Flight-Day Operations

Rendezvous, Proximity Operations and Docking

- 3-DOF rendezvous trajectory simulations
- 6-DOF proximity operations phase performance simulations
- Trade studies of relative navigation sensor accuracy
- Cis-lunar and Earth orbit relative navigation trades studies
- Relative navigation sensor design and performance

Simulation

- 6DOF detailed simulation
- FSW model development
- Mass modeling
- Engine modeling
- Disturbance forces

Flight Dynamics

- Pad dynamics during liftoff
- Modeling of separation
- Flight-day Dispersions
- Detailed multi-body dynamics
- Analysis for Rendezvous, Proximity Operations and Docking (RPOD)

Orbital Assembly, Operations, and Berthing

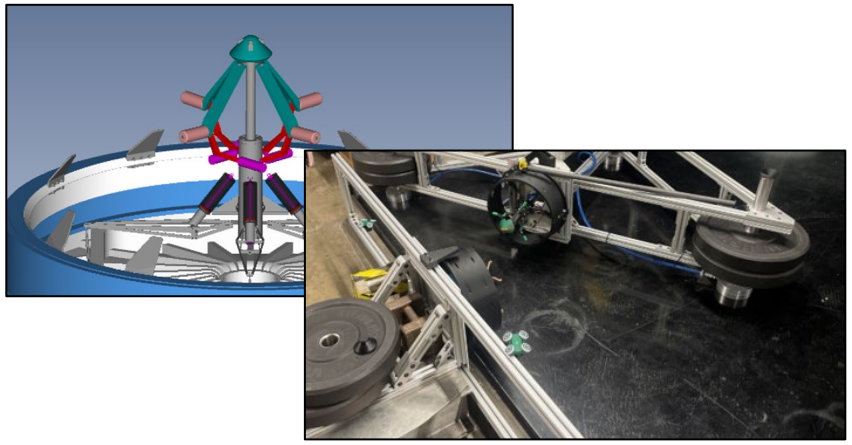
MSFC has a long history of orbital assembly, beginning with the development of docking systems to support Space Station Freedom (the precursor to the ISS), and culminating with the development of the Common Berthing Mechanism (CBM).

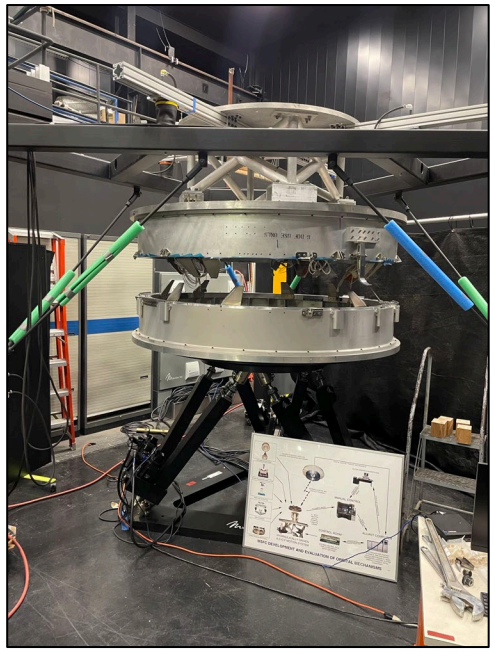
Decades of experience include integrated testing of robotic arms with the CBM using the Flat Floor, in conjunction with facilities such as the V20 Resistive Load Simulator (RLS). Integrated testing provides significant risk reduction to new programs.

This development work continues with investments in the next generation of orbital assembly systems and test facilities.

Orbital Assembly and Berthing expertise areas include:

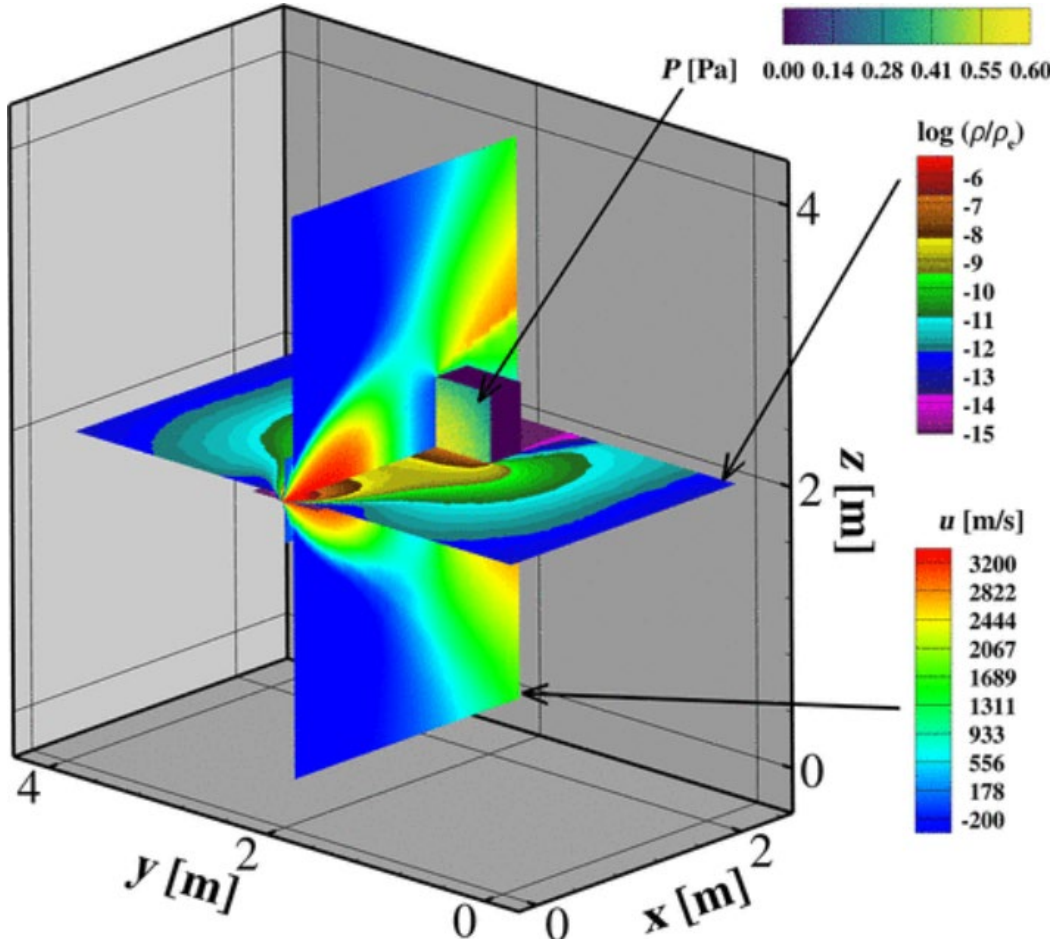
- Simulation of Docking, Berthing, and Orbital Assembly
- Integrated Analysis of Mechanism Dynamics and Structural Loads
- Rapid prototyping of mechanisms
- Test Support and Iterative Development
- Development of Test Equipment





Plume Impingement Modeling for Rendezvous, Proximity Operations, and Docking (RPOD), including pressure, heating and contamination:

- Engineering plume codes (RAMP/PLIMP)
- High-fidelity plume approaches (Loci-CHEM CFD, DSMC)



Structural and Mechanical Design, Analysis, and Fabrication

Marshall Space Flight Center has an extensive history in structural and mechanical design, analysis, and fabrication of space systems, launch vehicles, and spacecraft.

Design:

- Detailed design of:
  - Fluid & pneumatic systems, Ground & Flight Support Equipment, ECLSS components
  - Mechanisms (deployment & separation systems, docking/berthing, offloading, etc.)
  - Spacecraft, Launch Vehicle, Lander, Habitat primary & secondary structures
- Typical products include detailed CAD models, 2D drawings, 3D printed prototypes, model-based designs, geometric dimensioning & tolerancing, and tolerance stack-ups
- Design development supported by testing & rapid prototyping facilities including Automated Mechanisms Lab, Mechatronics Lab, and Mechanical Development Facility (MDF) machine shop

Strength and Life Analysis:

- Structural analysis including stress, fracture, fatigue, and strength verification
- Linear and nonlinear solutions, buckling and stability assessments
- Structural optimization including shape, size, and topology
- Define and support material characterization and structural testing

Dynamics:

•Coupled Loads Analysis to define structural loads and responses for launch vehicles, payloads, and landers
- Develop random vibration, acoustic and shock equivalent static loads

•Dynamic analyses to define structural characteristics such as aero-elasticity, sloshing, aerodynamic flutter, structural responses, and frequencies

•Define and support modal and vibration tests for model correlation and hardware verification

•Design component and large-scale vibration mitigation methods such as optimized additive mass, isolators, and traditional and novel dampers.

•High-speed data acquisition and video analysis to extract structural modes, object tracking, and removal of obscuring dust and debris.

Mechanical Fabrication and Development

MSFC maintains a state-of-the art Mechanical Fabrication and Development Facility with capabilities including the following a 7-axis mill, Vision-wide (large 5-axis mill) Vertical Turret Lathe (VTL) (large lathe 10ft OD), Cincinnati 30 V (large 5-axis vertical mill), Waterjet (cut plates up to 12ft x 5ft x 1ft), Precision Assembly (100k clean room environment, and Precision Cleaning (30k clean room).

MSFC 7-Axis Milling Machine Facility

This Lab supports some of the larger articles that are manufactured here at Marshall. This machine has seen the equivalent of an external tank that was needed to be machined. The machine has had Artemis I, II & III MSA go across the machine for final machining operations and has also been used for support of the LVSA and Centurion V.

Vision Wide Knuckle Head 5-Axis CNC

This piece of equipment has unique capabilities with a footprint of 244” X 130” X 48”, for the X, Y and Z axes. The 4th and 5th axes are driven off the head, which can swivel into a fixed angular position, as well as the capability to perform continuous motion for machining.

Precision Assembly Facility

This facility is where the integration of the flight hardware, in support of the ECLSS project takes place. This hardware is necessary for the operations on the International Space Station. ECLSS, which is Environmentally Controlled Life Support System, is critical to support the drinking water for the Astronauts on station. This area also accommodates the assembly of the Orion valve project, as well as the MSRR project.

Precision Cleaning Area

MSFC has the capabilities of meeting several requirements for Precision Cleaning. Examples include MSFC-SPEC-164, IEST-STD-CC1246E, as well as Visual Clean for NQS hardware. This area is state of the art for the for the precision cleaning operation for flight and non-flight hardware. With overhead cranes in place, large valves and an assortment of hardware may be precision cleaned. Brulin baths with the capability to pump tubing along with ultrasonic capabilities are found present here at MSFC fab & Assembly area.

Precision Cleaning

7-Axis Mill

CNC Machining

Precision Assembly

Welding/Fabrication

Manual Machining

Water Jet Cutting

Vision Wide

VTL

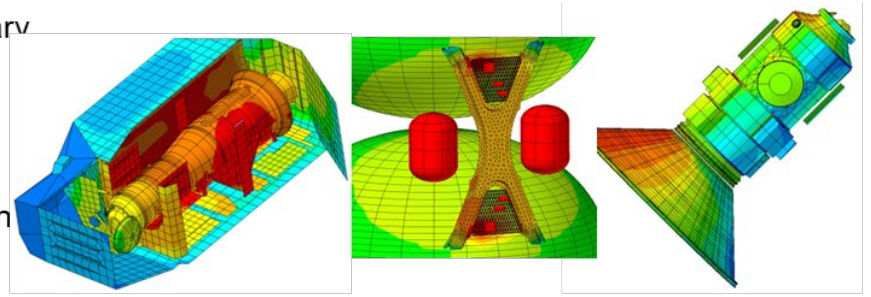
Cincinnati 30 V

MARSHALL SPACE FLIGHT CENTER

Thermal Design, Analysis & Test

Thermal Design:

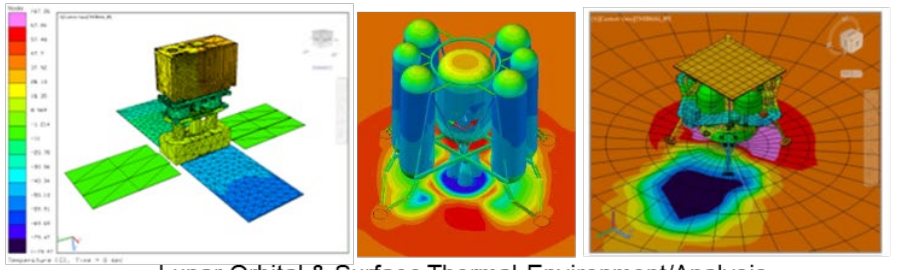
- Passive and Active Thermal Control for terrestrial, orbital and planetary satellites, launch vehicles, planetary landers/rovers, instruments, payloads, and Environmental Control Life Support Systems (ECLSS).
  - Thermo-optical Coatings, Multi-Layer Insulation, Radiators, Pumped-Loop single and two-phase systems, Heat Pipes, Thermal Conduction Enhancements and Isolation techniques.
- Thermal Protection for Cryogenic Propulsion and Vehicle Systems.
  - Low thermal conductivity structures for cryogenic propellant management, advanced MLI, Spray-On Foam Insulations, ablator materials, etc.



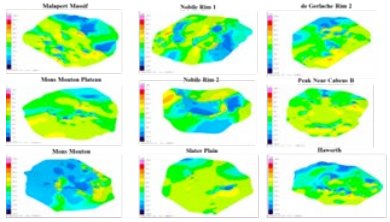
Launch Vehicle and Payload Thermal Analysis

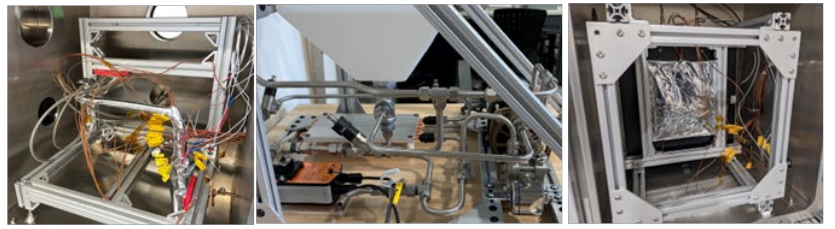
Thermal Analysis:

- MSFC Sponsored the Development of Thermal Desktop (now an ANSYS product). Advanced In-House User Community. Also use NX SimCenter, COMSOL, etc.
  - Terrestrial (Earth, Lunar, and Mars) applications, including ascent and descent transient analysis
  - Orbital and In-Space Thermal Analysis of payloads and systems
  - International Space Station payloads within and outside of the ISS
  - Conjugate Thermal/Fluids analysis with FloCAD & SINDA/FLUINT for active thermal control, Cryogenic Fluid Management & Boiloff Calculations
- MSFC's Generalized Fluid System Simulation Program (GFSSP)
  - Conjugate Cryogenic Tank Fill/Chill, Cryogenic Fluid Management, Pressurization, Blowdown, two-phase, non-condensibles, Boiloff, Priming, etc.
- Lunar and Mars Thermal Environment Development
  - Lunar Thermal Analysis Guidebook development (L-TAG, HLS-UG-001)
  - LUMINATE (Lunar and Mars Environments Analysis Team)
  - Advanced modeling of Lunar terrain impacts and landing site selection



Lunar Orbital & Surface Thermal Environment/Analysis

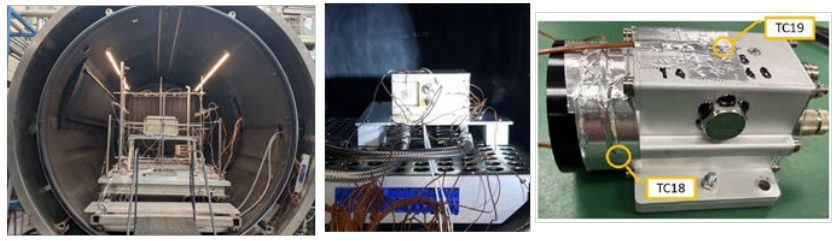




Thermal Development Testing in HI-TTeMP

Thermal Testing:

- Extensive thermal vacuum cycle, thermal balance & TPS test planning and execution experience, including flight hardware verification through acceptance, protoqualification, and qualification testing
- Thermal development testing in the Hub for Innovative Thermal Technology Maturation and Prototyping (HI-TTeMP) lab
  - Testing of novel thermal control hardware and systems design
  - Testing of system concepts to verify analysis assumptions and increase accuracy of assumptions
- Model correlation to test data to decrease analysis error and inform flight designs



Thermal Vacuum Testing

Optical Systems Design and Fabrication

The Marshall Space Flight Center specializes in optical mirror design, development, fabrication, assembly, test, and calibration of space-based normal and grazing incidence telescope systems. ***MSFC is one of only a few domestic organization that has routinely developed optical systems from concept to flight.***

Stray Light Test Facility (SLTF):

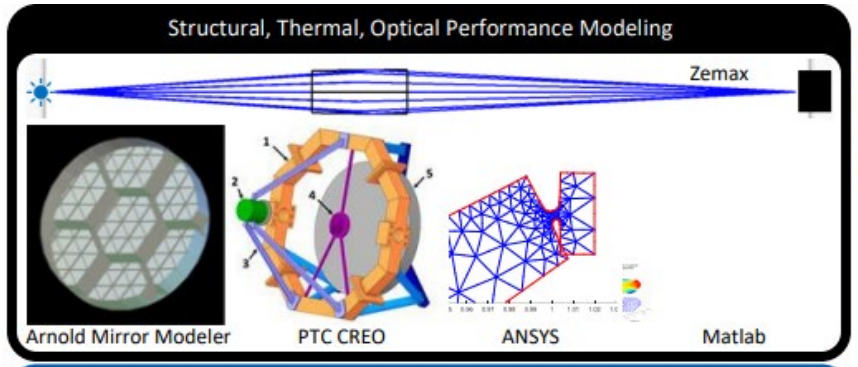
- This facility offers a low cost, quick-turnaround capability for testing x-ray technology development hardware and flight hardware calibrations for suborbital and orbital programs. The SLTF provides a unique suite of x-ray sources and detectors for a wide variety of x-ray tests.

X-Ray Cryogenic Facility (XRCF):

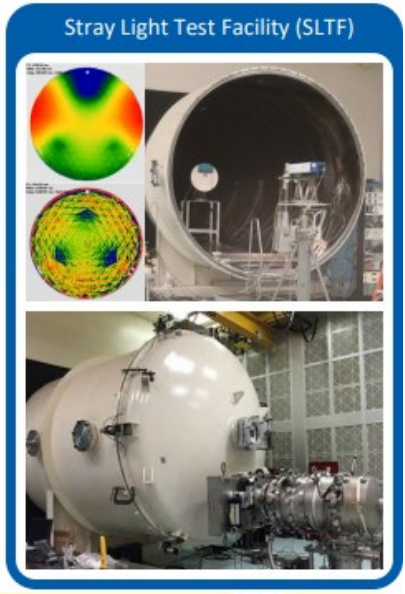
- MSFC's XRCF is an adaptable space environment simulation facility and the world's largest x-ray optical test facility including 4 ft cryogenic chamber, 4 ft pre-conditioning chamber, containment evaluation and monitoring chamber and ISO 6 and ISO 7 clean rooms.

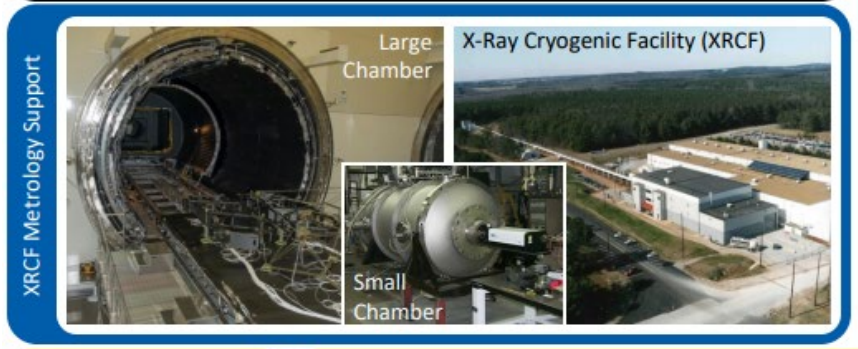
Optics Metrology and Testing:

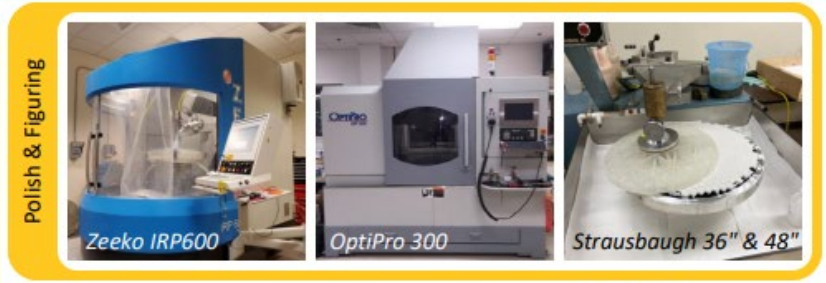
- ***MSFC is the sole domestic source for high-energy, full-shell X-ray (Wolter Type-I) replicated mirrors***
- Extensive metrology capability including interferometry, various CMMs, contact profilometers, 3D scanners.
- Optical surface characterization at ambient and at cryogenic temperatures.
- Optical sensor characterization in thermal vacuum environments.
- 100 m long EUV – X-ray vacuum beamline for rapid turn-around testing.



Systems Design & Analysis
Environmental Test & Metrology
Optical Fabrication & Assembly







Natural Environments

Terrestrial & Planetary Environments

Across All Phases of Flight

- Extensive expertise characterizing surface and atmospheric (aloft) environments:
  - Winds, temperature, humidity, pressure, lightning, density, precipitation, radiant energy, aerosols, sea state, sea surface temperature
- Terrestrial design environments are documented in the Cross Program Design Specification for Natural Environments (DSNE), SLS-SPEC-159
  - SLS, MPCV/Orion, EGS, HLS

Typical Support Functions

- Database development for engineering assessments
  - Prelaunch, Ascent, Descent and Post flight
- Lunar lighting and other planetary surface and atmospheric characterization
- Atmospheric weather launch constraint analyses
- Day-of-Launch trajectory optimization operations
- Planetary engineering-level atmospheric models (Global Reference Atmospheric Models – GRAM) widely used for high fidelity flight dynamic simulations of launch, entry, descent, landing, aero-capture and aero-braking.
  - Earth, Mars, Venus, Titan, Neptune, Jupiter
- Certification of meteorological instrumentation
- Participation in verification of proper use of required environments
- Engagement with other government agencies and private industry

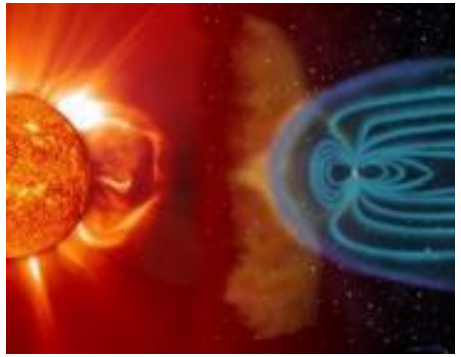
Space Environments

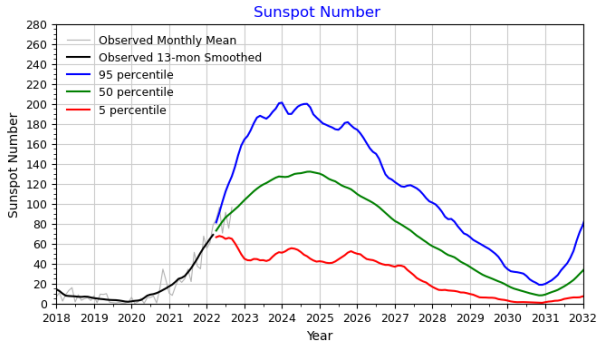
Across All Phases of Flight

- Extensive expertise characterizing environments:
  - ionizing radiation, meteoroids, plasma, spacecraft charging, natural thermal, lunar surface (regolith, ejecta, etc.), and atmospheric environments

Typical Support Functions

- Near-Earth design environments are documented in the Cross Program Design Specification for Natural Environments (DSNE), SLS-SPEC-159
  - ISS, SLS, Orion, Gateway, Human Landing Systems, and Exploration EVA.
- Integrated vehicle and vehicle docking spacecraft charging analyses
- Mission specific radiation environment characterization
- Radiation transport analysis.
- Support test plan development for environment equivalency
- Space weather operational constraint analyses
- Participation in verification of proper use of required environments
- Integrated vehicle spacecraft charging simulation using Nascap-2k
- Meteor shower forecasting (Meteoroid Environment Office)
- Long range solar forecasts, updated monthly, to support ISS re-boost planning
- Ground based Space Environment Monitoring to support Low Earth Orbit tracking and incursion detection





Systems Engineering and Integration (SE&I) Capabilities

Core Systems Engineering Principles

- Systems and Enterprise Level Thinking
- Large, Small and Technical Development Life Cycles
- Capability Engineering
- Critical Thinking
- Complex Systems Modeling and Analysis
- Managing Change
- Flexible and Tailored Approaches
- Balance Cost, Schedule and Risk

Technical Competencies

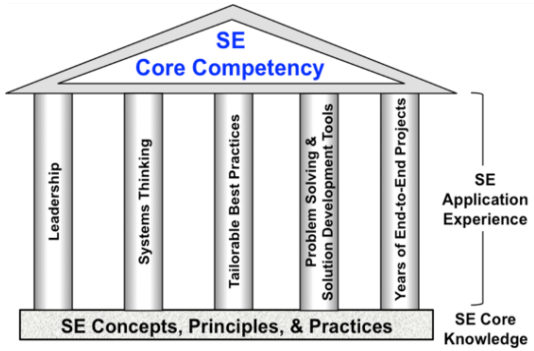
- Concepts and Functions
- Requirements Definition & Management
- Systems Architecting
- Technical Leadership
- Integration
- Interfaces
- Verification and Validation
- Systems Analysis

Systems Engineering Management

- Planning, Monitoring, and Control
- Technical Reviews
- Decision Management
- Enterprise Integration
- Digital and Model Based Engineering
- Integration, Assembly & Test
- Operations and Sustainment
- Configuration and Data Management

Specialty Engineering

- Mass Properties Analysis
- Imagery Analysis
- Human Systems/Human Factors Engineering & Analysis
- Modeling and Simulation
- Logistics and Supportability
- Ground Operations
- Software Systems Engineering



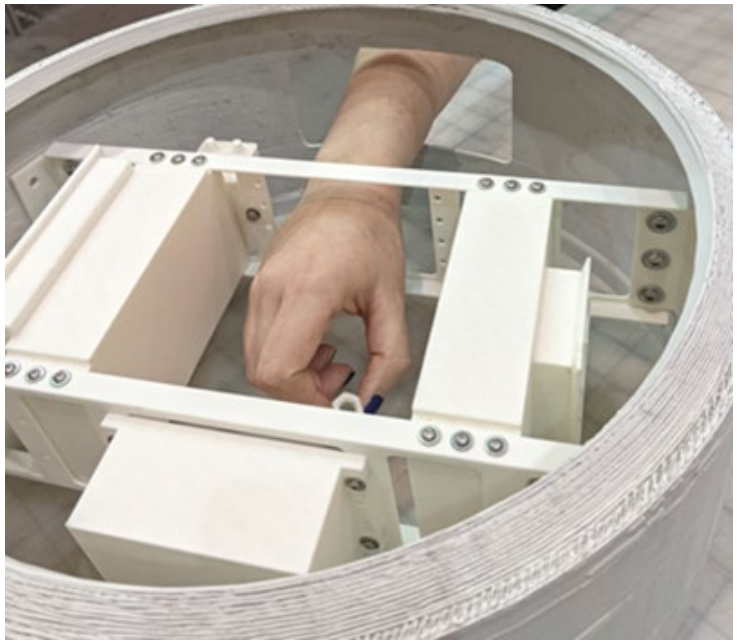
*We provide broad capabilities that enable <u>complex, cross-disciplinary technical integration</u> for the **SUCCESS** of the Customer.*

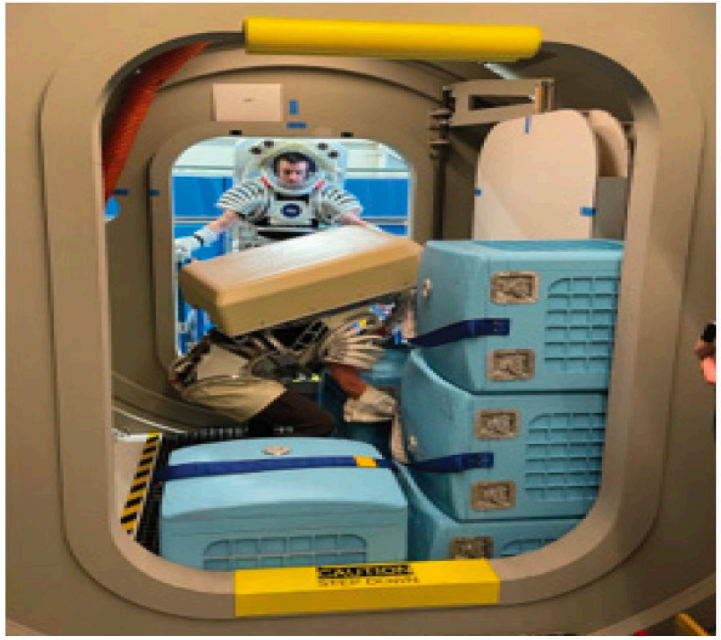
SE&I Capabilities: Human Systems Integration & Engineering

The Human Systems Integration & Engineering (HSIE) expertise at Marshall Space Flight Center brings a wide depth of experience in producing physical mockups and virtual environments of concepts and designs introduced for design evaluation through CAD models, requirements development, physical mockups, and virtual models. Marshall's HSIE can provide support for commercial destination mockups, design evaluations, and human factors engineering (HFE) analysis.

SLS Assessments with Participants within Various Anthropometric Ranges

MSFC maintains subject matter expertise for flight and ground system human factors studies and analyses. This has included high-fidelity full-scale mockups for part-task analysis and physical assessments of designs.





Utilization of Habitat Mockups to Test

SE&I Capabilities: Integrated System Health Management & Automation

Products

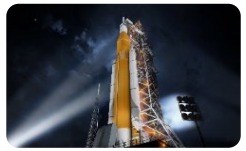
•MISSION MANAGEMENT •FAULT MANAGEMENT •ALGORITHM DESIGN, DEVELOPMENT, AND TESTING •INTEGRATED MISSION/CREW TIMELINES •CONTINGENCY PLANNING •cFS LIMIT CHECKER CODE •AUTOMATED TOOL DEVELOPMENT •OFF-NOMINAL ANALYSIS •MISSION PLANNING & ANALYSIS

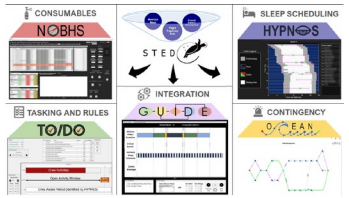
Tools

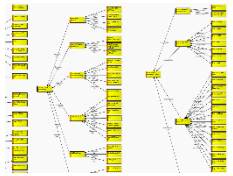
•TEST & IMPLEMENTATION TOOLS SUITE
•STATE ANALYSIS MODEL (SAM)
•SUITE OF TIMELINE EVALUATION AND DEVELOPMENT ENVIRONMENT (STEDE) •SYSTEM HEALTH, AUTONOMY, AND REDUNDANCY CONTROL LAB •NUMERICAL ABORT

Projects

•SPACE LAUNCH SYSTEM / ARTEMIS •MARS ASCENT VEHICLE •HUMAN LANDING SYSTEM •LUNAR TERRAIN VEHICLE •MOON TO MARS • SOLAR SAIL •GATEWAY

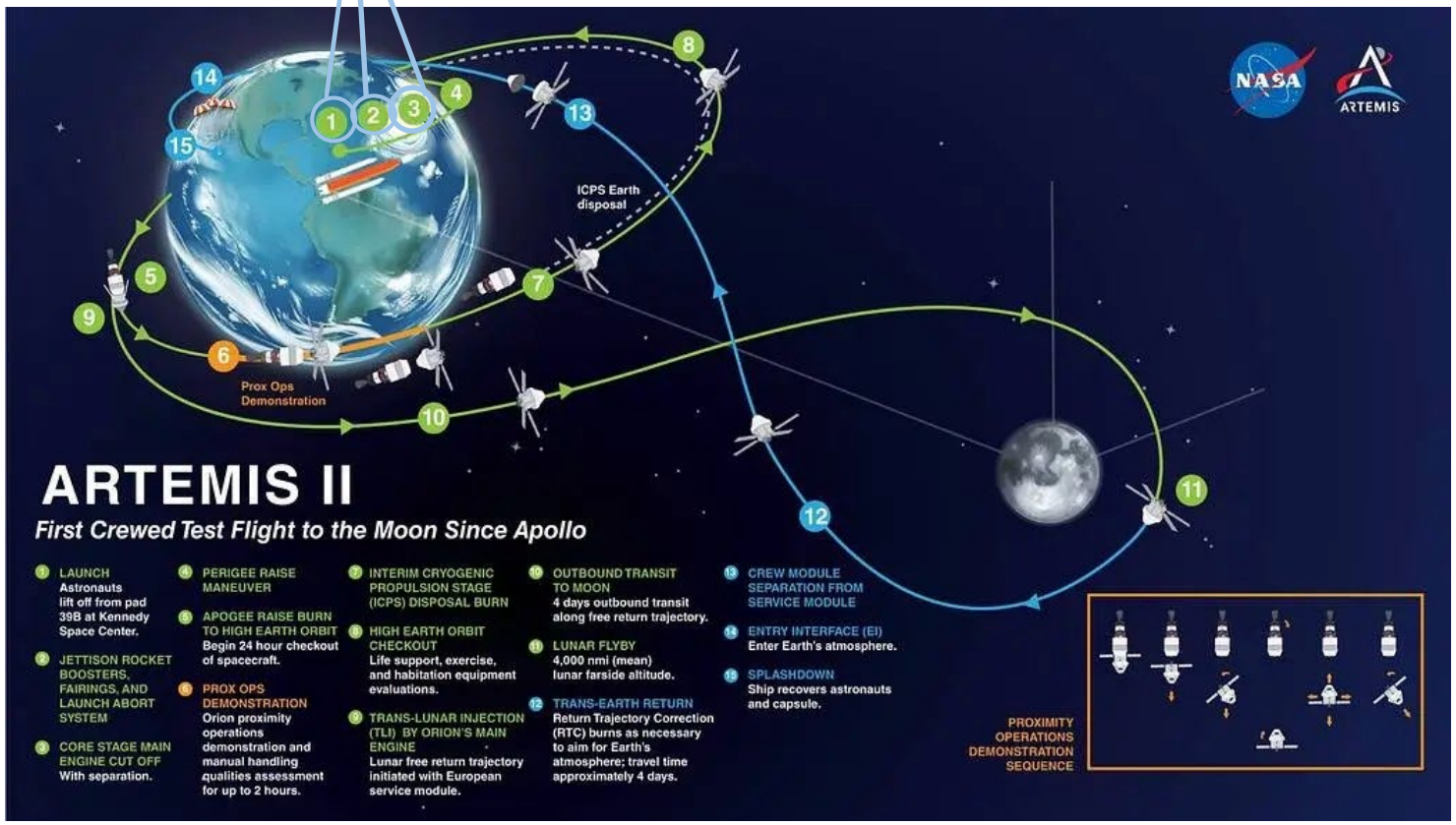






SAM

M&FM Critical Involvement



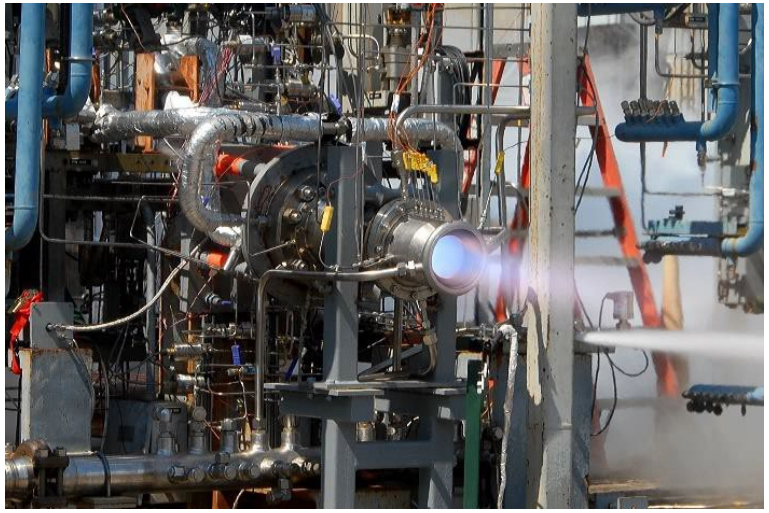
What is Mission & Fault Management (M&FM)?

Designing and integrating functions for the autonomous, nominal operation of a space vehicle, its elements and subsystems in accordance with the planned mission profile and timeline, along with the integration of its elements and subsystems related to the mission, crew, and its timeline. Also, developing fault/failure determination and response functions, Redundancy Management, Caution and Warning notifications, Safing actions, and Crew aborts.

MARSHALL SPACE FLIGHT CENTER

Specialized Test Capabilities: Propulsion Test Laboratory

Test Stand 115: small to medium scale combustion devices, subscale engine systems, chamber and nozzle material tests



Test Stand 116: high pressure engine systems, injectors, preburners, turbopumps, combustion chambers, igniters, seals, bearings, valves, engine subsystems, and small solids

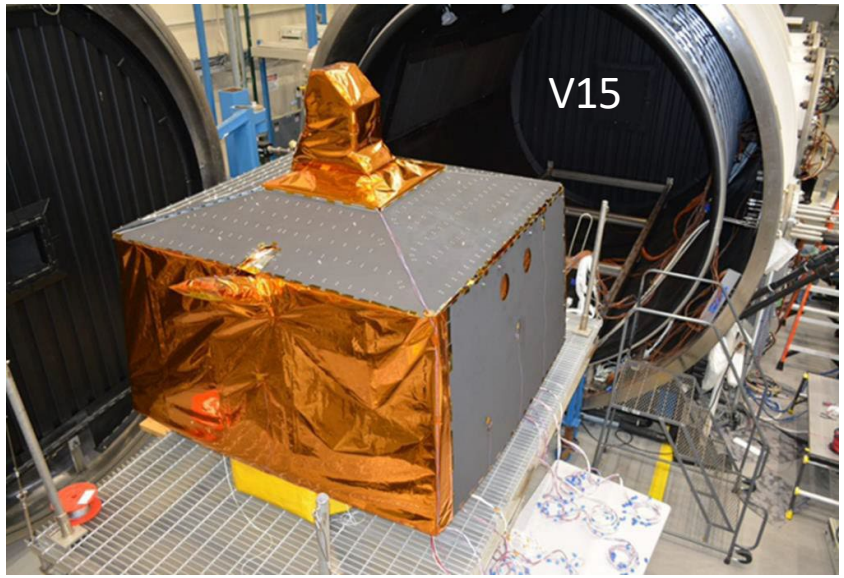
Test Stand 300: simulates ascent launch profiles and deep space vacuum for cryogenic fluid management; Testing includes loading cryofuels and managing in-space, full-scale propulsion systems, cryogenic subsystems, super insulated LH2 tanks

Hot Gas Test Facility: hydrogen/air combustion-driven environmental test facility capable of generating flow speeds up to Mach 4, convective heating rates from 4 to 50 Btu/ft2-s, and radiant heating rates up to 30 Btu/ft2-s in a 16-in × 16-in × 40-in test section

Solid Propulsion Test Facility: solids up to 100,000 lbf vertically and 172,000 lbf horizontally as well as Hydrogen Peroxide test articles

Specialized Test Capabilities: Environmental Test Facilities

12 Thermal Vacuum Chambers of varying size:
2 ft diameter x 2.5 ft
up to 20 ft diameter x 28 ft



- **Thermal-Humidity-Altitude Testing**: Environmental simulations of extreme temperatures, humidity, and high-altitude pressures
- **Life-Cycle Testing**: simulate decades of hardware performance in space
- **Optical Cleanliness Thermal Vacuum Bakeout**: stringent certifications of optical cleanliness used on sensitive hardware such as telescopes
- **Launch Simulation Testing**: simulate rapid pressure changes during launch and re-entry
- **Vacuum Bakeout**: for protecting contamination-sensitive hardware

Specialized Test Capabilities: Structural Strength Testing

SLS Engine Section Stand

Self-Reacting Cube

Test of Large and Small Structures

Compression

Tension

Torsion

Shear

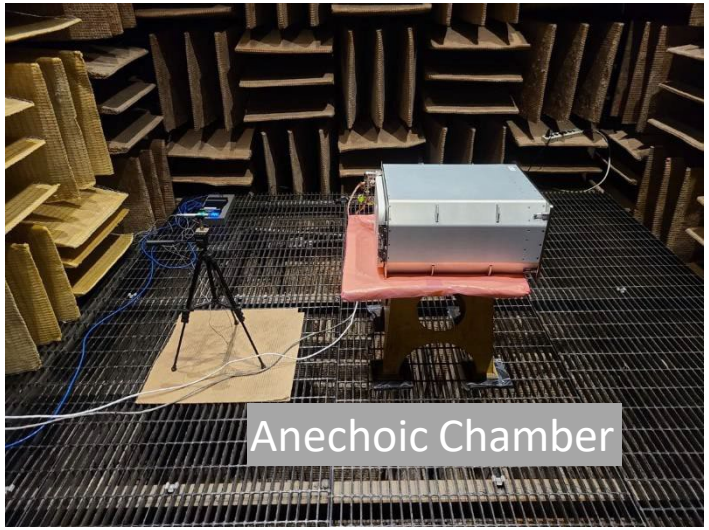
Traditional and non-contacting measurement options

Heat and Cryo Conditioning

Large channel count data acquisition system

SLS Hydrogen Stand

Specialized Test Capabilities : Structural Dynamics Testing


Anechoic Chamber

Acoustic testing using air-driven acoustic horn or speakers

Vibroacoustic Transmissibility testing

Development, Qualification, & Acceptance Vibration Testing

Separation System Testing

Reverberant Chamber

Vibration Lab

Shaker, Mechanical, Pneumatic, & Pyrotechnic Shock Testing

Modal testing at MSFC or customer site

Dynamic troubleshooting

Fluid slosh testing

Numerous input excitation options

Pneumatic Shock Machine

Traditional and non- contacting optical measurement options

Large channel count data acquisition system

Specialized Test Capabilities : Hypersonic Research, Development and Test

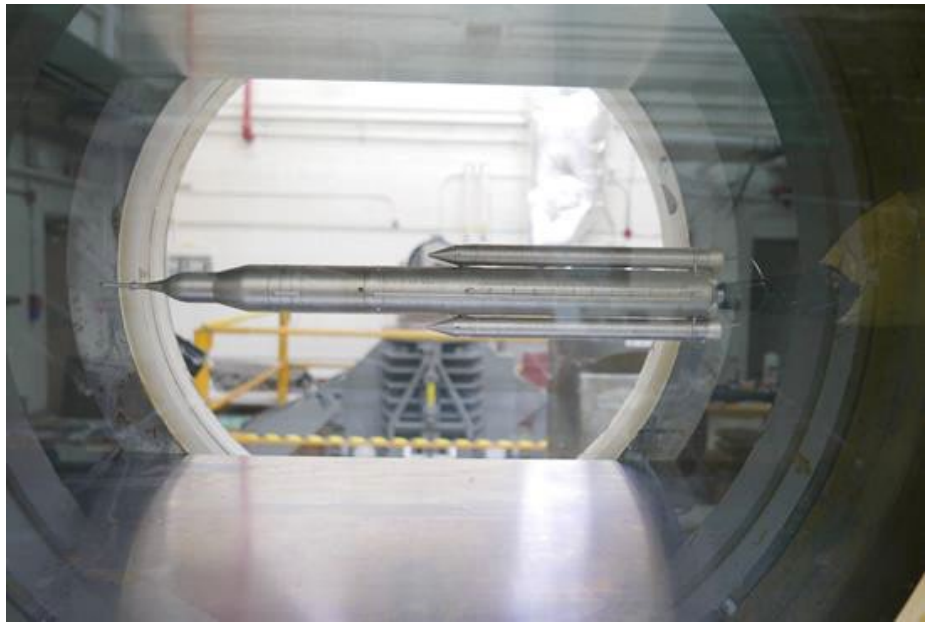
NASA has been involved with hypersonic work since the 1950s. Through highly successful programs including the Mercury, Gemini, Apollo, and Space Shuttle missions, NASA has developed deep expertise in hypersonic flight phenomena and operational experience with hypersonic vehicles.

Marshall Space Flight Center offers industry partners access to national-level test and analysis capabilities, leveraging decades of institutional knowledge to support collaborative hypersonic development programs. Our facility is equipped to handle sensitive and classified projects, enabling partnerships with industry, academia, and other government agencies on advanced hypersonic technologies.

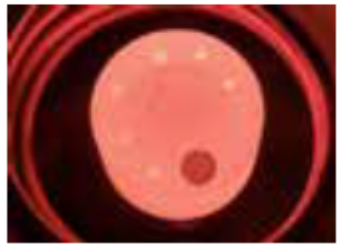
Hyper-Thermal Test Facility-Arc Jet

***MSFC Aerodynamic Research Facility**: Low-cost test alternative for early development of aerospace systems - subsonic/transonic/supersonic - speeds to Mach 6*

SLS Model In Wind Tunnel



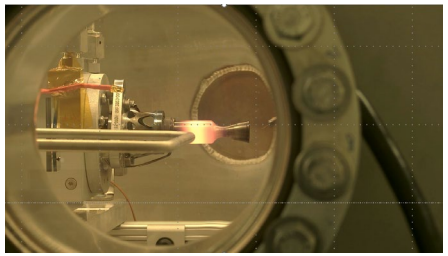
MSFC (ITF) Combined Effects Particle Impact Test Facility (CEPITF)

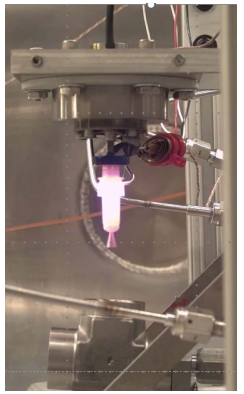
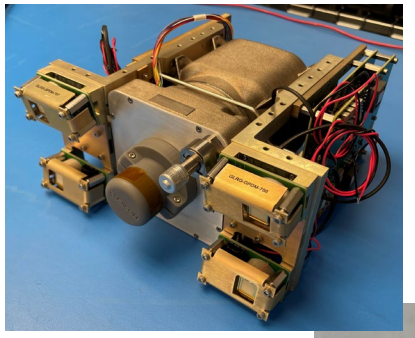
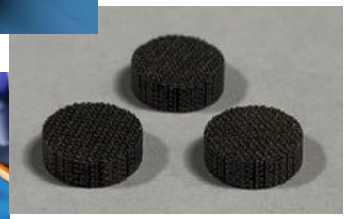
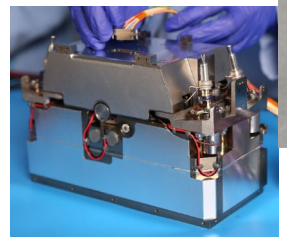


Plasma Torch Test Facility

Propulsion Technologies – Advanced Propellants Team

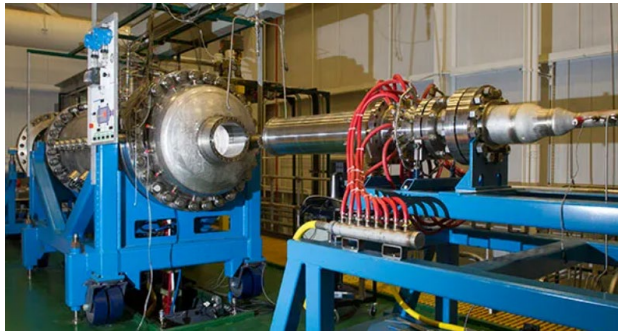
- **What we do:**
  - Mature advanced propellants, i**ncluding storable green propellants, from formulation through flight-qualified technologies** ready for spaceflight applications
  - **Provide flight propulsion system development, integration, ground processing, and operations**
  - **Design, build, and test thrusters and feed systems** for CubeSats, small spacecraft, and larger missions
  - Establish **propellant compatibility and safety protocols** – materials screening, chemistry evaluation, and handling procedures
  - Provide **integrated thermal / structural modeling, simulation, and testing** at MSFC.
  - **Collaborate across government, commercial, and academia** to standardize data, test methods, and flight-readiness criteria for advanced propellants and propulsion systems
  - Conduct **subsystem performance assessments** and **integrated propulsion–avionics–structures test & verification**
- **In-house Capabilities:**
  - **Propellant formulation & testing labs** – catalyst screening, high-throughput chemical thruster hot-fire, and high-vacuum system testing
  - **Thruster and feed-system test stands** – vacuum chambers with altitude simulation, high-speed diagnostics, and calibrated flow / leak measurement
  - **Materials compatibility & long-term storage evaluation** – systematic test protocols for metals, elastomers, coatings, and additive-manufactured parts
  - **Performance modeling & mission analysis** – validated tools for thruster sizing, propellant mass estimation, and system trades
  - **Engineering support for technology transition** – safety documentation, test data packages, and flight-certification pathways

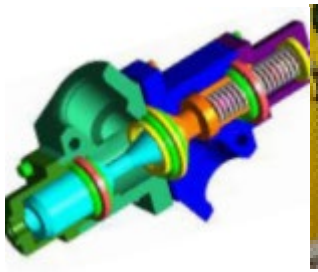


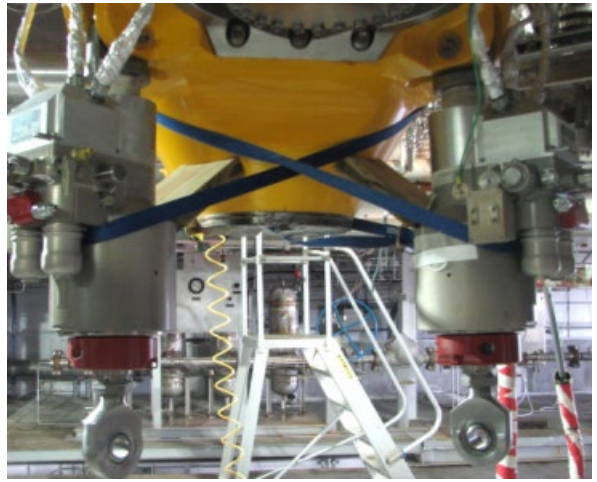





Propulsion: System and Component Test Capabilities

- **Cutting edge testing capabilities and extensive test facilities are available for supporting propulsion system testing and development in Marshall Space Flight Center's Propulsion Research and Development Laboratory and Component Development Area**
- **Propulsion Research Development Lab**
  - Vacuum chambers equipped for testing and characterizing in space thruster systems
  - Collocated with thrust vector control systems simulation and test facility
  - State of the art cryogenic fluid management component and system level testing
  - Capabilities for testing of green propellant thrusters and components under ambient and vacuum conditions
- **Component Development Area - Specialized Facility**
  - Rapid turn-around testing and evaluation
  - High risk technology assessment, fabrication, and development
  - Hardware investigations, inspections, anomaly trouble-shooting
  - Real-time valve modification and assessment
  - Multiple fluids supported, high pressure, cryogenic and high temperatures
  - Environmental chamber, two blast-proof test cells, hydrostatic test chamber
  - Helium mass spectrometer for leak detection, acoustic leak testing

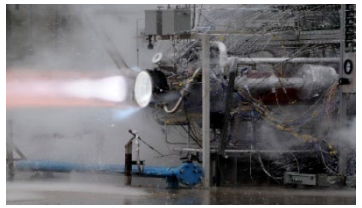


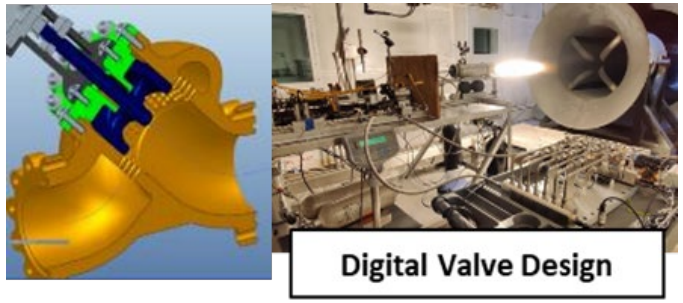


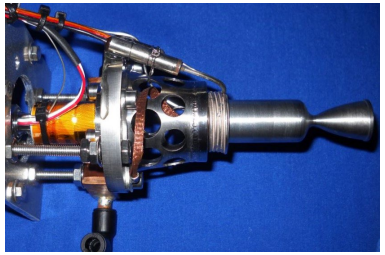


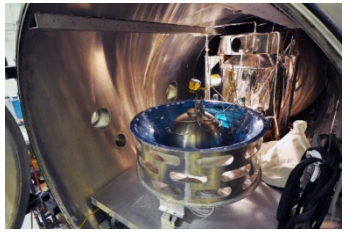
Propulsion: Spacecraft & Launch Vehicle Systems and Component Expertise

- **Design, development, and technology maturation for all types of propulsion system hardware**
  - Component design and technology development expertise includes turbomachinery, combustion devices, lines, valves, ducts, and thrust vector control
  - Industry leader in RDRE development – In house design, build and test capabilities
  - Electric pump expertise for spaceflight applications
- **Storable propulsion systems and components**
  - Experience with the design and analysis of pressure-fed and pump-fed storable propulsion systems.
  - Operational experience with in-space thruster systems
- **Advanced propulsion systems design and development**
  - Advanced chemical propulsion technologies: Cryogenic Fluid Management (CFM) & Green Propellant
  - Radiation modeling and mitigation for various programs examining shielding requirements and risks
  - CFM concept development, prototyping, evaluation and analysis of components & systems for spacecraft



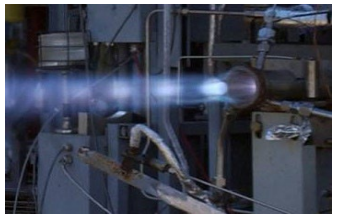


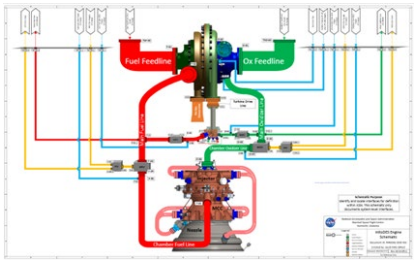


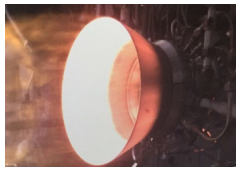


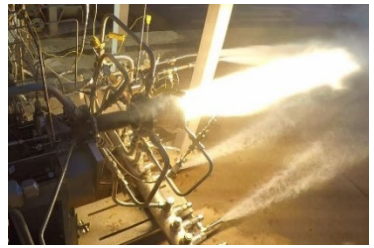
Propulsion: System Integration, Modeling, & Advanced Manufacturing

- **In-house design, development, and test expertise for spacecraft systems**
  - Propulsion feed system, pressurization, tanks, and propellant management for storable propellants and CFM technologies.
  - Component technology development for these systems including ducts, valves, actuators, CFM technologies, etc.
- **Pioneers in the use of advanced manufacturing (AM) techniques for propulsion applications**
  - Large material database of AM material properties – tensile, fatigue and thermophysical
  - Developed, hot fire tested & transferred to industry the technology to additively manufacture copper combustion chambers
  - Developing advanced manufacturing techniques for spacecraft components to dramatically shorten the manufacturing time of hardware in test today



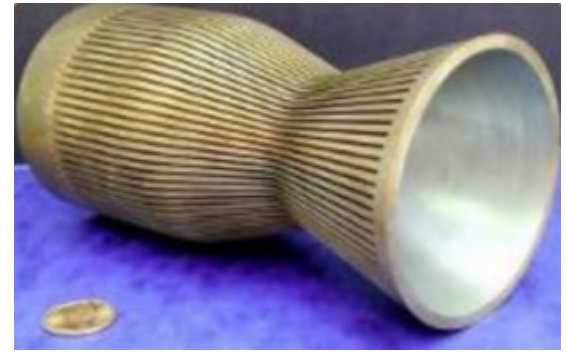


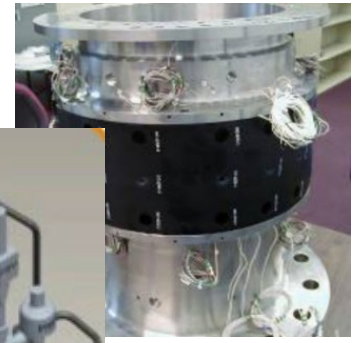


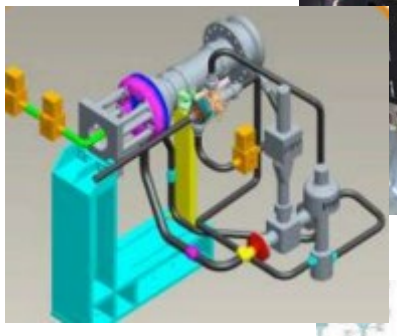


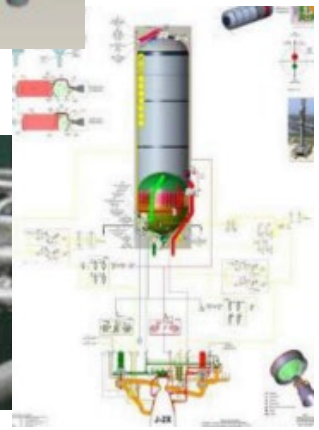
Propulsion: Detailed Design and Modeling Capabilities

- **Detailed design support from component-level to integrated system level. This includes the ability to integrate across or work within a vendor/partner's preferred design system.**
  - Detailed CAD models, drawings, design optimization, model-based designs, geometric dimensioning & tolerancing and tolerance stack-ups
  - Focus applications: combustion devices, turbomachinery, seal testing, lander, propulsion systems, cryogenic systems, engine systems, and main propulsion systems
  - Design integration and collaboration with outside vendors, academia, or other NASA groups (integrate their design or work within their integration effort)
- **In-house spacecraft engine system modeling capabilities and tools**
  - Systems engineering of spacecraft vehicle engines
  - Spacecraft engine design, integration, and test development
  - Spacecraft engine health & performance data assessment
  - Rocket engine transient simulation (ROCETS) usage and development for Steady-state and transient fluid flow analysis Engine System Power Balances, stand alone components and engine start up and shut down



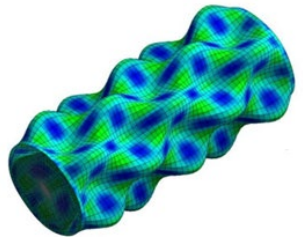
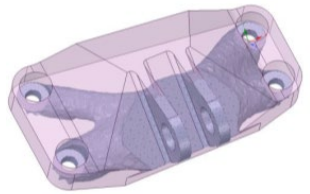
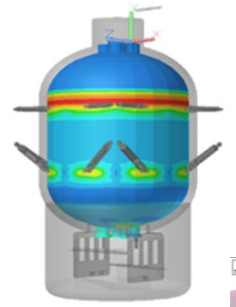
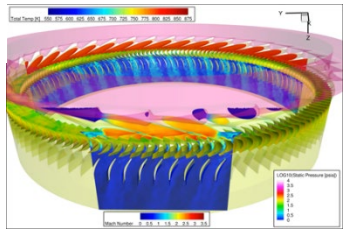
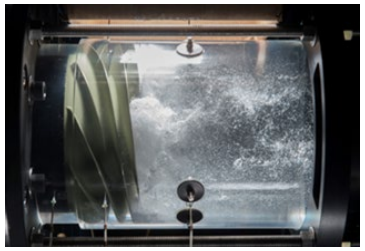
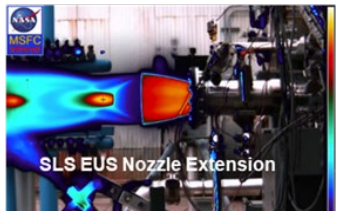






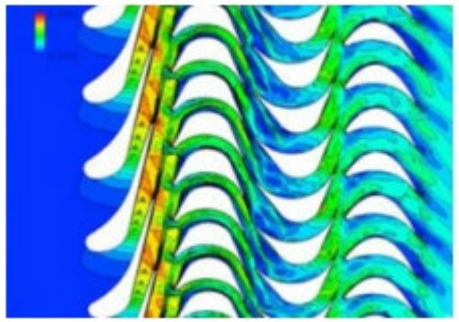
Propulsion: Detailed Analysis and Supporting Testing Capabilities

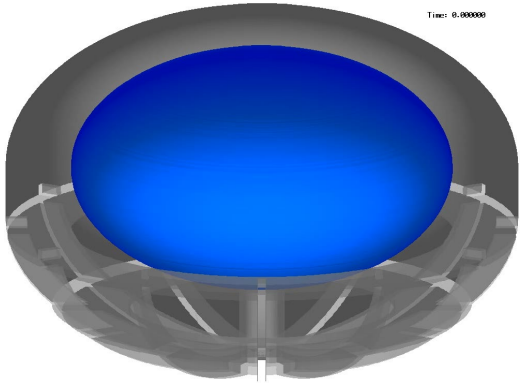
- **Detailed analytical capabilities include stress, thermal, loads, rotordynamics, structural dynamics, computational fluid dynamics, acoustics and vibroacoustics, steady-state performance, and transient modeling**
- **Detailed design and structural analysis capabilities from initial concept through manufacturing and testing**
  - Expertise in component dynamics, loads, and environments analysis; high-frequency dynamic response assessments
  - Fluid-structure interaction and thermal-structural and nonlinear assessments
  - High speed vibration data analysis: engine testing, rotating machinery, high speed data acquisition and health management
- **Thermal design expertise, thermal/fluids analysis support from propulsion component/subsystem level to integrated propulsion/lander level.**
  - Expertise in thermal analysis of propulsion system combustion devices, turbomachinery, engine systems and integration to vehicle system
  - Tools include Thermal Desktop, MSC.PATRAN/SINDA, ANSYS, FlowCAD
  - Expertise in Cryogenic Fluid Management (CFM) and derivation of environmental heat loads (i.e., orbital, planetary surface, induced)
  - Thermal/structural isolation design, cryogenic tank, cryo/ullage temperature and boiloff predictions.

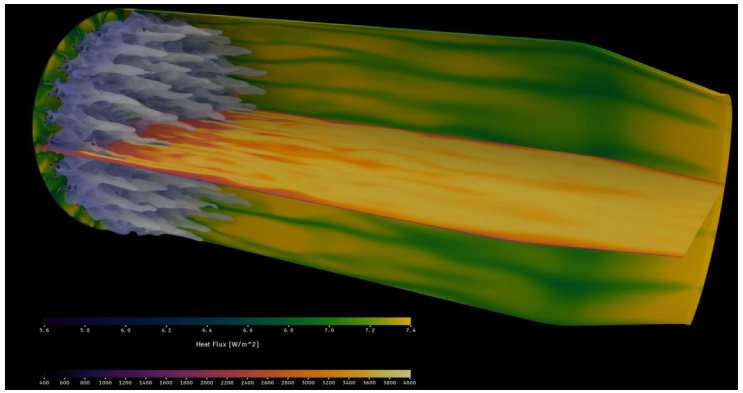







Propulsion: Detailed Analysis and Supporting Testing Capabilities

- **Expertise wide range of Computational Fluid Dynamics (CFD) applications using LOCI family of CFD tools developed by NASA and partners, across all stages of spacecraft hardware design, development and operational lifecycle**
  - Time-accurate engine component CFD analysis including turbomachinery, valves, ducts, combustion and both cryo. and storable propellant cavitation models
  - LOCI-STREAM-VOF: Unique, industry-leading, CFM simulation capabilities for propellant tank slosh, fill/drain and propellant transfer operations
  - Loci-Boltzmann: Coupled continuum-rarified flow solver for in-space plume expansion/impingement loads on vehicle body
- **Unique unsteady fluid dynamic characterization and high-frequency data acquisition test capabilities**
  - Combustion stability, POGO assessment, acoustics and Flow-Induced Vibration (FIV) characterization
  - Inducer waterflow test facility, turbine test facility and nozzle test facility
  - Digital Image Capture technology for vibration characterization
  - State-of-the-Art advanced thermography technology

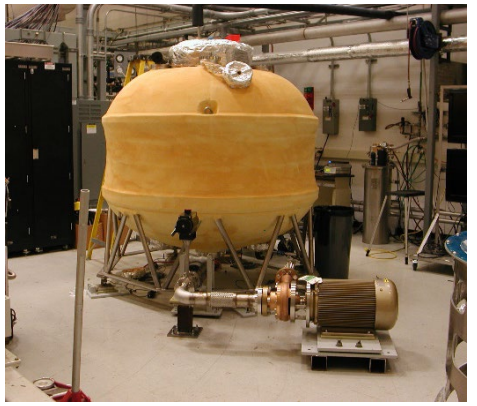


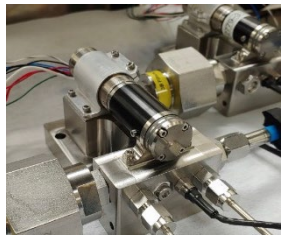




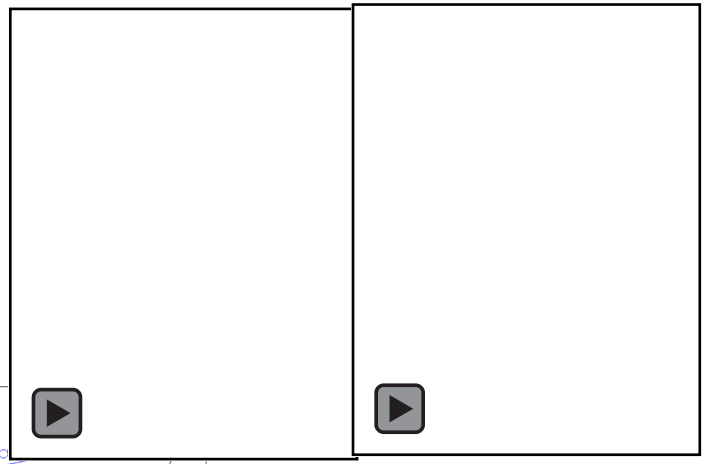
Propulsion: Technologies – In-Space Propellant Transfer Capabilities

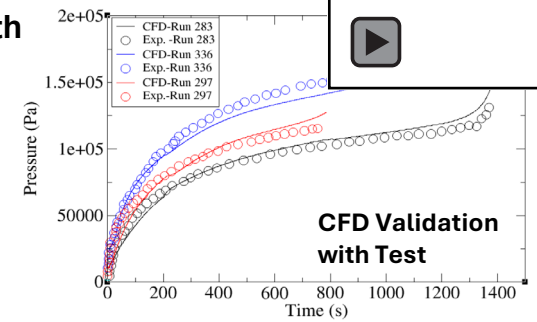
- **Significant testing experience and capabilities in propellant transfer and CFM related technologies**
  - Cryocooler testing and In-house technology development (NORA project)
  - Propellant transfer operations and mass gauging
  - Tank thermal / pressure control and liquefaction technique
  - Sensors, propellant acquisition and pressurization systems
  - Thermodynamic venting and cryogenic propellant mixing
- **Unique time-accurate fluid dynamic modeling capabilities related to orbital propellant transfer and CFM operations**
  - Generalized Fluid System Simulation Program (GFSSP) – Nodal-Network model tool developed at MSFC capable of simulating propellant loading and transfer over a wide range of propellants and conditions
  - LOCI-STREAM-VOF CFD solver software – Sharp interface CFD model capable of accurately modeling fluid-gas interface physics and thermodynamics
    - **Validated for no-vent tank filling and constant pressure tank draining modeling with change at gas-liquid interface for cryogenic propellants**
    - **Modeling of spray bars and thermodynamic conditioning of propellant**
    - **Ground-based acceleration and microgravity modeling capabilities**





Observed Dynamics: No-vent Filling (CFD: STREAM-VoF)



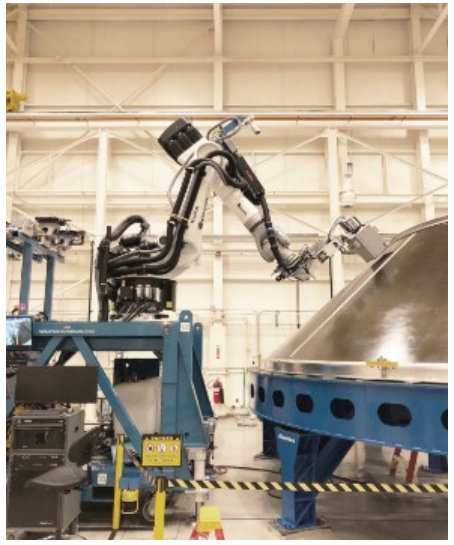


CFD Validation with Test

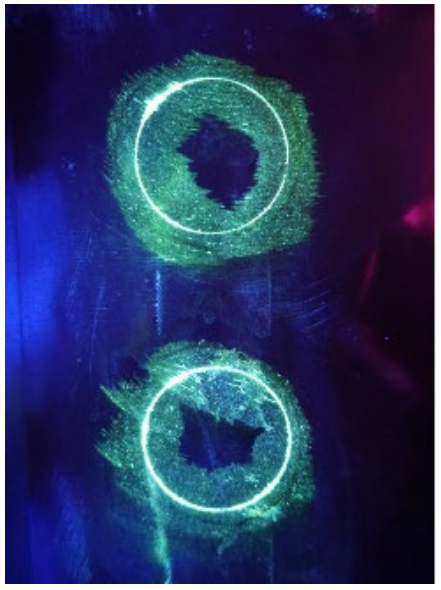
Materials & Processes Laboratory: NDE, Damage Tolerance & Fracture Control

Nondestructive Evaluation

- Ensures quality and integrity of materials, components, and systems without causing damage
- Supports all stages of product development: research, requirements, technique development, demonstration, and production integration
- Develops verification, validation, and certification programs for advanced Nondestructive Evaluation (NDE) methods
- Engages with academia, industry, and interagency stakeholders
- Inspection Methods include:
  - Ultrasonic (Conventional, Phased Array, Air Coupled, Electromagnetic)
  - Magnetic Particle & Liquid Penetrant
  - Radiography (Film & Digital)
  - Eddy Current, Thermography, Computed Tomography (High Energy, Large Format, Microfocus)
  - Shearography, Microwave, Acoustic Emission, Bond Testing



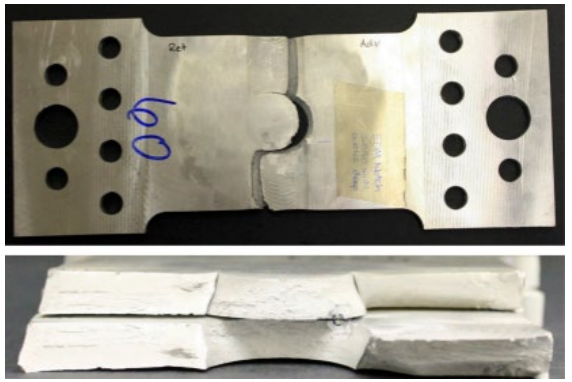
Large-scale automated inspection



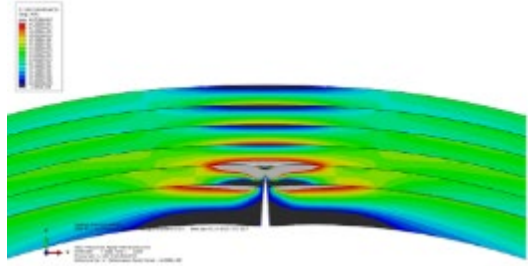
Fluorescent dye penetrant testing

Damage Tolerance & Fracture Control

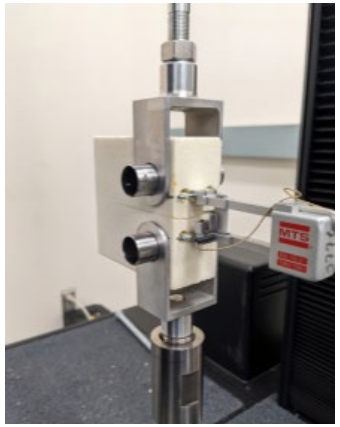
- Decades of experience supporting NASA flagship programs (e.g., Space Shuttle, SLS, HLS)
- Expertise in fracture control, damage tolerance, and risk mitigation
- Supports material selection, inspection methodology, and structural integrity assessments
- Key contributor to NASA Fracture Control Standard (NASA-STD-5019)
- Capabilities Include:
  - Fracture mechanics analysis (metallic & composite)
  - Finite element & boundary element modeling
  - Customized experimental techniques for fracture toughness & fatigue crack growth
  - Development of test matrices, cut plans, and post-test analysis
  - Additive manufacturing part certification support
  - Software tools for material test data analysis



Friction stir weld pull plug test



Layered structure fracture model



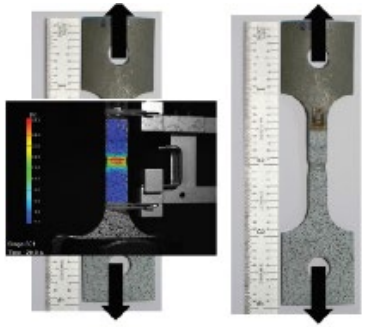
Compact Tension Test

Materials & Processes Laboratory: Materials Test, Chemistry and Contamination Control

Mechanical Testing

Conducts a wide variety of tests to characterize the behavior of materials under various conditions in various environments. This team can perform standard American Society for Testing and Materials (ASTM) test methods in addition to nonstandard mechanical tests in air, nitrogen, hydrogen, and methane from elevated temperatures to cryogenic temperatures. Engineers are available to provide guidance in test plan development and execution, specimen design, and cut-plan design. Skilled machinists on site are also available for manufacturing test samples using computer numerical controlled (CNC) and electrical discharge machining (EDM) tools

Tension Test Specimen in Liquid Hydrogen



Digital Image Correlation on Tensile Specimen

Chemistry

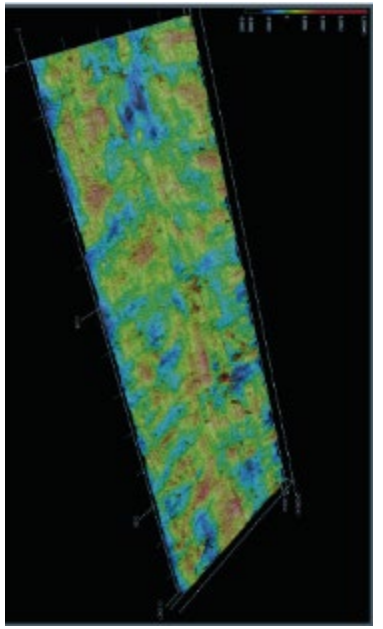
The chemistry lab is a fully equipped analytical chemistry laboratory that stands ready to perform any chemical analysis needed for NASA's exploration missions. Testing can range from verifying materials meet NASA specifications to identifying unknown materials or chemicals. Standard ASTM methods can be used, or custom testing methods can be developed to meet a customer's needs.

Ultraviolet-visual light spectroscopy to identify unknown chemical species

Tribology/Metrology

Conducts tests and analyses to characterize surface interactions in materials subjected to relative motion. Tribology is the science and technology of friction, lubrication, and wear. This includes natural and biological systems as well as common applications such as gears and bearings. Engineers in the Tribology laboratory can design experiments and perform tests to determine the tribological properties of materials and lubricants used in both standard and esoteric mechanical assemblies, simulating a wide variety of environmental conditions including extreme terrestrial environments and other low-vacuum operating conditions.

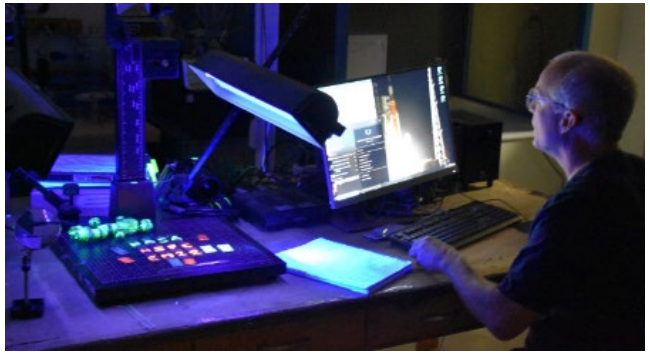
Pin on Disk Testing



Topography Map

Contamination Control

Provides contamination control support from project inception up to launch. Activities include development and implementation of contamination control plans, validation of clean work areas and clean rooms, and identification and remediation of contaminants on space flight hardware. The team actively evaluates novel, green-cleaning technologies to ensure NASA's ability to meet cleaning specifications despite the phase out of previously used, environmentally harmful solvents.

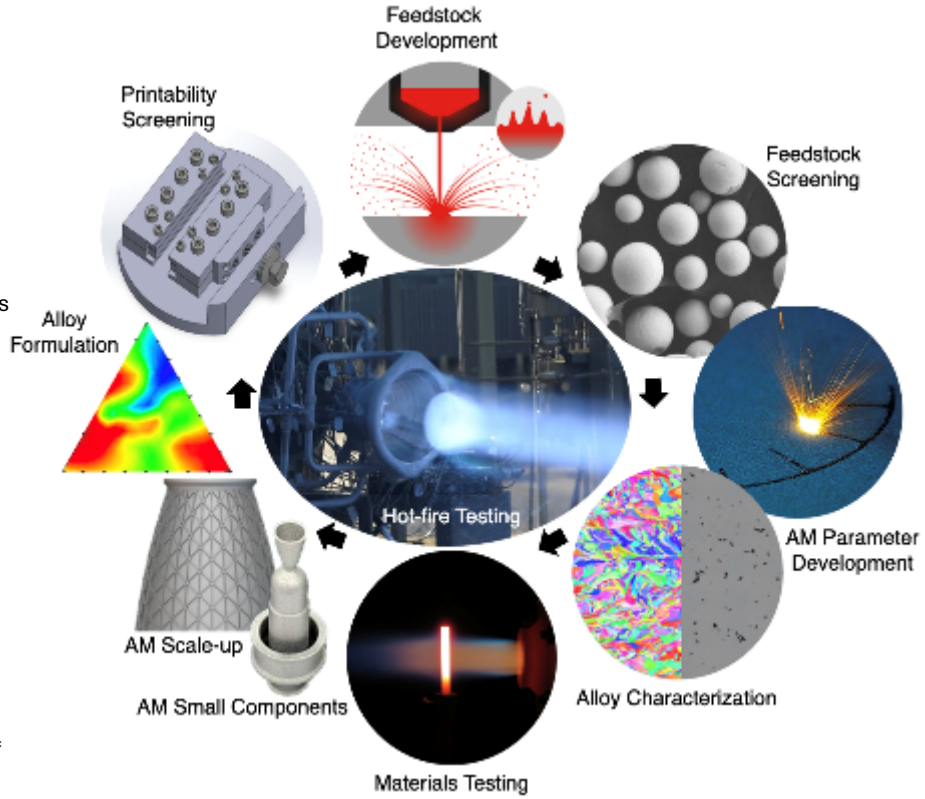


Ultraviolet light inspection of parts to verify complete removal of contaminants

Materials & Processes Laboratory: Materials Characterization and AM Alloy Development Capabilities

Material Diagnostics/Characterization

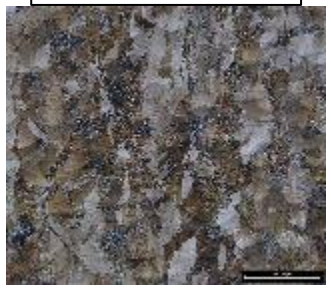
- Sample preparation
- Sectioning, Mounting, Polishing, and Etching
- Microscopy Services
  - Optical microscopy, 3D stereomicroscopy, scanning electron microscopy, laser confocal microscopy
  - Analysis of all material types (metallic, ceramic, composite, geological, and biological)
  - High-resolution images of surfaces and internal microstructures can be captured at magnification up to 1,000,000X
- Bulk Chemical and Crystallographic Analysis
- Energy and Wavelength Dispersive x-ray Spectroscopy (EDS and WDS in SEM)
- X-ray Diffraction (XRD)
- Electron Backscatter Diffraction (EBSD) in SEM
- Surface Analysis Services
  - Electron Spectroscopy for Chemical Analysis (ESCA)
- Metallic Materials Analysis
- RoboMet Automated Serial Sectioning
  - Automated serial polishing and microscopy for 3D evaluation of materials



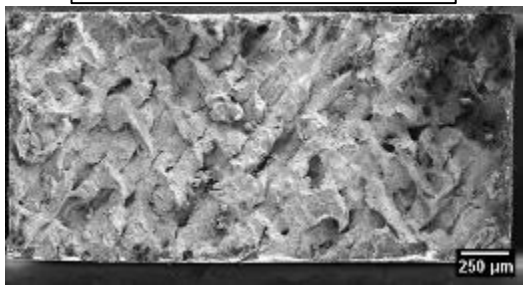
Additive Manufacturing Alloy Development

- Lab designed for rapid alloy development in AM and evaluation to reduce development cycle and cost to go from initial formulation to upscaling
- Capabilities:
  - ThermoCalc software for model-based approach
  - Arc melter furnace for initial ingot forming
  - High temperature furnaces both air and vacuum with capability to 2200°C
  - AMAZEMET Ultrasonic Atomizer for powder atomization with high temperature module for refractory alloys
  - EOS M100 L-PBF system for small volume AM parameter development
    - Reduced volume build plate and hopper to lower powder needs for parameter dev to <500g
  - XACT Metal XM200G L-PBF system being installed for newer and slightly larger build volume than EOS M100

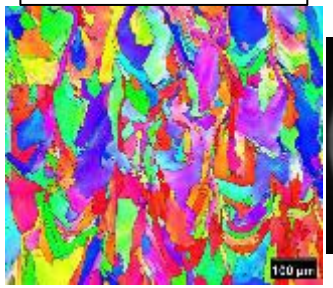
Optical Microscopy for Microstructural Analysis



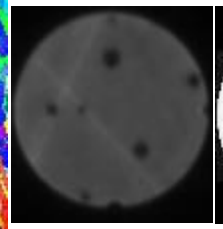
Fractographic Analysis with Optical or Electron Microscopy



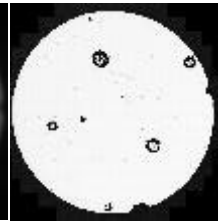
EBSD of AM Materials for Crystallographic Analysis



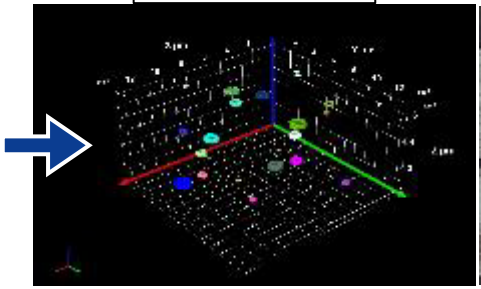
In-Situ Monitoring



RoboMet Slice



3D Defect Segmentation

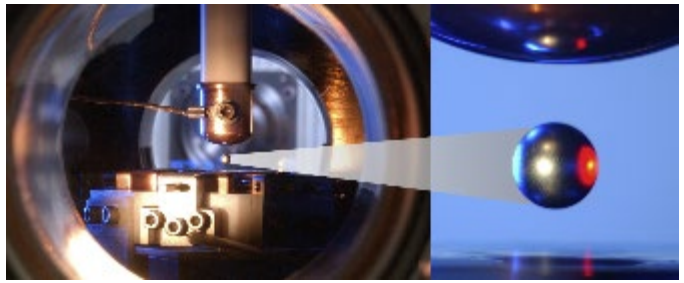


Metallography in aluminum 2219 laser weld

Materials & Processes Laboratory: Microgravity and Fundamental Research

RSD flight hardware integration

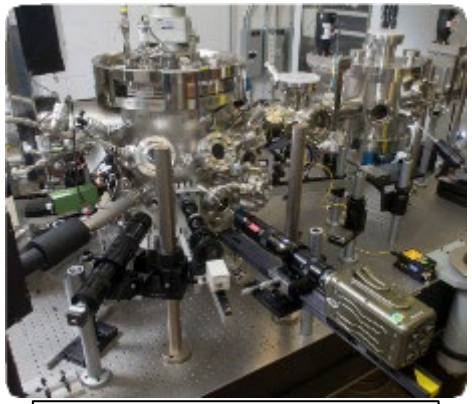
Laser Bending in Vacuum SS 304



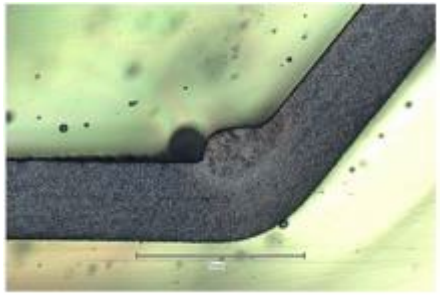
A sample levitated by the MSFC ESL lab

Material Science Fundamental Research

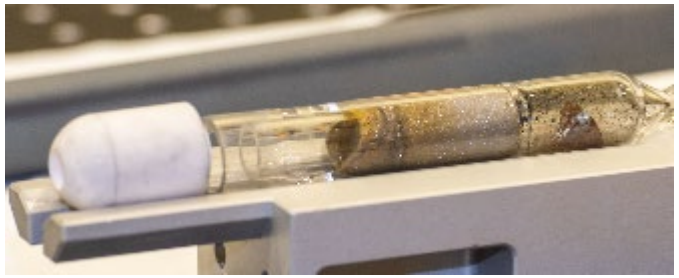
- MSFC provides Subject Matter Expertise and Project Scientist support for biological and physical sciences (BPS) research
- Project Scientists ensure the experiment maturation progresses and aligns to meet the science objectives of the investigation.
  - The project scientist, the principal investigator (PI), and project manager work as partners to ensure project success.
- MSFC currently has a portfolio of over 20 BPS projects
  - Most of which are investigations on ISS
    - Research in a variety of materials science and biophysics areas
      - Solidification
      - Crystal growth
      - Thermophysical properties
      - Nucleation
      - Biofilms formation
  - Also includes ground-based Physical Sciences Informatics (PSI) research
- Integrated Computational Materials Engineering (ICME)
- Electrostatic levitation (ESL) lab provides ground-based support for containerless processing PIs
- In-space Manufacturing research into laser welding informing on suborbital flights being investigated.



Primary Electrostatic Levitator



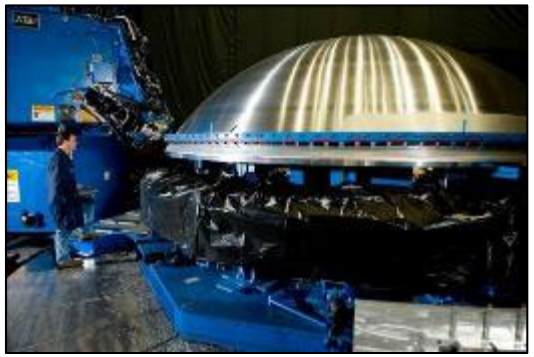
Laser Bending in Vacuum Ti-6V-4Al



Flight sample of ternary compound semiconductor

Materials & Processes Laboratory: Metal Processes & Manufacturing Capabilities

Service Category	Key Equipment	LEO Applications
Large Scale Aerospace Hardware Manufacturing	• Vertical Weld Tool (25’ tall) • Robotic Weld Tool (30’ dia) • Gantry CNC Weld Tool (30’ dia) / CY26 • VPPA Welding Systems	• Habitat module manufacturing • Structural framework manufacturing • Test stand & simulator manufacturing
Advanced Materials Processing	• Arc Melter • Hot Isostatic Presses • Spark Plasma Sintering	• Refractory alloy development • Component densification • Custom alloy production
Environmental Validation	• Stress Corrosion Testing • Salt Fog Chambers • Potentiostat Systems	• Life support system materials • Atmospheric exposure testing • Galvanic compatibility
Heat Treatment	• Vacuum furnaces • Cryogenic treatment • Specialized atmospheres • Hot isostatic pressing • Component stress relief	• Process development • Property optimization • Thermal cycling validation



Materials & Processes Laboratory: Nonmetallic Materials

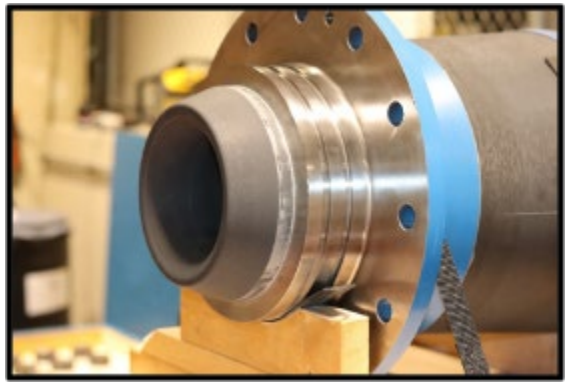
Polymeric Materials Team

MSFC Polymeric Materials Team has world-class expertise and test facilities to conduct nonmetallic material research and qualification. The team develops and qualifies polymer-based materials for spaceflight systems, with focus on cryogenic insulation, paints, primers, coatings, adhesives, seals, ablators, and thermal protection system processing.

- TPS Development Facility: Full range of launch-related TPS M&P development from feasibility to flight hardware. Supports large-scale automated/manual TPS applications (20’ × 27’ × 70’) in a controlled environment.
- TPS Characterization and Test Methods: In-process testing (density, plug pull, reactivity). Expertise and facilities to fabricate test specimens to ASTM and other standards.
- Thermal Vacuum Test: High-fidelity facility exposing TPS to vacuum and heating rates simulating ascent and re-entry.
- Coatings Development: Low-density, low-conductivity coatings with excellent insulation.
    - Coatings Spray Technology Booth
- Polymers Advancement Laboratory, Silicone Bonding Laboratory, Polymer Development Laboratory

Ceramics & Ablative Materials Team

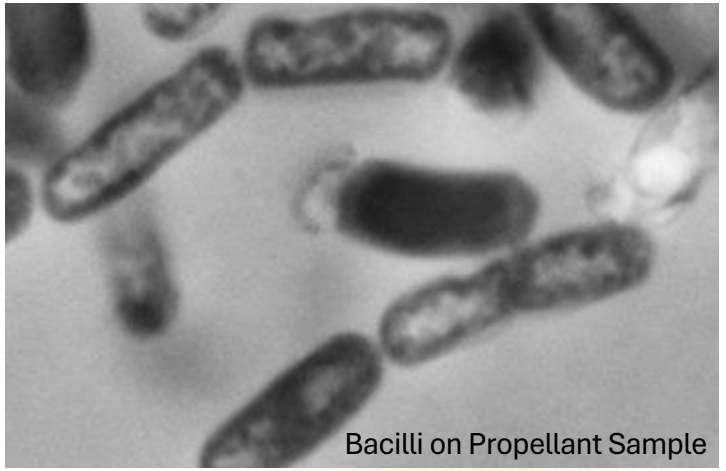
- Subscale Solid Rocket Motor Processing & Manufacturing: Supports development and testing of alternative materials for solid rocket motor systems.
- Plasma Torch Test Facility: Unique ablation facility that simulates erosive flow in solid rocket motor plumes; evaluates material ablation and particle erosion.
- Solid Fuel Torch: Mid-range subscale motor test for material response up to 60 seconds, with custom nozzle configurations.
- 11” Hybrid Rocket Test Motor: intermediate scale test facility for material maturation
- 24” Solid Rocket Test Motor: Large-scale test facility for qualification-level erosion performance and full-scale motor evaluations.
- Rubber Formulation Laboratory: Mixes, compounds, and tests rubber insulation formulations for motors and re-entry systems.
- Rubber Manufacturing Facility: Large-scale rubber processing for motor insulation.
- Analytical Chemistry Laboratory: Characterization of propellants, binders, insulation, and ablatives; techniques include SEM/EDS, GC-MS, FTIR, TGA, DSC.
- Mechanical Testing Laboratory: Strength, creep, stress relaxation, tensile, compression, and shear testing.
- Ceramics Development: High-temperature ceramics for nozzles, adhesives, paints, and structural applications; testing up to 3600°F.
- Extreme-Temperature Carbon- and Ceramic-Matrix Composite Nozzle Extensions for Liquid Rocket Engines.
- Ceramics Additive Manufacturing: New capability currently being established.

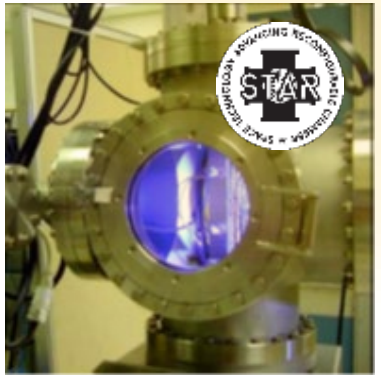


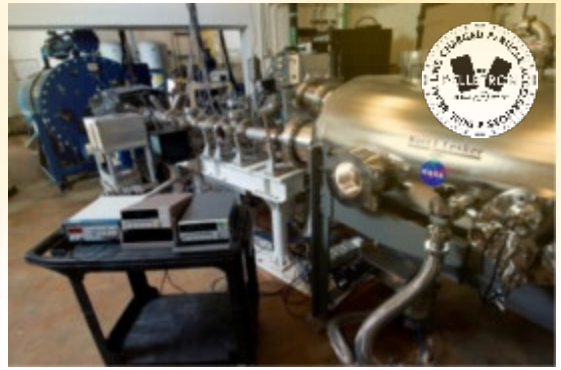
Materials & Processes Laboratory: Space Environmental Effects

- Charged Particle Radiation
  - Pelletron Accelerator : p+, e-
  - Solar Wind Test Facility : p+, e- , UV
  - Strontium-90 Source: e-
  - Electron and Proton Flood Guns
- Ultraviolet (UV) Radiation
  - X-25 Solar Simulators
  - Enhanced Near-UV
  - Combined Near-UV/Vacuum-UV
  - High Intensity Solar Environment Test (HISET)
- Atomic Oxygen
  - Atomic Oxygen Beam Facility (AOBF): 5ev Neutral Beam simulating LEO
- Plasma Interactions
  - Low Earth Orbit (LEO) / Geosynchronous Earth Orbit (GEO)
  - Electric Propulsion/Thruster Plume
- Planetary/Extraterrestrial Environments
  - Lunar Environments Test System (LETS): complete lunar surface environment simulation (p+, e- , UV, Quartz Lamps, Cryogenic shroud, 75 kg lunar simulant)
  - Planetary, Lunar, and Asteroid Natural Environments Testbed (PLANET): 2-meter diameter, 3-meter long chamber designed for high-fidelity planetary surface simulation; Large regolith simulant bed (lunar mare, lunar highlands, Martian simulants available); large lower port for deep drilling and resource extraction studies; High vacuum (10-6 – 10-7 Torr), ambient plasma, or Martian gas atmosphere; Additional environments: low energy electrons and ions, UV, solar illumination, 4-zone LN2 shroud
  - Can be modified to simulate Near Earth Object or Mars environments
- Materials on International Space Station Experiment (MISSE)
  - Decades of on-orbit experimental data & sample preparation expertise
- Impact Testing
  - Hypervelocity Impact Testing
  - Ballistic Impact Testing
  - Weather Encounter Testing – Hydrometeor Impact
- Planetary Protection
  - BSL-2 microbiological laboratory and a clean-room microbial sample library
- High Temperature Emissivity Measurement System
  - Temperature: 600 °C – 2600 °C; 10^{-7} torr vacuum, 0° – 180° incident angles

Impact Testing


Bacilli on Propellant Sample





Materials & Processes Laboratory: Advanced Composites Manufacturing

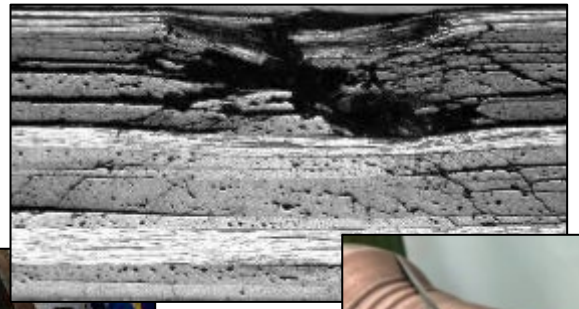
The composites team at MSFC has extensive experience in product development of a wide range of composite structures for a variety of applications. The team provides engineering expertise on a variety of applications and program types, including composites M&P consulting, failure investigations, technology development, sub-scale risk reduction, insight/oversight, and flight hardware production.

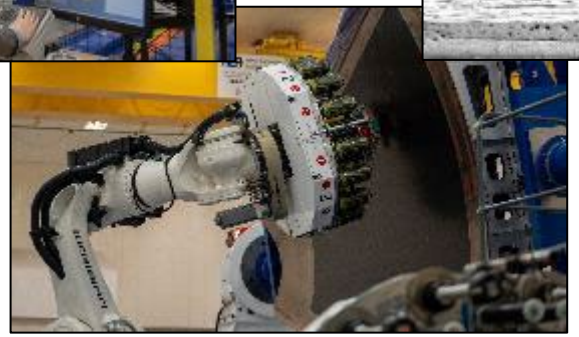
Engineering expertise areas include:

- Flight hardware development and production
- Certification of composite structures
- Manufacturing process development
- Adhesive bonding
- Failure analysis
- Damage and repair
- Specification development
- Assembly & integration

Application expertise areas include:

- Flight vehicle dry structures (up to 27.5 ft diameter)
- Bonded joints
- Lightweight structural jackets for engine nozzles
- Composite cryotank development
- Composite overwrapped pressure vessels (COPVs)
- Thermoplastic development





Facilities & Equipment

Automated fiber placement (AFP)

- 6-axis arm & track with horizontal rotator
- Up to 16 ft diameter & 30 ft long capacity
- ¼" & ½" slit tape capacity – up to 16 tows
- Integrated laser projector

Filament winding

- Two 4-axis winders – capacity up to 4 ft diameter & 15 ft long

Curing

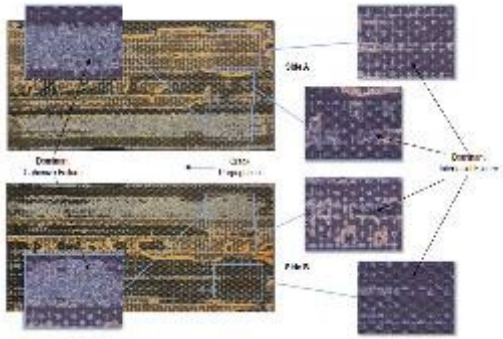
- Autoclaves (diameter x depth)
  - 18' x 23' – up to 350 psi & 400°F
  - 9' x 12' – up to 150 psi & 600°F
  - 4' x 6' – up to 240 psi & 650°F
- Ovens (width x height x depth)
  - 18' x 15' x 35' – up to 600°F
- Hot bonder – up to 400°F

Manufacturing & assembly

- Composite layup facility – 10,000 ft^2 clean work area
- Assembly & integration facility – 5,000 ft^2 class 8 clean room
- 3-axis automated ply cutting table
- Automated atmospheric pressure plasma treatment (APPT)
- Laser tracker

Material diagnostics

- In-situ water contact angle
- Optical microscopy
- Constituent and void content
- In-situ FTIR



Materials & Processes Laboratory : Additive Manufacturing & Digital Solutions

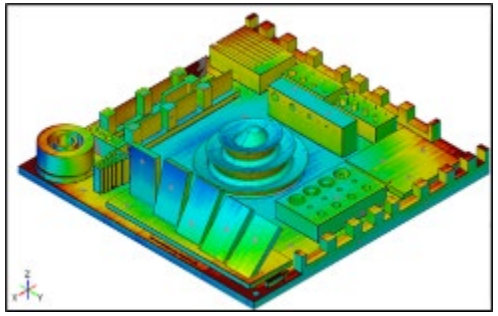
The additive manufacturing and digital solutions team provides engineering expertise for a wide variety of applications, from rapid prototyping to turbomachinery for liquid engine hardware to components for environmental control and life support systems. MSFC led the development of NASA-STD-6030, Additive Manufacturing Requirements for Spaceflight Systems, and has extensive experience working with industry to assist the qualification and certification of components for flight applications. The team also houses capabilities in manufacturing execution planning and in 3D scanning, providing engineering expertise for a variety of digital solutions needs.

Additive manufacturing expertise areas include:

- Certification of additively manufactured components
- Process development and characterization
- Machine parameter development
- Design for additive manufacturing
- Rapid prototyping
- Part production
- Specification development and standards adjudication

3D scanning expertise areas include:

- 3D part inspection
  - As-built inspection
  - Pre & post test evaluation
  - Failure investigation
- Reverse engineering & digital twin model development
- Digital assembly
- Match machining
- Live 3D scan data tracking
- Reverse data projection



Facilities & Equipment

Metal additive systems

- EOS M290 | L-PBF | 250 x 250 x 325 mm
- EOS M100 | L-PBF | 100 ø x 95 mm z
- Concept Laser Xline 2000R | L-PBF | 400 x 800 x 500 mm
- Velo Sapphire | L-PBF | 315 ø x 400 mm z
- DM3D 6-axis robotic arm | LP-DED | 12 ft by 8 ft by 10 ft
- RPMI 222XR | LP-DED | 600 x 600 x 600 mm
- 6-axis Cold Metal Transfer | WAAM | 8 ft x 5 ft x 12 ft
- Additec ElemX | Liquid Metal Jet | 300 x 300 x 120 mm

Polymer additive systems

- 3D Systems Viper | SLA | 254 x 254 x 254 mm
- 3D Systems 5000 | SLA | 508 x 508 x 508 mm
- Stratasys Fortus 900 | FDM | 914 x 609 x 914 mm
- AON M2+ | FDM | 450 x 450 x 565 mm
- Markforged Mark Two | FDM | 320 x 132 x 154 mm

Ceramic additive systems

- 3D Ceram C1000 Flexmatic | SLA | 320 x 320 x 200 mm

Misc. systems

- Concept Laser M1 | L-PBF | 250 x 250 x 250 mm
  - Open source upgrade by Laser Fusion Solutions
  - Processes multiple material systems, including regolith simulant
- Motiv vacuum and dust rated 6-axis arm | LP-DED | 3 ft arm reach
  - Modular end effector (20 kg max)

3D Scanning

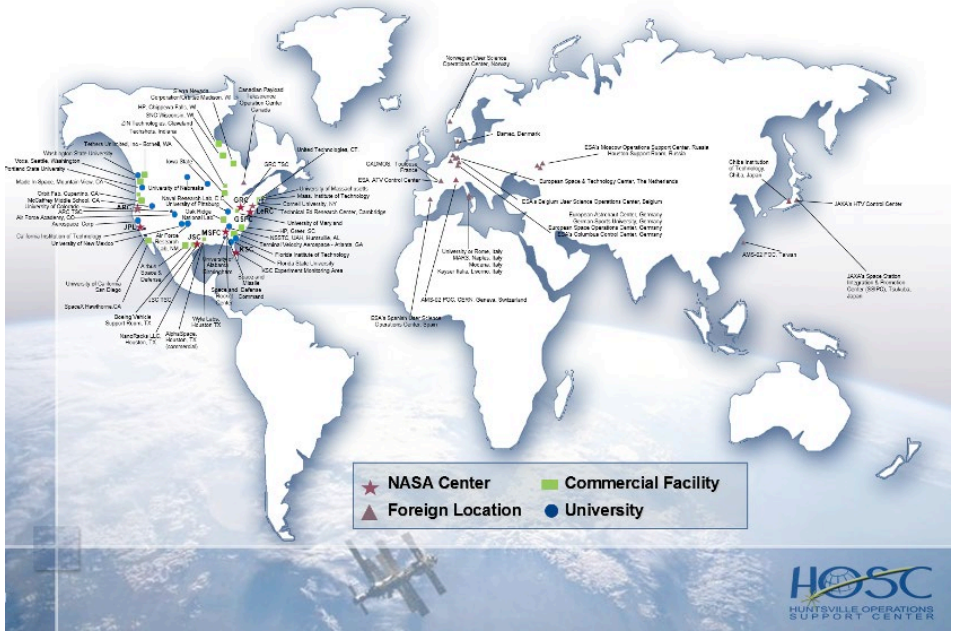
- Zeiss Atos V | Structured Light | 0.25” to 70’ hardware
- Zeiss Atos Q | Structured Light | 0.25” to 70’ hardware
- Zeiss TRITOP | Photogrammetry | 0.25” to 70’ hardware
- Surphaser 410HSX | Lidar | 220’ measurement radius

Payload and Mission Operations Division (PMOD) Overview

PMOD is NASA's premier supplier of science utilization and engineering mission operations services. PMOD enables all mission phases from planning, testing, simulating, prelaunch, and launch, through in-flight operations and post-mission objectives. PMOD's Huntsville Operations Support Center (HOSC) distributed architecture extends operational support globally to meet varying and unique mission criteria.

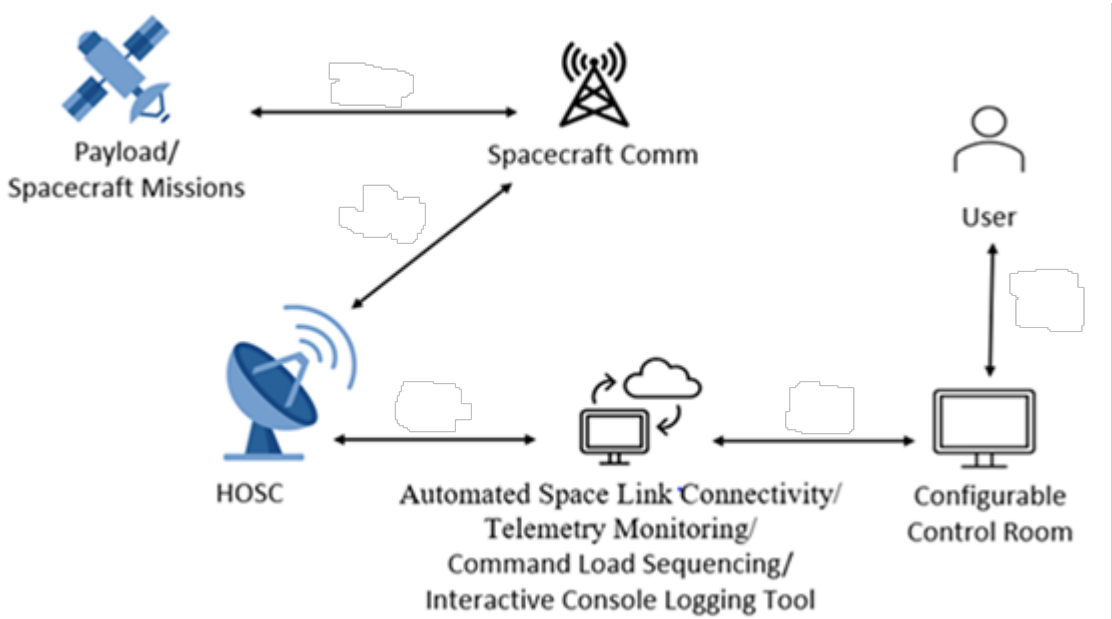
- HOSC secure mission systems provide turnkey connectivity to space-based assets from remote facilities or through onsite configurable control rooms.
- PMOD houses experienced flight controllers and engineers for subject matter expert consultation and/or direct mission support and delivers a wide variety of products including flight controller training, ground station software, autonomous operations tools, planning and procedure development, and more.

Enabling remote support around the world on a daily basis!



PMOD: Huntsville Operations Support Center (HOSC) Overview

- Operations support structure for NASA Mission Directorates as well as Commercial Entities
- Configurable infrastructure enables customizable and demand driven support, promoting shared costs
  - ➢ Configurable control rooms to support multi-mission requirements
  - ➢ Backup Control Center (BCC) capability
- Data storage and distribution infrastructure for multi-mission support
  - ➢ Distributed architecture allows for remote commanding, telemetry, voice, and video to provide flexibility to users
- Autonomous solutions to reduce human-in-the-loop requirements for operations concepts
- Facilities to support flight controller training and test facility interface



Commercial PL Ops

Commercial Crew

ISS Utilization Ops

Artemis Utilization Ops

Artemis BCC

HLS Eng Support

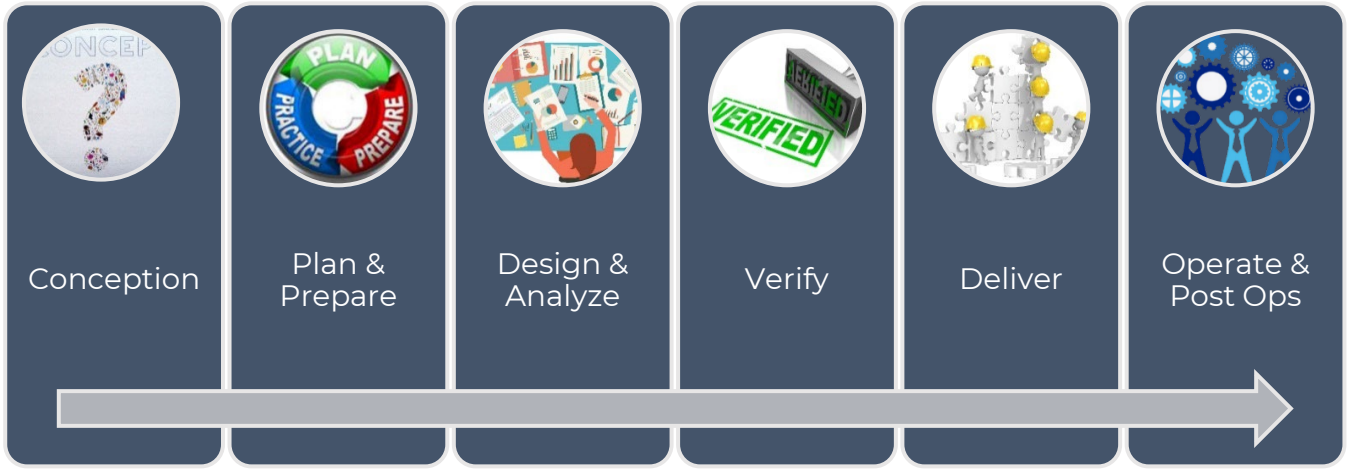
SLS Eng Support

SLS Limited Rights

ISS Back up Control

PMOD: What We Do – Mission Operations Integration and Planning

- Support operational concepts and project management for both crewed and uncrewed missions
- Develop mission documentation to include interface requirements documents, control documents, project protection plans, and regulatory filings
- Translate mission requirements into operational plans and procedures
- Manage development and verification schedules to ensure flight readiness of operational products
- Build plans to integrate competing priorities and resource demands
- Develop, test, and implement tools to maximize operational efficiency



End-to-End Integration to Ensure Operational Readiness!

PMOD: What We Do – Mission Operations Training

Tailored Training for Unique Mission Requirements!

Flight and Ground Controller Training and Certification

- Develop flight control concepts to meet specific mission needs
- Develop training courses, tools, techniques, and certification plans to produce competencies necessary for mission success

Remote Science User, Ground System Interface, and NASA Tools Training

- Provide customer training to enable successful operations and allow support from around the globe

XR (Virtual and Augmented Reality) Training Assessment Simulation Model Development

- Blending digital elements with virtual & physical training environments to enhance spatial awareness & practical engagement

PMOD: What We Do – Mission Operations Execution

Mission Execution

- Prioritize safety of the crew, vehicle and utilization hardware while maximizing scientific return
- Support dynamic replanning, adjusting to unexpected changes, to achieve mission objectives
- Execute a wide range of mission support, including ISS utilization operations, free-flyer missions, systems engineering operations, and science activities on the lunar surface and beyond

Configurable Control Rooms

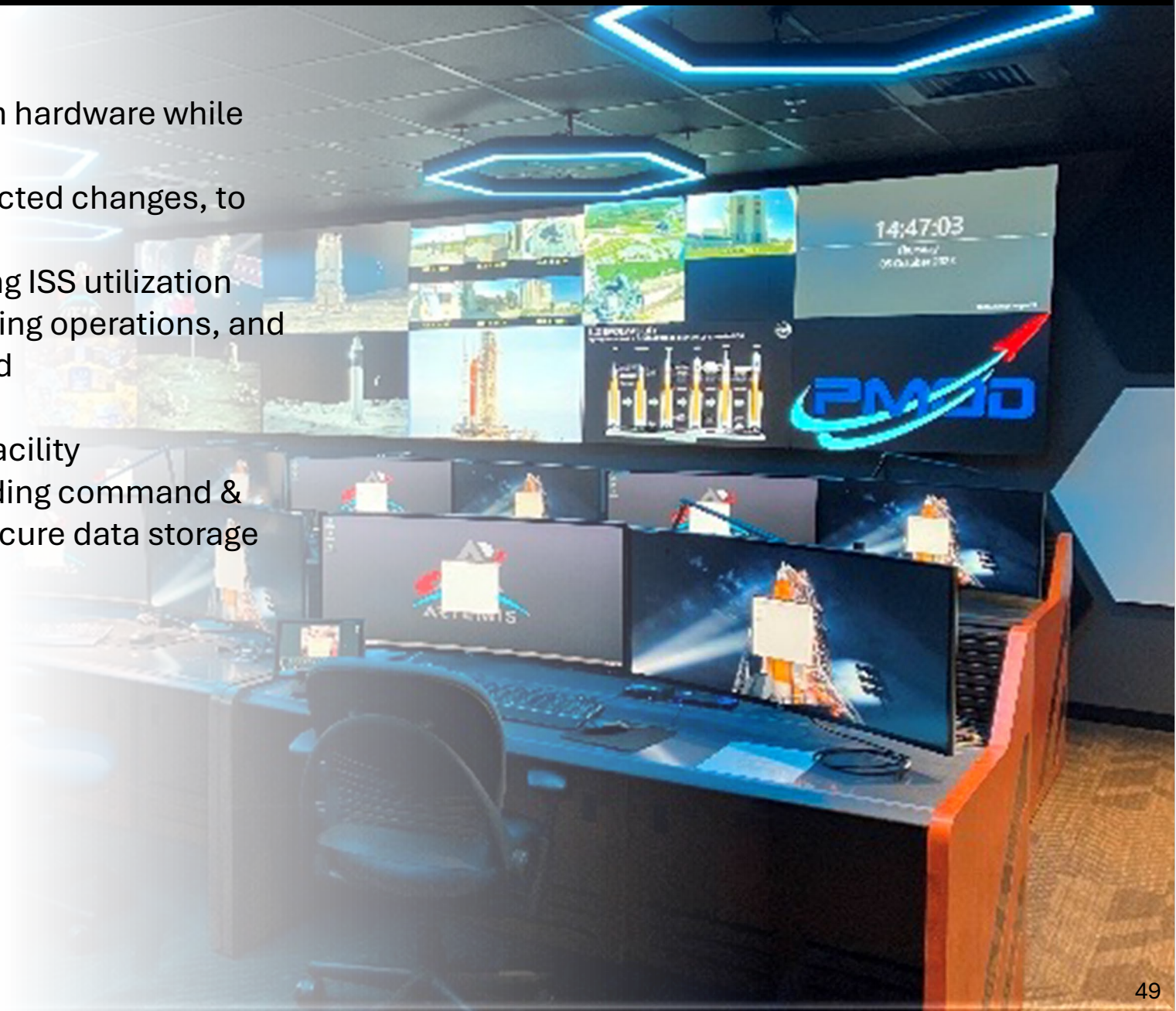
- 24x7, multi-mission ground systems operations facility
- Turnkey operations to meet mission needs, including command & telemetry, voice & video communications, and secure data storage

Customized Solutions & Ops Support Products

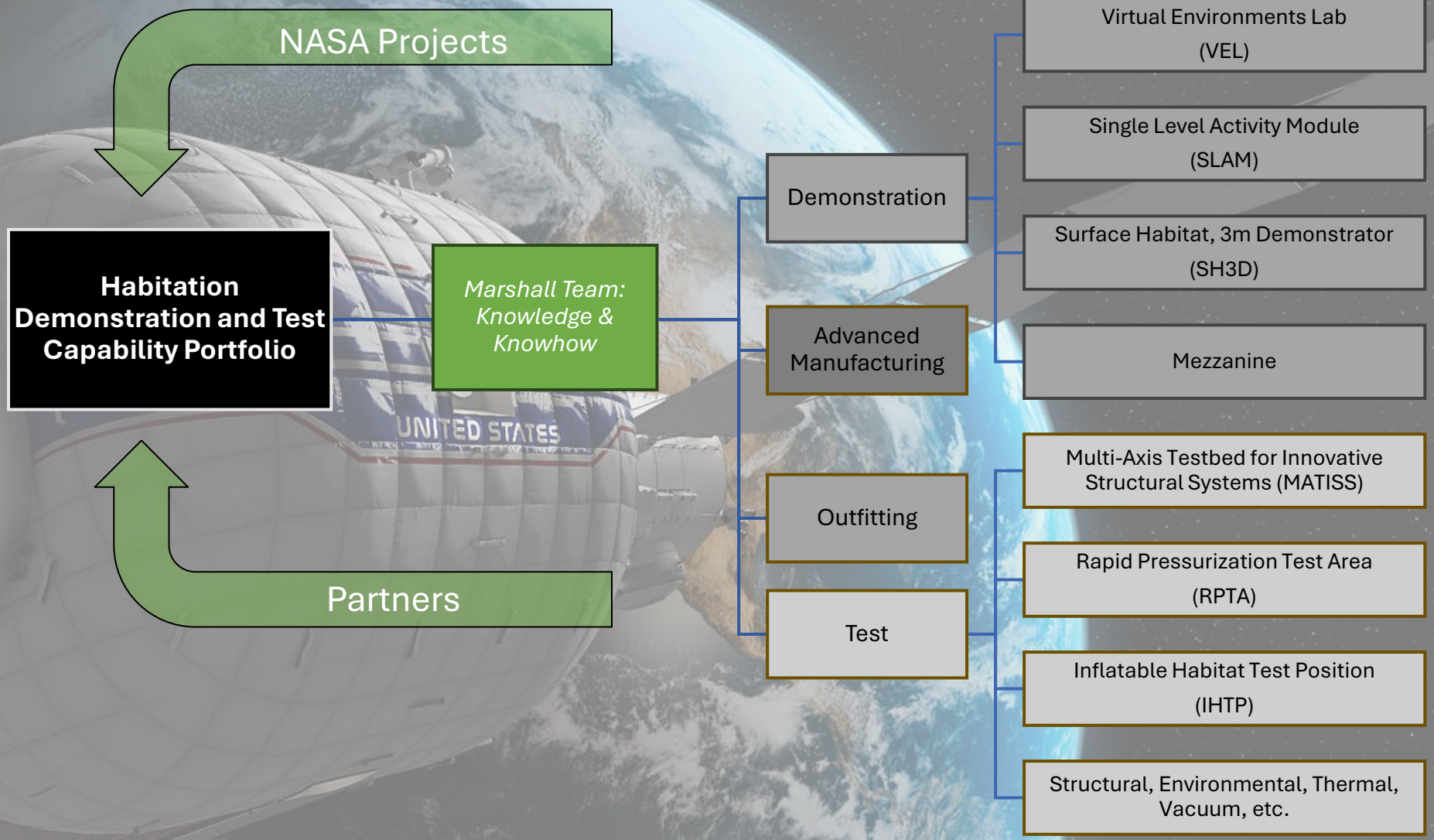
- Improve mission efficiency & adaptability
- Automated Space Link Connectivity
- Command Load Sequencing
- Interactive console logging

Autonomous Systems

- Services that reduce need for human-in-the-loop
- Modifiable operations support products



Habitation Systems: Marshall Habitation Capability Overview



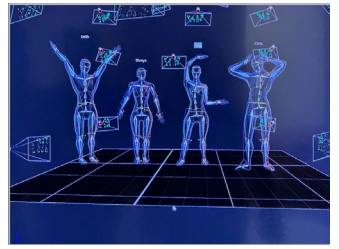
Marshall provides a broad spectrum of in-house capabilities necessary for cradle to grave support of complex habitation and spacecraft development and integration.

Habitation Systems: Virtual Environments Lab

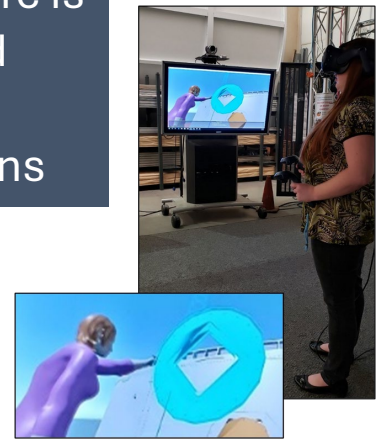
The Virtual Environments Lab (VEL) at MSFC plays an important role in developing cost effective human factors engineering (HFE) solutions. Virtual Simulation reduces physical mockup iterations, increases productivity through collaboration, and improves fidelity and quality of analyses. These findings provide early design influence, saving project cost and schedule.

Marshall's Virtual Reality (VR) capabilities allow users to conduct analyses and interact with 3D models in a virtual environment. This can be combined with other tools like motion capture, physical mockups, and Augmented Reality (AR) to improve the fidelity of an assessment for commercial destinations.

Human motions are tracked and recorded in real-time, generating a wireframe skeleton that is applied to a manikin within a virtual environment. This allows human participants to safely perform and evaluate a wide variety of operations tasks prior to fabrication.



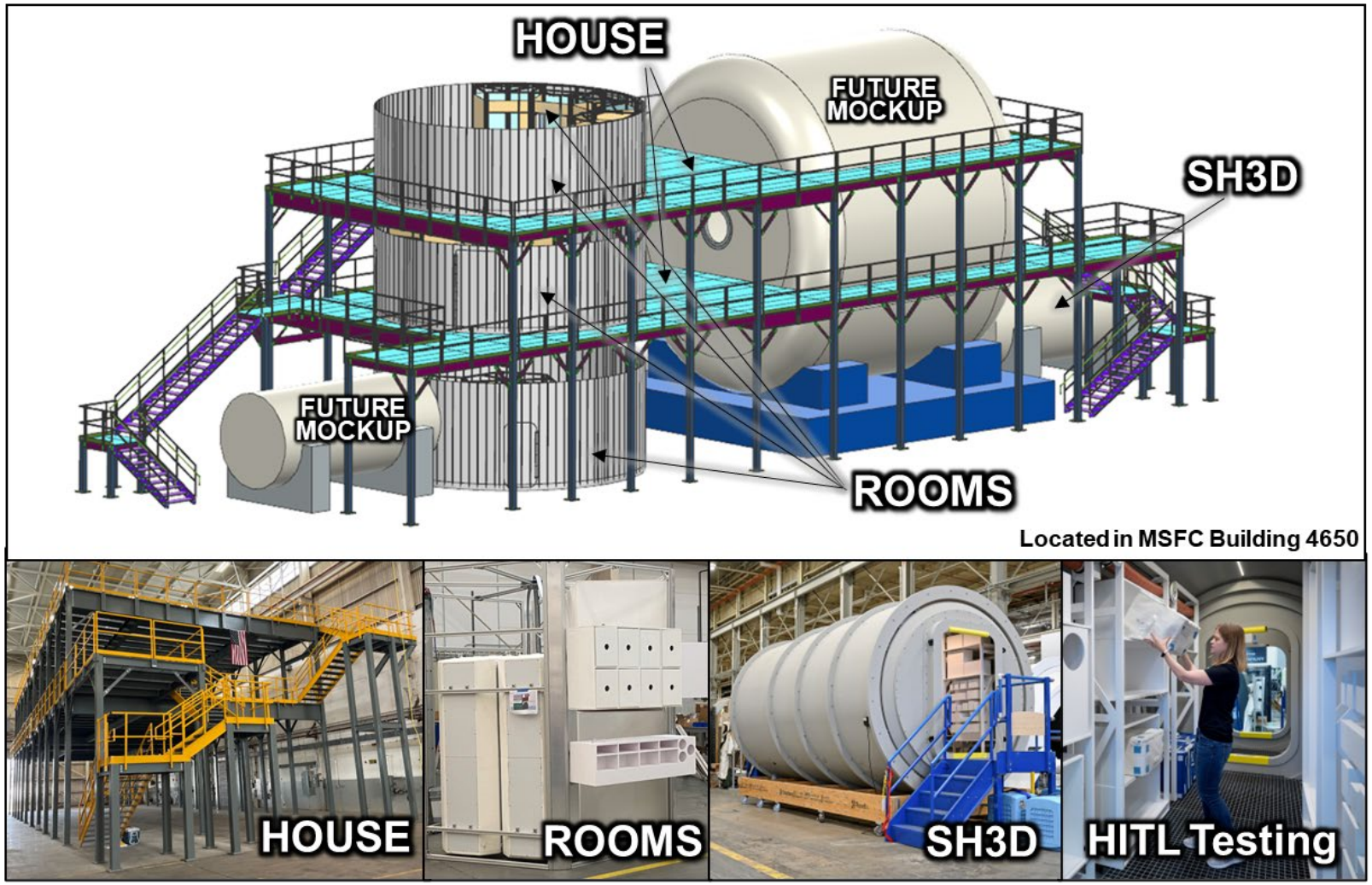
Human motion capture used in conjunction with human factors analysis software is important for verifying worksite design such as reach access, visual access, and tool clearance for ground support personnel. The analysis is also integral to the design of special tools, aids and platforms, and optimizing safe ground operations



Process Simulate Human (PSH) is a human modeling and simulation tool that provides the ability to quickly assess designs for a range of anthropometric human manikins as well as assessing tool fit and function.

Habitation Systems: Habitation Demonstration and Test

- **Full-scale spacecraft physical demonstration of future habitable systems**
  - Lunar/Mars Surface Habitation
  - In-space/Transit Habitation
  - Element Integration
- **Consists of HOUSE and prototypes, including SH3D and ROOMS**
- **Capabilities allow for:**
  - Full Scale mockups at common 3m diameter and 9m diameter sizes
  - Risk Reduction
  - Trade Space Refinement
  - Concept Validation
  - Human-in-the-loop Testing (HITL)
  - Technology Demonstration
  - Reconfiguration as concept evolves

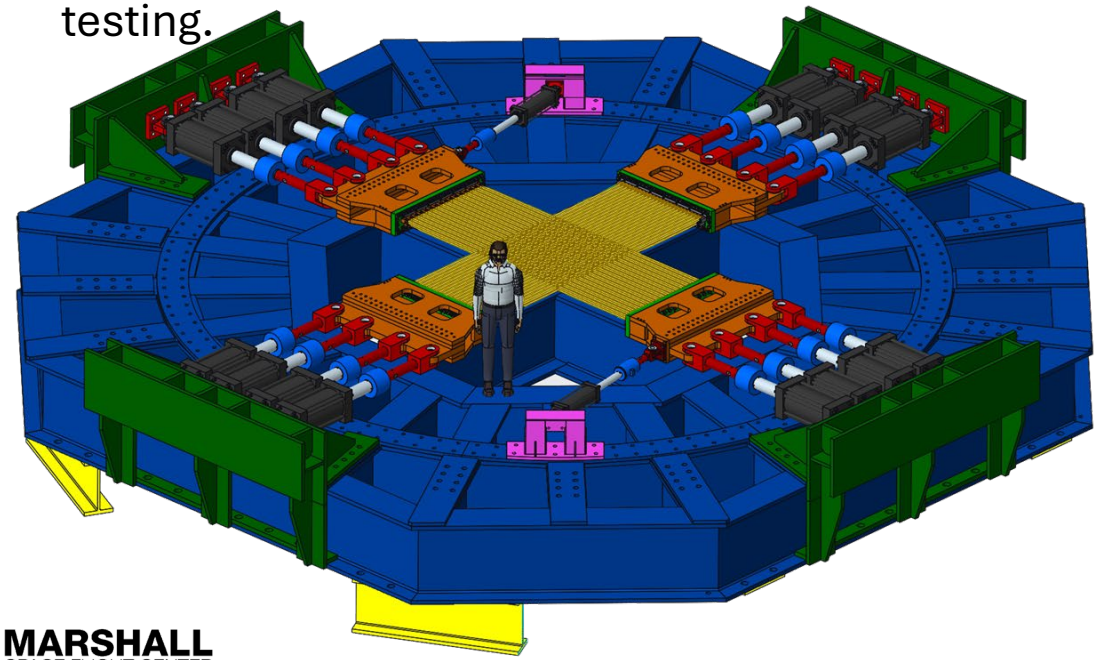


HOUSE: Habitation Outfitting Utilities, Structure & Environment
ROOMS: Representative Outfitting Of Multiple Spacecraft
SH3D: Surface Habitat, 3m Diameter
LAWN: Lunar Activity Workspace iNdoors

Habitation Systems: Advanced Structural Systems Testing - MATISS

Multi-Axis Testbed for Innovative Structural Systems (MATISS) is a versatile and customizable high-load, multi-axis test capability for characterizing the performance of large specimen panels of complex structural systems, such as softgoods and composites

MATISS allows for a suite of primary and developmental sub-component level tests, that aren't possible at a component level or feasible at a module level. These include characterization of elastic and shear moduli, damage and single-component failure testing, cyclical tests, and structural health sensor integration testing.



Metallic/Non-metallic sub-component structural climate-controlled testing platform at MSFC, Building 4650

MATISS Specifications

- Biaxial load capability: 960,000 lbf
- Test specimens from 4x4-ft to 16x16ft
- Temperature controlled via environmental enclosure
- Shear actuators provide additional test customization
- Testing target: Composites, softgoods, metallic and hybrid

Habitation Systems: Module Level Testing of Advanced Structural Systems

Rapid Pressurization Test Area

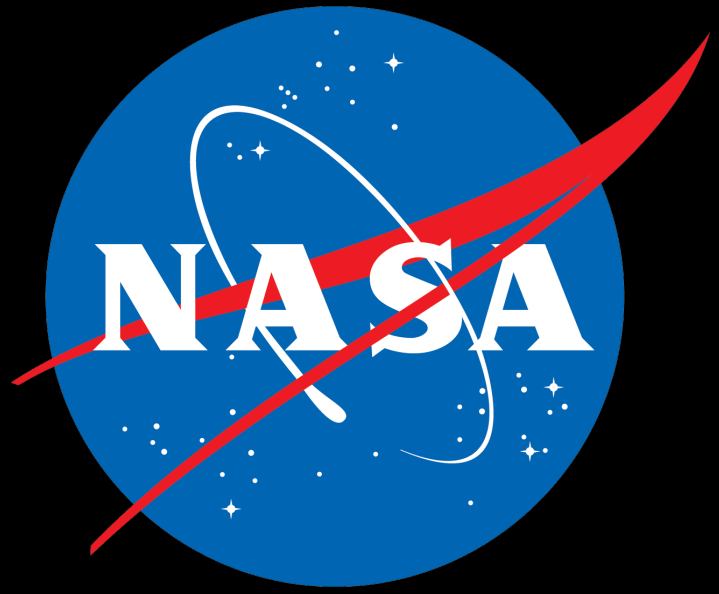
- 40’ W x 40’ L x 12” T concrete test pad
- Modular camera stands on concrete bases, which can be re-configured to support customer needs
- Variable position fluid valves (accurate control of pressure ramps to burst)
- Permanent power, instrumentation, and control systems to support robust operations

Sub-scale >>> Full-scale Modules

Inflatable Habitat Test Position 1 & 2

Facilitates simultaneous, variable duration creep test activities

- 16’ H x 30’ W x 30’ L | Roll Up Door: 12’ x 12’
- Fully Climate Controlled with power backup
- Remote control and monitoring of test
- High-speed cameras run on constant buffer until burst initiated trigger



National Aeronautics and Space Administration

Marshall Space Flight Center

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National Aeronautics and Space Administration

Michoud Overview

Michoud still remains one of the world's largest facilities with 2.2 million square feet of manufacturing, office, and warehouse spaces on 829 acres.

Steadfast workforce with a vast array of manufacturing skills for large-scale hardware production

Transportation infrastructure is already in place with a deep-water port on site and nearby interstate, railway, and airport

All listed facilities and capabilities are subject to availability of use based upon NASA mission priority as well as existing partnership agreement obligations.

MAF Business Tours
Eric Shoemaker, (504) 257-1258
eric.m.shoemaker@nasa.gov

Do Business with Michoud

NEW ORLEANS, LOUISIANA
MICHOUD ASSEMBLY FACILITY

Friction-Stir Welding

The benefits of friction stir welding include strength and higher quality welds, significantly reduced residual stresses, strong and flexible joints with low deformation, shrinkage and porosity. The process is relatively simple, fully automated, and can function well in any position.

NASA | MSFC
MICHOUD ASSEMBLY FACILITY
America's Rocket Factory

Product Building Capability

Aerospace

- Space Shuttle external tank
- Orion Crew Vehicle Ground Test Article
- Orion spacecraft crew module
- Boeing Delta II and Delta IV expendable launch vehicles
- SLS (Space Launch System) core stage

Automotive

- ocean thermal energy conversion
- shipbuilding
- railway rolling stock

Machine	X-axis	Y-axis	Z-axis	Turntable (TT)
UWS1	192 in.	246 in.	118 in.	20 ft.
UWS2	49 ft. 10 in.	22 ft. 8 in.	12 ft. 2 in.	22 ft.
RWT3*	93 ft. each weld machine	22 ft. 5 in. each weld machine	12 ft. each weld machine	3 annular TTs 20 ft. OD each 15 ft. ID each
PDS1	40 in.	120 in.	24 in.	–

**RWT3 has 2 weld machines that share a common X-axis*
OD = outer diameter
ID = inner diameter

Universal Friction Stir Weld System 6 Axis (UWS1)

- 16 ft. x 21.5 ft. x 10 ft. XYZ travels
- 2-axis gimballed weld head
- 30-ft. rotary table or 6 ft. rotary table (table-on-table)
- large scale complex contour friction stir weld capability
- self-reacting pin tool capability

Universal Friction Stir Weld System (UWS2)

- 44.5 ft. x 22.5 ft. x 12 ft. XYZ travels
- 5K lbs. – X, 15K lbs. – Y & Z loads
- 22 ft. rotary table and 22 ft. t-plate area
- large scale complex contour friction stir weld capability
- self-reacting pin tool capability

Universal Friction Stir Weld System (RWT3)

- 144 ft. x 22.5 ft. x 12 ft. XYZ travels
- 5K lbs. – X, 15K lbs. – Y & Z loads
- three 20 ft. rotary tables
- large scale complex contour friction stir weld capability
- self-reacting pin tool capability

Hi-speed Gantry Machining System – 5 axis (HSMC1)

- 23 ft. x 11.5 ft. x 5 ft. of XYZ travel (8 ft. under the spindle)
- 24,000 RPM, 60 HP spindle
- 790 inch-per-minute feed rates
- Siemens 840D CNC control with Siemens digital drives
- HSK type hi-speed tooling system with 20 tool automatic tool changer
- laser tool measuring and part touch probe measuring systems

Hi-speed Gantry Machining System – 7 axis (HSMC2)

- 32.8 ft. x 13 ft. x 11.4 ft. of XYZ travel
- C-axis (head rotation) ± 400 degrees
- A-axis (spindle rotation) ± 110 degrees
- 984 inch-per-minute feed rate

Michoud Harbor

The Michoud Harbor is connected to the Gulf Intracoastal Waterway (GIWW) that runs from Brownsville, TX, to Tampa, FL.

Utilities

- potable water
- sewages discharge/lift station and vacuum truck
- power: 480V/127V 3-phase; 120V/208V 3-phase

Attribute Data:

- mobile crane support: up to 90 tins
- lift truck support: up to 35,000 lbs.
- load rating of east and west docks: 500psf
- depth of water at bulkheads:
    - end of east dock: 25 ft.
    - end of west dock: 12 ft. at mean tide
- depth of harbor/turning basin: 25-30 ft.
- range of tide: normal tide runs 1-2 ft. astronomically (range varies due to winds)
- fendering/camels along wharf bulkheads
- 24-hour security presence
- lighted facility

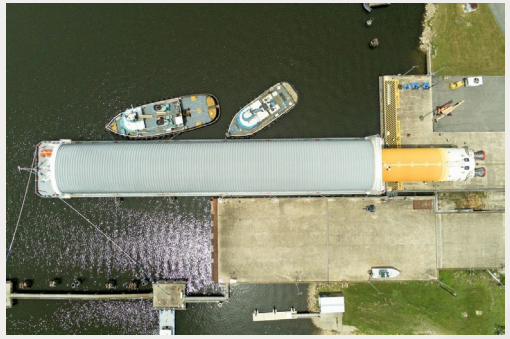
Distances:

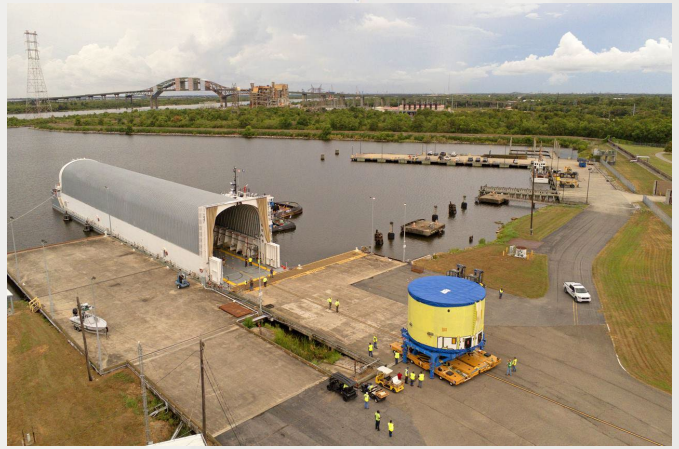
- 60 miles from Port of Gulfport
- 100 miles from the mouth of the Mississippi River to the Michoud Harbor
- inner harbor locks: 640 ft. L x 75 ft. W x 31 ft. D

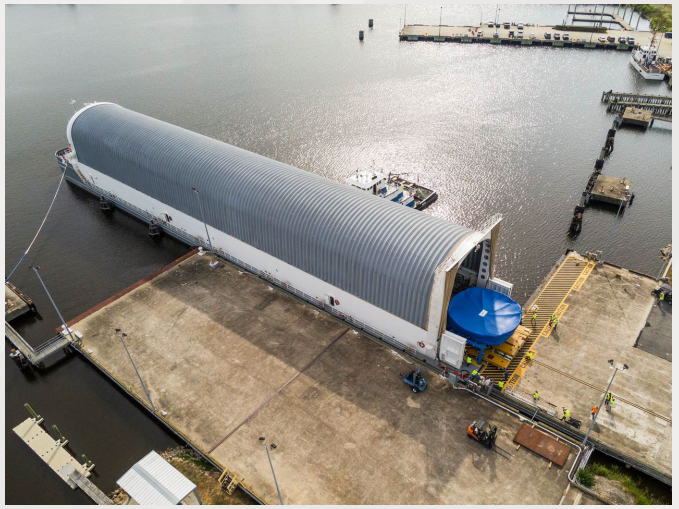
The Michoud Harbor contains an east and west dock with reinforced concrete slabs and beams supported on precast concrete piles.

- east dock: 75 ft. x 200 ft.
- west dock: 75 ft. x 100 ft.

A pier and dolphin system joined by a walkway on the east dock extends south into the harbor approximately 200 ft.







On-site Capabilities

Machine Shops

The machine shops boast nearly 40,000 square feet of machine tools dedicated to machining all shapes and sizes of aluminum, steel, and composite structures. This is a shared resource for use by Michoud tenants on an as-needed basis.

Michoud machine shops include easily accessible and ready-to-use equipment at a fraction of the cost to purchase, such as:

- lathes: small, medium, large, vertical, Computer Numerically Controlled (CNC)
- mills: small, medium, large, large CNC
- grinders, saws, and a full complement of sheet metal forming tools (sanders, shears, presses, rollers, etc.)
- CNC Equipment
- computer-aided design (CAD) / computer-aided manufacturing (CAM) capability
- five 5-ton bridge crane coverage with 32 ft. hook height

MICHOUD ASSEMBLY FACILITY

Machine Shop Equipment

Type of Equipment	Maximum Capability
shears	• 12 ft. W • 3/8 in. thick ferrous metals
bend presses	• 22 ft. bend L • 625 ton
Saws (ferrous/non-ferrous)	Ferrous material (i.e. aluminum) • 50 in. W x 12 in. L • 6 in. thick stock Non-ferrous material (i.e. steel) • 12 in. W x 20 in. L • 4 in. thick stock
plate rollers	21 ft. L 3 in. thick stock
flat stock and round pipe roller	• Round Stock: 2.5 in. diameter • Flat Stock: 3.5 in. W • 2.5 in. thick stock
lathes (both CNC and manual)	• 16 in. swing (ability to turn 32 in. diameter) • 25 ft. L
vertical turning lathes	• 6 ft. diameter x 6 ft. H with contouring capability
4-axis mill	• 47 in. x 47 in. x 35 in. XYZ • 360-degree full contouring capability
surface grinder	• 2 ft. W x 2 ft. H x 12 ft. L
precision boring	• W x 96 in. H x 12 ft. L • 30 in. bore depth possible
horizontal boring/mill center	• 10 ft. W x 96 in. H x 12 ft. L • 30 in. bore depth possible
horizontal boring/mill center various small scale manual high precision turning/boring/milling machines	small scale manufacture requirements

On-site Capabilities

Composites

Composite materials, as compared to many traditional manufacturing materials, offer weight reduction potential, greater strength to weight ratios, greater design flexibility, and excellent performance where there are moisture or corrosion issues.

NCAM Machining

The National Center for Advanced Manufacturing (NCAM), a partnership between NASA, the state of Louisiana, Louisiana State University, and the University of New Orleans, provides a vehicle for Michoud tenants to utilize state-of-the-art manufacturing equipment.

Autoclave Machining Center

Category	Capacity	Maximum Capability
Freezer	20 ft. x 40 ft.	-14 degrees Fahrenheit
Autoclave	0 ft. x 20 ft.	• 200 PSI and 525 degrees Fahrenheit • PC based controls and data collection
Oven	8 ft. x 8 ft. x 7 ft.	–
Hi-Speed Machining System 5-axis (HSMC1)	23 ft. x 11.5 ft. x 5 ft.	• 24,000 RPM, 60 HP spindle • 790 inches-per-minute speed rates • laser tool & part touch probe measuring systems
Hi-Speed Machining System 7-axis (HSMC2)	39 ft. x 13 ft. x 11.5 ft.	• 24,000 RPM, 60 HP spindle • 20-foot rotary table • head/tailstock: 10 feet travel & 18 feet diameter

National Aeronautics and Space Administration

NASA

Industrial Realty Group | 50 Acres

Approximately 50-acre greenspace development EUL with private developer for up to 99 years executed in 2021

Developer specializes in build-to-suit construction unique to Tenant needs.

Offers option for additional space over and above those offered in NASA-owned spaces.

Site Development

NEW ORLEANS, LOUISIANA
MICHOUD ASSEMBLY FACILITY

Kennedy Space Center

National Aeronautics and Space Administration

NASA Center Capabilities
Kennedy Space Center (KSC)

Center Points of Contact:

Primary POC

Eirik Holbert

eirik.holbert-1@nasa.gov

End-to End Government and Commercial Services: Ground, Launch, Transit & Spacecraft Systems

NASA's Kennedy Space Center offers world class expertise and capabilities in support of commercial launch services and commercial spacecraft system delivery services performing risk mitigation, manufacturing, ground processing, and launch operations.

The unique commercial services of the spaceport offers highly technically skilled professionals, mission assurance via world class technical insight into launch and space transportation architectures, full security for data protection, a vast successful history in innovative spacecraft and vehicle processing, and launch operations. KSC can provide consultation and assistance with various phases of ground processing including:

- Transportation services by rail, air, road and sea including lifting and handling
- Element arrival, transportation, inspection, testing
- Hazardous offline storage, handling, processing, servicing/de-servicing expertise
- Integration & testing, rollout to pad
- Hazardous and Non-hazardous payload processing facilities
- Assembly, encapsulation, transportation, vehicle integration facilities
- Mission integration and cross mission architecture risk reduction
- Launch and Landing Facility
- Launch pad recovery and logistics
- Hardware closeouts and final inspection
- Launch countdown simulation/training
- Command, control, operations, communications facilities & systems
- Flight Readiness Reviews (FRRs)

Link to KSC Capabilities

Exploration Technology

Link to KSC Capabilities

Cryogenics Technologies

- Thermal insulation materials for space environments
- 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

Exploration Research

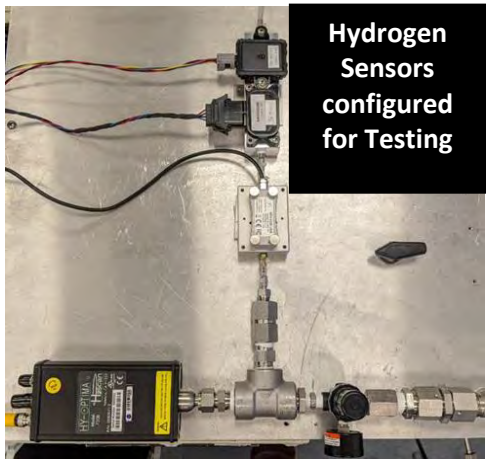
- Technologies to protect flight hardware and launch equipment from electrostatic discharges
- Scientific instrumentation for flight
- Logistics Reduction/Waste management/Recycling
- Crop Production/Management

Engineering & Testing Capabilities

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

- Hypergolic and cryogenic propellants
- Vehicle flight analysis
- Modeling and simulation
- Software development
- Materials and processes
- Flight crew equipment
- Systems engineering and integration
- Ground test and vehicle emulator operations
- Testing and laboratory capabilities support
- Avionics/Command & Data Handling

Hypergols Operations


Hydrogen Sensors configured for Testing

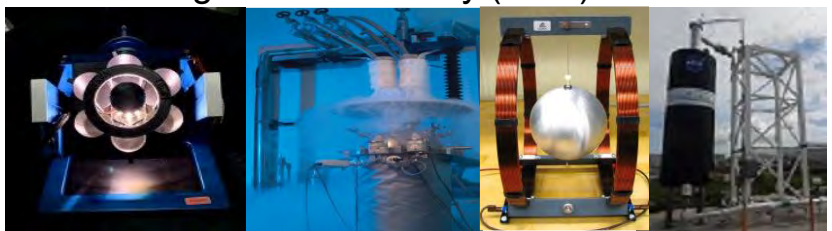
Contamination Inspection

Launch Equipment Test Facility

Link to KSC Capabilities

Facilities & Laboratories

- Advanced Imaging and Analysis Laboratory (AIAL)
- Animal Care Facility
- Applied Chemistry Laboratory (ACL)
- Applied Meteorology Unit (AMU)
- Applied Physics Laboratory (APL)
- Biomedical Engineering Research Laboratory
- Chemical Sampling and Analysis Laboratory
- Life Sciences Laboratory (LSL)
- Commercial Launch Control Center
- Precision Cleaning & Component Refurbishment
- Chemical Analysis (Propellants and Fuels)
- Cryogenics Test Laboratory (CTL)
- Customer Avionics Interface Development and Analysis Laboratory
- Design Visualization
- Electrical Development Laboratory (EDL)
- Electromagnetic Laboratory (EML)
- Electrostatics & Surface Physics Laboratory (ESPL)
- Environmental Microbiology Laboratory
- Fiber Optics and Communications 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)
- Plant Processing Area (PPA)
- Precision Measurement/Alignment Lab (PMA)
- Prototype Development Laboratory (PDL)
- Offline Clean room Payload & Science Processing Laboratories
- Standards and Calibration Laboratories
- Vibration Test Laboratory (VTL)
- On-orbit-experiment Control Rooms



Link to KSC Capabilities

John H. Glenn Research Center

Glenn LEO Technology

Integrated Electric Power Production and Distribution

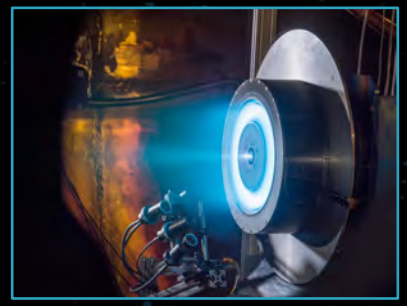
- Space power source development (solar, fuel cell, nuclear)
- Energy Storage (batteries, regenerative fuel cells)
- Advanced modular power management and distribution systems
- ISS EPS analysis: Perform power generation and consumption analysis for operations scenarios

Cryogenic Fluids Storage and Transfer

- Acquisition and transfer of fluids under reduced gravity
- Reduced boil-off and thermal management

Space Propulsion

- Electric, chemical, and nuclear-based technologies to extend exploration capabilities
- Extensive electric propulsion technology and testing capability



Microgravity Payload Development

- 25 years experience in fluid science and combustion research
- Long term operations of the ISS FCF
- Acceleration measurement systems
- Microgravity drop-tower research

HRP Risk Reduction Technologies

- Exercise counter measures
- Medical devices

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

Lewis Field Test Facilities: Low Earth Orbit Test Capabilities

World-Class facilities to verify cutting-edge technologies in space exploration.

Cleveland, Ohio

Lewis Field contains more than 150 buildings supporting work across aircraft propulsion, power, communications, propulsion, materials, and physical science.

Structural Dynamics Laboratory (SDL)

Structural dynamic testing to verify the survivability when exposed to vibration stress screening or a controlled simulation

Electromagnetic Interference Laboratory (EMI)

Electronic component testing, shielding effectiveness, and final qualification testing of hardware

Power Systems Facility

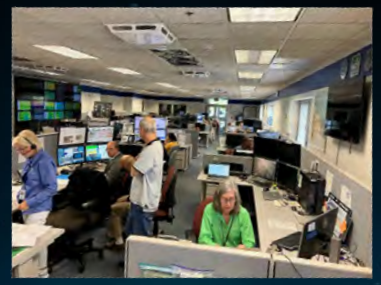
Development, testing, and validation of electrical power systems including a Highbay cleanroom.

Zero-G Facility

Premier facility for ground-based microgravity research, largest of its kind in the world (duration of 5.18 seconds)

Telescience Support Center (TSC)

Command and Control center for various ISS and space systems.



2.2 Sec Drop Tower

Rapid testing for study the effects of microgravity on physical phenomena.

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

Lewis Field Test Facilities: Low Earth Orbit Test Capabilities/Services

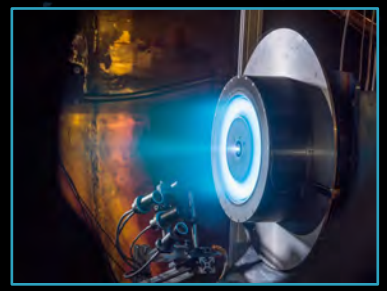
World-Class facilities to verify cutting-edge technologies in space exploration.

Cleveland, Ohio

Lewis Field contains more than 150 buildings supporting work across aircraft propulsion, power, communications, propulsion, materials, and physical science.

Electric Propulsion and Power Laboratory

Supports research and development of spacecraft power and electric propulsion systems



Compass Lab

Conducts rapid conceptual spacecraft designs for NASA, industry, and the scientific community.

Exercise Countermeasures Lab (ECL)

Advanced exercise development lab.

Electric Propulsion Research

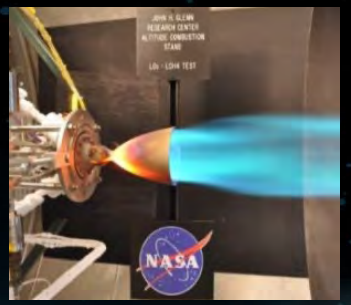
Eight vacuum chambers and five bell jars that provide the required simulated space to conduct fundamental research in space power and electric propulsion

Creek Road Cryogenics Complex

Test facilities for thermal protection systems required to provide long-term storage of cryogenic propellants in space

Chemical Propulsion Research Complex

Testing for chemical propulsion concepts and safer propellants for spacecraft thrusters



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

Neil A. Armstrong Test Facility: Space Environments Test Capabilities

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

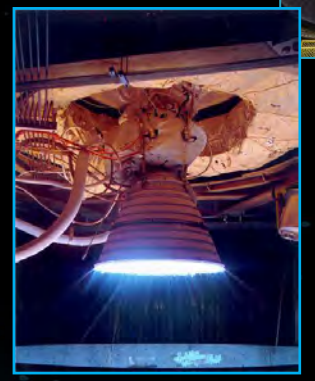
Space Environments Complex (SEC)

- The World's Largest Space Environmental Simulation Chamber
- Mechanical Vibration Facility (MVF)
- Reverberant Acoustic Test Facility (RATF)

2 of the 3 largest thermal-vacuum chambers in NASA (SEC and ISP)

Electromagnetic interference/ compatibility testing (SEC)

Highest capacity Mechanical Vibration Facility (MVF)



In-Space Propulsion Facility (ISP). Thermal-vacuum testing with propellants to allow full-scale upper-stage and rocket engines testing

Most Powerful Reverberant Acoustic Test Facility (RATF)

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

Glenn Research Center Capabilities

- NASA Glenn delivers innovations in propulsion technology and propellant management critical to future CLD innovations.
  - Expertise in propulsion systems (chemical, electrical, 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
  - Expertise in design, development, handling, storage, demonstration, and flight test of fluid systems including LOX/LH2, LOX/LCH4, LOX/RP-1, and NTO/MMH.

- NASA Glenn has a long history of power system development, including the ISS, and 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
  - 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, power system design, analysis, and modeling, and system integration.
  - Development of energy storage capabilities consist of research and development of batteries and regenerative fuel cells.

- NASA Glenn has been a pioneer and a long history of providing crucial Physical Science research and payload operations
  - Expertise in combustion science, including fire safety, fluid physics, material science, and soft matter and complex fluids.
  - Long history of physical science payload developments since the beginning of NASA's space exploration mission (Mercury – ISS).
  - Developed two key science facilities for ISS, Combustion Integrated Rack and the Fluids Integrated Rack, that have both made major discoveries.

- 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
  - 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.
  - Development of intelligent controls, smart micro- and nano-sensors, and harsh environment electronics.

https://www.nasa.gov/glenn-business-and-partnerships/

Ames Research Center

NASA Ames Capabilities/Facilities/Services

(List of Contents)

SILICON VALLEY
AMES RESEARCH CENTER

I. Hardware, Research Enablers, and Related Technologies…….Pages 3 - 20

II. Automation, Robotics, Planning Tools, Thermal Protection & Related Tech……Pages 22-33

III. Facilities & Other Capabilities……Pages 35-40

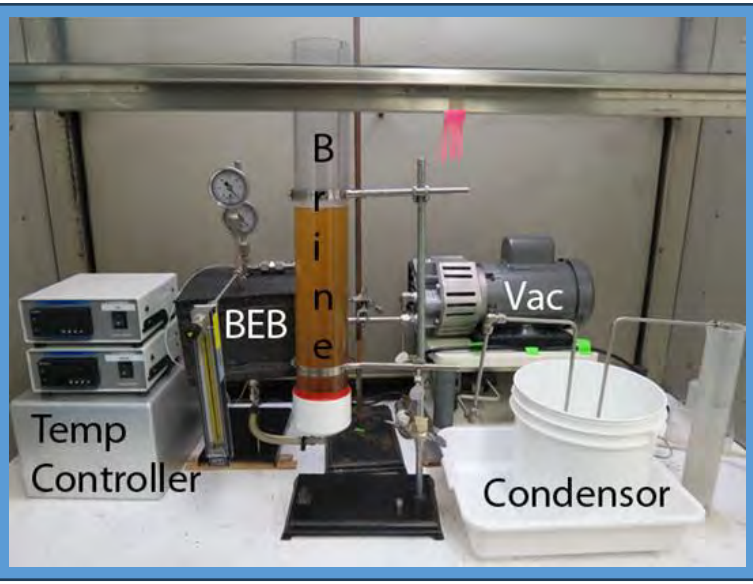
Please note, this is not necessarily a comprehensive list of Ames' capabilities/facilities/services. Contact us for more information (Sharmila.Bhattacharya@nasa.gov)

NASA SILICON VALLEY

AMES RESEARCH CENTER

HARDWARE, RESEARCH ENABLERS, & RELATED TECHNOLOGIES

Ames Universal Urine Processor (UUP)



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

The Universal Urine Processor would be capable to process both humidity condensate and raw urine with 100% water recovery. 100% water recovery.

SUMMARY

Current Status of the capability, notable achievements, and so forth, including how it compares with the State of the Art

SOA: NASA has no water processor capable of 100% water recovery, and required two processors to get above 85%.

KEY ATTRIBUTES / COMPETENCY

Bullet point list

- 100% water recovery. Proven by elimination of the green chromium hexahydrate evidenced by only white salt solid remaining (see small image)
- UUP operates in all gravitational environments (micro, partial, and full), thus only a single processor would be required for a Mars mission, not the three currently proposed (VCD & BPA for transit, and PUP for surface).
- No extreme stench released to the cabin, nor complex stench scrubber required.
- Could save up to 1 ton of mass for a 3-year Mars mission
- Dormancy tolerant as the bags can be replaced between missions.

HERITAGE

- Developed, tested, and presented at the technology down select for the brine processor.

APPLICATIONS BEYOND

UUP is applicable to Gateway and Lunar missions where dormancy tolerant processors are required. Also applicable to Mars for the same dormancy reasons as well as its applicability to both the transit and surface.

Ames Fluid Dynamic Mass Gauging (FDMG)

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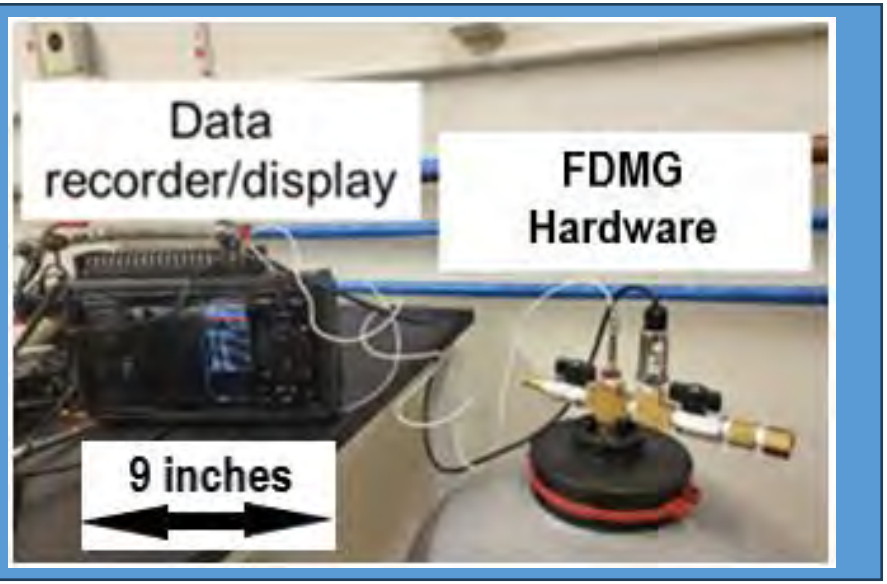


TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

FDMG is a technology for determining and monitoring the liquid volume within a tank in all gravitational environments (micro, partial, and full) with in-flight re-calibration capability

SUMMARY

SOA: NASA has no method of determining the volume of liquid within a tank in microgravity.

FDMG has demonstrated the ability to determine the liquid volume within a rigid bladder tank to <1% error of the tanks volume.

The mass and volume is nominally 1kg and 1L.

KEY ATTRIBUTES / COMPETENCY

- For tanks up to 75L, volume determination errors are <0.25L and as low as 0.03L (30 mL).
- Can operate under a variety of operational conditions making the FDMG applicable to most situations.
    - High or low pressure conditions
    - Choked flow or non-choked flow conditions
    - Operated in fill or vent mode
- In-flight recalibration easily done
- Not susceptible to drift issues as PVT methods
- Temperature effect only 0.15% per degree change.
- Automated process

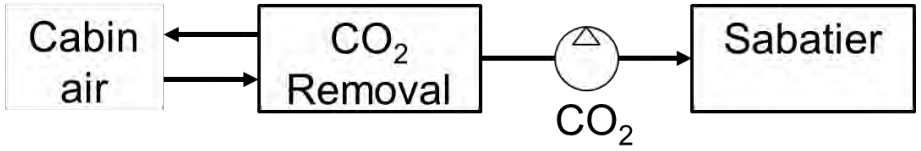
HERITAGE

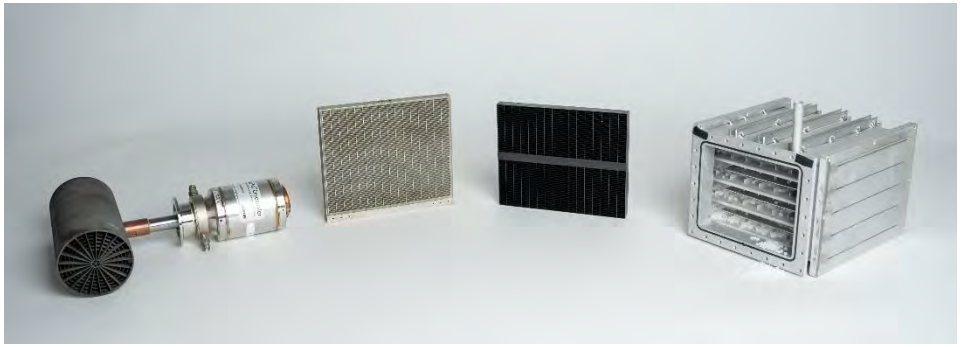
- Tested on a 75L Bladder ProSource Tank as is currently on the ISS. Fill conditions ranging from a full to an empty tank were tested. System had been upgraded to an automated system for operations using an NI DAQ system and python programing.

APPLICATIONS BEYOND

Applications for Gateway, Lunar, and Mars when knowledge of remaining liquid volume is critical for mission success, i.e., transit, pre-positioned, and dormancy supplies.

CO_2 Management Systems in Development at Ames





TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Highly reliable, regenerable CO_2 systems are required to minimize mass for long-duration crewed missions. Three unique methods have been in development to minimize mass, power, volume, and spares.

SUMMARY

- CDep tested at subscale and built at full-scale
- LACR tested at subscale and integrated loop with simulant fluid tested on ISS
- AC-TSAC full-scale extensively tested over 15 years, never replacing sorbent as never lost performance

KEY ATTRIBUTES / COMPETENCY

- **CO_2 cold surface Deposition system (CDep)** – sorbentless, thermally-driven CO_2 capture and pressurization https://hdl.handle.net/2346/94760
- **Liquid Amine CO_2 Removal (LACR)** – capillary, passive control of liquid sorbent/air interface enables continuous operation https://hdl.handle.net/2346/98761
- **Air-Cooled Temperature Swing Adsorption & Compression (AC-TSAC)** – passively provides constant pressurized CO_2 for reduction https://hdl.handle.net/2346/98823
- In-house capability to simulate crewed cabin environment, dry cabin air, and outlet from CO_2 removal system, including trace contaminants
- In-house CO_2/H_2O sorbent synthesis and analysis suite

HERITAGE

- CDep uses same coolers that transport samples from ISS
- LACR sorbent used to scrub submarines and flue gas, and geometry tested extensively on ISS
- AC-TSAC tested with both ISS CO_2 removal systems

APPLICATIONS BEYOND

Direct infusion into CLD, gateway, HLS, MPH, EHP, mars transit, ISRU, etc.

Ames Waste Group - TRASH COMPACTION AND PROCESSING SYSTEM

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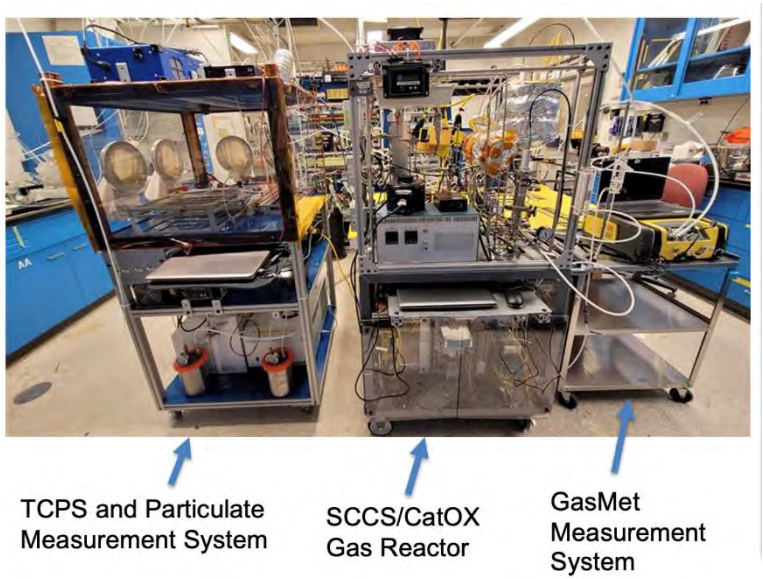


Trash Compaction and Processing System

Ability to process a day's worth of non-metabolic trash for a crew of four.

SUMMARY

Through NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) program, commercial partners have developed 3 generations of test systems. The latest one will be part of an ISS Technology Demonstration in January of 2027.

KEY ATTRIBUTES / COMPETENCY

- Trash volume reduction by up to 70%
- Trash stabilization to rigid tiles
- Reduce smell
- Safens trash by heating it to 150C to inhibit biological growth
- Water recovery greater than 90%
- Treats exhaust gases for toxin removal by using a carbon bed, CatOx reactor, and LiOH bed
- 500W average power, 750W peak power
- 2.2 kg trash per load
- 8 to 12 hours per completed TCPS cycle
- Product "tile" can be used for radiation shielding

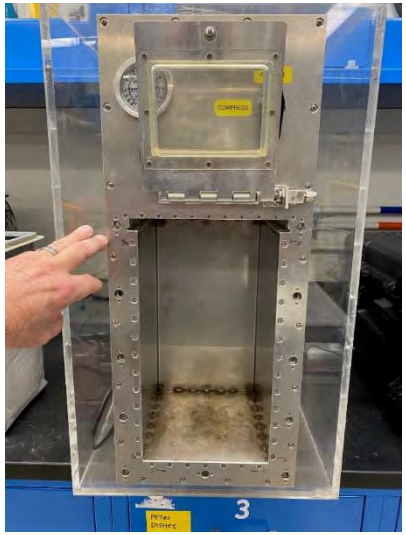
HERITAGE

- Concept originated with US Navy to densify trash so it would sink
- Space applications and test build commenced in 2003
- Over 20 years experience in waste processing technology development

APPLICATIONS BEYOND

Water recovery from trash. Trash safening systems. Gas processing technologies.

Mechanical Trash Compactor



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

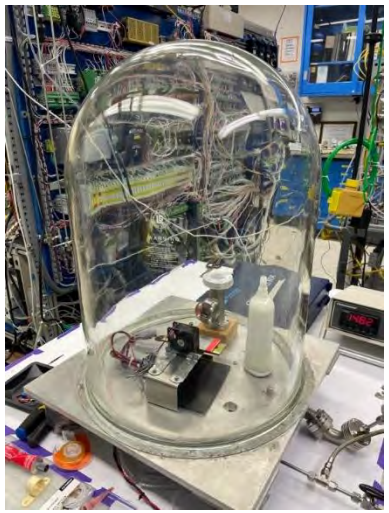
Develop a mechanical, non-heated, low mass, low volume, and easy to use mechanical trash compactor for use while in transit or on a planetary surface.

SUMMARY

A refurbished benchtop test rig is used to study compaction pressure, dwell time, volume reduction, spring back and system capacity for trash management.

The information obtained will be used to develop a prototype which minimizes mass, power, and volume, leading to a favorable Equivalent System Mass rating. Issues with odor and long-term storage will be investigated.

Filters for Long Term Waste Storage



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Develop long-term waste storage systems to prevent planetary contamination from terrestrial microbes escaping the waste containers. These microbes can confound planetary scientists in the search for extra-terrestrial life.

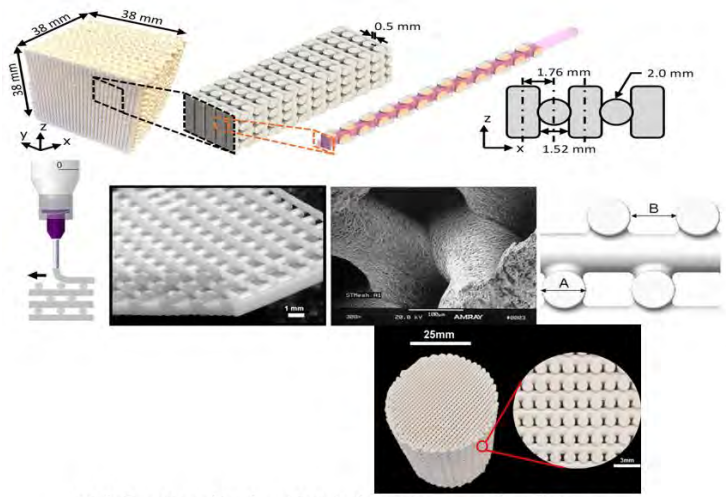
SUMMARY

Use of a filter is the simplest, direct, and most cost-effective potential solution. The filtration system that allows volatiles to boil off and escape containment but keeps microorganisms contained within

Filtration system is to last for at least 50 years. Filter clogging and phase change present significant challenges

The filter design will be handed over to the logistics container designers. Filters can work with any type of containment system.

Multifunctional Materials for Contaminant Removal



Multifunctional Sorbent Prints for CO2 removal and storage
(Agata ICES-2024-346 and Cerano ICES-2924-275)

KEY ATTRIBUTES / COMPETENCY

- Custom 3D-printed sorbents for CO_2 removal, thermal control, and contaminant removal
- Custom 3D-printed silver doped ceramic lattices for potable water disinfectant.
- Integration of machine learning for trade studies and knowledge graph development
- Advanced heating systems with 3D-printed titanium water heat pipes and embedded heater wires.
- Use of piezoelectric components for solid-liquid separation

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Spacecraft ECLSS must be compact, energy-efficient, and reliable. NASA faces challenges with sourcing suitable materials, as COTS products may not align with mission timelines or performance needs. This work enables multifunctional, reconfigurable components tailored for long-duration missions and harsh environments.

HERITAGE

- Adsorbent beds using COTs adsorbent pellets.
- The use of iodine for potable water disinfectant.

SUMMARY

The multifunctional 3D-printed devices that perform CO_2 capture, water recycling, thermal management, and silver ion dosing. Advances include adaptive formulations, integration with ML for automated material screening, and compact hardware designs. Compared to the state of the art, these systems are lightweight, customizable, and offer dual or triple functionality.

APPLICATIONS BEYOND

- The developed technologies can be infused into both space mission scenarios and terrestrial applications
- Closed-loop water and air systems for planetary bases
- Portable water disinfection for disaster relief or remote locations

CO_2-Based Biomanufacturing Platform and Facilities at Ames "Make it there, not take it there"

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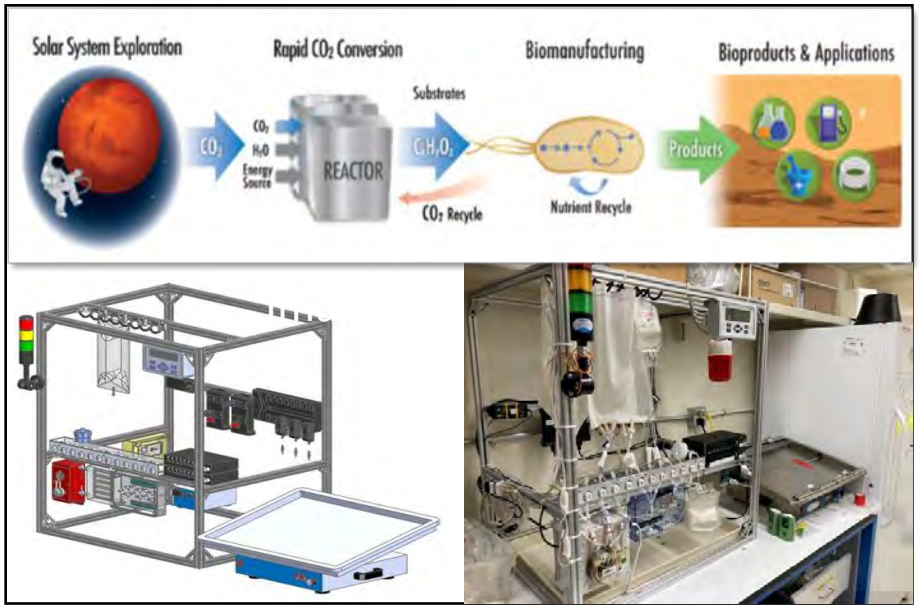


TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Reduce logistics, cost and risk of resupply: provide mission consumables from in-situ resources e.g. nutrients, fuels, feedstocks, plastics, pharmaceuticals, addressing NASA shortfalls 1583, 1584, 1518, 1524,1525, 1610.

SUMMARY The CO_2-Based Biomanufacturing facilities within the Bioengineering Branch at NASA Ames are at the forefront of biomanufacturing in space. Over 2000 sq ft laboratory spaces, standard and custom bioreactors, purification subsystems, in-house analytical capabilities and relationships with vendors allow for rapid engineering of microbes, subsystems, and platform build design through validation.

KEY ATTRIBUTES / COMPETENCY

- Custom developed bioprocessing platform for use in resource limited environments, variable gravity conditions.
- BioManufacturing from waste streams or CO_2 derived feedstocks. Liter scale. His tag purification scheme.
- Flexible modified COTS design with reconfigurable, subsystems that are re-usable/replaceable, can be packaged for middeck locker volumes.
- Semi-autonomous operation and processing, requiring no tools for assembly and minimal crew time.
- Multiple media formulations developed including minimal medias using CO_2-derived feedstocks, formulations based on waste utilization, brine, or salts from regolith.
- Genetic engineering and bioprocess development and optimization. Bioreactor materials expertise.
- Decades of experience in developing biological platforms for use in space, from concept and requirements,to drawings, build, test, verification and delivery.

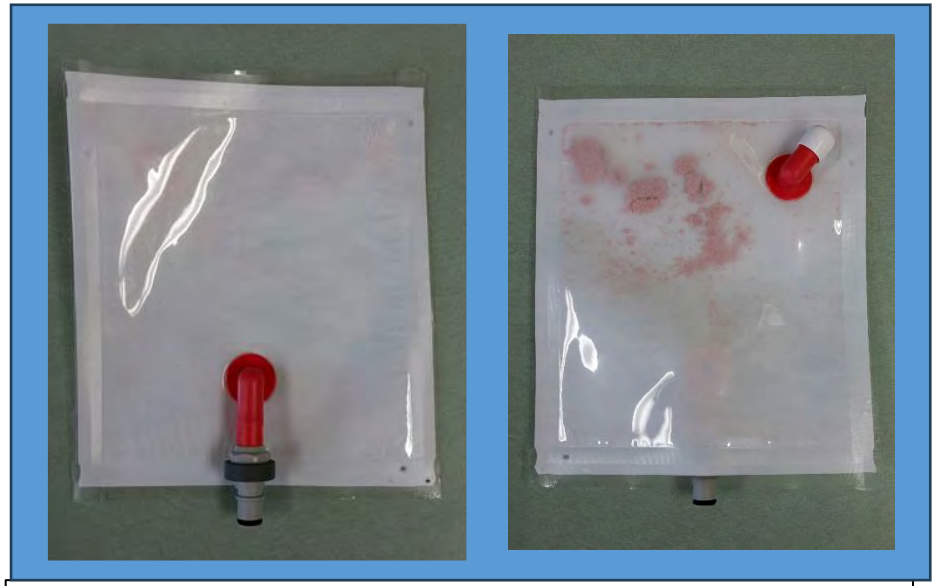
HERITAGE

- Tested using biomanufacturing model organisms, bacteria and yeasts, secreted and cell bound products.
- Custom cell lysis units developed with Claremont Biosystems based on units flown on ISS.

APPLICATIONS BEYOND: bioreactors and platform subsystems can be integrated into closed loop life support systems, biomining, waste recycling and materials recovery.

Soundararajan, M., Paddock, M. B., Dougherty, M., Jones, H. W., Hogan, J. A., Donovan, F. M., ... & Settles, A. M. (2023). Theoretical design of a space bioprocessing system to produce recombinant proteins. *npj Microgravity*, *9*(1), 78.

Personal Water Reclamation System at Ames



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Providing water and reducing wastewater volumes on orbit.

SUMMARY

The Personal Water Reclamation System (PWRS) is a passive individual water purification device that provides hydration fluids and reduces the volume of wastewater. The system saves mass the first time it is used.

KEY ATTRIBUTES / COMPETENCY

- Personal water treatment
- Passive water treatment.
- Provides an engineered hydration drink for crew consumption.
- Provides hydrated food product for for crew consumption.
- Reduces the volume of wastewater.
- Reduces risk because it treats an individual crew members urine for their own reuse.

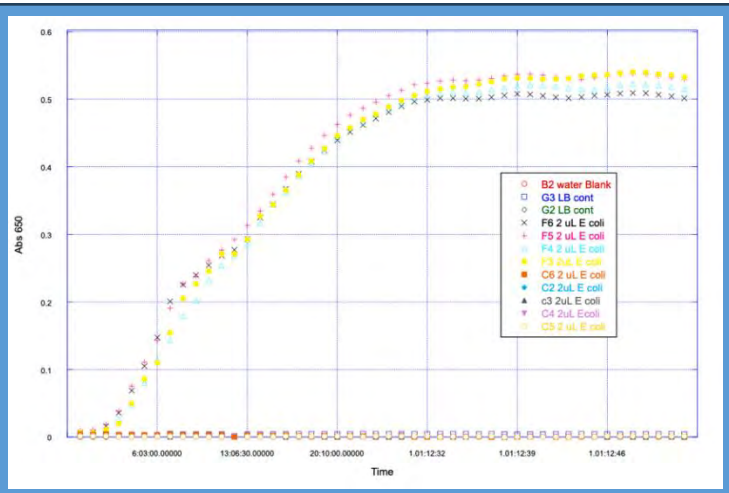
HERITAGE

- PWRS has been been tested in space.
- PWRS has been tested using real human urine and the product been consumed by humans.

APPLICATIONS BEYOND

- Disaster relief
- Disadvantaged communities water purification.

Microbial Control of Stored Potable water



E. Coli growth as a function of time in hours in pure water or LB using a 2 uL of overnight grown culture

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Storing water for long periods of dormancy on a spacecraft will require reliable microbial control or the use of complex sensors to verify potability. NASA currently has no water quality standards that will guarantee bacteria will not grow in potable water stored for long periods of time.

SUMMARY

This work proposed is to develop a set of laboratory verified water quality specifications and materials of construction standards based on redox potential that will prevent microbial growth in potable water. Maintaining the potability of stored water supplies and plumbing distribution systems is a key challenge for spacecraft. Our work, shown above, has shown that water quality standards can be developed that prevent bacterial growth.

KEY ATTRIBUTES / COMPETENCY

NASA water quality standards address human health concerns

NASA water quality standards do not address long term bacterial growth control. Biocides are used to control growth.

Biocides are consumed when they kill bacteria, so they need to be replaced.

This means that for long term storage of water biocide injection and mixing would be required

Alternatively, water quality specification can be developed that will prevent bacterial growth thus not needing biocide or biocide replenishment.

This task will develop water quality specification and materials of construction require for ground-based preparation of water.

HERITAGE

NASA water quality standards address human health concerns.

Results by our group and others have shown that bacteria can not grow in 100% pure water.

APPLICATIONS BEYOND

Potential applicability scenarios

BioNutrients at Ames -Fermented Food, On Demand Nutrients native and genetically improved products

Add water and incubate 12- 48 hours

On-demand nutrient production from fully dehydrated system – yeast, yogurt, and kefir fermented foods, with or without GMO.

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Nutrient supply and nutrient degradation in prepackaged food system is a known challenge for space exploration. Fermented foods (commercial or GMO) can supply needed dietary nutrients and compounds using minimal mass, power and volume for long duration missions.

Addresses **NASA Shortfalls** in food/crew health and performance and New technologies for increased shelf-stable food system shelf-life: 1524, 1525, 1610,1620.

Current Products

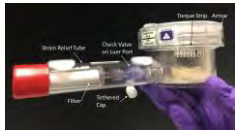
- Yeast: carotenoids (β carotene, zeaxanthin)
- Yeast: carotenoids, riboflavin, folate (multi-nutrient cultures)
- Yogurt – commercial, yogurt GFP
- Kefir – commercial
- Serial production - yogurt

KEY ATTRIBUTES / COMPETENCY/ HERITAGE

Data on >5years of lyophilized, ambient storage of microbes in ISS – BioNutrients has 7 successful runs with yeast products, 2 runs making yogurt and kefir.

Additional ISS data: 9 additional strains, multiple treatments, UV irradiated potential novel strains, omics information. Media (YPD/yeast formula), non-fat milk powder, edible pH indicator and additives.

Low volume, low mass "bioreactor" systems/ Materials data. Space flown bioreactor designs – polycarbonate hardshell with PTFE membrane and FEP flat pack bag designs, up to 6 years shelf life.



Materials test data: gas permeability, biocompatibility, and workabilityfor bioreactor development.

2000 sq ft laboratory space, decades of experience

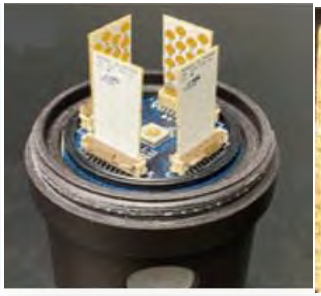
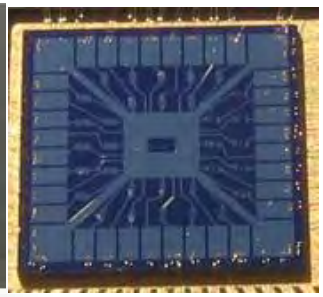
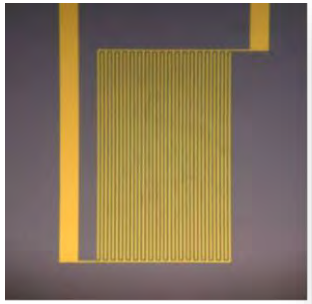
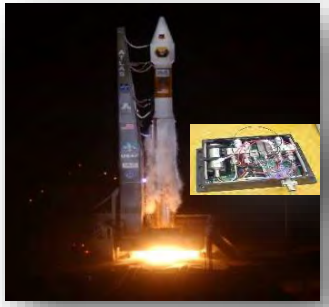
APPLICATIONS BEYOND

Microbial cultures can deliver fats, protein, vitamins as well as pharmaceuticals in low mass and volume systems, requiring minimal resources. Future developments will include pasteurization and other safety measures. A future space kitchen may have on demand fermented food and nutrients prepared from microbial cultures. The future medicine may be an engineered ready to eat yogurt or kefir.

Ball, N., Hogan, J., Hindupur, A., Kagawa, H., Levri, J., & Sims, K. (2020, July). BioNutrients-1: Development of an on-demand nutrient production system for long-duration missions. 2020 International Conference on Environmental Systems.

Ball, N., Kagawa, H., Hindupur, A., Kostakis, A., Hogan, J., Villanueva, A., ... & Gresser, A. (2021, July). BioNutrients-2: Improvements to the BioNutrients-1 nutrient production system. 50th International Conference on Environmental Systems.

Ames Electronic Nose / Chemical Detection

KEY ATTRIBUTES / COMPETENCY

- Individually addressable multi-channel sensing
- Integrated temperature, pressure, and humidity sensing
- Detection limit range: ppm to ppb
- Response time in seconds at room temperature
- Reproducible from sensor to sensor
- Room temperature operation
- Low power: µW to mW/sensor
- Easy integration
- Sensor chip size is 1x1cm^2 with 12-256 channels

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

An intelligent, compact, highly sensitive, low-powered, fast responding analytical tool replicating the human olfactory system capable of identifying and classifying complex mixtures of chemicals and odors.

HERITAGE

- Tested aboard a US Navy Satellite and International Space Station
- Multiple peer-reviewed journal publications and US patents
- This E-Nose technology is licensed by many startups for their applications in health diagnosis (diabetes, flu, cardiovascular disease, various types of cancers, etc.), and environmental monitoring.

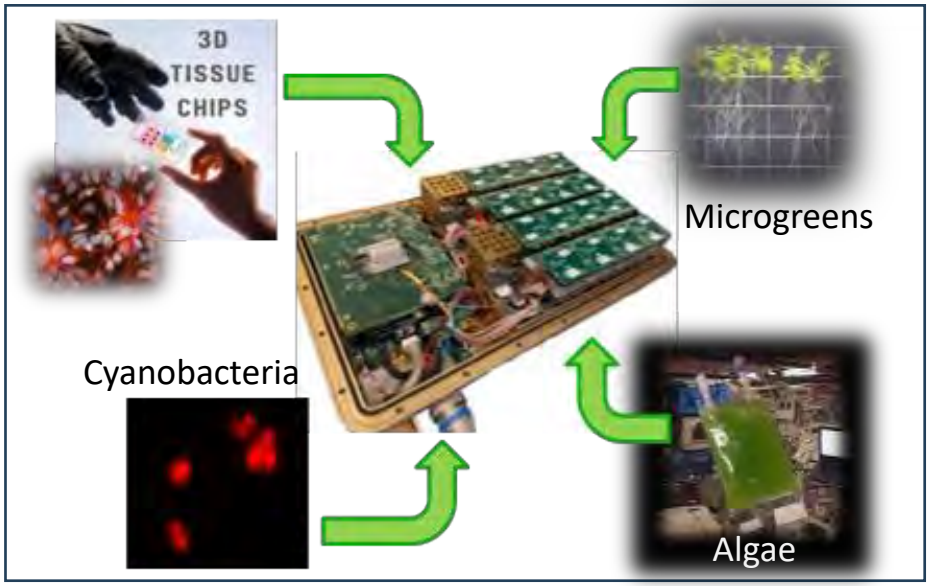
SUMMARY

NASA Ames spaceflight-proven robust E-Nose technology with its current TRL of 5-6 has been demonstrated for many NASA, DHS, HHS, DoD, and other commercial applications. Integration of sampling, sensing and computing in a one platform allows in-situ, real time, automated measurement compared to other SOA detection systems.

APPLICATIONS BEYOND

E-nose can be utilized for fire detection, crew health and safety, fuel leak detection, food safety and air quality monitoring.

Ames BioSensor instrument



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Versatile flight-validated (TRL9) instrument capable of accommodating and supporting a variety of biological organisms with dedicated microfluidic, optical, and thermal control capabilities.

SUMMARY

Microfluidic-based instrument fully developed at Ames Research Center. The BioSensor has a modular design with up to 18 fluidic cards and hundreds of samples to study the effect of the space environment on biological organisms.

Robust design adaptable to meet a variety of science requirements on different platforms, including low Earth orbit (LEO), ISS, free-flyers, landers, etc.

KEY ATTRIBUTES / COMPETENCY

- TRL9: Developed for BioSentinel mission to study effect of cosmic radiation on model organism (budding yeast). All instruments validated in LEO (ISS) and in deep space.
- Modified for LEIA CLPS mission to study effects of lunar environment on biology and on biomanufacturing.
- Proposed for upcoming lunar missions to screen for microgreen crops and algae/cyanobacteria (*i.e.*, in situ food and antioxidant production).
- Compact radiation detectors within the same enclosure.
- 256-288 bio samples in 16-18 fluidic cards. Each card with dedicated fluidic, optical, and thermal subsystems.
- Mass: ~5 kg (15.8 x 14.5 x 16.6 cm); Power: 3.55 W; Data: 0.004 GB/day

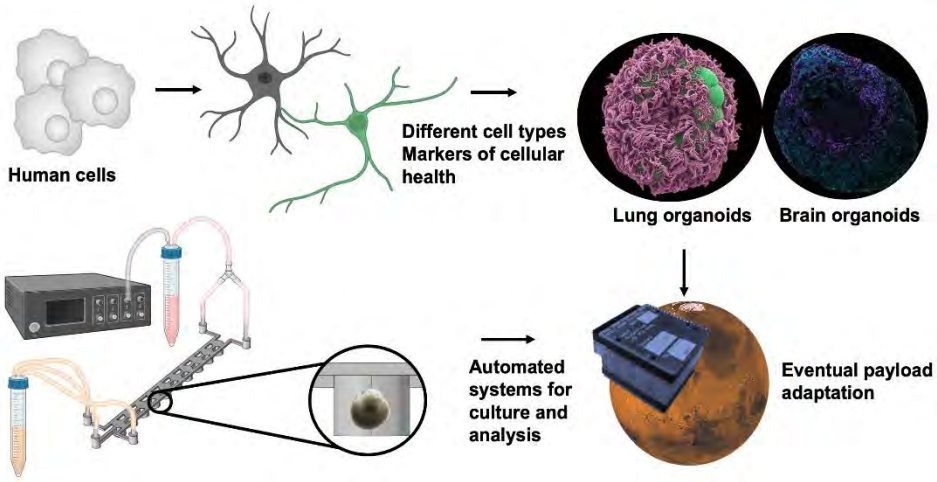
HERITAGE

- Flight heritage from BioSentinel deep space (Artemis I, Nov 2022 – present) and ISS (2021-2022) missions.
- LEIA lunar surface mission, launching to the Moon onboard CLPS lander NET 2027.

APPLICATIONS BEYOND

Proposed to perform experiments on different LEO and BLEO platforms and with a variety of organisms (plants, algae, organoids) and observation approaches (microscopy, fluorescence, luminescence).

Human organ models at Ames for Human Health in Deep Space



KEY ATTRIBUTES / COMPETENCY

- Long-lasting, personalized, human lung and brain organoids
- Genetically engineered cellular reporters of biological effects of ionizing radiation
- Microfluidic systems for organoid maintenance on bench
- Fluorescence, luminescence, absorbance and dissolved signaling molecule-based quantification of biological responses

HERITAGE

- Human organ models for space biomedical research
- Autonomous biological payloads on small satellites and microfluidic development for biological payloads
- Image- and media analysis-based quantification of biological responses
- Simulated chronic and acute space radiation

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

1. Precision health to investigate and mitigate astronaut health risks in deep space.

2. Automated payloads for space biology research beyond low-Earth orbit.

SUMMARY

We have developed long-lasting, complex, human organ models for understanding deep space-mediated impairments to central nervous system and respiratory system, as well as a microfluidic system for sustained culture. Our next goal is to adapt our model to a fully automated flight payloads in and beyond low Earth orbit.

APPLICATIONS BEYOND

- Individual assessment of astronaut health risk and countermeasure efficacy.
- Spaceflight and space radiation as an analog to accelerated aging for benefits to terrestrial biomedical research.

Ames Vented Fly Box Hardware Suite

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TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Robust hardware suite for fruit fly (Drosophila melanogaster) investigations in space

- Designed to meet a variety of science requirements while minimizing the use of constrained resources (crew time, mass, volume, conditioned stowage)

SUMMARY

- Full complements of flight- and ground-certified hardware available to support testing, flight and ground controls
- Operations require minimal crew time and no prior training
- Designed for ambient stowage over full mission duration
- Integration and operations products largely reusable between missions

KEY ATTRIBUTES / COMPETENCY

Vented Fly Box (VFB)

- 1.5U anodized aluminum box (10cm x 10cm x 14.2cm)
- Screened vent holes support passive gas exchange
- Internal foam tray secures vials and prevents movement
- Accommodates data loggers to monitor temperature and relative humidity (optional)

Sample Vials

- 15 polystyrene vials with cellulose acetate plugs (commercial off-the-shelf, *Drosophila* lab standard)
- Food composition and initial quantities/life stages of organisms tailored to meet science requirements

Payload Container Foam

- Closed cell foam provides secure stowage to minimize effects of launch and landing
- Interconnected channels support air-exchange
- Accommodates passive or active dosimeter to monitor radiation exposure within the payload container (optional)

HERITAGE

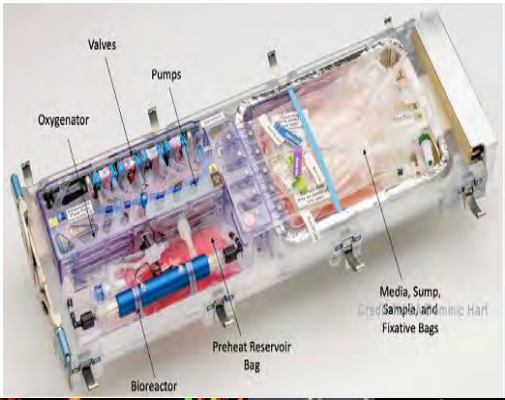
Used successfully for multiple ISS investigations

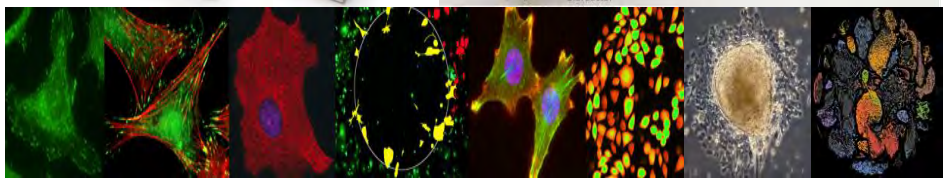
- Fruit Fly Lab-02/SpaceX CRS-11: effects of microgravity on cardiac function, structure and gene expression
- Fruit Fly Lab-03/SpaceX CRS-14: altered virulence of a natural parasite of *Drosophila*
- Planned for use in two upcoming investigations

APPLICATIONS BEYOND

- Adaptable for other organisms with similar volume and environmental requirements
- Customizable to support different platforms, sample quantities, and stowage constraints

Ames Bioculture System





Automated Bioculture and Sample Preservation in Space

- Mammalian Cell and Organoid Culture
- Yeast and Microbial Culture
- Small Organism Culture (C. Elegans, Tardigrades, etc.)
- CO2 or Other Gas Supply and Gas/Liquid Exchanger
- Bioreactor Temperature up to 37oC,
- Medium Supply Bag, Sump Bag, Sample Bags
- Refrigerated Compartment for Medium and Sampling Storage
- Variable Flow Rate Pumping
- Three Levels of Containment for Hazardous Samples/Reagents
- Configurable Valve-Controlled Flow
- Remote Monitoring/Operation From Ground or by Astronauts
- N=10 Durable Housing Cassettes With Disposable Flowpath

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

The NASA Bioculture System addresses the challenge of growing cells, organoids, microorganisms, and small organisms in microgravity in a highly automated and controlled environment for biological experimentation in space. This hardware specifically supports the ability of NASA HRP and Space Biology to conduct investigations addressing human crew health in deep space.

HERITAGE

- Based on the Space Shuttle Cell Culture Module (CCM) Hardware Concept
- Newly Re-Designed for ISS Express Rack Interface With Enhanced Features
- Successfully Flight Validated and Used with Cell, Organoids, and Small Organism Cultures

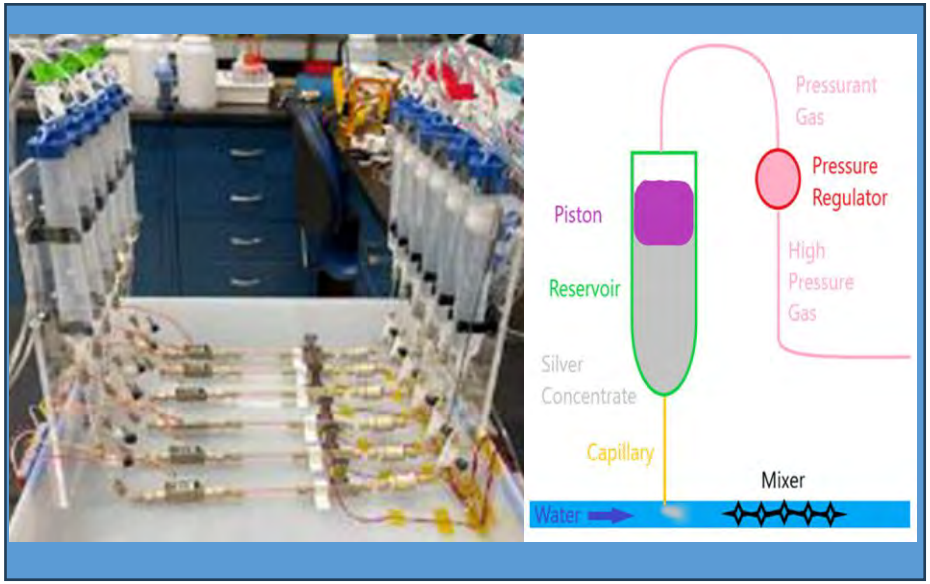
SUMMARY

Current Status is flight approved for ISS, with successful spaceflight heritage. The NASA Bioculture System is likely the most advanced and capable spaceflight hardware for microgravity cell biology in existence.

APPLICATIONS BEYOND

The NASA Bioculture System ISS form factor can be adapted for deep space and Moon/Mars exploration, using a single cassette unit as a basis for a reduced mass and volume design, where internal number of bioreactors increase from 1 up to 6, and autonomous experimental operation time is increased from 30 to 90 days

Ames Direct*INJECT*



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

DirectINJECT is a method for injecting a controlled volume without the need for mechanical pumps.

SUMMARY

SOA: NASA uses mechanical pumps which have largely proven to be unreliable in lifetime and dosing volumes.

Capable of dosing continuously or intermittently at dose rates from low μL to high mL per minute flow rates.

Has demonstrated 40 weeks of dosing with only 10% variation.

KEY ATTRIBUTES / COMPETENCY

Bullet point list

- Non-mechanical method of dosing for high reliability
- Ability to change dosing rates
- Average dosing rates can be verified using Fluid Dynamic Mass Gauging technology (submitted separately)
- Low ESM system (nominally 1kg and 1L)
- A 1 μL/min dosing system demonstrated long term flow stability of 10%

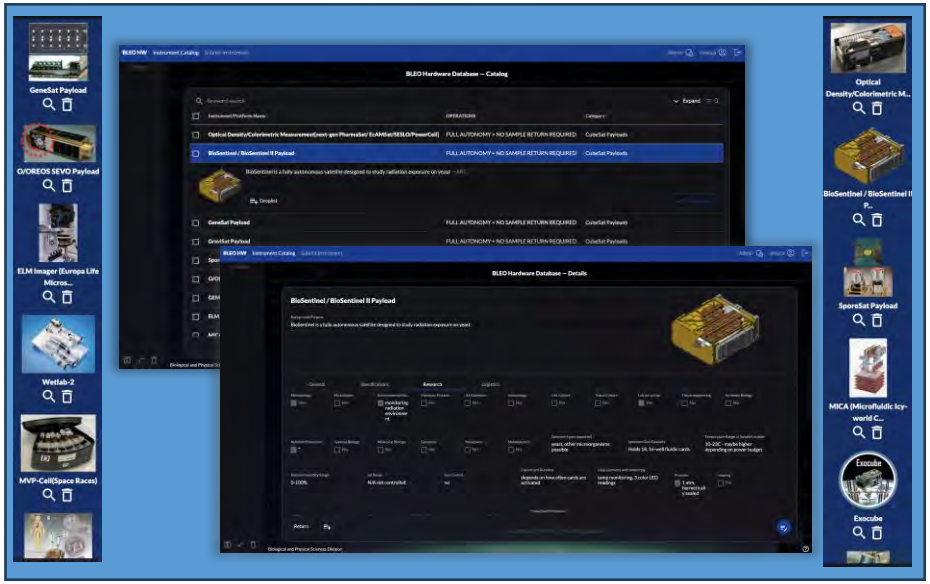
HERITAGE

- Laboratory testing and development

APPLICATIONS BEYOND

Applicable to Gateway, Lunar, and Mars missions where dosing is required. Dosing applications include biocide and urine pretreat.

Ames Space Life Sciences Hardware Database



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

To provide to the public a searchable database, integrated into the NASA Open Science Data Repository (OSDR), describing hardware for spaceflight biology and physical sciences experiments, past and current.

SUMMARY

SLSHD has two primary goals.

Understanding the past: Provide reference information about the experimental hardware that was used to generate the data and samples present in other OSDR databases.

Shaping the future: Facilitate design of experiments or new hardware by providing users with a comprehensive understanding of what capabilities already exist.

KEY ATTRIBUTES / COMPETENCY

SLSHD is currently in development. Initial public release is planned for fall 2025. Community participation will be required to ensure robust content.

Anticipated features of SLSHD:

- Individual entries containing technical specifications for dozens of instruments and payloads for the biological and physical sciences in space. Will include instruments that are previously flown or flight-ready, compatible with ISS, CLDs, or beyond-LEO platforms.
- Intuitive user interface with Search, Compare Instruments, and Export Data functionality.
- Links to related datasets and specimen entries on other OSDR repositories, and to related publications on Space Life Sciences Library.
- Built-in mechanism for users to suggest new entries or corrections.

HERITAGE

- OSDR enables access to diverse forms of space-related data from experiments and missions that investigate biological and health responses of terrestrial life to spaceflight. SLSHD benefits from the existing robust structure and active user community of OSDR.

APPLICATIONS BEYOND

SLSHD could serve as the go-to reference for payload developers and researchers designing new experiments for Commercial LEO Destinations.

Ames Open Science Data Repository (OSDR)

https://www.nasa.gov/osdr/

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

NASA OSDR addresses the technical and scientific challenge of ensuring the accessibility, standardization, and long-term usability of complex, multimodal biological and biomedical datasets from spaceflight and ground analog experiments. By implementing FAIR data principles and providing advanced bioinformatics tools, OSDR overcomes barriers to data integration, interpretation, and reuse, enabling researchers to derive new insights into the effects of spaceflight on terrestrial life.

SUMMARY

With over 500 public studies curated for reusability, the NASA Open Science Data Repository (OSDR) provides access to space-related data from experiments and missions that explore the biological and health responses of terrestrial life to spaceflight. By enabling over 100 publications, OSDR has maximized scientific return and the return on investment for both spaceflight and ground-based experiments. Recognized globally as the premier space biology and biomedical data repository, OSDR hosts data generated by multiple space agencies, research institutions, and commercially funded experiments.

KEY ATTRIBUTES / COMPETENCY

- Maintain and expand a maximally open-access, FAIR (Findable, Accessible, Interoperable, and Reusable) data repository.
- Curate and provide public access to spaceflight and ground analog experiment data, including ‘omics, physiological, behavioral, and environmental telemetry data.
- Facilitate streamlined submission processes and foster partnerships to enhance OSDR studies through sample sharing or data augmentation.
- Generate new insights by processing preserved spaceflight samples and integrating them into existing studies.
- Develop community-driven guidelines for sample processing, metadata curation, and data management to ensure long-term usability.
- Provide intuitive public visualization tools for space-relevant datasets, including radiation dosimetry, environmental telemetry, and biological response data.
- Foster scientific collaboration through OSDR Analysis Working Groups and educational programs like GeneLab for Colleges, Universities, and High Schools.
- NBISC Biorepository: Follows best practices and standards to archive over 100,000 biospecimens from space and ground analog experiments, ensuring accessibility for research and discovery.

HERITAGE

- Over 500 public studies curated for reuse and scientific discovery.
- Over 100,000 biospecimens available for request and reuse by global scientific community.
- Implementation of 60+ standardized metadata and data processing frameworks.
- Integration of commercial astronaut data, including Inspiration4 (I4) mission datasets.
- Collaboration with the European Space Agency (ESA) for space omics data standardization and sharing.

APPLICATIONS BEYOND

OSDR has demonstrated its ability to share commercial astronaut data through controlled data access, integrate data from other space agencies, and establish international consortiums while enabling the launch of new companies. With established standards and adoption by the global science community, OSDR provides a unified platform that reduces the need for individual companies to develop separate data-sharing systems. Its ability to ensure interoperability accelerates scientific discovery and enhances knowledge by enabling the integration of multiple datasets for deeper insights into space biology and biomedical research.

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AUTOMATION, ROBOTICS, PLANNING, THERMAL PROTECTION & RELATED TECHNOLOGIES

Astrobee Free-Flying Robots in LEO
A Proven Platform for Intra-Vehicular Robotics

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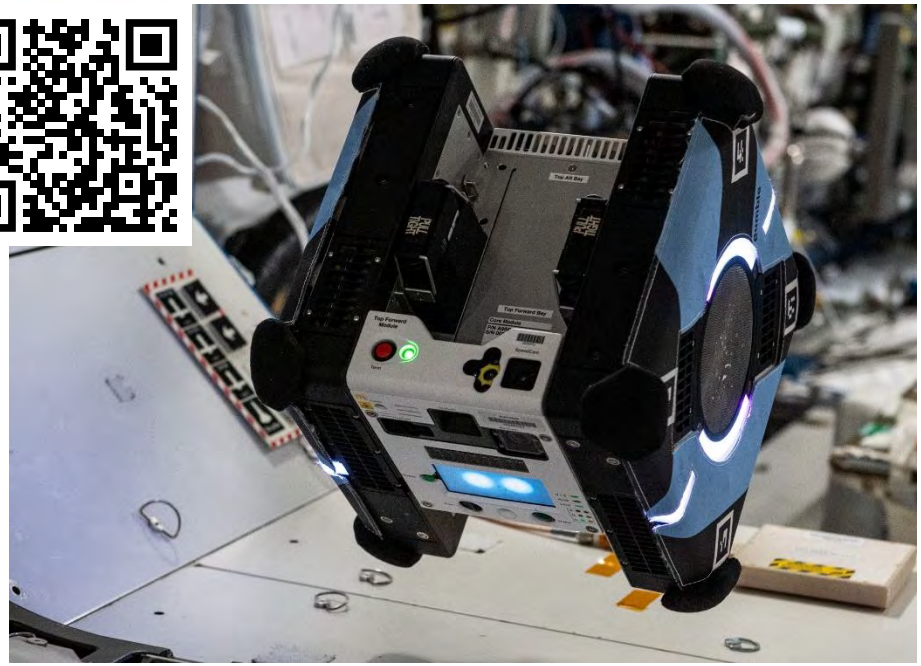
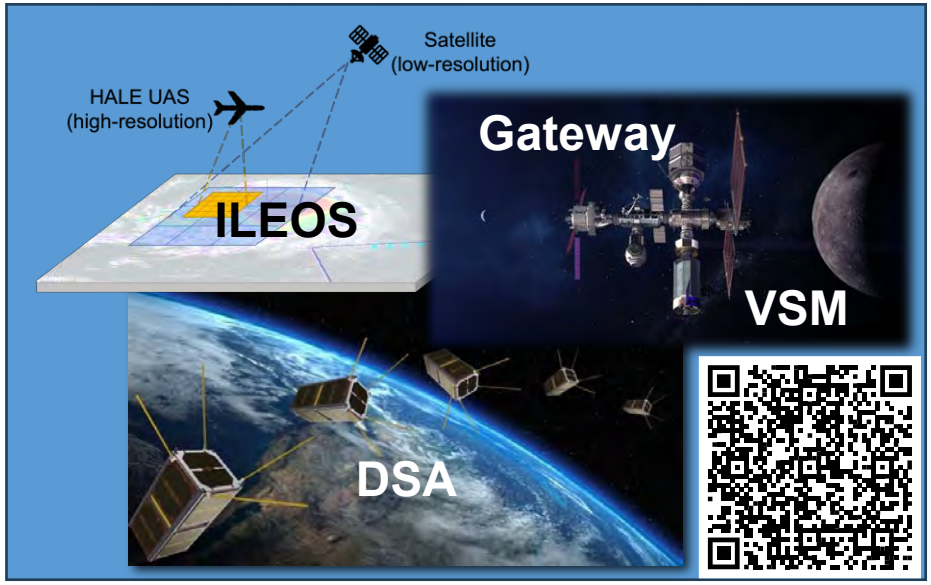


HERITAGE
- Meets strict ISS integration and safety requirements, crew appreciate low acoustic noise
- Hundreds of ISS activities flown, over 1000 operating hours
- Utilized on ISS by 17 guest science investigations, including hosting educational robotics competitions for thousands of students from all over the world
- Designed to host guest science: 3 payload bays with quick-swap capability and independent processor devoted to running guest software
- Astrobee API exposes robot commanding and telemetry interfaces to guest software running onboard and on the ground
- Well-established on-ramp for easy guest science payload and ops integration
- Well-established ISS procedures for payload operations

KEY ATTRIBUTES / COMPETENCY
- Autonomously fly throughout station using vision-based localization without artificial landmarks
- Holonomic 6-DOF propulsion can simulate any prop configuration
- Forward- and aft-facing RGB and depth imagers
- 2-DOF arm with gripper enables perching on handrails and transporting objects
- Operate over two hours on a single battery charge, no consumables, can charge autonomously using dock
- Fully autonomous plan execution continues even through loss-of-signal periods; ground operators can oversee ops when space-to-ground link is available
- Autonomously collect imagery to build panoramic tour of station interior, or perform close-up targeted inspection
- Multiple Astrobees can inter-communicate and fly together

APPLICATIONS BEYOND: Bring to your station!
- No station modifications needed
- Astrobee itself (9 kg) uses WiFi networking
- Optionally upmass multiple Astrobees (3 have flown to ISS and more on the ground)
- Optional docking station (20 kg) provides berths for two Astrobees, enabling autonomous dock/undock and recharging.
- Dock uses 120VDC power and optional wired Ethernet, mounts to wall with Velcro
- Without dock, crew can easily swap and charge batteries using a standalone charger

Planning and Scheduling



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

We build automated planners to solve planning problems with **Complex temporal constraints, Limited resources, Over-subscription and optimization, Uncertainty.** Applications include **Mission Planning, Control and Autonomous Systems.**

SUMMARY

The NASA Ames Planning and Scheduling Group has extensive experience delivering planning and scheduling software to NASA missions involving ground, flight, and surface operations, across the spectrum of NASA endeavors on Earth, in space, and for planetary exploration. Our customers span every NASA mission directorate; we have achieved numerous 'firsts' in both human and robotic spaceflight

KEY ATTRIBUTES / COMPETENCY

Developing automated planning and scheduling software to address NASA's many and diverse planning and scheduling needs. Automated planning and scheduling systems that are essential components of autonomous spacecraft, deep space probes, planetary rovers, and autonomous vehicles. Current projects include:

- Distributed Spacecraft Autonomy: Autonomy technology for Small Spacecraft Swarms
- Intelligent Long Endurance Observing System(ILEOS): technology to plan high altitude UAS missions
- Gateway Vehicle System Management: automated planner for NASA's Gateway mission
- Spaceport Throughput Analytical Resource: throughput analysis for Kennedy Space Center
- D-SHIELD: automated planning for fleets of Earth-observing satellites

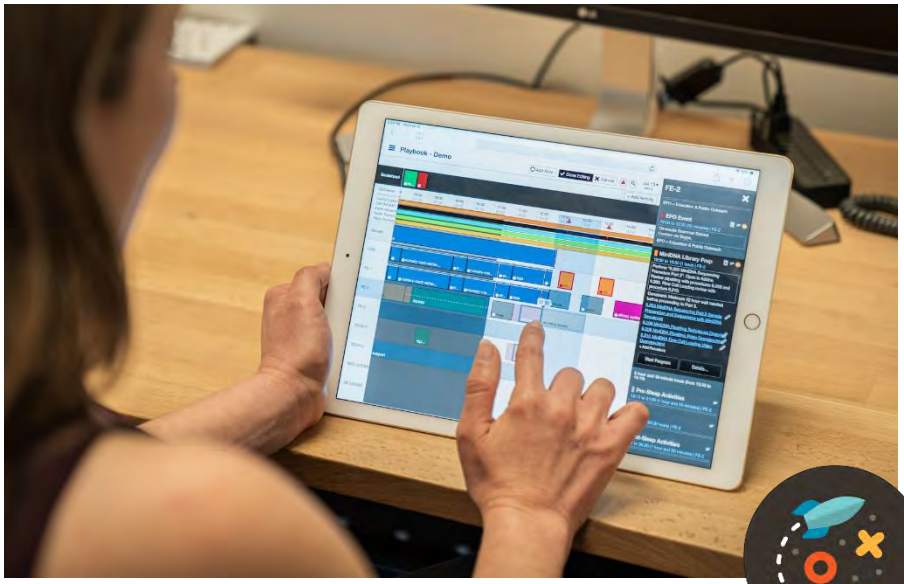
HERITAGE

- Remote Agent: first AI planner in Deep Space
- MAPGEN: Activity Planning for Spirit and Opportunity
- Autonomous Systems and Operations: human spaceflight autonomy technology development and demonstrations
- Autonomy Operating System: automated plan execution for UAS
- Solar Array Constraints Engine: ISS Solar Array Operations Planner

APPLICATIONS BEYOND

Helioswarm mission planning, HLS, Lunar Infrastructure, future Mars missions

Collaborative Planning, Scheduling, and Execution Software for Space Operations: Playbook



TECHNICAL CHALLENGE ADDRESSED

Enabling completion of highly constrained, operational objectives through a collaborative, web-based planning, scheduling, and execution software for space missions.

SUMMARY

Playbook is a next-generation planning, scheduling, and execution tool that allows collaborative editing, shared activity status, and integrated multimedia chat and procedures. This easy-to-use software checks activity and plan resources and constraints, providing aids to resolve violations. Activity Dictionary flexibility allows for robotic, payload, and/or human activity planning. Playbook is currently provided as a software-as-a-service to NASA customers across different mission directorates.

KEY ATTRIBUTES / COMPETENCY

- Activity/plan constraint and resource modeling, as well as real-time checking.
- Imports for static profiles / states, graphed alongside the timeline. Real-time calculations of profiles based on activity scheduling/rescheduling.
- Multiple views: horizontal timeline, waterfall, table, and calendar (monthly).
- Support for defining and scheduling of template activities.
- Enables unique crew-centric capabilities: self-scheduling, scheduling of task list activities, and addition of crew notes.
- Multimedia chat interface, supporting images, video, audio, and files.
- Navigator workspace, supporting multiple schedules.
- Planner workflow (in-work > active timelines), API support.

HERITAGE

Members of the Human-Computer Interaction Group (Human Systems Integration Division at NASA Ames) have contributed to scheduling software platforms for two decades, supporting Mars, ISS, and Lunar programs.

Playbook is currently used in CLPS and Earth analog missions (HERA, CHAPEA). A variant of Playbook (COCPIT) is currently used for the Mars2020 rover.

APPLICATIONS BEYOND

Additional customers enhance and expand capabilities across various types of missions.

POC: J. J. Marquez, jessica.j.marquez@nasa.gov

https://hci.arc.nasa.gov/work/playbook.html

Cross-Program Integrated Data Systems (CPIDS)

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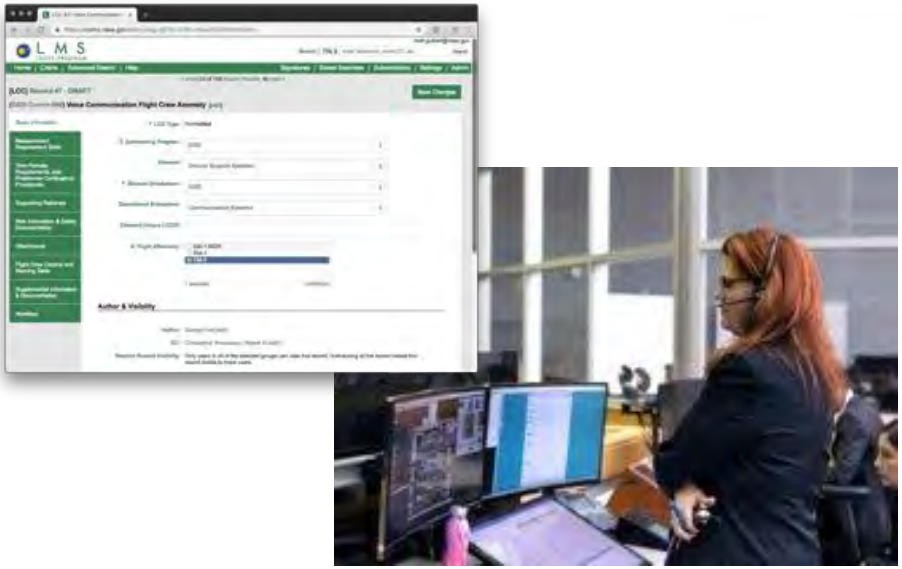

TECHNICAL CHALLENGE ADDRESSED

Collaborative, web-based structured data systems to support distributed teams with data management.

SUMMARY

CPIDS is a team of Human-Computer Interaction (HCI) professionals using human-centered research methods and design principles to develop web-based, collaborative software for decision support for safety critical missions.

We produce a suite of enterprise date integration applications to capture and associate safety, engineering, and operations data for human spaceflight programs.

KEY ATTRIBUTES / COMPETENCY

- Our main product is **Mission Assurance Systems (MAS)**, a platform of ~30 configurable instances based on user needs, ranging from problem reporting to safety data management to work authorization documents.
- Other products include Schematics Catalog (securely upload, search, and navigate schematics collaboratively) and Cross-Program Search (search records and surface links across applications while respecting permissions)
- All offered applications are in operations and are used by Moon-to-Mars and Artemis programs, ISS, WSTF, etc.
- Notable applications include: CP-Hazard, ISS Hazard, CP-LMS, CP-OMS, CP-FMEA, and more.
- Notable features include: digital signatures for asynchronous workflow management, version history to support configuration management, and role-based permissions for distributed read, write, and edit access.

HERITAGE

The CPIDS team and MAS applications have been operational for 20+ years. These applications have been used in support of ISS safety engineering, White Sands Test Facility and Arc Jet Test Facility operations, and Artemis I launch operations and will be used to support future Artemis missions.

APPLICATIONS BEYOND

Any needs for capturing, reviewing, managing, or integrating structured data.

POC: Liz Wagstaff (elizabeth.wagstaff@nasa.gov), NASA Ames

Aerothermodynamics and Thermal Protection Systems (TPS) for Low Earth Orbit (LEO) Return

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TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

NASA Ames assists with aeroshell design and analysis for LEO return and has provided Conformal PICA (Phenolic Impregnated Carbon Ablator) and SIRCA (Silicone Infused Refractory Ceramic Ablator) for the entry aeroshells of emerging commercial space companies. Ames continues to partner with commercial space companies on lower cost TPS options.

SUMMARY

LEO down-mass options are of great interest in the growing LEO economy. NASA Ames provides Government expertise and intellectual property to emerging commercial space companies in aeroshell design and analysis.

NASA Ames has expertise in aerothermodynamics and thermal protection system (TPS) materials and integration approaches that can be applied to the selection and sizing of the TPS for aeroshells. NASA developed TPS materials can also easily be tech-transferred to allow companies to make their own material for their missions and further commercial growth.

KEY ATTRIBUTES / COMPETENCY

NASA Ames develops and validates entry system design and analysis tools including: DPLR, a hypersonic flow solver for convective heating prediction; NEQAIR, a spectral radiation transport solver for radiative heating prediction, and FIAT, a material response solver for in-depth temperature prediction. All tools are available for release to commercial space companies.

Conformal PICA is a NASA invented ablative TPS that is more mass/cost efficient than state-of-the-art rigid PICA and fully capable of handling LEO return forebody environments.

SIRCA is a NASA invented ablative TPS fully capable of handling LEO return aftbody environments.

HERITAGE

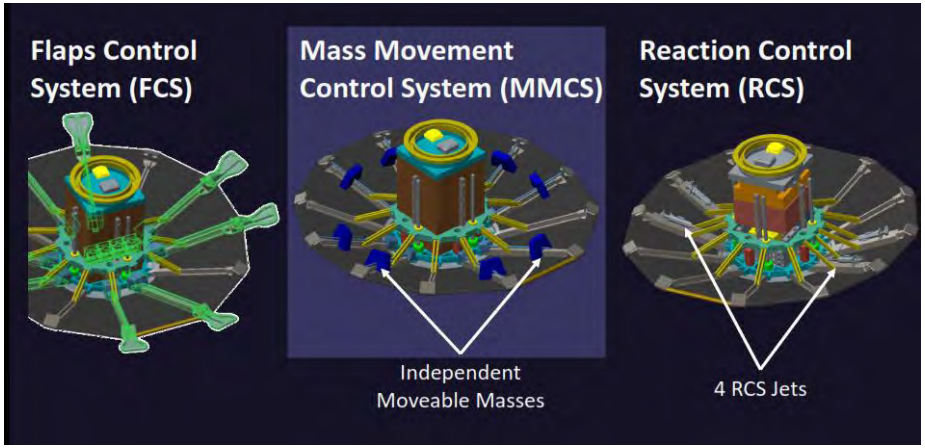
- Ames has supported the design of all NASA LEO return missions to date with its aerothermodynamics and TPS expertise.
- Rigid PICA flew on Stardust, MSL/M2020, and OSIRIS-REx.
- PICA is made by FMI who produces the FiberForm preform for PICA. FiberForm is no-longer commercially available and is only made for NASA (Dragonfly and MSR SRL). Minimum order costs in the $millions.

APPLICATIONS BEYOND

NASA developed tool and TPS technologies can also be leveraged for Lunar Return and Mars missions.

POC: Matt Gasch – NASA Ames Research Center

Non-Propulsive Control Systems for Low Earth Orbit Return



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Depending on the entry vehicle design, non-propulsive control systems may result in substantial performance gains for ballistic/lifting and guided entries. They may replace entry thruster control systems and offer increases in the amount of payload volume and mass available for missions while maintaining precision targeting of a descent initiation point. This could be advantageous for both heritage rigid entry capsules and unconventional deployable entry systems.

SUMMARY

NASA developed guidance and control tools to explore and design non-propulsive control systems and compare against heritage reaction control systems (RCS) to understand advantages that such novel control systems could introduce with respect to volume, mass, and maneuverability. Most recently, the Agency has begun providing precision guidance and control system support to commercial space transportation to advance space transportation applications of mechanically-deployable entry systems.

NASA Ames Capabilities

- Patented technology, Aerospace Vehicle Entry Flightpath Control (U.S. Patent No. 11,772,828).
- Mechanical design and system engineering of different types of non-propulsive control systems that include but are not limited to control surfaces such as flaps or trim tabs, center of gravity shifts via mass movement, aeroshell shape morphing, or any combination of these.
- Generation of anchored aerodynamic databases for a high-fidelity understanding of aerodynamics and aerothermodynamic performance of non-propulsive control systems.
- Three degree-of-freedom (3-DOF) analysis of trajectory simulations and 6-DOF simulations to understand vehicle stability and control envelope.
- Monte Carlo analysis to define solution robustness.

HERITAGE

- Leverage control system development achieved for mechanically-deployable entry system architecture and design applications.

APPLICATIONS BEYOND

- Reentry and aerocapture applications for future space systems.

NASA POC: Sarah D'Souza (TSS)
sarah.n.dsouza@nasa.gov, NASA Ames Research Center

Mechanical Deployables for Low Earth Orbit Return

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NASA Ames Capabilities

- Design and System Engineering: Operational implementation planning utilizing ADEPT
- Aerothermal Environment Predictions: CFD simulations of flight vehicle during hypersonic aerothermal heating
- ADEPT TPS Material Selection and Design Support: TPS (Thermal Protection Systems) material trade studies and preliminary TPS sizing (thickness predictions)
- Structural Design Support Consultation on deployment system design and stowage leveraging ADEPT lessons
- Arc Jet Testing: test planning and execution of initial material screening tests in the NASA Ames Arc Jet Complex

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Hypersonic deployable decelerators can enable reentry and aerocapture missions by overcoming launch vehicle shroud and secondary payload packaging constraints. NASA Ames has established expertise that is relevant to this novel technology by way of its development of a mechanically-deployable hypersonic ADEPT (Adaptable, Deployable Entry Placement Technology) decelerator.

HERITAGE

- Leverage ADEPT TPS architecture and design application

APPLICATIONS BEYOND

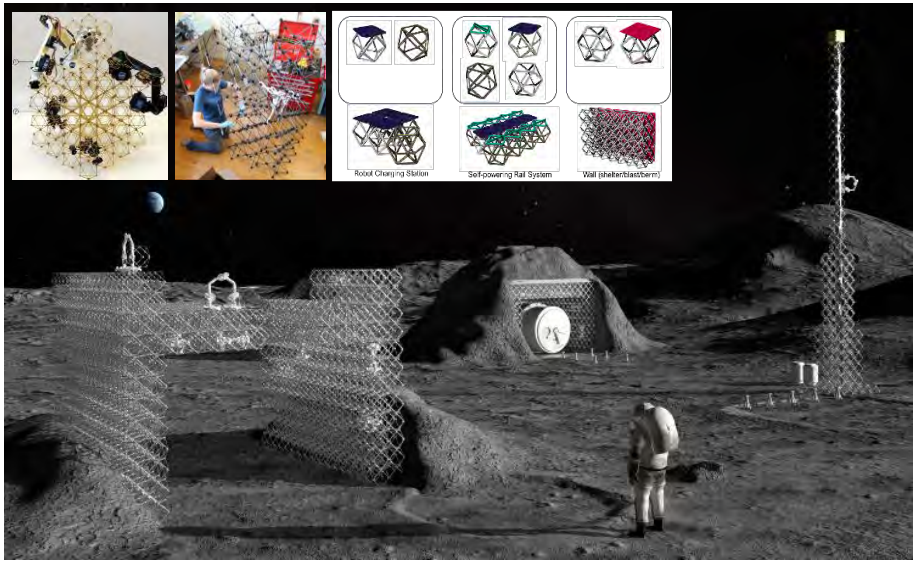
- Reentry and aerocapture applications for future space systems

SUMMARY

After a decade of developing ADEPT, NASA Ames is now providing support to commercial space transportation development activities, including design and testing, to advance space transportation applications of mechanically-deployable hypersonic decelerators.

NASA POC: Paul Wercinski (TSS) paul.wercinski@nasa.gov

Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS)



TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Autonomous assembly, monitoring, repair, & reconfiguration of high-performance structures that suit demanding static or dynamic structural applications. Autonomous repair and reconfiguration offers manufacturability, scalability, and significant application lifecycle advantages.

SUMMARY

Technology to enable robust and scalable autonomous assembly and maintenance of infrastructure. Structural assembly and management system consisting of a composite building block-based structures and algorithmically coordinated teams of simple low-cost robots. Applications include primary structures and as reinforcement for composite methods utilizing low beneficiation local materials (i.e. concrete, lunarcrete, or marscrete).

KEY ATTRIBUTES / COMPETENCY

- Algorithmic structural systems and robotics to enable mission adaptive autonomous infrastructure.
- Multifunctional meta-materials and structural systems - modular and reconfigurable metamaterials, with reconfiguration energy costs that are orders of magnitude less energy than producing or recycling conventional materials with the same performance.
- Cooperative task specific modular robotics, using programmable/reversible assembly and reconfiguration algorithms
- building block strategy for autonomous robotic assembly and maintenance of high-performance structures.

HERITAGE

- Ground demonstration of the robots and many physical building blocks that are autonomously assembled to multiple structures. https://www.science.org/doi/10.1126/scirobotics.adi2746
- Shape morphing aircraft structures, ultralight structural materials w/ tunability & repairability (MADCAT Project).

APPLICATIONS BEYOND

Cost reduction for long-duration missions, autonomous assembly of on-orbit space port structures, increased capability / system robustness / mass savings for lunar surface habitat structures, large aperture instrumentation…

Robots for Human Explorers

Intelligent Robotics

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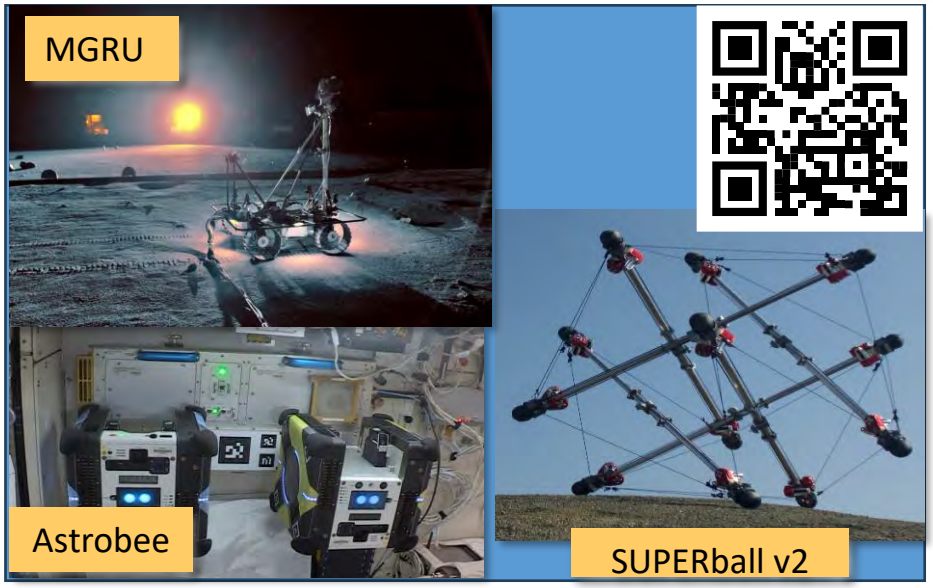

KEY ATTRIBUTES / COMPETENCY

Improving efficiency and productivity of missions through use of intelligent robotics technology

Before Crew

- Recon (scouting) and prospecting
- Site preparation, deploy equipment, etc.

Supporting Crew

- Inspection, mobile cameras, and sensor networks for monitoring
- Heavy transport and mobility

After Crew

- Follow-up and close-out work
- Site survey, infrastructure maintenance, etc.

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

- Increase human productivity
- Improve mission planning and execution
- Transfer some tasks to robots, e.g. dangerous, tedious, repetitive, and long-duration

HERITAGE

- Free-flyers, drones, and rover platforms – *MGRU, Astrobee, SUPERball v2, KREX-2*
- Extensive analog field testing experience in Hawaii, Mojave, Atacama, Devon island, Lava Beds, etc.

SUMMARY

- Robots to aid human exploration of extreme environments, remote locations, and uncharted worlds.
- Applied research in computer vision, human-robot interaction, mapping, mobility systems, and decision-making.

APPLICATIONS BEYOND

- Human-robot teams for defense, civil inspection, and disaster response

Perception and Navigation

Intelligent Robotics

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TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

- Navigation and mapping for robotic exploration of extreme, unstructured, and GPS-denied environments
- New measurements and observation approaches to maximize scientific output of missions

SUMMARY

- Novel sensor systems and software enabling safe, efficient, any-time traverse
- Range of modalities from software-assisted human ops to sliding autonomy to fully autonomous navigation
- Past successes in land, sea, air and space domains

KEY ATTRIBUTES / COMPETENCY

- Guidance, navigation and control for dark and gps-denied environments, including hazard identification, localization, and visual odometry; State estimation and statistical decision making
- High-quality 3D mapping and modeling of planetary terrain and features for scientific purposes
- Observation strategies including intra-vehicular inspection, monitoring of transient phenomena (plumes, clouds, flows), and high-speed flyovers
- Sensor characterization and calibration from novel prototypes to spaceflight qualification
- Computational imaging and intelligent optics design
- Cameras, LIDAR, IMU, star trackers, thermal vision, RADAR, driver lighting systems, and more…

HERITAGE

- VIPER and Astrobee flight mission GNC
- ISS and Gateway inspection and maintenance (ISAAC), riverflow monitoring for earth science (Streamflow RiOS), icy moon EDL (ICICLES), cave exploration

APPLICATIONS BEYOND

- Safeguarding and navigation for humans including EVAs and terrestrial disaster response

Exploration User Interfaces

Intelligent Robotics

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KEY ATTRIBUTES / COMPETENCY

- Design of interfaces and displays; capabilities for visualization of data in 2D and 3D
- VERVE framework for developing interfaces to remotely operate robots
- Tools for science data visualization (xGDS, OpenMCT) and geospatial processing (Ames Stereo Pipeline)
- Many tools and packages are open sourced and maintained at ARC
- Operations procedure development and operator training expertise

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

- Enable operation of robots across a range of distances and mission cadences: human explorers with robot teammates, remote operation from Earth, and post-exploration science analysis

HERITAGE

- Vast experience in operations across missions and modalities: planetary rovers (VIPER, RP, ATHLETE), humanoids (Valkyrie), self-driving cars (Nissan), on-orbit servicing (Dragonfly), freeflyer teams (Astrobee), etc.
- Experience across various operational tempos and time delays relevant to Terrestrial, ISS, Lunar, Mars, and Europa.

SUMMARY

- Interfaces for human control of robots and robot teams; planning and oversight of mission objectives; and geospatial assessment of instrument and sensor data
- Presenting information to maximize situational awareness while balancing cognitive load

APPLICATIONS BEYOND

- Commercial autonomous driving, terrestrial applications for human-robot teams

Software Architecture and Simulation

Intelligent Robotics

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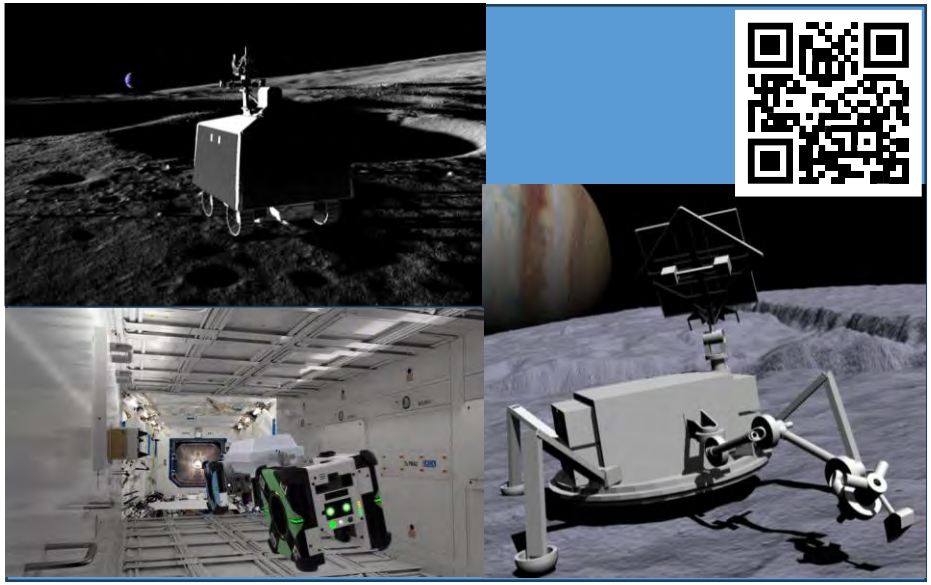

KEY ATTRIBUTES / COMPETENCY

- Reliable architectures and flight software for high-performance missions
- Experience with rover, drone, free-flyer, cubesat, and lander architectures with single and multiple robots
- Competences include CFE/CFS, ROS, Space ROS, DDS, etc.
- Virtual environments for software-in-the-loop simulation to develop navigation capabilities, refine concept of operations, and verify requirements
- High-fidelity physical testbeds of space environments, such as the Granite Lab and Lunar Lab, serve as digital twins for simulators, supporting hardware-in-the-loop testing

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

- Intelligent robotics software for long duration and mission-critical applications
- Use of innovative physical and virtual simulation capabilities for rapid, low-cost developments

HERITAGE

- Simulators for Moon (RSim), Europa (OceanWATERS), ISS (Astrobee Sim), UAVs (RiOS)
- Physical test environments including Lunar Lab, Roverscape, and Granite Lab

SUMMARY

- Flight and ground software for VIPER mission – first NASA rover intended to explore Lunar poles
- Astrobee software named NASA Software of the Year Runner-Up (2020)
- DSA-Starling demonstration of first fully autonomous distributed space mission with cubesats

APPLICATIONS BEYOND

- Commercial autonomous driving, drone swarms for defense, agricultural robotics

NASA SILICON VALLEY

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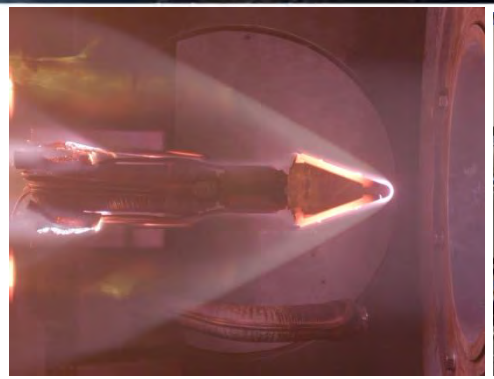
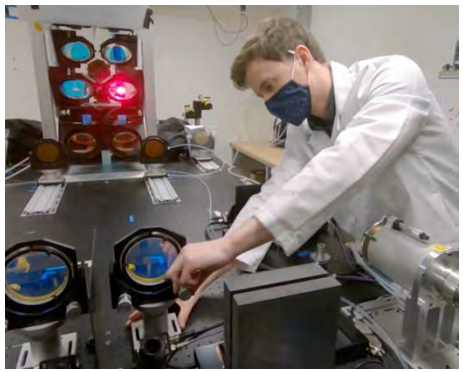
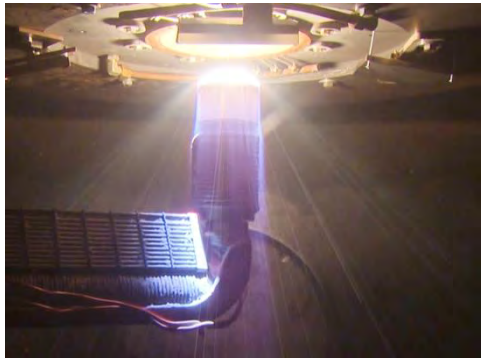
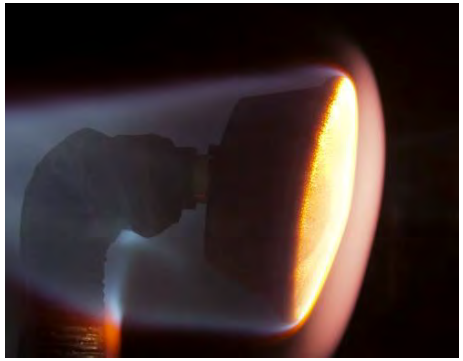
FACILITIES & OTHER CAPABILITIES

Arc Jet Test Capabilities

KEY ATTRIBUTES / COMPETENCY

- World class thermal protection material testing expertise spanning 60 years
- One of a kind test facilities in class
- High definition, high fidelity data, imagery, and videographic capabilities to suit any test objective including novel flow characterization capabilities and diagnostics/instrumentation advancement
- Experience with novel test configurations including actuated test hardware
- 200 kW of continuous wave laser irradiance with a max capability of 80 kW/cm^2 of radiative heating
- 60 MW, 20MW, 10 MW, and 30kW convective arc heaters supporting stagnation, wedge, and panel test configurations

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

High enthalpy, high temperature reentry testing for ablative, shape-stable, and insulative thermal protection material systems and structures

HERITAGE

- Industry, Government, and Academic testing since the Apollo Program
- 100+ test article tests per year over the past 20 years

SUMMARY

Arc jet facilities, such as those operated by the Thermophysics Facilities Branch at NASA Ames, are critical to any hypersonic or orbital reentry mission. NASA provides world class ground-based simulation of flight entry conditions and holds the experience required for delivery of high quality, meaningful, and actionable arc jet data.

APPLICATIONS BEYOND

The facilities are increasingly supporting commercial space and DoD hypersonic needs. There is also investment in low cost, high throughput capabilities.

Peter Race, NASA Ames Research Center

Multi-Mission Operations Center

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NASA'S MISSION CONTROL IN SILICON VALLEY

Agile and cost-effective operations resource for multiple simultaneous missions. Ready-to-use environment reduces cost and start-up time, shortens provisioning, and allows missions to focus more on science and less on infrastructure.

SUMMARY

Rooted in a deep history of flying large and small spacecraft, commanding payloads, and performing science data processing. The MMOC attributes allow projects to effectively perform all mission operations functions, including planning, scheduling, commanding, telemetry processing, and science analysis.

KEY ATTRIBUTES / COMPETENCY

- Facilities: Two mission operations facilities (N240 & N244). Remote operations available.
- Network: Ames Mission Network (AMN), dedicated solely to mission traffic. Connectivity to NASA centers, ground stations, external partners.
- Voice System: Mission Next Gen Voice (MNGV), standardized and customizable.
- Hardware and Software: Windows and Linux consoles, high-end computing Unix servers, cloud computing. Accommodation of any command and telemetry software. Mission collaboration and issue tracking suite provided.
- Services: Sys admin, IT security, database admin, network engineering, software/system design and procurement.

HERITAGE

ISS (Biology Research, SPHERES/Astrobee), Kepler/K2, LCROSS, IRIS, LADEE, SOFIA, STPSat-5, GeneLab, Starling, BioSentinel, VIPER

APPLICATIONS BEYOND

Increasingly supporting commercial space, providing expertise in areas such as IT security, interconnections, public policy, technical architecture.

POC: Justin Pane, justin.pane@nasa.gov

Mission Design Center (MDC)

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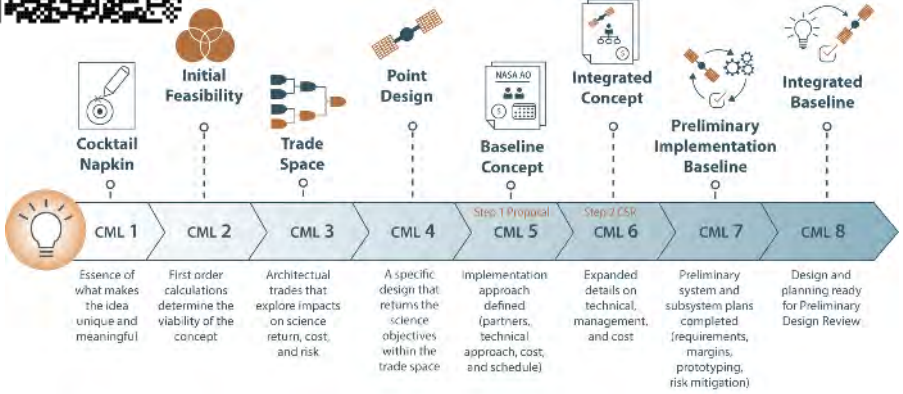
https://www.nasa.gov/ames-engineering/spaceflight-division/mission-design-center/

We utilize the *Concept Maturity Level* framework to develop your mission concept.



MISSION CONCEPT DESIGN AND DEVELOPMENT

- **Supporting:**
  - Competed Missions/Projects
  - Assigned/Directed Projects
  - Technology Demonstrations
  - Commercial Partnerships
  - Idea Development
  - Architecture Studies
  - Focused Trade Studies
  - Hand-off to proposal development teams.

KEY SERVICES PROVIDED

EXPERTISE

- Concurrent Engineering
- Mission Design & Trajectory Analysis
- Launch Vehicles, Flight Systems, & Propulsion Systems
- Mechanical Design, Structures & Mechanisms
- ADCS, C&DH, Communications, Power, Thermal Analysis
- Entry, Descent, and Landing Concept Design
- Cost Estimation
- Systems Engineering & Risk Analysis

Manufacturing & Test Division, Engineering Directorate

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KEY ATTRIBUTES / COMPETENCY

- **Machining & Instrumentation Branch (RMX)**: Flight Hardware Manufacturing, Wind Tunnel Models & Instrumentation, Precision Multi-Axis Machining, Additive Manufacturing, Prototypes, Design-For-Manufacturing, Reverse Engineering, Non-Destructive Evaluation, Inspection, Production Planning & Control, AS9100
- **Metal & Composite Fabrication Branch (RMF)**: AWS Certified Welding and Inspection, Water-jetting, Laser Cutting, Plasma and Oxy-Fuel Cutting, Sheet Metal Forming and Joining, Design-for-Manufacturing, Production Planning, AS9100
- **Engineering Evaluation Lab (EEL)**: Extreme Environmental Testing, Vibration & Shock Testing, Thermal-Vacuum Testing, Strain Measurement, Structural Testing, Modal Analysis, Specialized Calibration, Mass Property Measurement
- **Flight Processing Center (FPC)**: Flight system assembly, integration, and test. Class 100k & 10k cleanrooms, assembly and test labs, material control and storage solutions.

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

-Cradle-to-grave support of the engineering manufacturing, integration, test, and qualification process.

-Flight hardware fabrication, design-for-manufacturing, precision instrumentation fabrication and integration, hardware inspection, integration and assembly, environmental evaluation and analysis.

HERITAGE

- *Thousands of projects over 80 years,* ranging from early NACA airfoils to prototypes of the Boeing 777, through supporting flagship programs, such as Apollo, Shuttle, and Artemis.
- *Hundreds of customers,* including those within every NASA center, Air Force, Army, Navy, DoE, USGS, Industry, and Academia.

SUMMARY

Since the founding of Ames, the Manufacturing & Test Division has provided fabrication solutions for research hardware development, prototype exploration and development, consultation in manufacturability and management of fabrication projects. The division has *some of the most skilled technicians in the world*, transforming abstract ideas into tangible hardware for aeronautics, space flight and the advancement of science.

APPLICATIONS BEYOND

The division has expanded into collaborative manufacturing SAA's, with familiarity and adaptability to support a wide array of hardware development and testing needs. Current SAA's even scope manufacturing research, such as for high-rate composites.

PoC: Dr. Alex Mazhari, Deputy Division Chief, Manufacturing & Test. a.mazhari@nasa.gov

NASA Ames Animal Program and Facility

TECHNICAL / SCIENTIFIC CHALLENGE ADDRESSED

Animal research allows our understanding to move the Countermeasure Readiness Level (CRL) from 1 to 9 and to improve treatments for astronauts. At low CRL, we aim to understand basic biological responsese to environmental stressors. At mid-CRL, we aim to test and validate countermeasures in animals ahead of subsequent tests during a space mission.

SUMMARY

Ground-based facilities and expertise are critical for understanding the mammalian response to spaceflight. At the NASA Ames Animal Facility, scientists can mimic various environmental stressors with rodents and connect with key downstream infrastructure like our behavioral testing core, Imaging Facilities, Biospecimen Sharing Program, and GeneLab and the Open Science Data Repository.

KEY ATTRIBUTES / COMPETENCY

Ground-based capabilities

Rodent Hindlimb Unloading

Singly housed for mouse or rat

Pair-housing for mouse

Ionizing radiation

Animals shipped from NASA Space Radiation Lab @ Brookhaven National Lab

Centrifugation

Combinatorial Stressors

Dietary / Pharmacological Countermeasures

Breeding Colonies

Specialized techniques per PI and Vet team

HERITAGE

70 years of animal research in space has yielded fundamental and applied understanding of the organism's response to the spaceflight environment (NASA's *Translational Cell and Animal Research*)

APPLICATIONS BEYOND

Basic biology

Translational science and personalized medicine

Open Science Data Repository

NASA Ames Support of Commercial LEO Destination Companies

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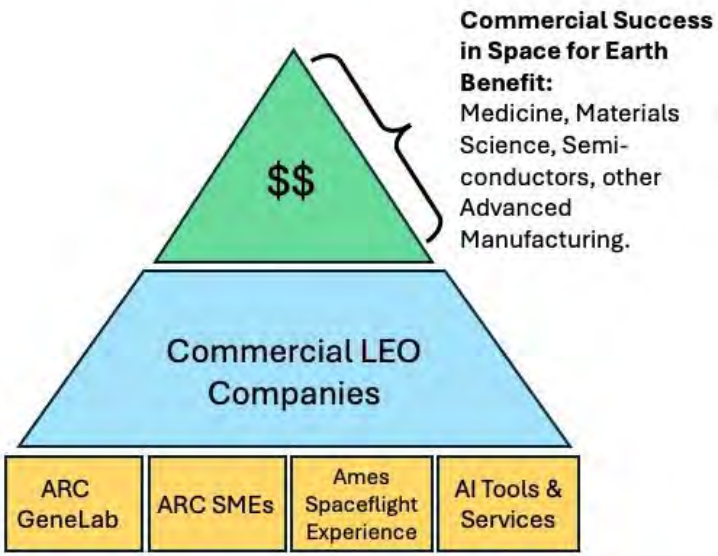
Commercial LEO Destination companies have the power to enable discovery, tech development, novel medical tools, bio-manufacturing and revolutionary manufacturing capabilities, to fuel US competitiveness for industries of the future. CLDs are the *Supply* side of the endeavor. But without *Demand*--without payloads in CLD launch vehicles and spacecraft, the CLDs cannot achieve commercial success.

NASA Ames proposes to support CLDs to develop the Demand for space goods, services, and products by providing subject matter experts, space test facilities and analytical capabilities (such as GeneLab, and AI analytical support services), to serve multiple agencies and customers. NASA Ames can provide the needed flight technical support (technical and flight integration services), based on Ames' proven pioneering space flight experience. Likely targets include stem cell applications for terrestrial medicine with special emphasis on cancers, neurodegenerative diseases (including Alzheimers Disease), and medical devices uniquely enabled by space development. Many of these examples are drawn from the success of NASA's InSpace Production and Applications (InSPA) program, which was originally developed at ARC. NASA's Commercial Orbital Transportation Services (COTS) program that led to the exceptional success of ISS and SpaceX, (including Dragon's Heat Shield), enabled the rise of commercial space companies on both the Supply side and the Demand side of the rapidly developing space economy. In addition, NASA Ames was instrumental in initiating and ensuring the success of the International Space Station National Lab.



POC. Dan Rasky (daniel.j.rasky@nasa.gov)

Public-Private Support Guide (PPSG) Attachment B.6

Goddard Space Flight Center

Goddard Space Flight Center

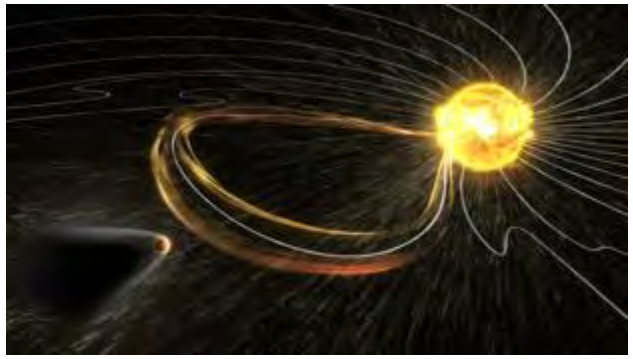
POC: Dr. Mark Lupisella, Exploration Integration Manager
Mark.L.Lupisella@nasa.gov

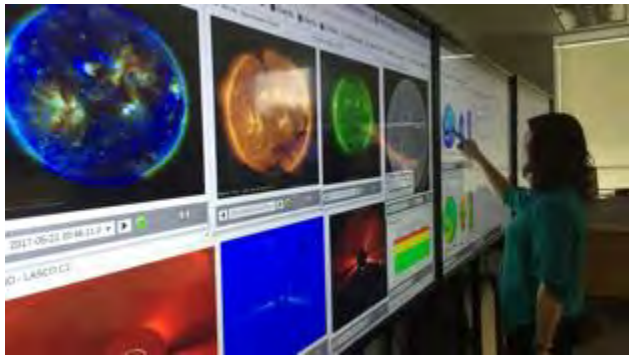
Goddard brings comprehensive capabilities to space activities

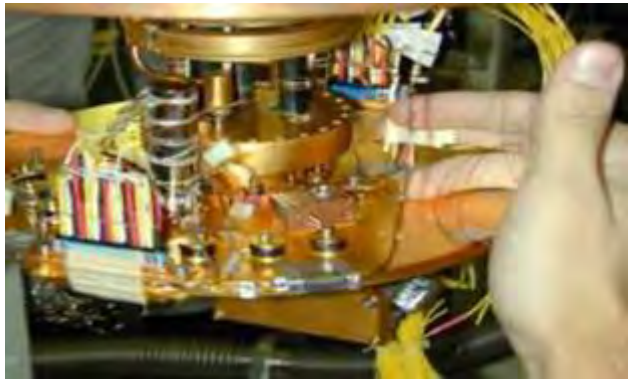
- **Extensive experience in architecting, end-to-end mission development and engineering complex systems, including payloads, interfaces, integration & test, & flight operations (including space weather integration)**
- **Science instruments and payloads for flight and ground systems**
- **Ability to remotely operate without crew – many flight missions over 50+ yrs**
- **Extensive communications and navigation capabilities**
- **Robotic servicing, crew-robotic tools & interfaces**
- **Facilities and launch capabilities for end-to-end mission lifecycle**

Operating in the space environment

- **Sophisticated laboratory studies** to enable an understanding and make predictions of the space environment and how to deal with these challenges
- **Monitoring and predicting the space weather environment,** including modeling and anomaly assessment, e.g. Moon to Mars Space Weather Office and Community Coordinated Modeling Center
- **Specialized instruments and sensor platforms have been designed to** operate successfully in the harsh space environment and advance scientific understanding of the earth and space environment
- **Advanced cryogenic systems** with specialized materials selection and realistic test facilities enable operation in a highly variable thermal environment, including for sample management
- **Analog operations research** can be applied to low earth orbit space activities and ground truth operations
- **Space cloud computing** architectures and radiation mitigation

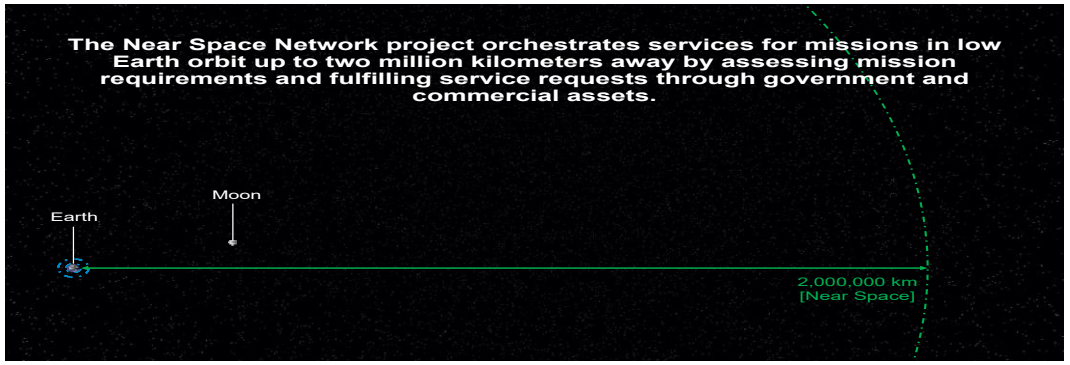




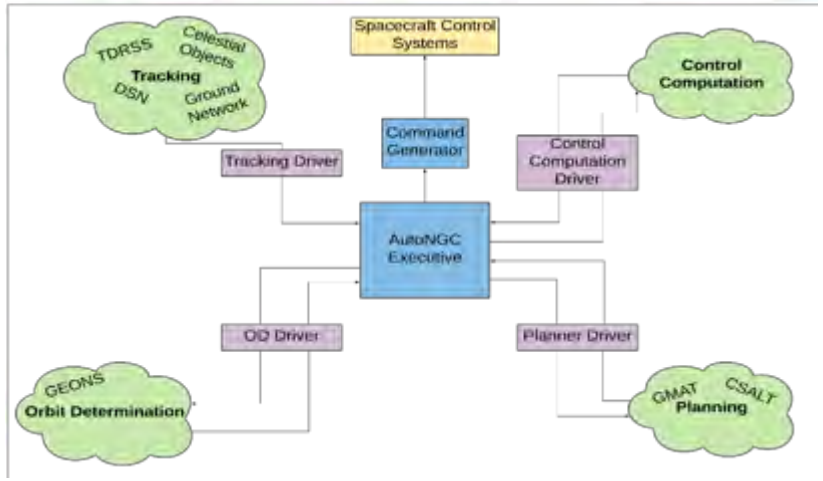


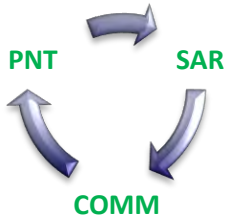
Communications & Navigation

- **Near Space Network:** The Near Space Network (NSN) 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 (direct to earth) and non-DTE services within the NSN service volume, including Government and Commercial providers, will be orchestrated and provided via NSN
  - Facilitate networked communications between orbiting assets



- **Autonomous Navigation, Guidance and Control ("autoNGC"):** Onboard, autonomous software that integrates and controls guidance, navigation and control hardware and software.
  - Enables rapid, onboard autonomous decision & control for time-critical activities.
  - Autonomous navigation, guidance and control enable deep space missions, including in-space servicing and assembly.

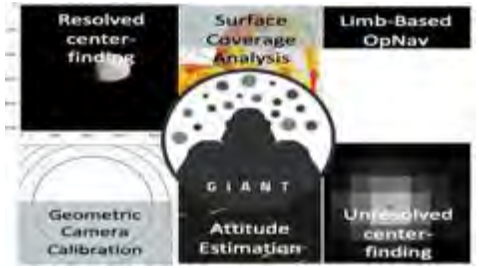




- **Search and Rescue (SAR)** capabilities – based on international SAR messaging standards and surface operations experience. Flexible architecture allows for beacon integration into vendor suit systems, enabling emergency location capability and astronaut health signaling supporting a wide ecosystem of commercial users

- **3D Lidars:** High speed hazard detection scanning lidars for precision proximity operations and autonomous navigation.

- **Image Analysis:** The Goddard Image Analysis and Navigation Tool (GIANT) is a high-fidelity software suite for performing precision optical navigation. Allows for rapid design using imaging planning.

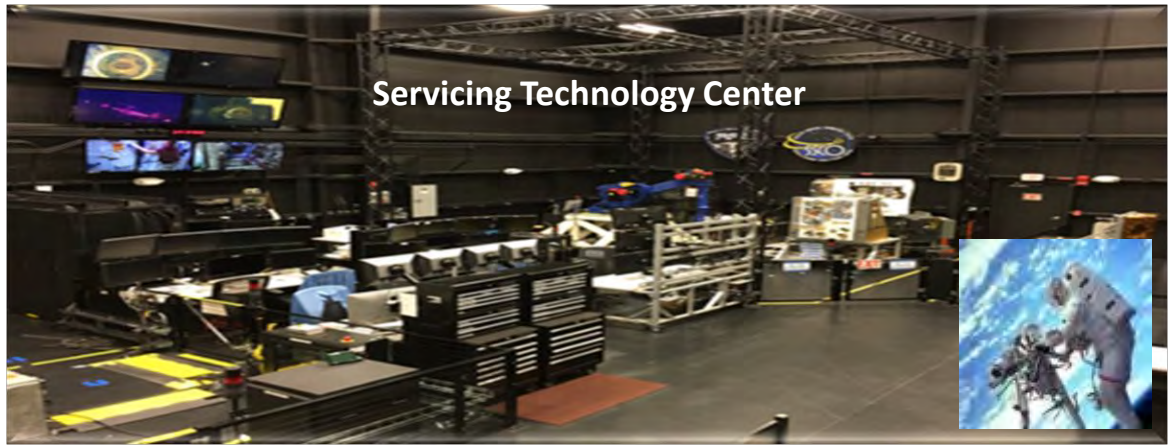


Robotics and Servicing

>25 years of Expertise in Robotics, Servicing, & Tool Development

- Flight validated state-of-the art facilities for servicing hardware and software development and evaluation, including tool level contact dynamics and flexible mode analysis/simulation
- Rapid and successful development of >190 astronaut and robotic tools
  - Hubble Space Telescope and Alpha Magnetic Spectrometer Human robot servicing missions and NASA's Return-to-Flight tool suite.
  - ISS robotic servicing technology demonstrations, and On-orbit Servicing, Assembly, and Manufacturing
- Expertise in adapting, ruggedizing, qualifying, and flying COTS hardware and scientific instrumentation for the space environment, astronaut handling, and remote tele-operations
  - Robotic External Leak Locator (RELL) successfully located external ISS fluid leaks with its mass spectrometer and ion vacuum pressure gauge
- Extensive experience and proven methods to establish modular hardware interfaces for robotic and crew servicing that extend operational lifetime
- Experience from HST/robotic servicing with battery replacement, deployable booms, sample return support with custom stowage, power harnesses, blind mate connectors
- Lidar sensor experience with Kodiak development for providing on-orbit servicing, assembly, and manufacturing situational awareness during rendezvous and proximity operations
- Mission planning, simulation, and execution of >40 in-flight servicing tasks
- Robotics operations and software development with compliance control for ISS servicing demonstrations

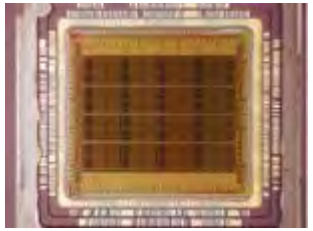
Expertise and facilities to implement, advise, or consult



Engineering and Technology

Coating and Optics Capabilities

- Coatings for spacecraft surfaces, radiators, windows, reflective/anti-reflective visors, etc.
- Low-cost ultra-thin polymer coatings for contamination mitigation



EEEE 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

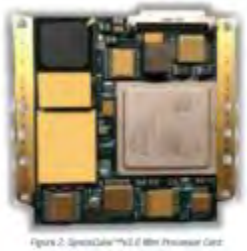
- Radiation Effects & Analysis Group assesses effects of the space radiation environment
- Presently supporting the development of radiation tolerant display technology.

Modular Unified Space Technology Avionics for Next Generation Missions (MUSTANG)

- Architecture provides a suite of electronic modules for highly reliable and reconfigurable avionics systems.

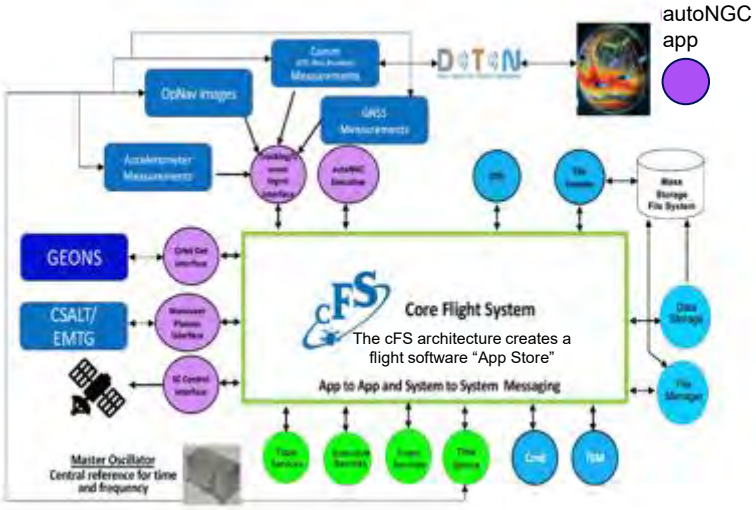
Fiber Optics and Photonics

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



SpaceCube

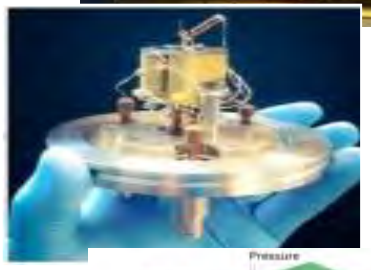
- Intelligent multi-purpose avionics system that system incorporates several miniaturized electronic cards for mix-and-match 1U (10 cm × 10 cm) cards.

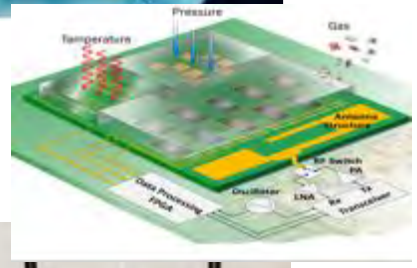


Core Flight Software

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

Sensor & Instrument Development





- **Experienced technology development and flight build organizations** for 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 to hold and operate them. For example:
  - Cloud-Aerosol Transport System (CATS) is a remote-sensing laser instrument on ISS that measures the distribution of Earth's atmospheric dust, smoke, air pollutants, and haze.
- **High heritage sensors** to provide knowledge of the space and earth environment
  - Assess dose risk to astronauts.
  - Photonic integrated circuits and freeform optics.
- **Miniature sensors and instruments**
  - Astronaut hand-held instruments
  - Compact thermal camera for point-and-shoot applications
  - Detector micro-electronic packaging and characterization
  - Multifunction nanosensor platform for low SWaP, high sensitivity, molecular detection
- **In-situ ground truthing and remote sensing** of earth and key space weather and environmental indicators

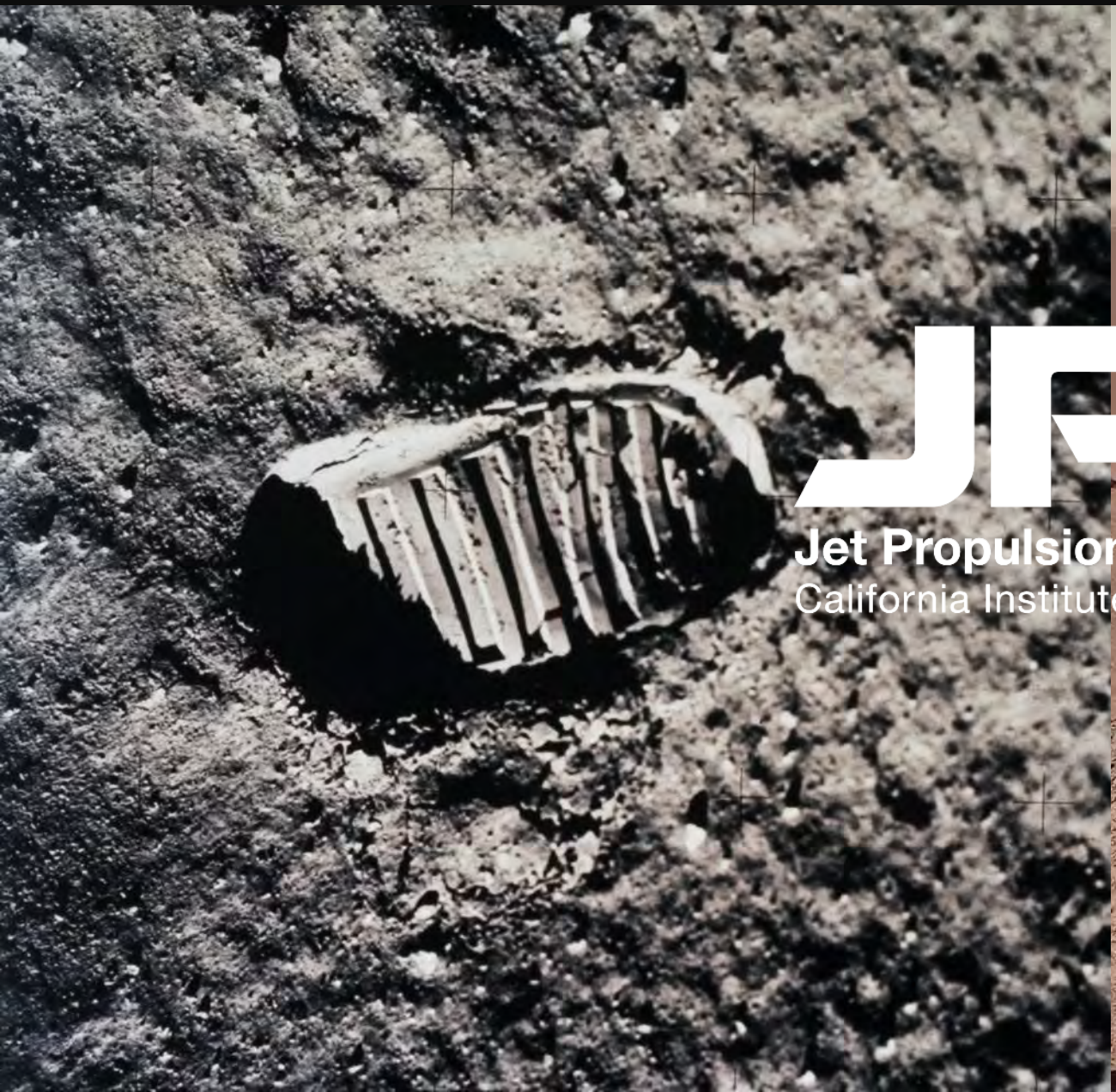
Facilities

- **Flight validated state-of-the art facilities for qualifying spaceflight & servicing systems:** hardware, software & ground testing for robotic and astronaut tools with assets that simulate mission operations
- **Moon to Mars Space Weather Analysis Office and the Community Coordinated Modeling Center** together provide space weather analysis using modern space research models in support of mission health and safety
- **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
- **Mission Design Lab, Instrument Design Lab, Architecture Design Lab** for rapid design and advanced concept development using multiple platforms
- **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, and detector micro-electronic packaging and characterization
- **Wallops Flight Facility** provides safe, rapid and cost-effective access to space for technology demonstrations

Public-Private Support Guide (PPSG) Attachment B.7

Jet Propulsion Laboratory (JPL)

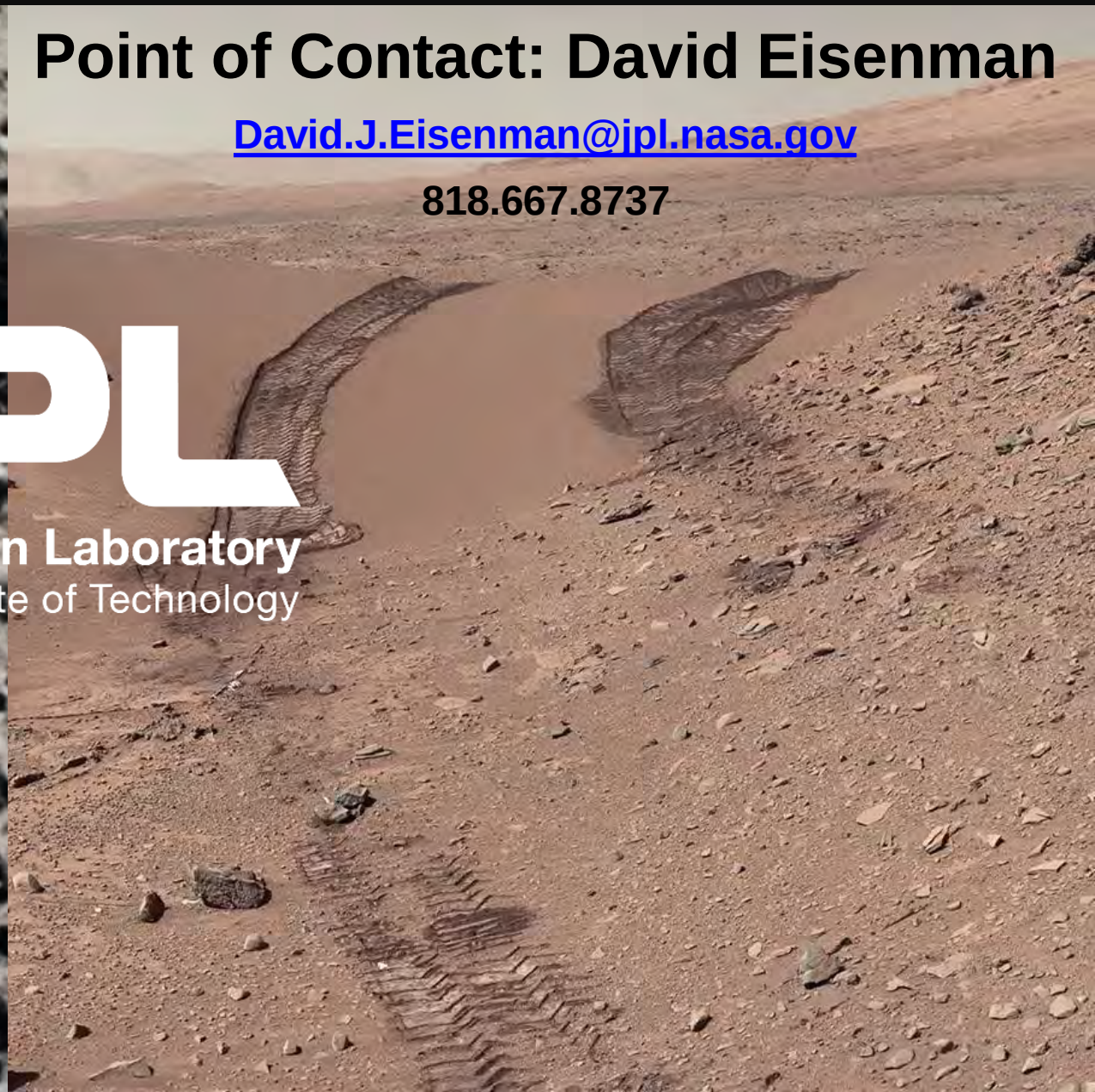
Center Capabilities - Jet Propulsion Laboratory



JPL

Jet Propulsion Laboratory

California Institute of Technology



Point of Contact: David Eisenman

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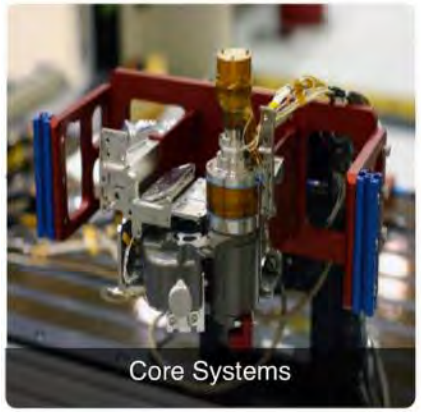
818.667.8737

JPL Mission Analysis, Operations, and Navigation

National Aeronautics and Space Administration

Monte Capabilities



- **Monte, a state-of-the-art astrodynamic Python library, is JPL's signature astrodynamic computing platform, supporting all phases of space mission development from early space design and analysis through flight navigation services.**
- **With over a decade of operational use on NASA's most demanding space robotic missions, Monte provides a platform on which users can build their own custom aerospace tools.**
- **It supplies the basic astrodynamic infrastructure --- trajectory models, coordinate frames, high precision time, astrodynamic event searches, sensitivity analysis, numerical integrators, optimization, etc. --- allowing you to focus on the problem at hand.**
- **All this capability comes with extensive hyperlinked documentation, from introductory tutorials to low level mathematical details.**
- **In addition to JPL missions, Monte is used to perform IV&V of JSC FOD Navigation tools, and to perform "shadow" Navigation for NASA International Partner missions.**

https://montepy.jpl.nasa.gov/

https://ammos.nasa.gov/pdf/Brochure-MONTE.pdf

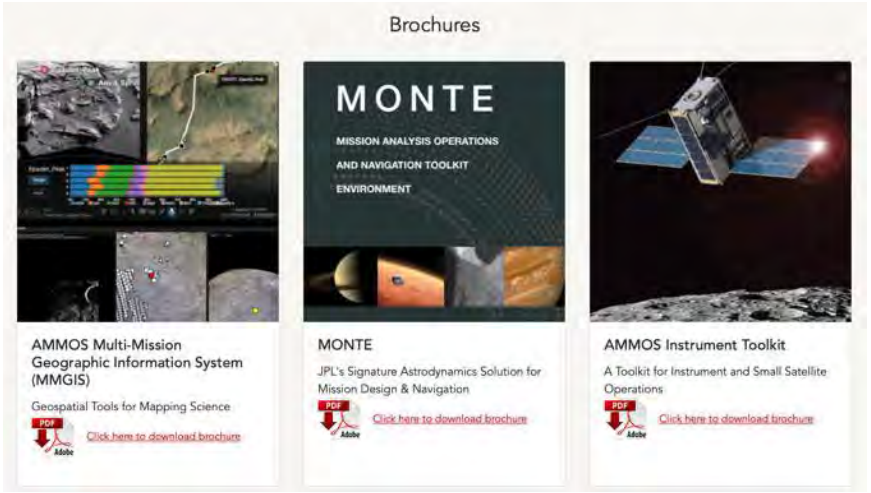
JPL Advanced Multi-Mission Operations System (AMMOS)

National Aeronautics and Space Administration

https://youtu.be/rMDuzunjLF0

https://youtu.be/wsvjaPYEAUk

- **The Advanced Multi-Mission Operations System, or AMMOS, is a set of mission operations and data processing capabilities for robotic missions through an "Ops in a Box" approach.**
- **AMMOS is a low-cost, highly reliable system utilized by more than 50 missions, including planetary exploration, deep space, earth science, heliophysics, and astrophysics, by NASA, ESA, industry, and academia.**
- **The AMMOS Catalog and Brochures provide a comprehensive overview of operations capabilities in the form of products and services available to support flight projects and experiment investigations.**

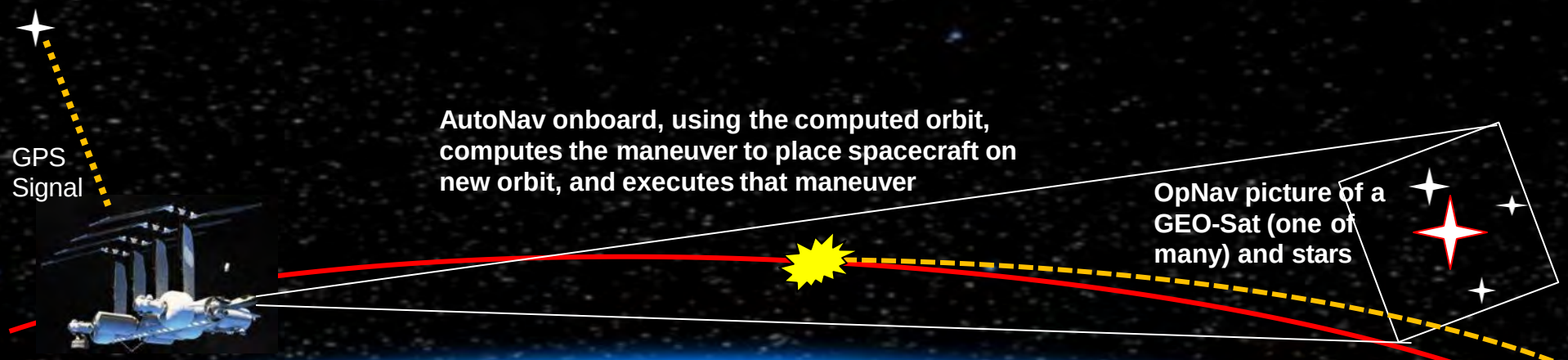


https://ammos.nasa.gov

Using JPL AutoNav to Maintain Orbit in LEO

National Aeronautics and Space Administration

- From LEO, the most practical means of Orbit Determination (OD) is via GPS observations
- JPL's AutoNav could be readily modified to use GPS rather than optical measurements to perform an orbit estimate (GPS does not estimate orbits on its own)
- GPS is dependent on the continuous operation of the MEO constellation of GPS satellites which are vulnerable to solar coronal mass ejections (CME's); these can put spacecraft temporarily or even permanently out of commission, which is one reason why the Do D is extremely interested in GPS-denied orbital navigation
- A LEO spacecraft equipped with AutoNav and a modest camera could perform OD to the level of 20 m in a few minutes using pictures of GEO-Sats, providing critical back-up for crew safety
- GPS on Earth or in orbit can give 1 m position estimates, but 20 m is more than ample for OD
- Armed with a GPS (*or* a GEOsat) OD, AutoNav can readily and continuously compute the needed maneuvers to keep a LEO spacecraft on the needed or new trajectory (including for collision avoidance) and regular orbital maintenance

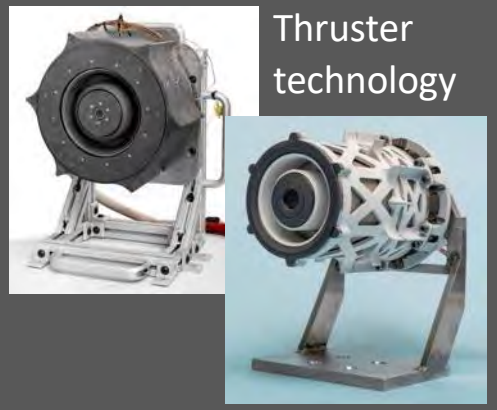


JPL Electric Propulsion

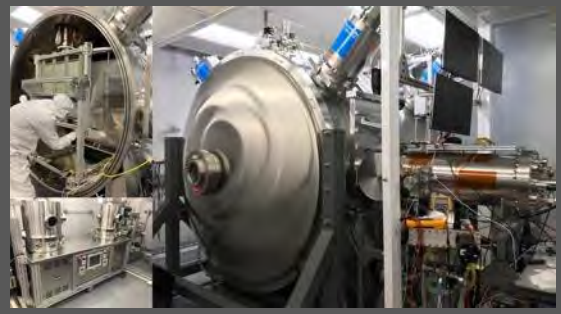
National Aeronautics and Space Administration

State-of-the art, end-to-end capabilities in electric propulsion

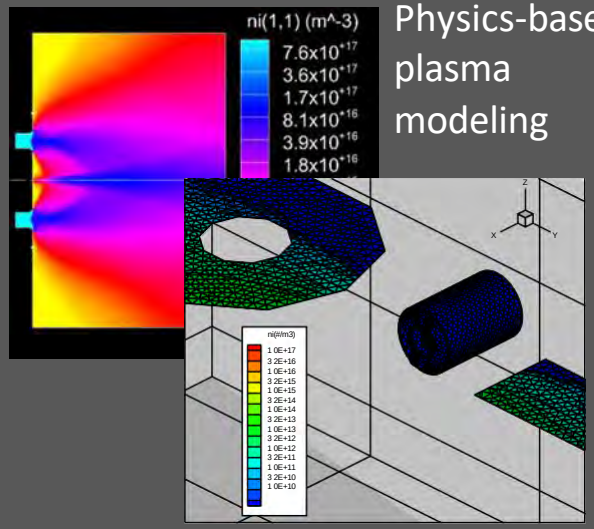
- Technology Development & Qualification
  - Extensive experience developing and qualifying electric thrusters for flight application (NSTAR→Dawn; Colloid Thrusters → LISA Pathfinder; HERMeS/AEPS → PPE)
  - Hall thruster and other technology available for licensing (e.g., 1 kW MaSMI, 10 kW H10)
- Vacuum facilities & diagnostics
  - Vacuum facilities optimized for testing Hall thrusters, gridded ion thruster, electrosprays, and MPD thrusters
  - Vast array of diagnostics for measuring performance, stability, thermal, and erosion of thrusters
  - Deep expertise in long-duration wear testing and thermal cycle qualification testing of electric thrusters
- Physics-based plasma modeling
  - World-class codes for simulating Hall thrusters, hollow cathodes, ion optics, and plumes
  - Extensive code validation allows for use in design and life qualification for flight
- Flight Implementation
  - Only NASA Center to fly EP on operational science missions (Dawn and Psyche)
  - Deep-expertise in Mission Design & Navigation enabled by world-class trajectory solvers



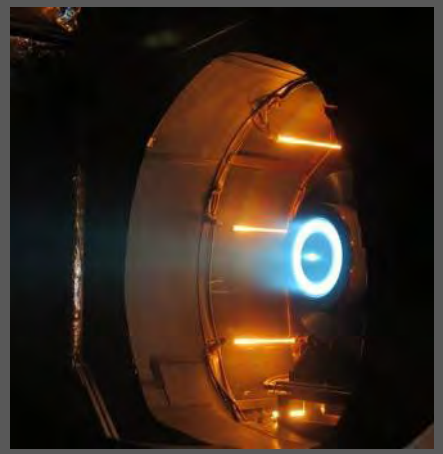
Thruster technology



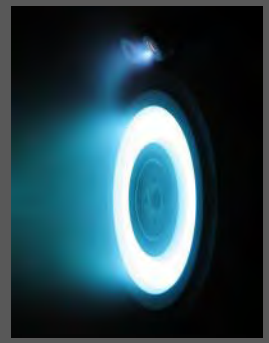
Vacuum facilities & diagnostics



Physics-based plasma modeling



Flight Implementation



ep.jpl.nasa.gov

JPL High Performance Spaceflight Computing

National Aeronautics and Space Administration

HPSC SoC: Led architecture and design of the HPSC System-on-a-Chip processor and software with Microchip. Have done numerous tutorials on function and best use of HPSC. At the center of driving the HPSC ecosystem and vendors developing HPSC based products and derivatives.
JPL leads the NASA "HPSC Community of Practice" to train NASA on HPSC usage.

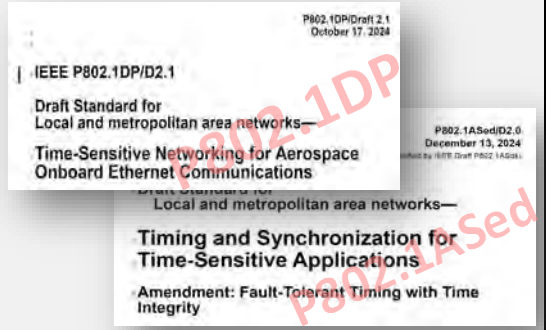
Advanced Avionics Lab: Applied performance engineering to characterize HPSC based avionics solutions (power, performance, resiliency, software).

Leading HPSC based avionics architecture study/prototyping to define reference architectures for next gen:

- Autonomy
- Communications
- Advanced sensors
- Compute at the edge
- Distributed avionics

TSN Ethernet Lab: Leading efforts in the TSN specification development within IEEE 802.1DP and 802.1ASed.

TSN lab established for validation, analysis, and characterization of TSN for space.



HPSC Software: Leading software development work for HPSC including flight software frameworks, optimized libraries, models and development tools.

Advanced algorithmic development optimized for HPSC.

HPSC technical depth from SoC, software, hardware to complete systems

JPL Avionics Systems for Commercial Space Stations

National Aeronautics and Space Administration

Avionics System Engineering

- **Architecture** – Specify, size, extend and optimize computing systems
- **Full Stack Support** – Diagnose & repair issues from IC to system of systems
- **Scalable Compute** – HPSC plus AI & ML, cFS and FPrime s/w frameworks
- **Standards** – Participate in defining interoperable industry standards

Embedded Systems

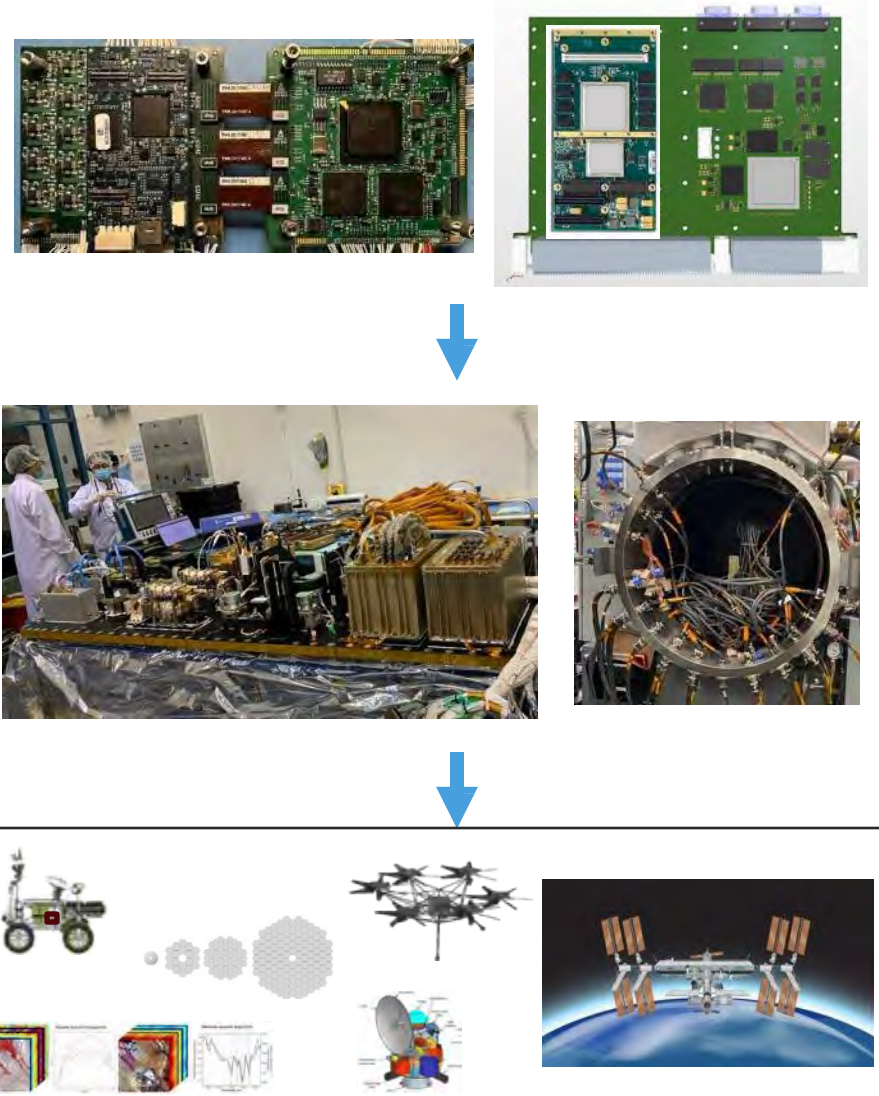
- **Design** – Define & deliver computer enabled autonomy, C&T, G&C, Navigation, Networking, etc.
- **Analysis** – Find & repair mission crippling errors prior to deployment
- **Integration** – Bring a chip, a board, an assembly or system together & verify it

Mixed Signal Electronics

- **Design** – Custom digital and analog solutions with minimal size, weight & power
- **Analysis** – Signal integrity, radiation, parts stress, power and reliability analyses
- **Qualification** – Radiation testing, TVAC, and full environmental qualification

Ground Support Equipment

- **Design** – Define & deliver equipment for board-level or hardware-in-the-loop flight system tests or launch support
- **Analysis** – Signal integrity, parts stress, power and reliability analyses
- **Safe Integration** – Design to keep hardware under test safe
- **Visibility** – Visibility of GSE state and easy correlation with flight system state



JPL Environmental Monitoring for LEO Space Stations

National Aeronautics and Space Administration

Atmosphere Monitoring

- *Electronic Nose (ENose)* – chemical sensor to detect, identify, and quantify leaks and spills of selected volatile organic compounds; ISS tech demos
- *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.)* – deployable miniature GCMS; ISS tech demos
- *Laser Air Monitor (LAM)* – prototyped miniature , low power tunable laser spectrometer to monitor major atmospheric constituents to reduce risk before major Orion procurement
- *Portable Tunable Laser Spectrometer (PTLS)* – measures CO_2 pockets ("bubbles") in cabin air; ISS tech demo
- *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

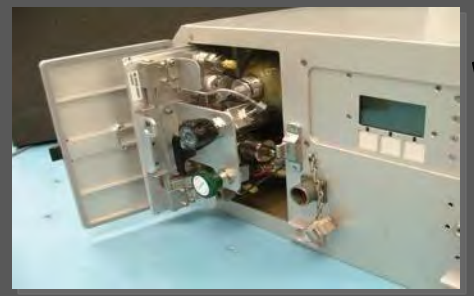
- *Combustion Product Monitor (CPM)* - Miniature, low power laser spectrometer to continuously detect and measure fire gases (HCl, HF, HCN, CO, CO_2, O_2); SAFFIRE-VI tech demo

Water Monitoring

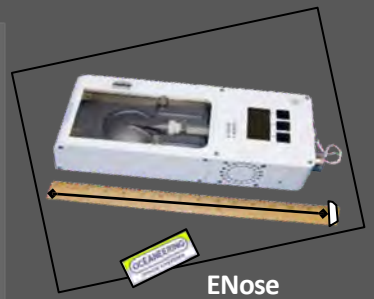
- *Organic Water Monitor (OWM)* – measure organic content of potable water; ISS tech demo partnered with JSC
- *Mini Tunable Laser Spectrometer (MTLS) subsystem inside mini Total Organic Caron Analyzer (miniTOCA)* – measures gasified CO_2 in drinking water; shrinks size of current ISS TOCA
- *Spacecraft Water Impurity Monitor (SWIM)* – front end to S.A.M. to volatilize water and measure with a high precision mini GCMS, plus electrophoresis to measure inorganics in water

Microbial Monitoring and Mitigation

- *Comprehensive vehicle microbial surveys & assessments, Biofilm mitigation tech dev*
- *Water Sample concentrator* – concentrates amount of microbes in potable water to improve measurement



VCAM



ENose

S.A.M.

CPM

PTLS

PLSS CO_2 Sensor

LAM

Water Sample Concentrator

JPL can leverage it's Mars Planetary Protection expertise and facilities to map and monitor the microbial condition of LEO habitats

National Aeronautics and Space Administration

Microbial Tracking-3 (MT-3) was the third investigation in a series to catalog and characterize potential disease-causing microorganisms aboard the International Space Station (ISS).

MT-3 Objectives: Identify bacteria and fungi and monitor them to understand if they could be:

- Disease-causing (virulent),
- Resistant to antibiotics, or
- Prone to causing illness (pathogenicity).

Detect living microbial populations, their location and distribution inside the ISS, and fluctuation (dynamics) over time.

Determine the distribution and selection of antimicrobial resistance and virulence genes in microbial genomes in the ISS environment.

NASA Astronaut Jack Fisher swabs surfaces in the ISS to collect microbe samples for the MT-3 investigation.

Swabs were returned & analyzed in JPL and partner laboratories using state-of-the-art microbial characterization techniques.

JPL Power Systems for Commercial Space Stations

National Aeronautics and Space Administration

Power System Engineering

- **Architecture** – Complete specification, sizing, and optimization for power systems
- **Energy Balance** – Modelling of vehicle energy balance over any mission profile
- **System Integration & Operations** – Power systems integration & operations in any mission environment

Solar Arrays

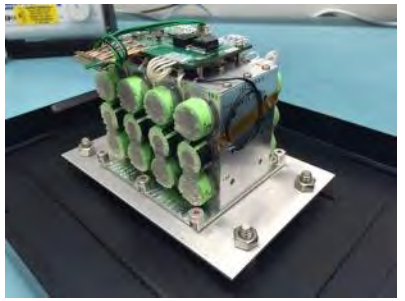
- **Design** – Full solar array design including cells, panels, arrays, and deployment
- **Analysis** – IV curve generation for any orbital or surface mission profile
- **Cell Testing** – Illumination, radiation, and environmental testing
- **Array Qualification** – IV performance, gravity-offloaded deployment, TVAC

Batteries

- **Design** – Full battery design including cell electrolytes, commercial cell selection, battery assemblies, battery packaging, and harnessing
- **Cell Testing** – Complete testing, including cell cycling, pulsed discharge, and TVAC
- **Assembly Qualification** – Full environmental qualification

Power Conversion and Distribution Electronics

- **Power Conversion** – GaN-based power converter solutions for Solar Arrays, spacecraft bus interfaces, electric propulsion, motor control, and point of load
- **Power Distribution** – Fault-interrupting distribution electronics for standard loads, pyrotechnic devices, deployers, and heater systems
- **Bus Control** – Battery charge control, fault management, and telemetry collection
- **Qualification** – Radiation testing, TVAC, and full environmental qualification

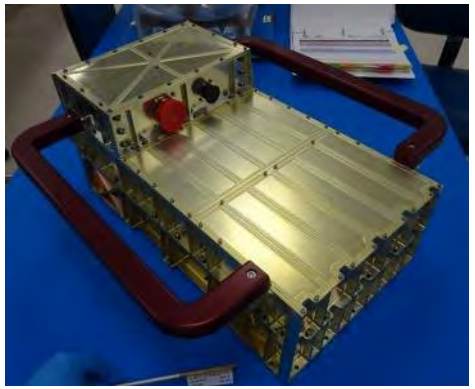


https://electrochem.jpl.nasa.gov/

JPL Battery Capabilities for Commercial Space Stations

National Aeronautics and Space Administration

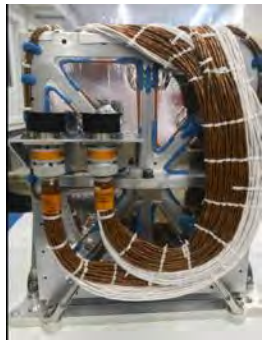
JPL Battery Mission Support



Europa Clipper (2024)
Small COTS 18650 cells,
large capacity battery
low magnetic signature design

Battery Test Facility (2025)

MER (2004)
1st custom prismatic cells,
RHUs, heaters, aerogel
and thermal switches



Mars 2020 Perseverance Rover (2020)
Large capacity prismatic cells

JPL Battery Development

- Requirements Development
- Battery Sizing and Design Approaches
- Development of Custom Cell Solutions
- Close Interaction with Multiple Cell Vendors
- Power Sub-System Integration
- Battery Charge Management Systems
- Battery Safety Mitigation Approaches
- Environmental Testing Capabilities
- Thermal Management Approaches
- Battery Acceptance/Qualification Testing
- Mission Relevant Cell Testing
- Battery Performance Modeling Support
- Battery Degradation Estimation
- Mission Operations Support

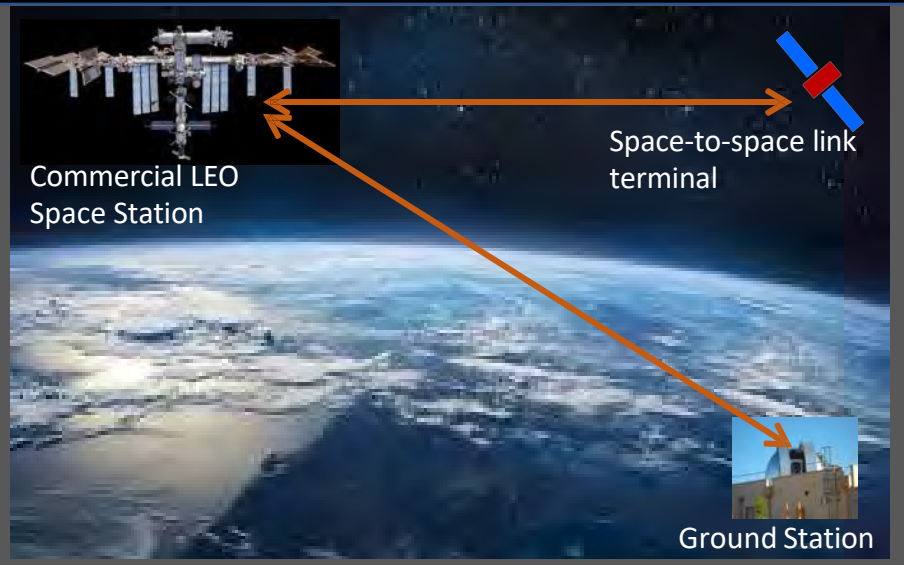
https://electrochem.jpl.nasa.gov/

JPL Optical Communications for LEO

National Aeronautics and Space Administration

JPL can leverage capability for high-rate optical links with ranging developed for distances from LEO to deep space

- Bi-directional data transfer (0.1 – 10 Gb/s)
- Feeder links from Moon surface and orbiters
- Low size weight and power flight terminals
- Mitigate atmospheric turbulence for space-to-ground high-rate data transfer
- Unregulated optical spectrum prevents bandwidth congestion

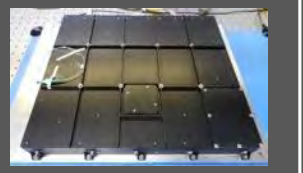


Flight technologies

- Sub-microradian laser pointing control
- Gimballing for large field of regard access
- Flight qualified lasers

22cm 4W transceiver
onboard Psyche spacecraft
Ongoing technology demonstration
22 – 495 million kilometers

Laser Transmitter Assembly for Deep Space Optical Communications ***(DSOC)***



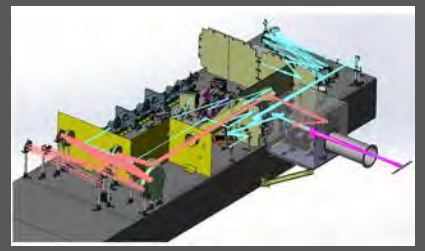
2 cm 1W transceiver
onboard International Space Station
Operated from 2014-2016
400- 1400 km

6cm 4 W airborne terminal
Tested in air-to-ground links
9-15 km

Ground technologies

- Optical link acquisition
- Coherent receivers
- Uplink comm and ranging

1m diameter ground telescope
< 2 arcsecs bling pointing accuracy
Degrees/sec LEO orbit spacecraft tracking day and night
Ground station for NASA's Lunar Laser Communications Demonstration (LLCD)
Low-earth orbit spacecraft tracking,
NASA's Optical Payload for Lasercom Science (OPALS) on ISS
High-rate laser transmitter to space assets
Service DTE and forward link from/to LEO platforms



Superconducting nanowire single photon detector (SNSPD) array for photon-counting receiver
DSOC and NASA's ARTEMIS II crewed mission

Adaptive optics
NASA's Laser Communications Relay Demonstration (LCRD) from GEO
Terabyte Infrared Delivery (TBIRD)
Receive coherent links from LEO @ 10 - 200 Gb/s

JPL Flight-Proven Arm Design, Build, and V&V

National Aeronautics and Space Administration

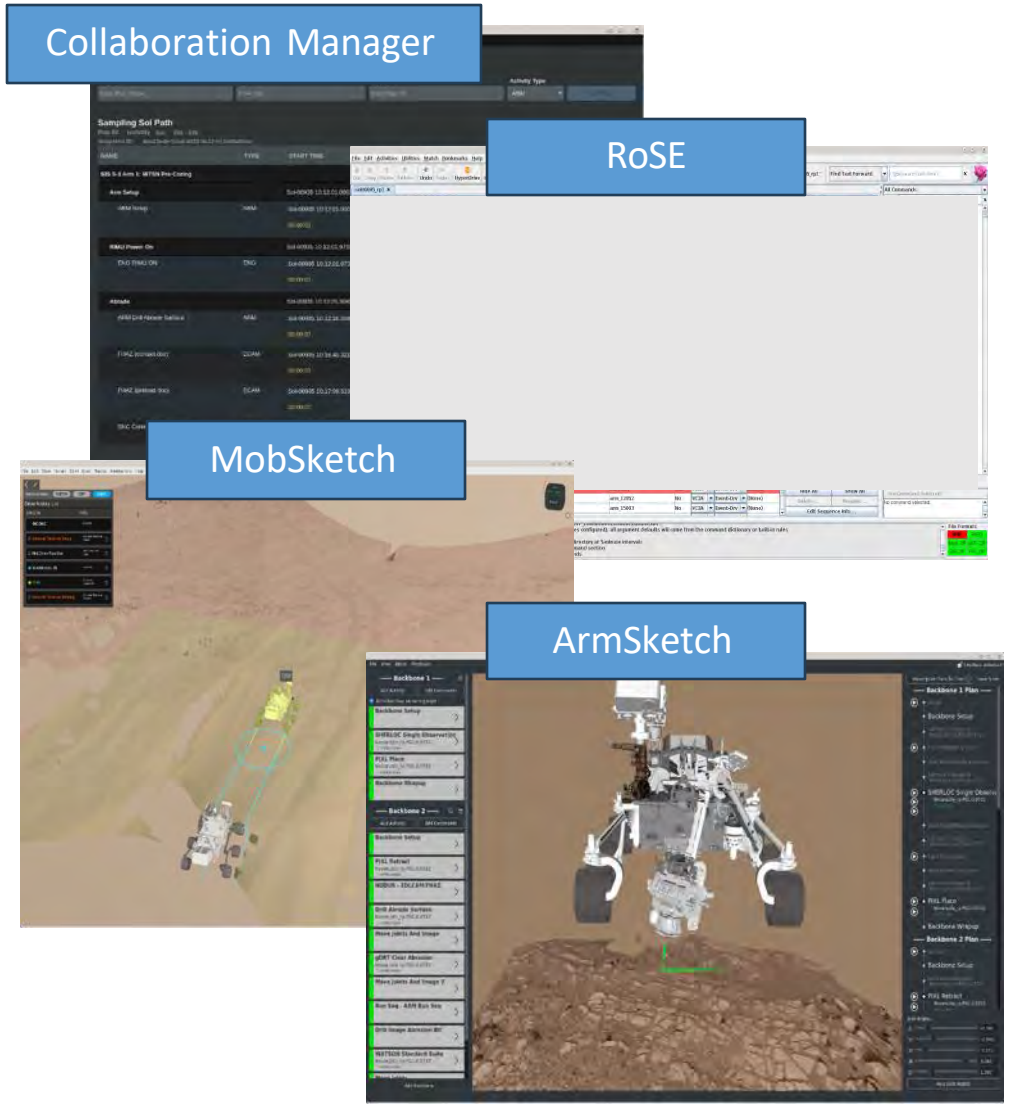
JPL Flight-Proven Ground Operations Tools for Robotic Arm Activities

National Aeronautics and Space Administration

NASA

Robotic Sequencing and Visualization Program (RSVP) Tool Suite

- **Collaboration Manager – Ingest plan activities into RSVP and receive updates to the plan**
- **RoSE – Data-driven text-based Robot Sequence Editor for manual command editing**
- **MobSketch – Interactive movement planner and movement command generation tool**
- **ArmSketch – Arm sequence generation tool using path planning algorithm with collision avoidance capability**



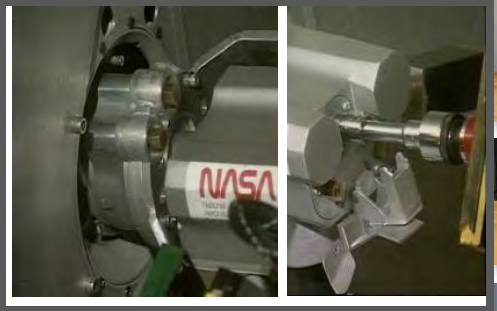
JPL Space Robotic Manipulation – from Mars to ISAM & LEO

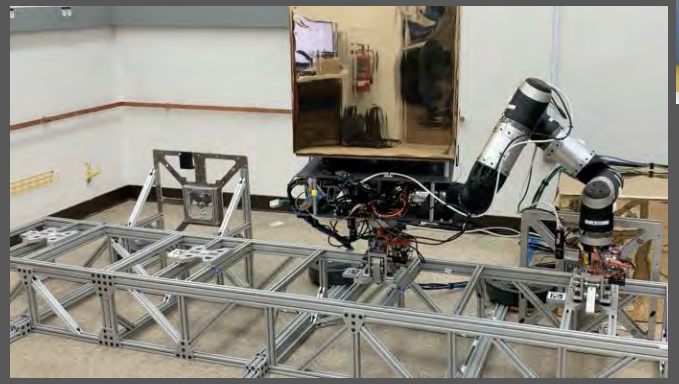
National Aeronautics and Space Administration

Flight Experience

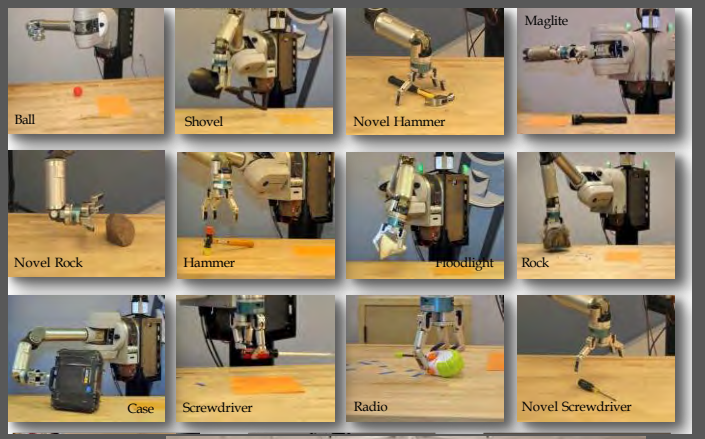
- Vision guided, force-torque controlled, dexterous manipulation (algorithms, software)
- Robotic manipulation avionics (motion control & compute)
- Novel end-effectors and payload interfaces for ISAM
- Fault protection and recovery
- M&S for concept evaluations and flight operations
- Robotic systems engineering from CML-3 to TRL-9
- Test beds, V&V and Integration

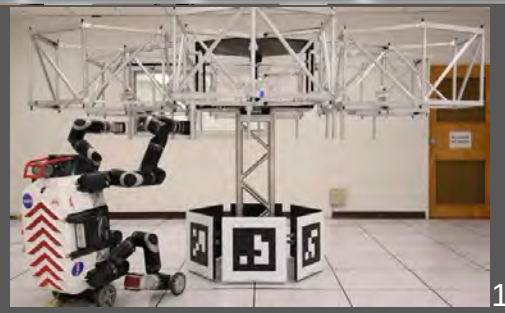
COLDArm uses BMG gears and can operate down to -180°C without a heating source





New Technologies

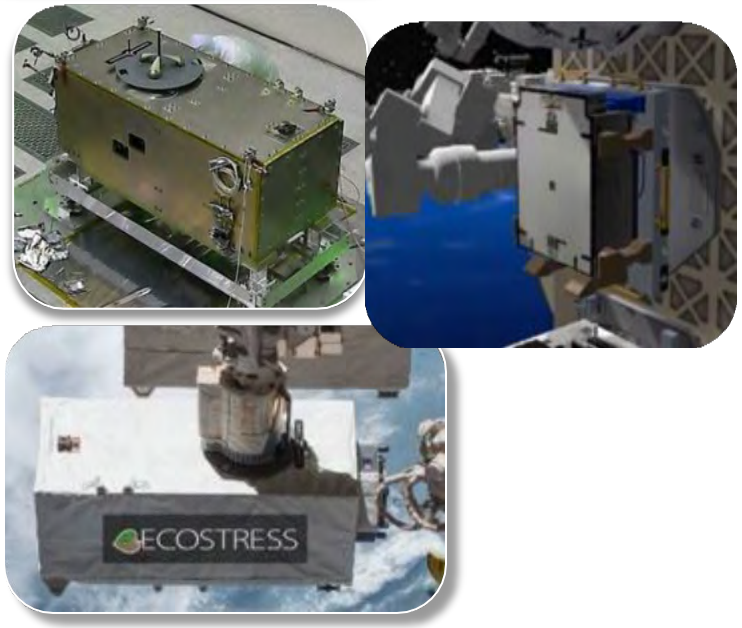




ISAM@JPL

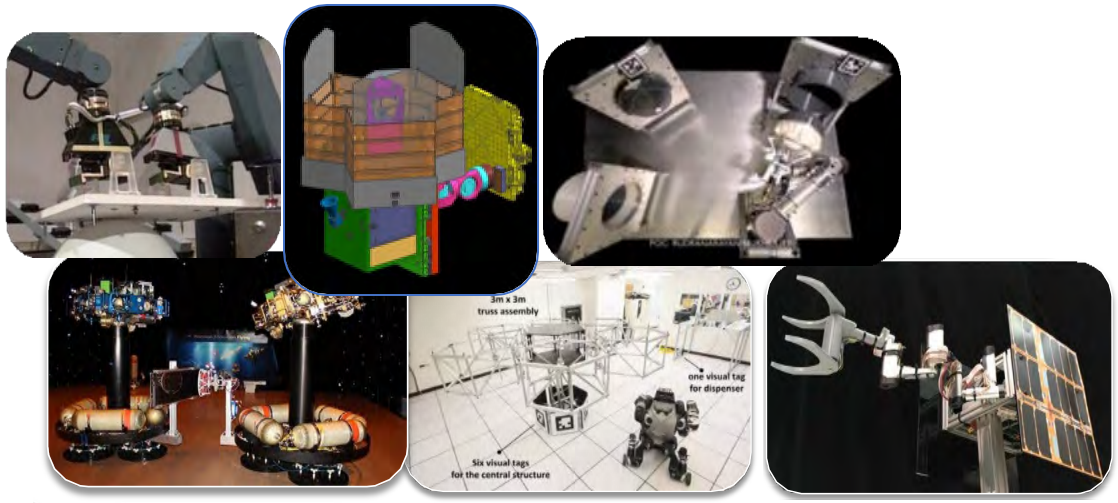
1 **JPL has led high profile concept studies / technology readiness or risk assessments**

NOAA GOES, NASA ISAT, DARPA RSGS, NASA Habitable Worlds Observatory Servicing, Commercial persistent platforms among others



2 **JPL has developed science payloads that were robotically integrated on ISS. Experience applicable to ISAM concepts for post-launch in-space robotic payload assembly**

For e.g., EMIT, ECOSTRESS, OCO-3



3 **Over 30 years, JPL has developed robotics and autonomy technologies for ISAM. Mars robotics experience is highly applicable to ISAM**

Materials Development & Advanced Manufacturing

JPL has significant end-to-end capabilities in additive manufacturing, metallurgy, materials development, and infusion

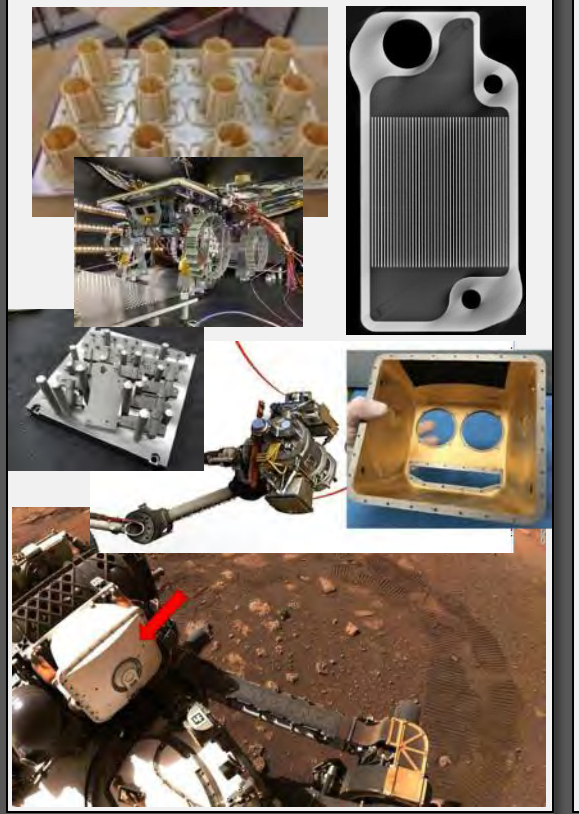
National Aeronautics and Space Administration

Metal Additive Manufacturing:

JPL has flight-qualified LPBF printers for Al and Ti with heritage in flagship missions. Multi-material and alloy development capabilities have been used for other 30 patents. Multi-functional parts

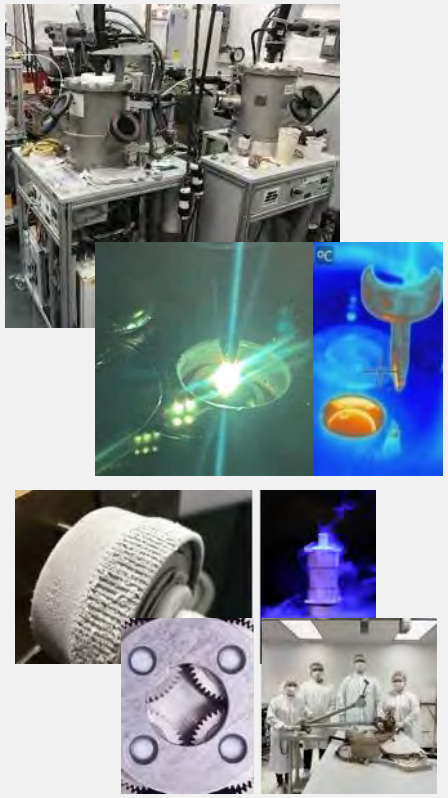
Flight Heritage:

JPL has qualified and flown 3D printed metal parts on the Perseverance rover on Mars (MOXIE and PIXL) as well as a parts on Europa Clipper. JPL has flown polymer parts widely, including on Cosmic2 and Sentinel6. Custom wheels developed for lunar rovers, CADRE



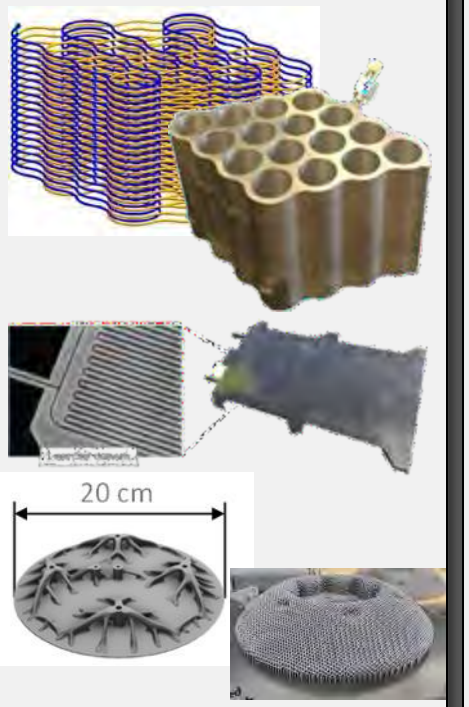
JPL Metallurgy Lab:

JPL has a metallurgy lab/foundry that supports alloy development, in-space manufacturing, and recycling. Used to develop BMG Gears program later infused into COLDArm. Lab supported FAMIS flight experiment on ISS for processing metals



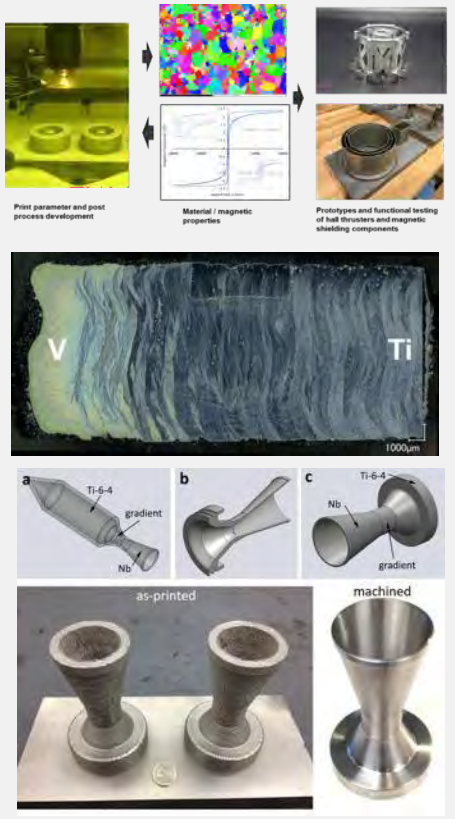
Advanced Thermal, Lattice & Design for Manufacture:

JPL develops advanced thermal solutions leveraging additive manufacturing. Embedded thermal into structural parts. JPL does topology optimization for generative designs and develops crushable lattices for Mars sample return and other hard landers



Multi-Material Parts

JPL has pioneered the development of multi-material 3D printing for a variety of applications in rocket nozzles, thermal, thrusters, and magnetic components. Patents have been licensed to commercial industry and are being widely used



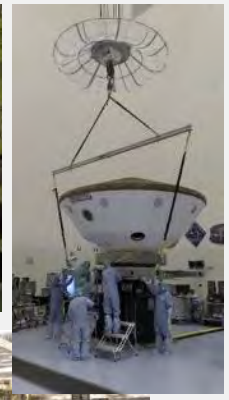
JPL Mechanical Fabrication, Test, ETL, and ATLO

Providing end-to-end spacecraft manufacturing, environmental and dynamics testing, and ATLO

National Aeronautics and Space Administration

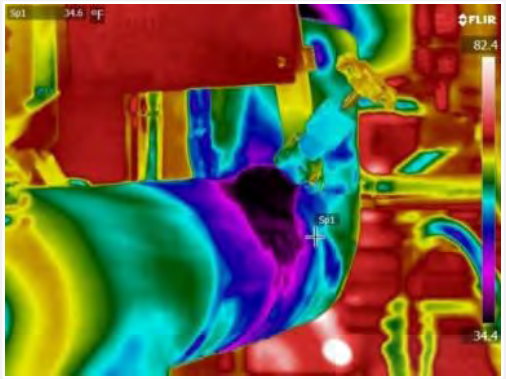
Environmental Thermal, Dynamics and Instrumentation

- System level thermal/vacuum testing
- Bake-out and contamination control
- Vibration, acoustic, shock and static testing
- Mass properties and pryo testing



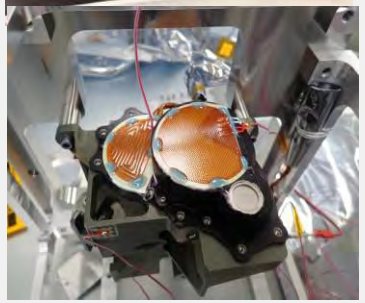
Pressure Systems

- Supports JPL pressure systems
- Certifications of pressure systems and development of new pressure systems
- Analysis and NDE



Actuators and Payload Mechanisms Services

- Thermal blanket and paint
- Pyrotechnics installation and test
- Flight hardware handling and assembly
- Optomechanical fabrication and test
- Electromechanical assembly and test



Propulsion, Fluid and Assembly Test and Launch Services

- Propulsion systems fabrication and propellant handling
- Heat rejection/cold plate fabrication and testing
- Precision cleaning

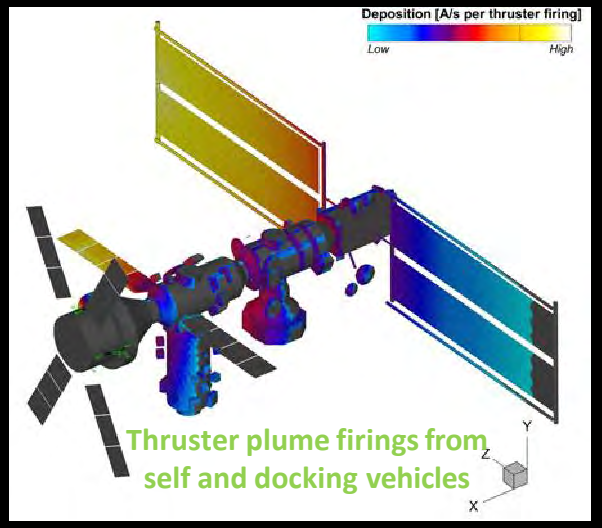
Manufacturing Engineering and Precision Machining

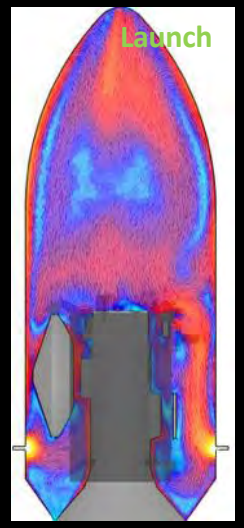
- Design for manufacturing
- Multi-axis CNC machining
- Large components
- High Precision machining
- Welding and sheet metal fabrication
- Water jetting and 3D printing services
- Manufacturing engineering

JPL Contamination Control for Commercial LEO Space Stations

National Aeronautics and Space Administration

Mission	Commercial Space Stations
Mission Type	Commercial Space Station
Contaminant Transport Vectors	• Materials outgassing • Thruster plume firings from self and docking vehicles • Vacuum venting (ECLSS) and leakage
Vehicle Sensitivities	• Permanent deposition of molecular contaminants and particulates • Thruster plume induced contamination and erosion (mechanical damage) • Thermo-optical property degradation • Star-tracker performance
Impacts	• Meeting design life • Power generation (solar array performance) • Heat rejection (thermal control systems performance) • On-orbit operations (including EVA, proximity operations) • Crew health and safety





Contamination Control Technologies with Direct Application to Design, Development, Integration, Testing and Space Operations

Contaminant Source Characterization

- **Particle adhesion and Resuspension**
  - Testing
  - Modeling
- **ASTM E1559 Materials Outgassing Rate Data Analysis**
  - Outgassing rate characterization
  - Multi-species outgassing model
  - Mass spectrometer data analysis
- **Thruster plume modeling**
  - Monopropellant
  - Bipropellant
  - Electric
  - Solid
- **Venting and leakage**
  - Fluid leakage sources
  - Multiphase vacuum venting

Contaminant Transport

- **Direct Flux (molecular)**
  - View-factor based modeling
  - Raytracing/Monte Carlo
- **Molecular Return Flux**
  - BGK based model (Boltzmann kinetic equation)
  - Direct Simulation Monte Carlo (DSMC)
- **Plume Contaminant Transport Model**
- **Particle Redistribution Model**
  - CFD model coupled with a particle drag/adhesion model
- **Thermal Vacuum Modeling**
  - Molecular simulation

Contamination Effects

- **Particle Obscuration Modeling**
- **Thermo-optical property degradation**
  - Combined effects (contamination + ultraviolet radiation exposure)
  - Characterization of solar absorptance
- **Optical Scatter Model**
  - In development
- **Thin Film Effects model**
  - CALCRT update
- **Ionizing Radiation Effects**
  - In development

JPL Analytical Chemistry & Material Analysis

National Aeronautics and Space Administration

Analytical Chemistry Laboratory (ACL)

- The ACL maintains capabilities in chemical analysis, spectroscopy, materials, failure analysis, contamination analysis, experimental design and instrument R&D
- This ACL possesses many different types of advanced analytical instrumentation and specialized laboratory tools that are used to support flight projects, instrument development and planetary research
- The ACL possesses uniquely qualified staff that provide service laboratory support

EXPERTISE & EQUIPMENT

- General Chemistry and Analysis
- Instrument and Method Development
- Contamination Identification
- Failure Analysis
- Spectroscopy and Spectral Interpretation
- Materials Compatibility
- Optical Materials Measurement
- Surface Analysis and Surface Modification
- Synthesis: Aerogels, Molecular Getters, Thermoelectrics
- Metal Analysis
- Propellant Chemistry and Compatibility
- Particle identification, sizing, counting
- Microscopy, metrology, micro-topography
- Analysis of meteors, fossils, planetary analogs
- Materials & Polymer Analysis
- Vibrational Spectroscopy
- Surface Analysis
- Optical Spectroscopy

JPL Environmental Test Laboratory (ETL)

National Aeronautics and Space Administration

The JPL **ETL** is a crucial facility that ensures spacecraft can withstand the harsh conditions of space and launch. ETL simulates these environments to verify that spacecraft will function as intended during their missions.

- **Purpose**: The ETL's primary function is to test spacecraft and their components under conditions that mimic the space environment, including extreme temperatures, pressures, vibrations, acoustics, shock and radiation.
- **Importance**: This testing is essential for mission success, as it helps identify potential weaknesses and ensures the spacecraft can survive the rigors of launch and operation in space.
- **Facilities**: The ETL houses various specialized facilities, including:
  - *Thermal Vacuum Chambers*: Simulate the vacuum of space and extreme temperature variations.
  - *Vibration Testing Equipment*: Mimics the vibrations, acoustics and shock experienced during launch & deployments.
  - *Radiation Testing Facilities*: Assess the impact of radiation on spacecraft components.
- **Capabilities**: The ETL's capabilities extend to:
  - *Thermal cycling*: Testing the ability of components to withstand repeated heating and cooling cycles.
  - *Thermal shock*: Testing the ability to withstand rapid temperature changes.
  - *Highly Accelerated Life Testing (HALT)*: Identifying potential failure points through extreme stress testing.
- **Other Relevant Labs**: In addition to the ETL, JPL also has other specialized test facilities, such as the *Electric Propulsion Laboratory (EPL)* and the *Extreme Temperature Qualification Laboratory (ETQL).*

JPL 25 foot TVAC

https://youtu.be/I67cTs-AjNg?si=s-bdDpYjYBKzDt8X

https://www.youtube.com/live/UyuELtpBDH0?si=gJiZFdeN_WEiYAi4

JPL Radiation Effects Laboratory (RAD)

National Aeronautics and Space Administration

JPL Flight-Validated Modeling & Simulation

National Aeronautics and Space Administration

DARTS

Multi-mission, high-fidelity, physics-based modeling and simulation tools for orbiters, aero flight, ground vehicles and robotics

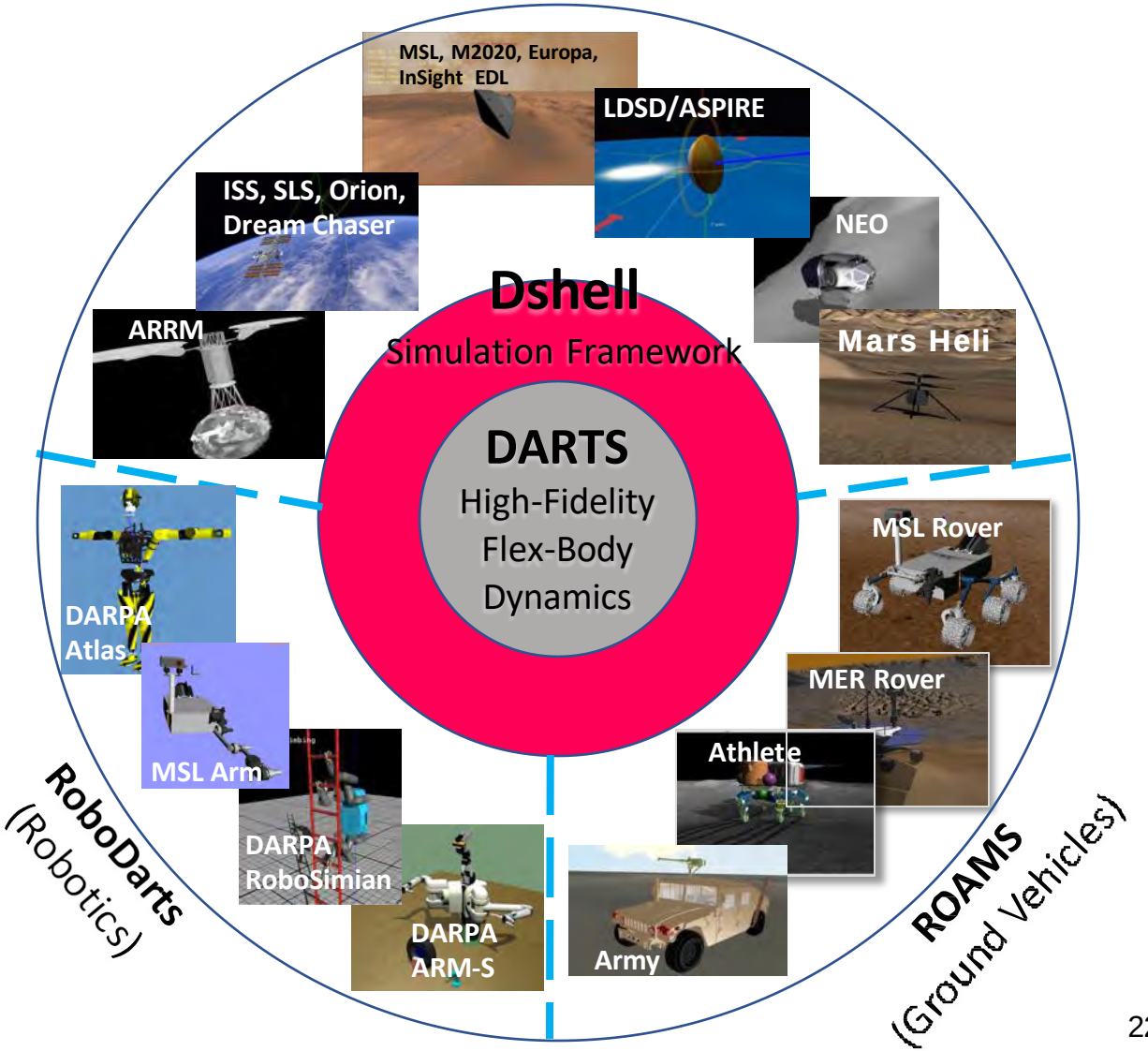
Example Applications:

- Earth orbiting vehicles, planetary cruise & orbital spacecraft, Entry descent and landing (EDL), Ascent & Launch vehicles, Near Earth Object (NEO) spacecraft
- Rotorcraft, airships/balloons
- Rovers and other ground vehicles
- Robot Mobility and Manipulation

Key tools:

- **DARTS** (dynamics) & **Dshell** (sim framework)
- **DSEND** (EDL), **ROAMS** (rovers), **HeliCAT** (rotorcraft), **RoboDarts** (robotics)
- **SimScape** (terrains), **IRIS** (GPU-accelerated ray tracing)
- **COMPASS** (used by JSC for ISS, SLS, Orion, and Artemis missions)
- Used by an Industry Partner

DSENDS, HeliCAT, FLOATS (Flight Dynamics)



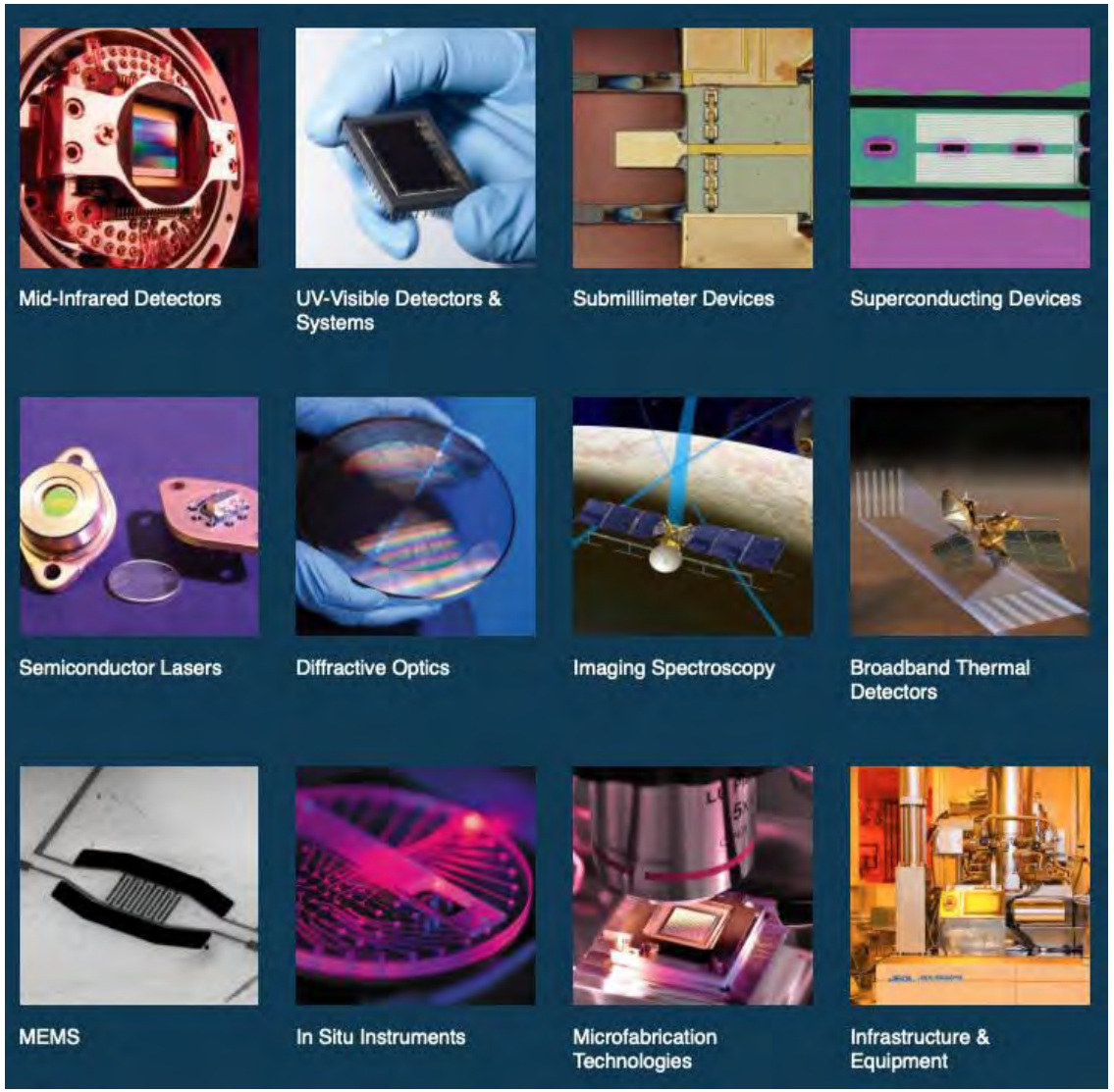
JPL Microdevices Laboratory (MDL)

National Aeronautics and Space Administration

Big things come from small technologies

The Microdevices Laboratory (MDL) is dedicated to the study of micro and nano-fabrication techniques. Since 1989, MDL has provided end-to-end capabilities in support of design, fabrication, and characterization of advanced components and sensors. Research and development activities at MDL have produced seminal contributions to the microdevice technology revolution.

MDL Core Competencies



JPL Innovation Foundry (*Team X*)

National Aeronautics and Space Administration

- The JPL Innovation Foundry brings together the practical application of concurrent engineering methods and tools for spacecraft design, and experts across the mission concept lifecycle to rapidly develop innovative space mission concepts and technologies.
- Team X is designed to spark ideas, test assumptions, understand decision options, and mature mission concepts through collaborative capabilities.
- By leveraging these capabilities, a Team X customer can accelerate concept development, ensuring that solutions are technically viable and aligned with mission objectives, key milestones, technology readiness, and cost.
- This approach increases the chances of success through real-time feedback, rigorous analysis, and collaborative input.
- Team X has a proven track record of success in conceptual mission design and systems engineering, demonstrated by its role in shaping thousands of space mission concepts.
- Additionally, the team's expertise in cost and technology assessments has been instrumental in informing decision-making for high-profile NASA missions and National Academy decadal surveys.

JPL's Team X in action. Team X Subject Matter Experts are highly experienced engineers that collaborate across disciplines, using a rapid iterative design process to develop innovative solutions for complex mission challenges.

Public-Private Support Guide (PPSG) Attachment B.8

Langley Research Center

Commercial LEO Development Program

Center Capabilities: NASA Langley Research Center

Primary Point of Contact

Chris Giersch
Associate Director for Partnership Development
STMD Langley Point of Contact
Space Technology and Exploration Directorate
christopher.e.giersch@nasa.gov

NASA Langley

Our Role in NASA

EXPLORE Moon to Mars

As NASA prepares for human exploration of deep space, Langley Research Center engineers, researchers, and technicians are developing innovative technologies for future space exploration.

- **Design, develop, and demonstrate entry, descent, and landing systems to enable robotic and human space explorations**
- **Design, develop, and demonstrate advanced space structures for long duration deep space missions**
- **Design, develop, and demonstrate concepts and technologies for autonomous in-space assembly of space structures**

Entry, Descent, and Landing

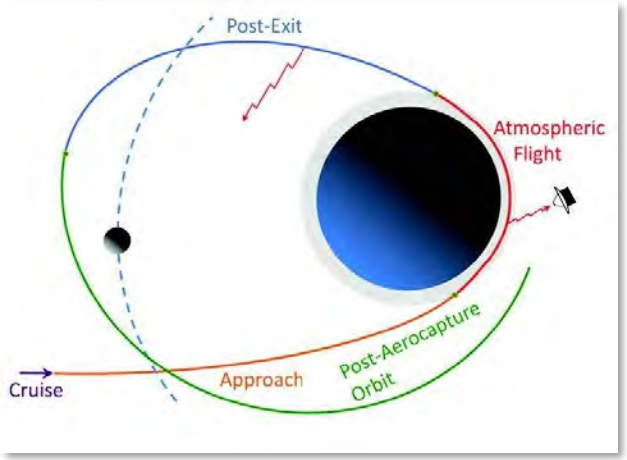
Overview

Langley is leading the way in EDL systems' technologies by designing, assessing, and optimizing vehicle systems for EDL and trans-atmospheric flight at Earth as well as other planetary bodies of the solar system. Additional capabilities include the characterization of flight environments, predicts the flight mechanics necessary to generate trajectories for vehicle projects, and integration of an entire vehicle system.

Areas of Expertise

- Advanced Hypersonic and Supersonic Entry Systems
- Mission Design and Flight Operations
- Mission Critical Software Design
- Atmospheric Characterization
- Entry Systems Modeling
- Aeroshells and Thermal Protection
- Integrated Systems Simulations
- Aerobraking
- Aerocapture
- Entry Trajectory Analysis

Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID)



Aerocapture

Facilities

- EDL HPC Cluster Complex
- Langley Aerothermodynamic Laboratories (LAL)
  - 31-Inch Mach 10 Air Tunnel
  - 20-Inch Mach 6 Air Tunnel
  - TDT
  - Unitary
  - 8-Foot High-Temperature Tunnel
- Vertical Spin Tunnel
- National Transonic Facility (NTF)

Structures and Materials, Advanced Manufacturing

Overview

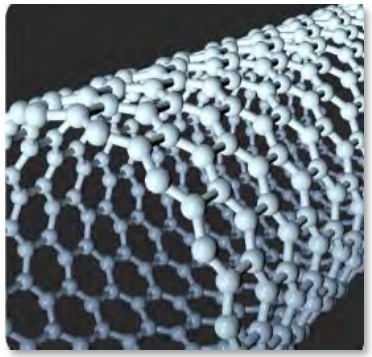
Langley focuses on advancing state-of-the-art lightweight structures, materials and manufacturing methods, playing a vital role in advanced and additive manufacturing of metals and composites, high temperature composites and ceramics, hybrid metal systems, and structural concepts to design, manufacture, validate, and sustain advanced aerospace vehicles and systems.

Areas of Expertise

- Advanced Materials and Processing
- Structural Mechanics and Concepts
- Structural Dynamics
- Topology Optimization
- Additive Manufacturing
- Material Synthesis, Coatings and Treatment
- Advanced Metallic Fabrication

ISAAC

Fabrication of up to 16.5 m long composite booms



Carbon Nanotube

Facilities

- Integrated Structural Assembly of Advanced Composites (ISAAC)
- Composite and Polymers Laboratory
- Materials Research Laboratory
- Mechanical and Thermal Loading
- Structural Dynamics Laboratory
- Large Structures Lab
- Flight Test Article Lab

Autonomous In Space Assembly

Overview

Langley is developing concepts for safe and reliable autonomous systems to supplement human operations, including mechanisms that can maneuver, assemble and service structures. Langley's primary focus is autonomous assembly, both on-orbit and on planetary surfaces, that bundles the disciplines of modeling and simulation, autonomous systems, structures and mechanisms, and systems analysis into a modular capability.

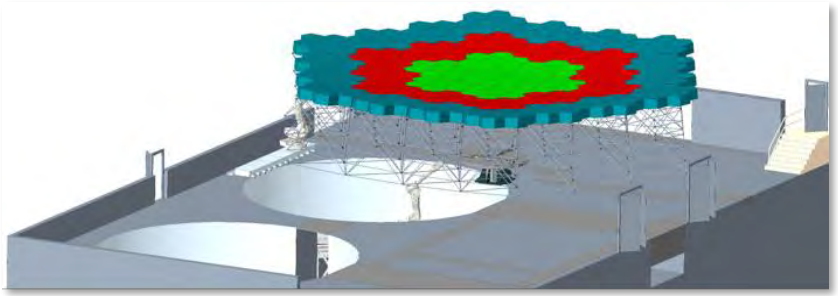
Area of Expertise

- Modular and Reconfigurable Structures
- Structural Assembly Operations
- Deployable and Assembled Structures
- Robotic Assembly Interfaces
- Precision Assembled Space Structures
- Flight Structures Test and Evaluation
- Autonomous Robotic Manipulator Software
- Modeling and Simulation

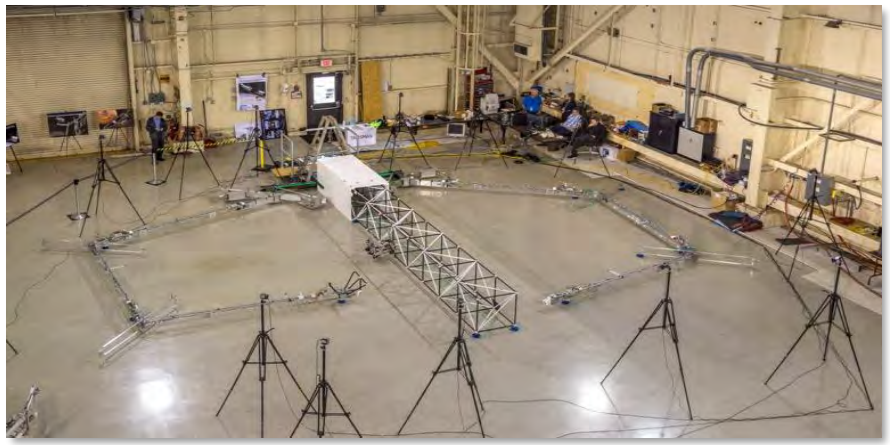
Deployable Composite Boom (ACS3)

Facilities

- Structure and Materials Resolution Lab
- Spacecraft Structures and Dynamics Lab
- Trusted Autonomous Operations Test Facility



Precision Assembled Space Structure



Spacecraft Structures and Dynamics Lab

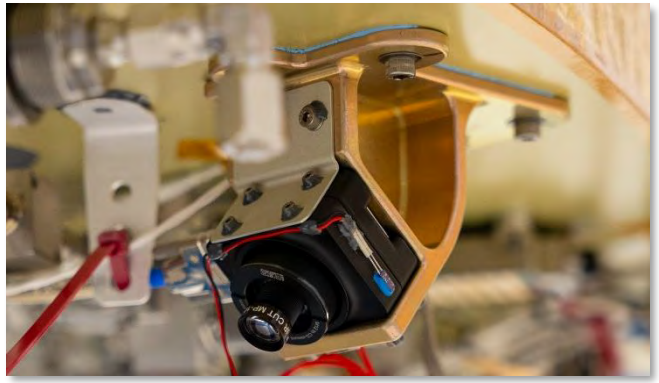
Space Flight Instruments

Overview

Langley conducts research, designs, and develops state-of-the-art electro-optical instruments and sensors to provide both remote sensing and in-site measurements for scientific, exploration and aeronautic applications. Additional capabilities include design analysis, prototype and flight systems development, management and support of instrument field test campaigns, and flight instrument projects and missions.

Areas of Expertise

- Lidar Technology Development
- Calibration and Radiometry
- Optical Design and Analysis
- Algorithm Analysis
- Active and Passive Sensor Systems
- Laser Materials Modeling and Development
- In-house Flight Instrument Fabrication
- Quantum Mechanical Modeling
- Sensor Calibration and Data Analysis
- Laser Technology Development



Stereo Cameras for Lunar Plume Surface Studies (SCALPSS)

Navigational Doppler Lidar (NDL)

Facilities

- Wireless Intelligent Systems E3 Research Lab (WIS3R)
- Fourier Transform Spectrometer Lab
- Optical Detectors Test Lab
- Optical Metrology and Calibration Lab
- Spectrometers Development Lab
- Remote Sensing Interferometer Development Lab
- Vacuum Test Chamber
- Ambient Pressure Thermal Test Chamber
- Surface Reflectivity Measurement Facility
- Pressure Transducer Characterization System

Radiation Protection and Habitation

Overview

A major effort for Langley's Radiation Protection team has been devoted to accurately assessing crew radiation exposure inside the spacecraft. Additional capabilities include the use of soft goods, composites, and advanced materials for in-space habitation systems.

Areas of Expertise

- Crew Radiation Exposure Assessment
- Radiation Environment Modeling
- Habitation and Radiation Requirements
- Radiation Analysis and Shielding Design
- Human Risk Models
- Vehicle Shielding Assessments
- Developing and Evaluating Textile Fabrics
- Softgoods and Materials Assessment

Radiation protection vest prototype

Inflatable Habitat

Radiation Analysis Software

- OLTARIS: Assessment of Radiation in Space
- NAIRAS: Nowcast of Atmospheric Ionizing Radiation System

OLTARIS On-Line Tool

Intelligent Flight Systems

Overview

Langley is transforming aviation and aerospace through adaptive and autonomous systems, human-machine teaming solutions, integrated flight systems, and new vehicle and operational concepts. LaRC expertise and capabilities include solving vehicle operational challenges, flight path management, human-machine interfaces, and methods and metrics for evaluating complex human-machine systems and operations.

Areas of Expertise

- Fault-tolerant Architectures for Space Applications
- Anomaly Detection in Complex Collaborative Control Paradigms
- Human Operator and Autonomous System Integration
- Crew Automation/Robotics Interaction Modeling
- Onboard Console Design
- Safety-critical Avionics Systems
- Autonomous Navigation and Reconnaissance
- Control-Theoretic Multivehicle Coordination
- Real-time Flight Software
- Command and Data Handling Systems
- 3-D Imaging flash LiDAR terrain mapping
- Sensor fusion/perception for avoiding obstacles and hazards, estimating position and orientation

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

Facilities

- Aerospace Controls Research Lab
- Systems Integration Lab
- Test and Evaluation Simulator
- Space Flight Simulator

Software

- Autonomous Entity Operational Network (AEON) - Robotics software and communications framework
- Baseline Environment for Autonomous Modeling (BEAM) - Blended reality simulation tool for test and evaluation

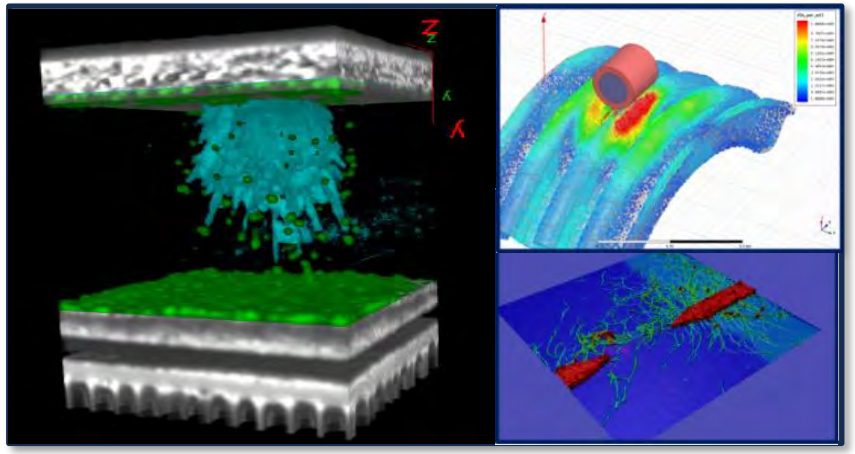
Damage Tolerance and Reliability, Structural Health Monitoring

Overview

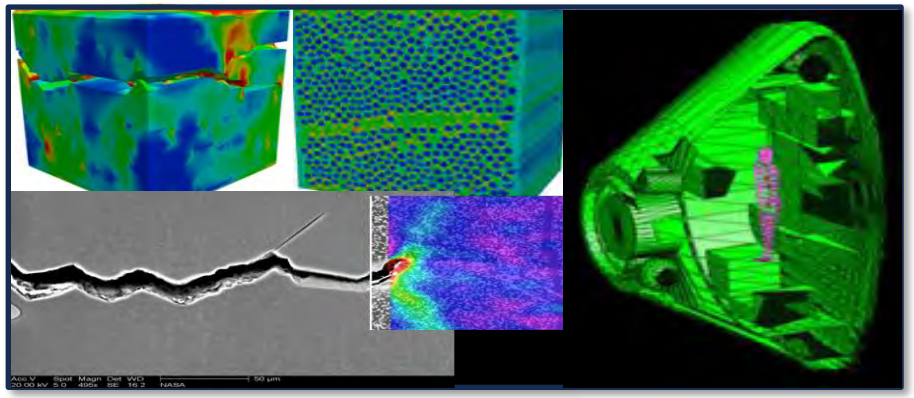
The Structural Analysis team at LaRC has extensive experience in vehicle design, structural health monitoring, finite element methods, probabilistic methods, failure analysis, safety assessment, and tool development. The team conducts a broad-based research and technology program that quantifies behavior, durability, and damage tolerance of structural materials for aerospace applications.

Areas of Expertise

- Advanced Nondestructive Evaluation (NDE) Techniques
- Structural Health Monitoring
- Fatigue and Fracture Testing of Sensory Materials
- Material Life Prediction
- Extreme Thermal Cycling on Composite Structures
- Durability, Damage Tolerance, and Reliability of Structural Materials
- MMOD and Regolith Impact Damage
- Lunar Dust Mitigation Technology



Nondestructive Evaluation Sciences



Durability, Damage Tolerance, & Reliability

Facilities

- NDE Laboratory
- Materials Research Laboratory
- Mechanical and Thermal Loading Light Alloy
- Laboratory
- Hazardous Testing Facility

Public-Private Support Guide (PPSG) Attachment B.9

Stennis Space Center

Stennis Space Center Capabilities

Jason Richard
Propulsion Business Manager
Strategic Business Development Office
Jason.A.Richard@nasa.gov

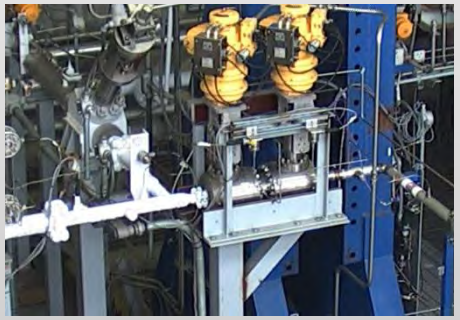
March 31, 2025

SSC Facility Capabilities

- 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
- Component and System Testing and Validation:
  - Extensive test capability and experience to support development and problem resolution in support of components
  - Cryo expertise and ultra-high pressure and high flowrate capability at the E-1 Test Facility
  - Cryo shock, pressure testing, and cavitation testing of valves, ducts, or flex joints
  - Simulated Altitude testing for small propulsion systems at the E-3 Test Facility
  - Demonstrated experience through testing for NASA and commercial partners at multiple test stands

E-1 Test Facility

E-3 Test Facility

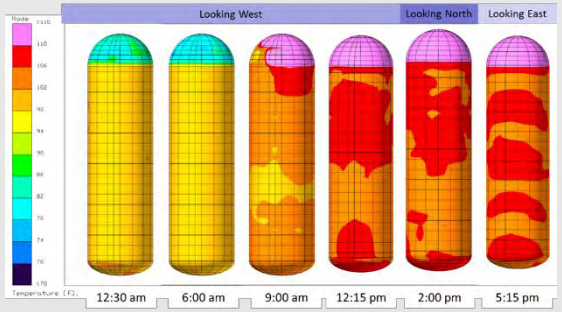


Developmental Test of Liquid Oxygen Valve

Validation of Liquid Oxygen Duct

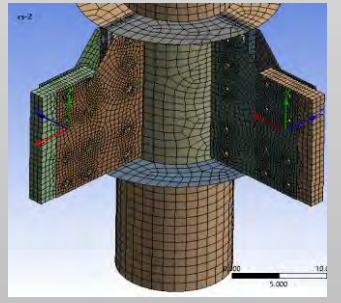
SSC Engineering Capabilities

- **Design, Development, and Fabrication of Test Equipment:**
  - Extensive capabilities in detailed design, analysis, integration, and testing:
    - Cryogenic Piping System Design and Analysis
    - Pipe Support Design and Analysis
    - Pipe Flexibility and Stress Analysis
    - Fluid/Thermal System Analysis
    - Protuberance Analysis
    - Thrust Structural Design and Analysis
    - Data Analysis
    - CFD Modeling
    - Acoustic Analysis (Including Detonation/Deflagration)
    - Diffuser and Ejector Systems for Simulated Altitude Testing
- **Structural Design & Analysis**
  - Structural Dynamics and Integration
    - Structural Dynamic Analysis including vibration, acoustics, and shock
  - Structural Design, Development, and Analysis
    - Structural Strength Analysis
    - Multi-element design integration
  - Thermal Analysis and Control
    - Thermal Environments Analysis and Characterization



Thermal Modeling

CFD Modeling

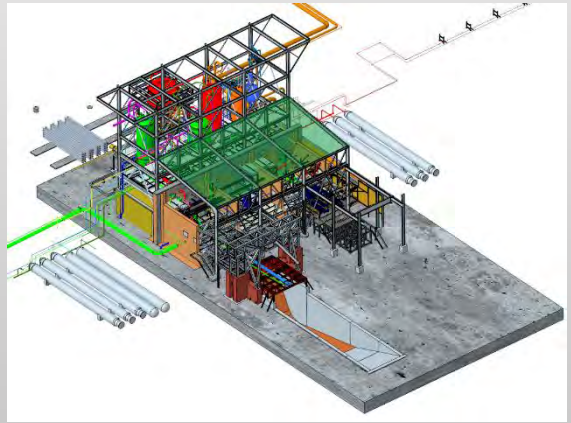


FEM Structural Analysis

SSC Engineering Capabilities

- **Software Design, Development, and Test Experience**
  - NASA's Data Acquisition Suite (NDAS) is an in-house developed data collection and analysis software suite designed to support rocket propulsion testing.
- **Systems Engineering & Integration**
  - Technical Management
    - Risk Management
    - Operations/Supportability/Sustaining Engineering
  - System Design and Definition
    - Interface Definition, Integration and Management
    - Complex Systems Integration
    - Interface Verification
  - Test and Verification
    - Verification Planning, Development and Execution
    - Requirements Definition and Management
    - System Validation
  - Systems Analysis
    - Mass Properties Analysis and Management
    - Model and Simulation Management and Planning
    - Integrated Logistics Planning
  - Model Based Engineering

NDAS



Model Based Engineering

SSC Autonomous Systems Development

- Create safety-critical autonomy solutions for ground systems and space missions
  - Digital Twin using Model-Based Systems Engineering
    - Virtual model that encompasses architecture & behaviors
  - Anomaly Detection
    - Identify anomalous behaviors and trends that deviate from nominal
  - Real-time Failure Modes and Effects Analysis (FMEA)
    - Diagnose the probable cause of the anomaly and determine effects, based on available knowledge and information
  - Automatic Strategy Creation
    - Create plans and schedules, and execute tasks to resolve or mitigate issues
  - Autonomous Mission Operations
    - Systems and systems-of-systems that can operate without human intervention
- Capability Maturity Model Integration (CMMI)
  - Achieved Level 2 rating

Public-Private Support Guide (PPSG) Attachment B.10

Independent Verification and Validation Facility (IV&V)

NASA's Independent Verification & Validation Program

The NASA Independent Verification and Validation (IV&V) Program exists to help **mitigate software, system, and security risks** on NASA missions. Created as a result of the Space Shuttle Challenger accident, IV&V is responsible for providing a systems engineering function that is focused on **partnering with missions to improve reliability, find defects earlier, reduce cost, and reduce risk related to safety-critical and mission-critical software**.

In 2019, the IV&V Program's building in Fairmont, WV was renamed the *Katherine Johnson Independent Verification and Validation Facility* in honor of West Virginia native and NASA "hidden figure" Katherine Johnson.

Point of Contact: Jarrod Petersavage
jarrod.m.petersavage@nasa.gov

IV&V Capabilities (1 of 2)

- **Mission-Focused Partnerships:** Unlike regulatory or audit functions, IV&V operates as a systems engineering ally, collaborating with missions to reduce development costs and enhance success rates through tailored, practical solutions. IV&V provides actionable data to customers and stakeholders that drives changes to system and software projects and informs key decision makers throughout the lifecycle.
- **Enabling Commercial Success:** The IV&V Program actively collaborates with commercial partners, adapting its approaches to align with modern software development practices. IV&V aims to enable—not impede—mission success and is eager to expand engagement with commercial partners.
  - Currently performing IV&V on these commercial missions:
    - SpaceX and Blue Origin Human Landing System (HLS)
    - Axiom Exploration Extravehicular Activity Services (xEVAS)
  - Software Surveillance activities*:
    - SpaceX and Boeing Commercial Crew Program (CCP) developments
    - Extravehicular Activity and Human Surface Mobility (EHP) Lunar Terrain Vehicle (LTV) – PLANNED
    - Commercial Low-Earth-Orbit Development Program (CLDP) – PLANNED
    - *Support the overall NASA engineering and Safety and Mission Assurance (SMA) insight roles. Detailed reviews of vendor software plans/products related to safety criticality

IV&V Capabilities (2 of 2)

- **Reducing risk, increasing mission success, increasing high quality products, reducing cost/schedule impacts.**
- **Real Impact on Software:** Each year, IV&V identifies and collaborates with developers to resolve thousands of software defects, safeguarding mission integrity, performance, and security. IV&V prioritizes impactful defects and maintains an exceptionally high true positive rate (greater than 95%) for all identified issues.
- **Proven ROI:** Missions receiving full software IV&V have a strong track record of success—no software defects leading to loss of mission or crew—demonstrating a clear return on investment for NASA's safety and mission assurance. Over 30 years of partnership with NASA's highest-profile missions.
- **Innovative Evolution:** The IV&V Program continuously advances its processes, leveraging decades of safety-critical embedded system development best practices and defect data. Innovations such as digital twins for testing, AI/ML integration, and Model-Based Systems Engineering (MBSE) help IV&V adapt to emerging risks like cyber threats, ensuring relevance in a dynamic landscape.
- **Cost-Effective Operations:** Based in West Virginia, the IV&V Program delivers exceptional value by leveraging competitive civil service and contractor labor rates, as well as low facility costs, while remaining within driving distance of Washington, D.C.

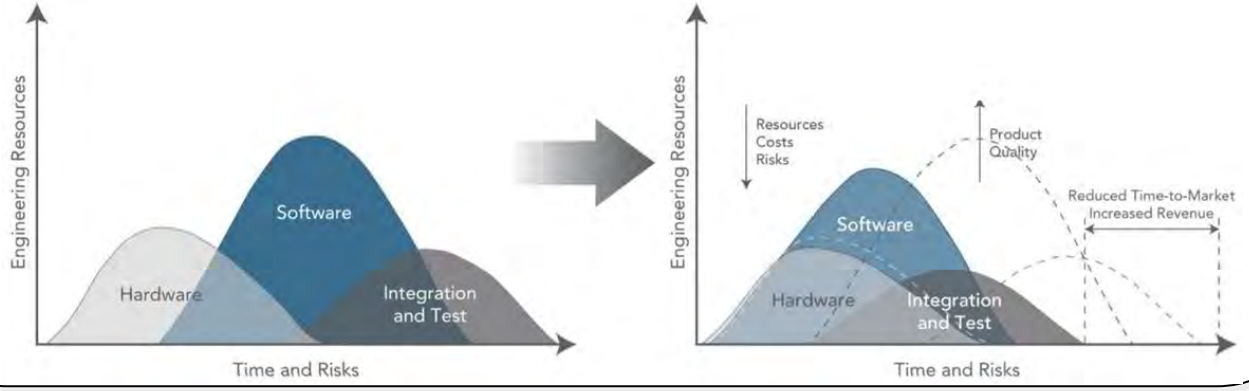
Software Digital Twins

"The most valuable spacecraft component that never leaves earth"

Fail Virtually, Succeed Actually

Software Digital Twins Enabled Via Hardware Emulation

1. Software Digital twins **shift** the traditional software development cycle
2. Software Digital twins **increase** test resources
3. Software Digital Twins **expose** high severity issues



Condense entire flight system to a laptop or cloud solution

1. Flight computer hardware is **emulated**
2. Sensors/actuators are simulated
3. Flight software binaries executed **unmodified**
4. Ground operations software integrated as-is

Software Digital Twin Benefits

- ✓ **Cost:** Enables parallel development efforts
- ✓ **Schedule:** Accelerates develop timeline (test without flight hardware) & enables automation (CI/CD pipelines)
- ✓ **Testing:** Increased failure scenario and edge case testing
- ✓ **Development Efficiency:** Reproducible test environments supporting multiple disciplines (FSW, GSW, GNC, Ops, V&V)

JSTAR is a Software Digital Twin Factory

- ✓ Agile, repeatable, and proven approach
- ✓ 20+ Software Digital Twins spanning NASA & OGAs
- ✓ Numerous high severity issues discovered

JSTAR – A Software Digital Twin Factory

Mission	Platform
Integrated Tri-Program Simulation	ARRISTOTLE
Roman Space Telescope (WISP)	WISP
Europa Clipper	ECHOES
Gateway	Gateway-in-a-Box
Exploration Ground System (EGS)	GS2
HLS Space-X	HOOTL
James Webb Space Telescope (JWST)	JIST
Open-Source Design Reference Mission	NOS3
Psyche	PHASE
Space Launch System	S3
Multi-Purpose Crew Vehicle (MPCV)	SOCRRATES
LM Product Line	Soft Sim
International Space Station	MADE

JSTAR Digital Twin Components and Products

- **Ground System Software**:
  - AIT
  - AMPCS
  - ASIST
  - COSMOS
  - ITOS
  - OpenC3
  - OpenMCT
  - YAMCS
- **FSW**:
  - Core Flight System (cFS)
  - F Prime (JPL)
- **Communications**:
  - 1553
  - CAN
  - Ethernet
  - I2C
  - SPI
  - SpaceWire
- **Dynamics**:
  - Trick
  - Goddard Dynamic Simulator
  - Simulink
  - 42
- **Processor Emulation**:
  - Simics
  - QEMU – open source
    - GR740 / GR712
    - RAD750
    - PPC
    - Custom SoCs
- **Design Reference Missions**:
  - NOS^3
- **Training Packages**

Digital Twins Uncover High Severity Issues

Mission	Finding	Impact
Project A	Incorrect simulator code for the Right Booster Avionics Hydraulic Power Unit Controller #1 model results in a failure to activate during ALS, resulting in the vehicle entering off-nominal PAD_SAFING mode	Incorrect code in the simulator test environment HPUC model will result in essential capabilities of the Booster Avionics HPUC not being tested under nominal conditions.
Project A	Crash of the IDE or ODE partition occurred during Core Stage Flight or Core Stage Flight with Boosters, an Abort Recommendation indicating “Failure of Flight Critical Software” was not issued as required	Failure to report an abort condition will result in the loss of the FSW to report severe conditions that negatively impact mission success and safety
Project B	Inverted Gyro Data Validity Flags in Gyro Sensor Processing	Loss of Mission
Project B	Incorrect Command Hexadecimal in SCS 094 "COMM_Reset_Transponders	Loss of Communications
Project C	FSW writing to read-only register due to legacy code re-use	Incorrect hardware usage; Memory Corruption
Project C	FSW write to read-only downlink channel register fields	Incorrect hardware usage; Incorrect downlink configuration

Digital Twins Benefit to CLDP

Mission	Description	Impact to CLDP
Accelerated Development Timeline	• **Early software development before hardware availability** • Parallel development approach for software and hardware • Component-based architecture for custom hardware models	• **Enables commercial providers to start software development earlier** • Reduces schedule risk across multiple missions • Supports diverse commercial implementation approaches
Risk Reduction through Simulation	• **End-to-end testing of complex operations** • Test flight software against simulated hardware failures • Validate command sequences before execution • Increase TRL of flight software development, integration, and specific algorithms in a flight-like environment	• **Supports commercial providers with varying flight heritage** • Provides verification before costly hardware integration • Identifies potential issues before mission execution • Enables quantifiable risk assessment
Knowledge Continuity Across Missions	• **Consistent training environment for operations team** • **Repository of verified simulation components** • Standardized interfaces between NASA & commercial systems • Established pathway from simulation to flight operations	• **Creates reusable assets for future opportunities** • Maintains consistent processes across multiple deliveries • Facilitates knowledge transfer between missions • Establishes programmatic continuity despite provider diversity

Mission Protection Services (MPS) – System Security Analysis

- IV&V Mission Protection Services (MPS) include software security risk assessment, mission and system cybersecurity assessment and threat research, and verification and validation of space and ground software security control implementations.
- **Analysis and Assessment of Mission:** MPS focuses on the mission's overall security posture by building a security strategy and identification of hazards while in development.
- **Assessment Tests Can Include:**
  - Evaluation of vulnerability and risk management
  - Evaluation of electronic and physical controls
  - Analysis to determine the ground truth of implemented systems
  - Technical analysis of traditional and embedded systems
  - Simulation and testing of detection and response by systems and personnel
  - In-depth security assessment that involves utilizing vulnerabilities and digital twins

Software Analysis Services:

- Alternate Standards Assessments
- Verification and Validation Testing
- Static Code Analysis
- Code Coverage Analysis
- Software Safety Hazards Analysis, FMEA, FMECA
- Software Reliability and Fault Management Analysis
- Software Security Assurance
- Cloud Security Assessments
- System Assessment and Authorization (A&A) Services
- Code Quality Risk Assessment (CQRA)

NASA IV&V: Additional Examples of Analysis and High Severity Findings

Finding Type	Analysis Approach	Finding Description/Impact
Incorrect Code	Emergent Behavior Analysis	Emergent Behavior analysis of the segment transition capability revealed that the order of synchronization that Timeline and Vehicle Manager (TVM) uses at the start of each minor frame introduces the potential for bad data to be synchronized. If two TVM counterparts are out of synch during synchronization, the synchronization may result in setting event detection flags that have not actually occurred. If this occurs during a critical mission segment, such as EDL, the erroneous event detection may result in prematurely triggering irreversible sequences, such as forward bay cover jettison or parachute deployment. Premature execution of these critical sequences may have catastrophic consequences, including total loss of vehicle.
Missing Test Article	Verify Test Execution by Inspection of Test Cases, Inputs and Results	The test case is missing the verification of this Core Stage Flight sub-requirement. There will be no test to confirm the essential capability of sending engine shutdown commands during Core Stage Flight.
Incorrect Design	Design Analysis	The system validates and expands event status. Validation errors can occur for this particular state. An expansion error can also occur if the system is unable to read event data definitions from its internal caution and warning reconfiguration file. If a validation or expansion error occurs, the system internal caution and warning process aborts and is automatically restarted. If two such aborts occur within 20 seconds, then the system declares a repetitive process failure and initiates a shutdown of the entire function. In that case, human intervention is required to restart the function, or to reboot the system. Following restart, each system would then individually fall into a case (2) restart scenario. This could result in the total loss of the command and control capability provided by the system, as well as the redundancy provided by having multiple systems.
Incorrect Design	Validate Interface Requirements by Inspection Against Component Interfaces	Missing design for interface time exchange requirements could result in a mismatch of implementations, ultimately resulting in a negative impact to any number of many critical and essential time-dependent capabilities, such as guidance, navigation, and control, resulting in Loss of Mission/Loss of Vehicle.
Incorrect Code	Code Analysis	The effect of the coding error is that the orbit insertion burn complete flag is being monitored during a trajectory correction maneuver (TCM) and the TCM burn complete flag is being monitored during the orbit insertion burn. This will prematurely terminate the orbit insertion burn, which would result in the spacecraft failing to enter orbit and continuing to fly by the planet with no capability to return to a successful orbit, resulting in a loss of mission.
Missing Requirements	Requirements Analysis	IV&V identified an issue regarding 14 deleted TVM requirements for Network Router Card (NRC) commands. The requirements were deleted with rationale that the functionality would be moved to Communications and Tracking (CMT). IV&V determined neither the requirements nor the functionality had been moved to CMT or any other Computer Software Configuration Item (CSCI). The NRC is the external gateway for the vehicle that handles Data Exchange Messages for telemetry, commands, and command responses. This missing requirements and functionality could have resulted in loss of vehicle.

Public-Private Support Guide (PPSG) Attachment B.11

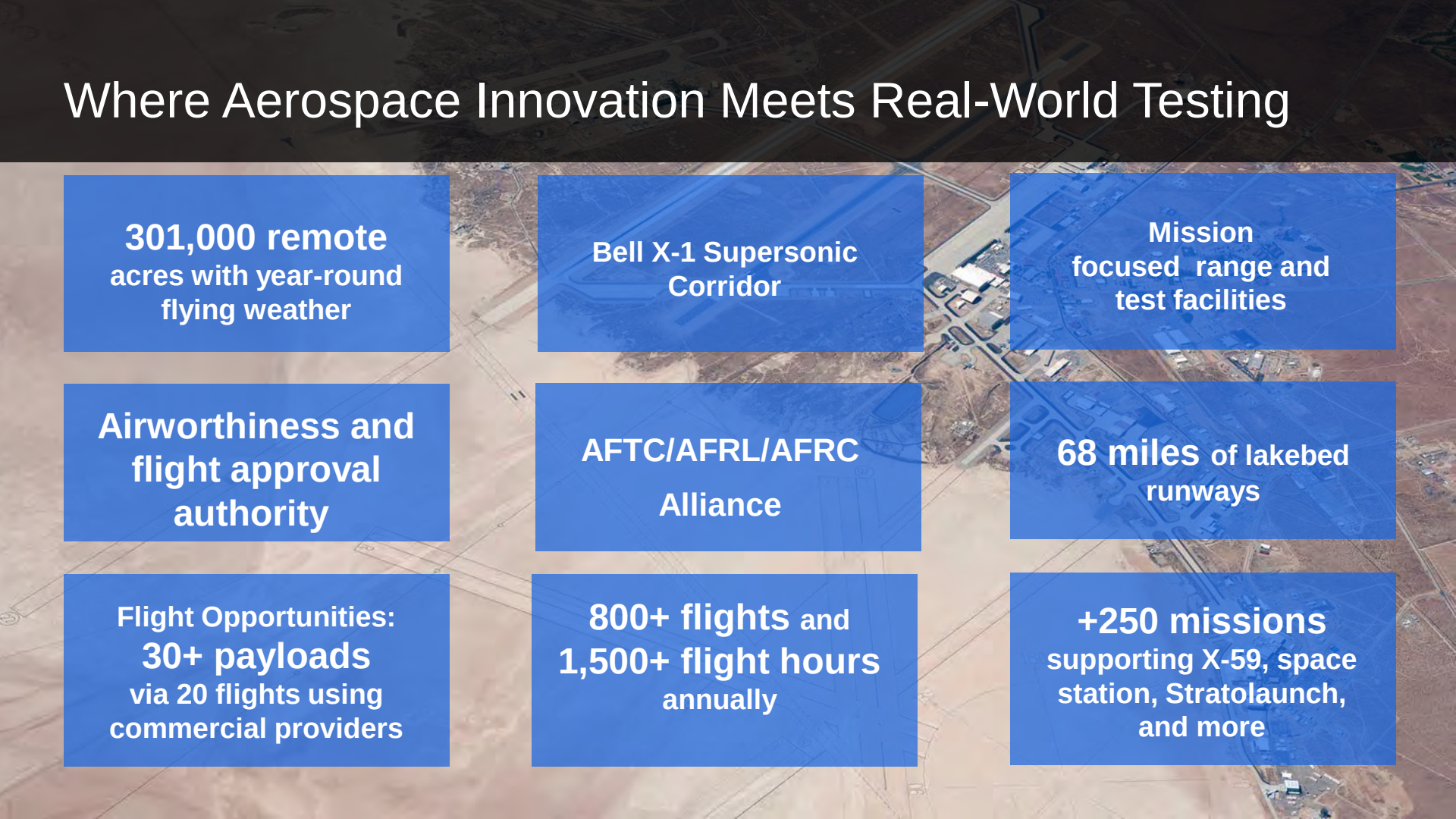
Armstrong Flight Research Center

NASA Armstrong Flight Research Center

Innovation Takes Flight Here

Patricia Ortiz – Branch Chief of Space Projects and Partnerships (Acting) - AFRC Industry POC

Where Aerospace Innovation Meets Real-World Testing



301,000 remote
acres with year-round flying weather

Bell X-1 Supersonic Corridor

Mission focused range and test facilities

Airworthiness and flight approval authority

AFTC/AFRL/AFRC Alliance

68 miles of lakebed runways

Flight Opportunities:
30+ payloads
via 20 flights using commercial providers

800+ flights and 1,500+ flight hours
annually

+250 missions
supporting X-59, space station, Stratolaunch, and more

The Armstrong Team: Expertise that Powers Flight Innovation

WHO WE ARE

- Pilots, mechanics, and technicians
- Engineers & Researchers
- Mission support specialists
- Project managers and financial analysts

WHAT WE DO

- Conduct high-risk atmospheric flight research and technology integration to revolutionize aviation and pioneer aerospace technology
- Rapidly demonstrate promising space technologies through suborbital testing with industry flight providers
- Conduct airborne remote sensing and science observations

HOW WE GET IT DONE

- Unique testing and simulation facilities and one-of-a-kind airspace capabilities
- Expertise in creative test development and evaluation
- Collaborative network of aerospace researchers and developers

Capabilities and Facilities Drive Innovation

NASA Armstrong integrates complex developmental systems from concept to flight. Armstrong combines world-class expertise with state-of-the-art infrastructure to transform aerospace innovation into proven flight technologies.

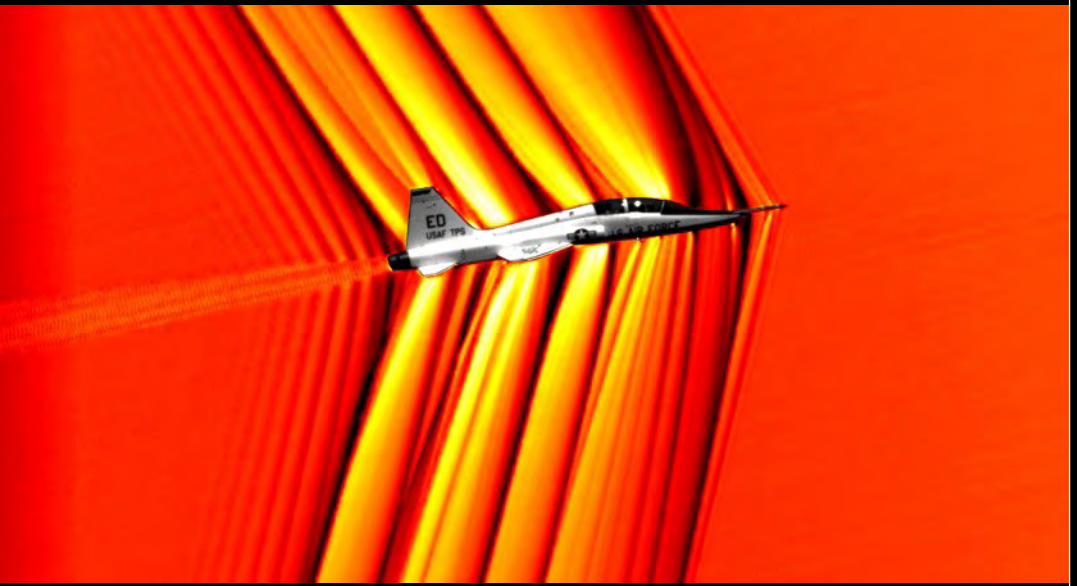
Powered by: ***Engineering Research | Atmospheric Flight Research | Unique Range and Test Facilities | Lab in the Sky | Mission-Critical Talent***

Engineering Research

Our engineers develop technologies that reduce aircraft noise and fuel use, get you gate-to-gate safely and on time, and transform aviation into a new economic engine at all altitudes.

- Airworthiness and flight safety assessment with tailored requirements based on mission complexity
- Technology development and testing in relevant environments to accelerate maturation
- Multidisciplinary applied research across aerodynamics, propulsion, flight controls, structures and avionics
- Engineering analysis and airworthiness substantiation through simulation and ground testing
- Experimental system prototyping, fabrication, and modification at all levels
- Safety critical software and system verification and validation

Atmospheric Flight Research



Armstrong's atmospheric flight research expertise spans hypersonic to UAS operations, delivering comprehensive capabilities that safely advance aviation technology through real-world flight validation.

- Research experiment design and specialized test planning with custom instrumentation
- Ground and flight test execution across any flight envelope including hypersonics
- Local and global flight operations with real-time data collection and monitoring
- Routine and specialized aircraft maintenance and research operations
- Large and small UAS operations in restricted airspace and test ranges
- Flight termination systems and comprehensive range safety authority

Unique Range and Test Facilities

Specialized range and test facilities provide unmatched capabilities for comprehensive flight research, from ground-based structural testing to real-time flight monitoring and high-fidelity mission simulation.

Flight Loads Laboratory
Conducts mechanical-load and thermal studies of structural components and complete flight vehicles and performs calibration tests of vehicle instrumentation for real-time determination of flight loads

Dryden Aeronautical Test Range
A network of radar, telemetry, and communications assets that monitor, process, and record data from test flights in restricted special-use airspace and transmit that information to mission control

Research Aircraft Integration Facility
High-fidelity simulators help pilots prepare for complex missions by replicating cockpit controls and flight condition and allow engineers to test and troubleshoot real aircraft systems in simulated flight conditions—without ever leaving the ground

Lab in the Sky: Advanced Flight Research Fleet

Armstrong's comprehensive aerial laboratory and diverse fleet of research aircraft pushes the boundaries of flight, from light aircraft to rocket-powered X-planes.

- Research platforms include F-15B test bed, Gulfstream aerodynamics research vehicles, and ER-2 high-altitude aircraft
- Support aircraft fleet with F-15D, F/A-18, and King Air mission support and chase planes
- Unmanned aerial systems including Global Hawk for high-altitude, long-duration missions
- Experimental X-planes advancing breakthrough flight technologies
- Subscale Flight Research Lab developing model aircraft for low-risk flight data collection before full-scale testing

Mission-Critical Talent: The Armstrong Advantage

Armstrong's dedicated team of innovators possesses the specialized skills to safely execute demanding flight research missions, advancing emerging technologies from concept through experimental testing.

- **Pilots, mechanics, and technicians** with the specialized skills to execute the most demanding flight test operations and missions
- **Engineers** with experience in a wide range of aircraft, flight regimes, systems, and test approaches
- **Researchers** develop and innovate in Aerospace Technology, Instrumentation, and Flight Test Techniques
- **Mission support specialists** that ensure the smooth operations of center functions crucial for success
- **Project managers and financial analysts** with the skills to ensure that research is performed on time and within budget, maximizing value to our customers

Technology Investment Focus Areas

Hypersonics

Autonomy

Efficient Aviation

Current Mission Portfolio focus

Aeronautics

- X-59/Quesst Mission/sonic boom mitigation
- AAM/Autonomy research and flight demonstrations
- High temperature materials and structural testing for hypersonic applications

Airborne Science

- Earth observation, satellite calibration, disaster response
- Worldwide deployments
- ER-2, C-20, G-IV, B-200 platform aircraft

Other

- Global Hawk/Skyrange hypersonic test data relay/collection in support of TRMC
- Flight Opportunities Program enables microgravity research leveraging non-NASA suborbital flight capabilities

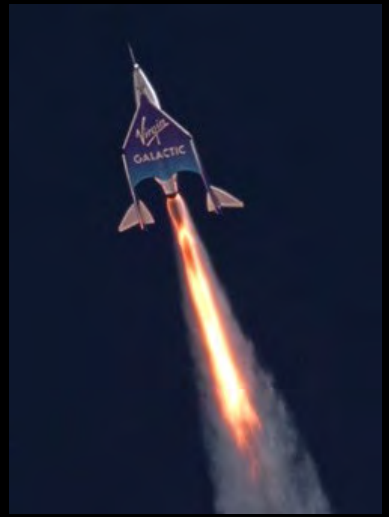
Transforming promising aerospace concepts into flight-validated solutions that advance national priorities.

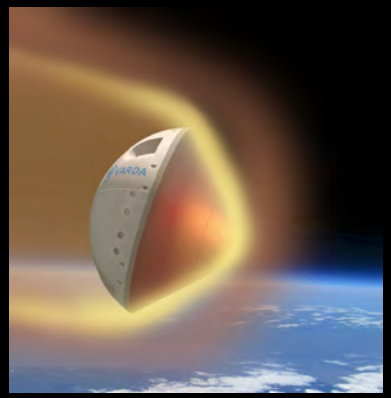
Armstrong Flight Research Center

nasa.gov

NASA
EXPLORE SPACE TECH
Flight Opportunities Program
Armstrong Flight Research Center

NASA’S FLIGHT OPPORTUNITIES PROGRAM





Credits (clockwise): Virgin Galactic, NASA/Matthew Kuhns, Blue Origin, Zero Gravity Corp., SpaceWorks Enterprises, Varda Space Industries., and Austin Buttlar

Suborbital Rocket-Powered Vehicles

Credits: Virgin Galactic

- Astrobotic
- Blue Origin
- Rocket Lab USA Inc.
- Virgin Galactic

High-Altitude Balloons

Credits: World View Enterprises

- Aerostar International LLC (acquired Near Space Corporation)
- Angstrom Designs
- World View Enterprises

Parabolic Flights

Credits: University of California, Berkeley

- Zero Gravity Corp.

Orbital Platforms Hosting Payloads

Credits: Varda

- Astro Digital
- Loft Federal
- Momentus Space
- Rocket Lab USA Inc.
- Space Exploration Technologies (SpaceX)
- Spire Global
- Tyvak Nano-Satellite Systems (Terran Orbital)
- Varda Space Industries

NASA.GOV/FLIGHTOPPORTUNITIES

Visit our websites for more information and resources, including our newsletter and monthly Community of Practice webinars.

Reach out:

NASA-FlightOpportunities@mail.nasa.gov