Welcome

Whitney Young

Academic & International Partnerships Manager

February 22, 2022

EXPLORE MARSHALL

National Aeronautics and Space Administration

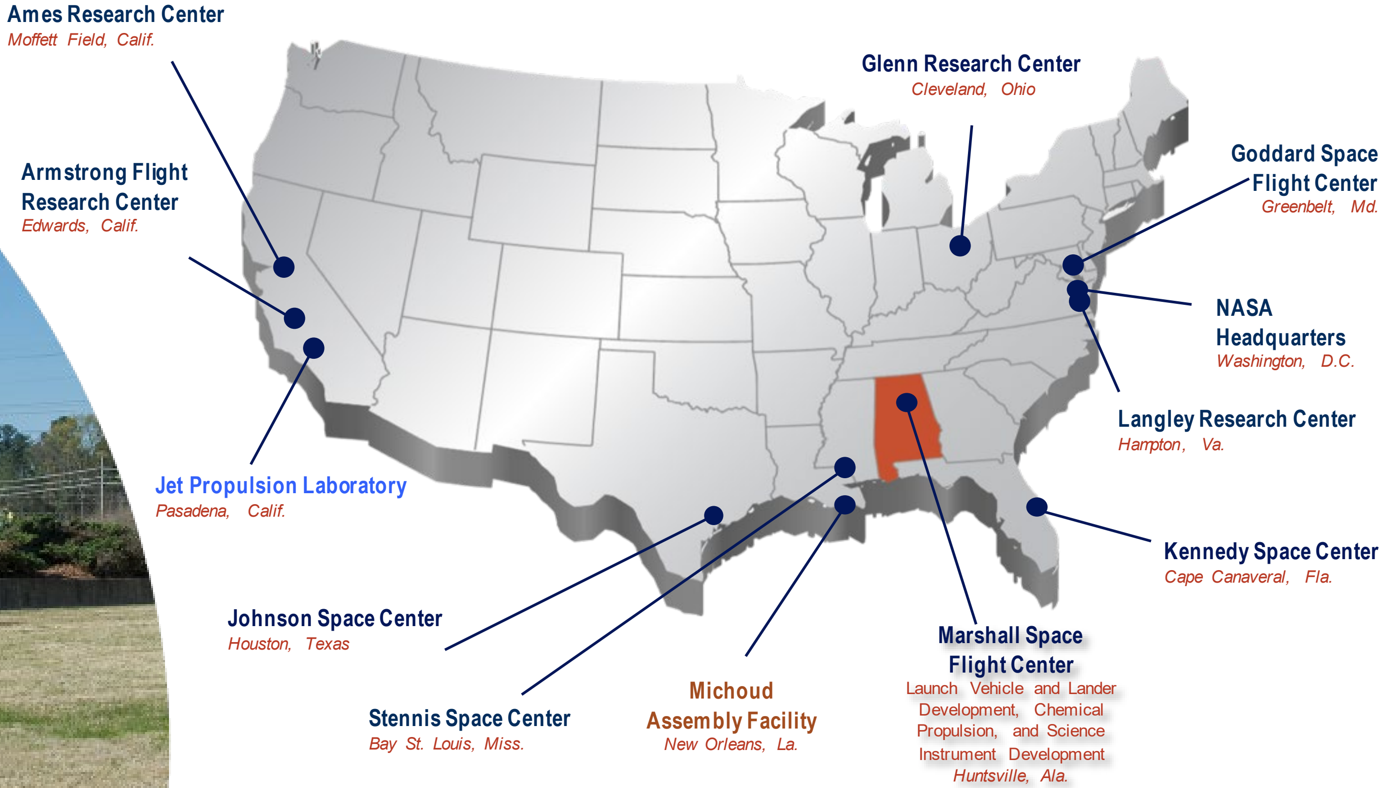
MSFC Overview

Dave Burns
Office of Science and Technology, Manager

February 22, 2022

National Aeronautics and Space Administration

EXPLORE MARSHALL



Marshall Space Flight Center

"Rocket City" Fast Stats

2nd largest research park

2nd largest concentration of high-tech workers

Highest concentration of degreed engineers

#1 best place for STEM workers

Top 10 city for Career Opportunities

Redstone Arsenal

41,000 employees

$50B in annual Federal budgets

Marshall's Community

Marshall Space Flight Center

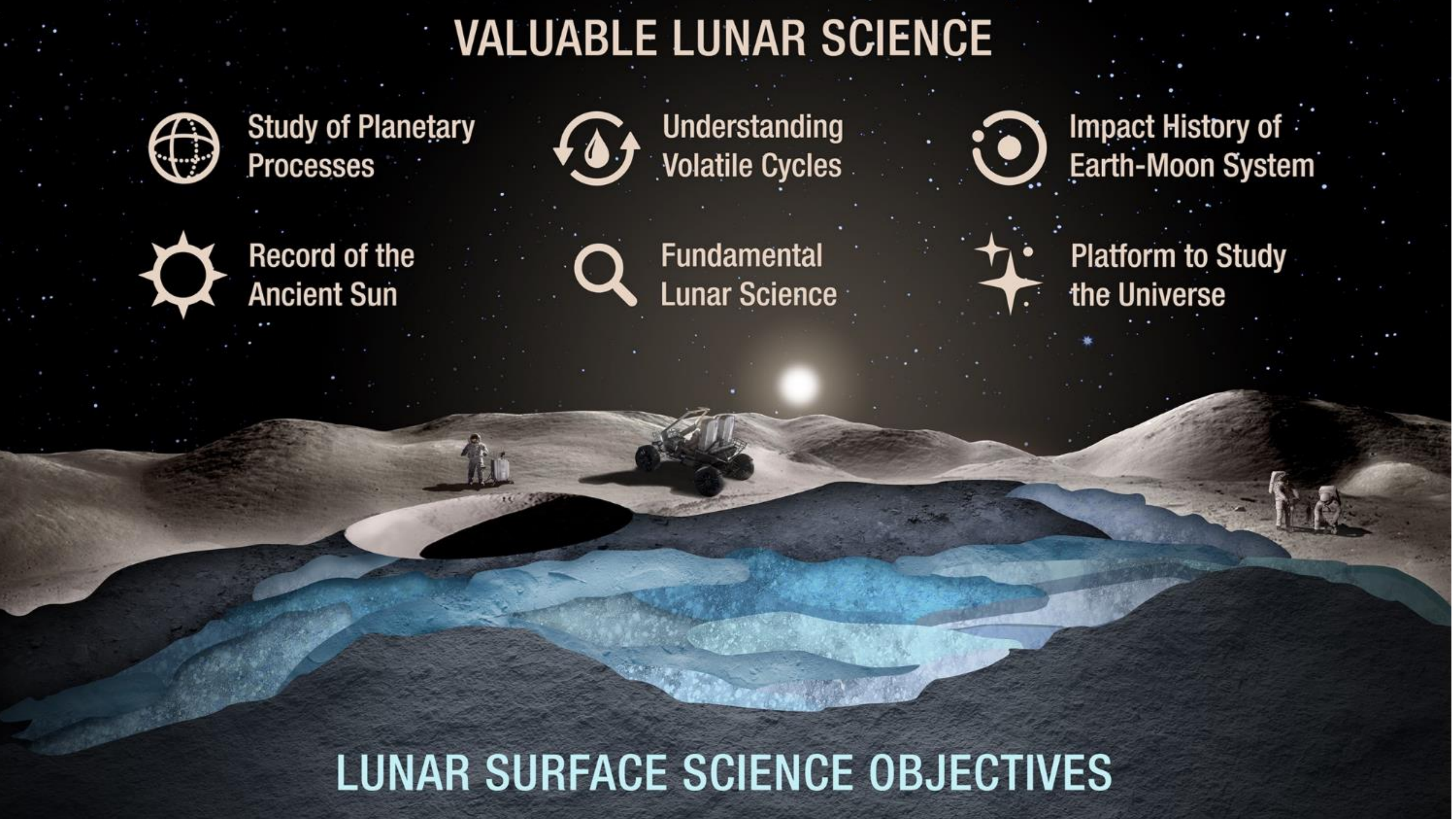
- 7,000 civil servants and contractors
- Delivering vital propulsion systems and hardware, world-class space systems, and state-of-the-art engineering technologies and cutting-edge science and research

Living and Working in Space
IXPE
Mars Ascent Vehicle
Traveling To and Through Space
Enabling Commercial Space & National Security
Understanding Our World and Beyond
MICHOUD ASSEMBLY FACILITY
Marshall’s Future Mission Areas

ARTEMIS I First human spacecraft to the Moon in the 21st Century

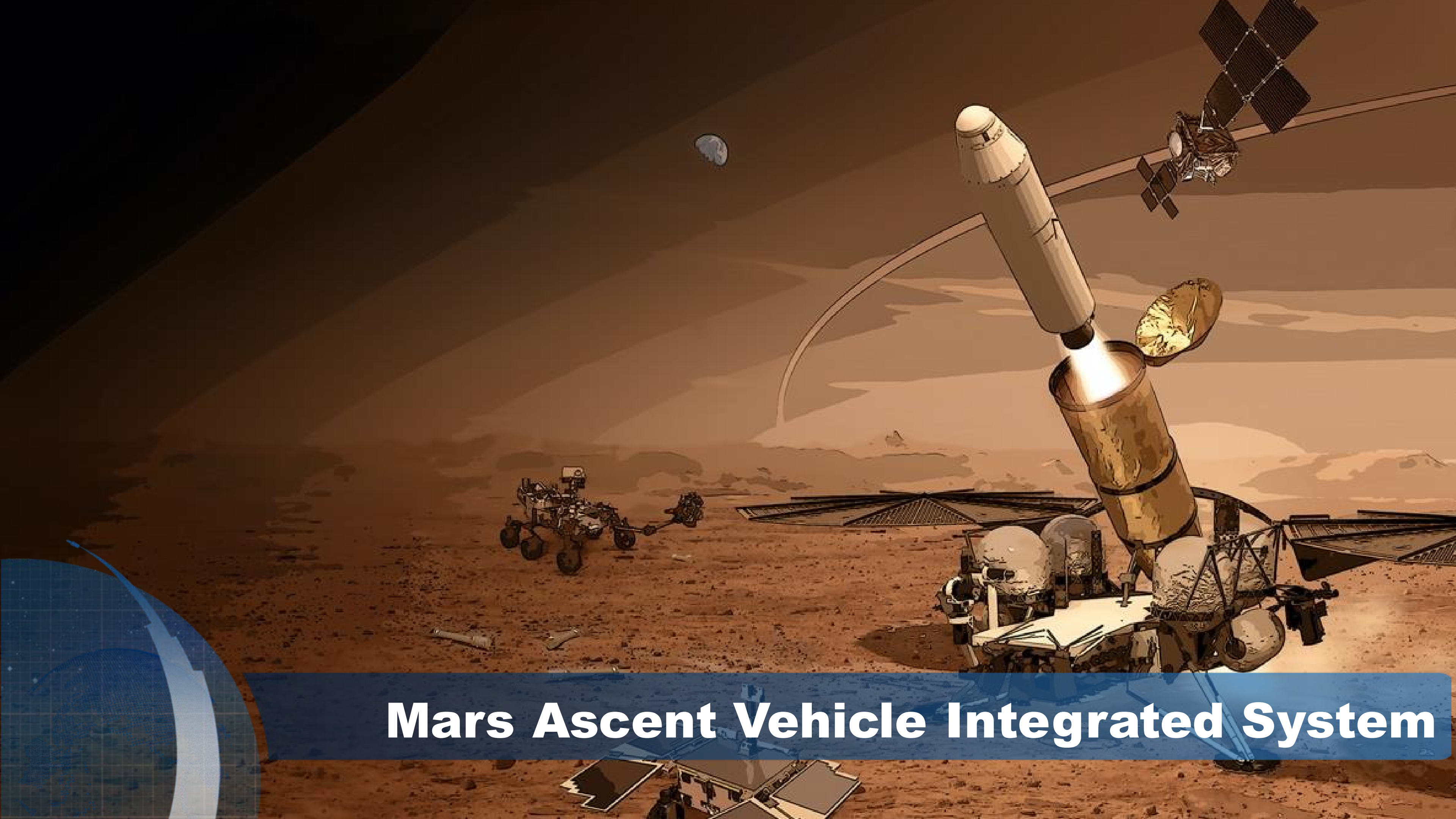
ARTEMIS II First humans to orbit the Moon and rendezvous in deep space in the 21st Century

ARTEMIS III Crew board the human landing system for expedition to the lunar South Pole


VALUABLE LUNAR SCIENCE
Study of Planetary Processes
Understanding Volatile Cycles
Impact History of Earth-Moon System
Record of the Ancient Sun
Fundamental Lunar Science
Platform to Study the Universe
LUNAR SURFACE SCIENCE OBJECTIVES


Astrophysics
Heliophysics
Earth Science
Planetary Science
Biological and Physical
Sciences on ISS


Developing Technology for Lunar Surface
Construction

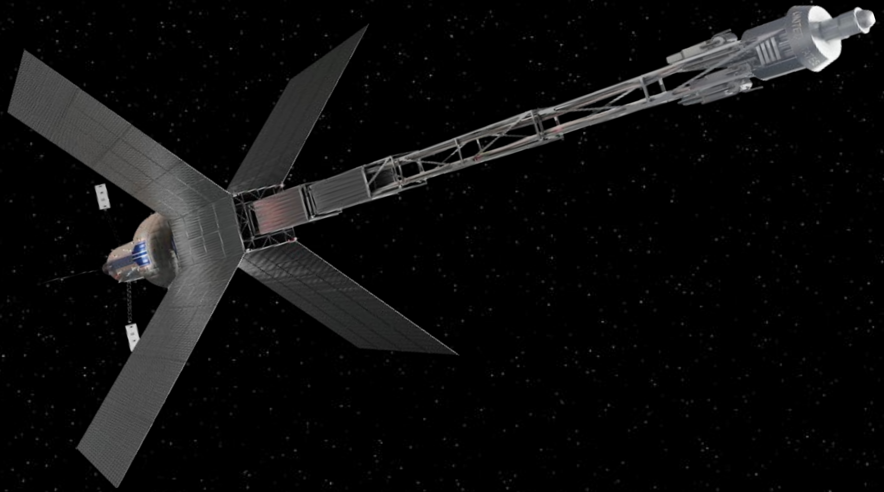


Mars Ascent Vehicle Integrated System

Space Nuclear Propulsion

Nuclear Thermal Propulsion

- High Thrust
- High Performance
- Short Propulsion Operational Times
- Short Trip Times
- Robust Abort Capability

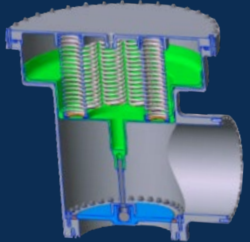


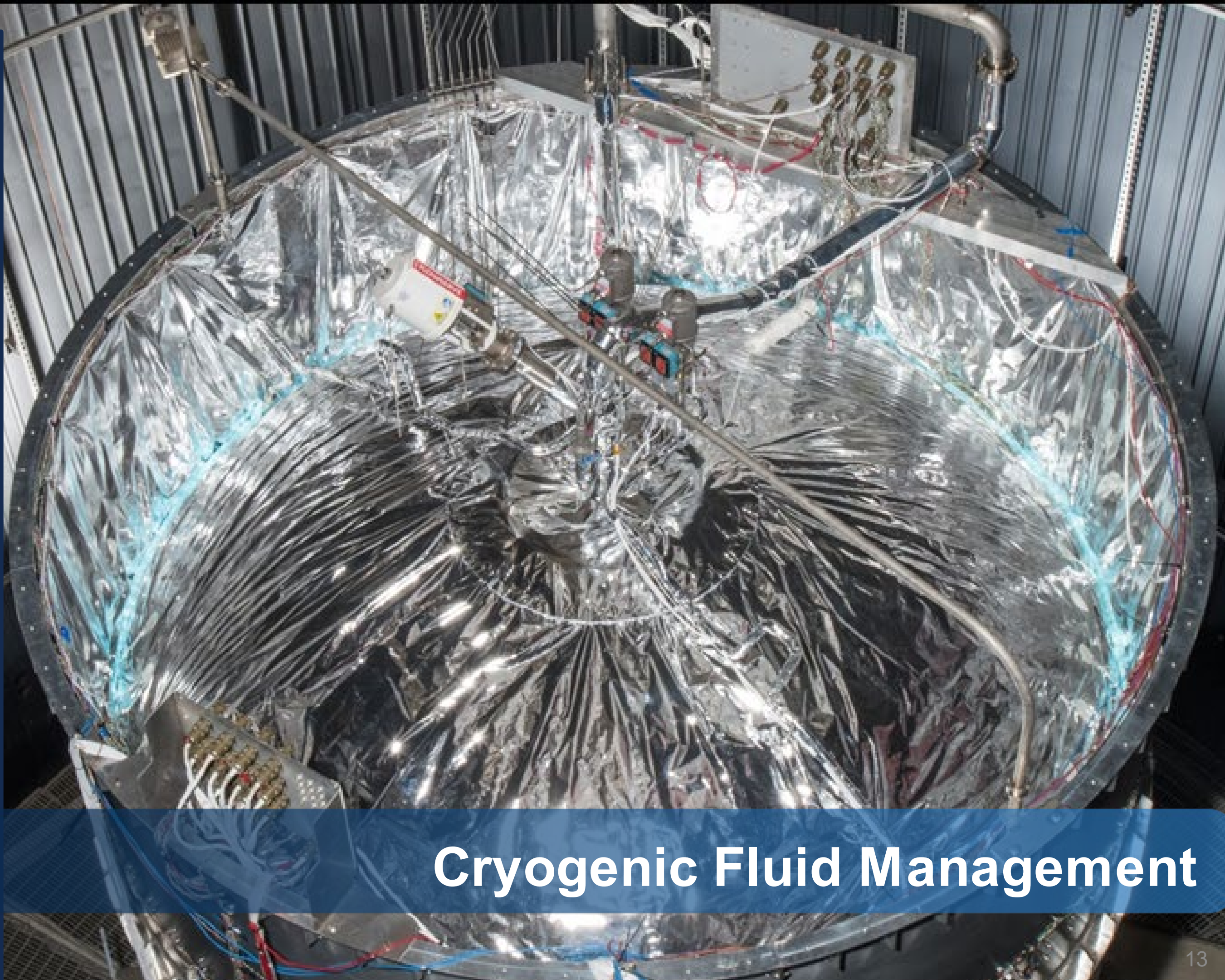
Nuclear Electric Propulsion

- Very High Performance
- Continuous Access to Electrical Power
- Potential to be combined with Chemical Stage for increased thrust capability

G–
558066

CFM for Liquid Hydrogen





Cryogenic Fluid Management

Payload Operations and Integration Center

SLS Engineering Support Center

24/7, 365 Support of ISS

Mission Operations

ARTEMIS

HUMANITY'S RETURN TO THE MOON

Dr. Dale Thomas
Director, Alabama Space Grant Consortium
Professor and Eminent Scholar in Systems Engineering
The University of Alabama in Huntsville
February 22, 2022

STILLMAN COLLEGE

UAH

SHELTON STATE COMMUNITY COLLEGE

Alabama Space Grant Consortium

Industry University Community

est. 1989

FAULKNER UNIVERSITY 1942

UAB

BEVILL STATE COMMUNITY COLLEGE

UNIVERSITY OF NORTH ALABAMA 1830

USA

ALABAMA STATE UNIVERSITY 1867

DRAKE STATE COMMUNITY & TECHNICAL COLLEGE

U.S. Space & Rocket Center

CALHOUN COMMUNITY COLLEGE

AAMU's 2021 Scholarship Recipients

Balloon Launch with UAH's Space Hardware Club

Auburn's 2019 Rover Team

The Alabama Astrobotics Team was invited to Space Grant's 30th Anniversary Celebration on Capitol Hill in 2019.

"Marketing NASA's Patent Portfolio" poster session

TENNESSEE VALLEY CORRIDOR

NASA/MSFC ACADEMIC PARTNERING WORKSHOP

TUESDAY, FEBRUARY 22, 2022

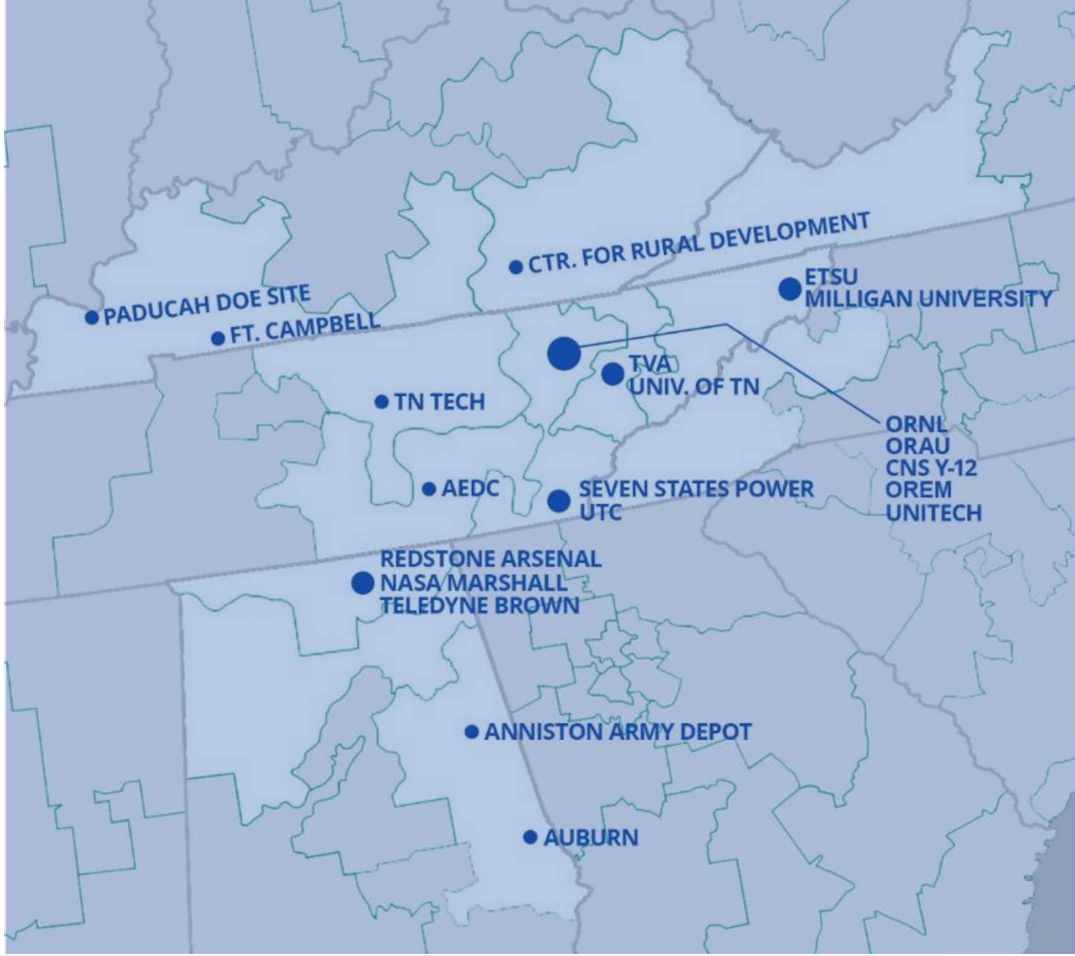
TVC

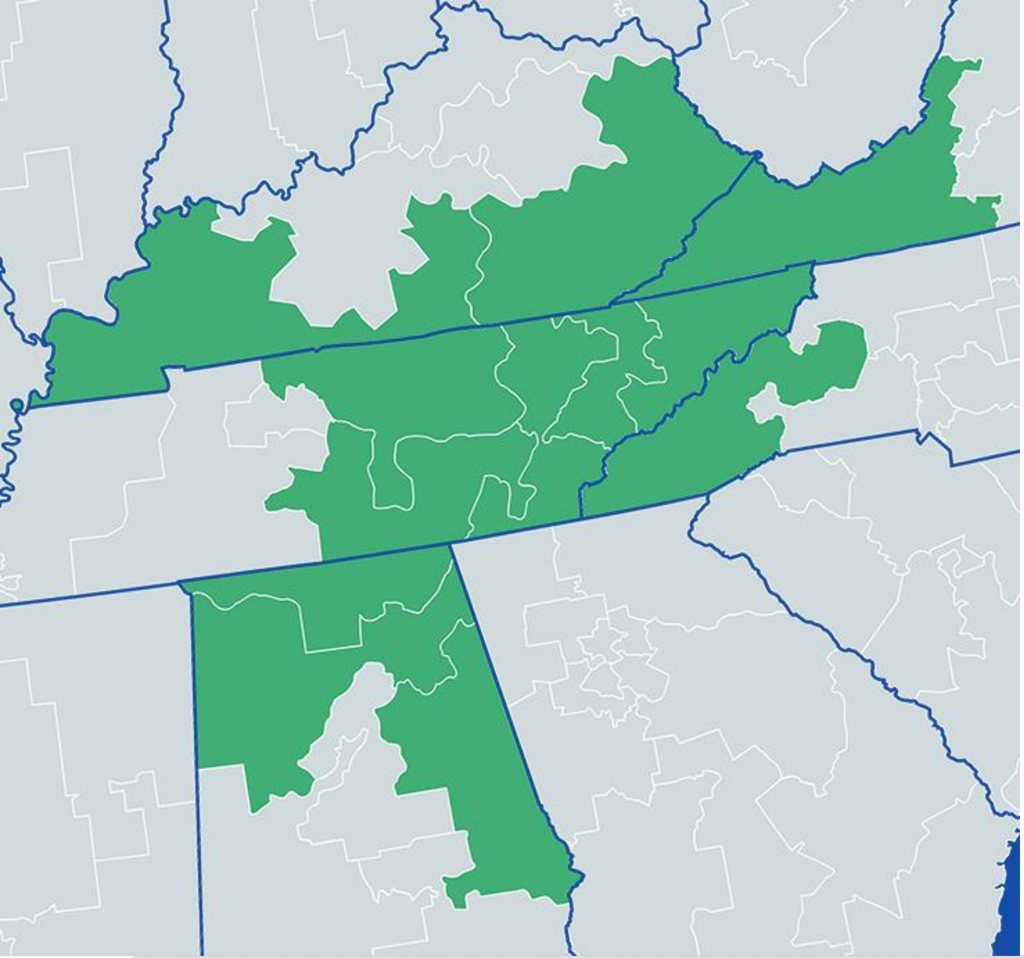
AL • KY • NC • TN • VA

THE CORRIDOR

The Tennessee Valley Corridor represents a footprint of **12 congressional districts** in:

- **Tennessee**
- **Alabama**
- **Kentucky**
- **Virginia**
- **North Carolina**





TVC
ECONOMIC IMPACT

TVC Leadership Council Members, Federal Agencies, & Partners within the TVC account for:

$75B Annual Federal Spending

82 Federal Agencies

150k Federal Employment

FROM IDEA TO IMPACT

1980s

THE IDEA

Governor Lamar Alexander had a vision to create an "Oak Ridge Corridor" linking the Department of Energy facilities in Oak Ridge, TVA and UT to showcase the wealth of brainpower in the mid-East region of Tennessee.

1995

THE CREATION

Congressman Wamp founded an annual Science & Technology Summit to convene representatives from government, academia and business to collaborate on ways to bring greater attention to the economic impact of the Department of Energy missions in Oak Ridge.

Today

THE COLLABORATION

The TVC has expanded to include 12 congressional districts across the southeast, promoting initiatives to advance federal missions in the Corridor and encouraging on-going collaboration in energy, science, environment, space, national security and education.

TVC

AL • KY • NC • TN • VA

OUR VISION:

Promote the Tennessee Valley Corridor’s national leadership in science and technology through regional cooperation.

OUR MISSION:

Sustain the Tennessee Valley Corridor’s existing federal missions, compete for new federal investments and leverage these investments to grow more private sector job opportunities.

STRATEGIES

Convene Key Leaders
in the TVC on a regular basis to create relationships, working collaborations and common goals.

Communicate the TVC's reputation
the TVC's reputation as an important science and technology center, internally and externally.

Align the focus
of the TVC with those of the TVC Congressional Caucus, the TVC Leadership Council and other partners.

Celebrate the accomplishments
of TVC organizations and individuals in promoting the TVC Vision and Mission.

Create & implement program initiatives
to further the TVC's mission.

CURRENT INITIATIVES

TVC 2022 FEDERAL AGENDA

Annually, the TVC issues recommendations on important issues to the region and submits these recommendations to the 12-member TVC Congressional Caucus, which is chaired by Congressman Chuck Fleischmann.

TVC WORKFORCE INITIATIVE

Assuring a quality workforce is critical to the success of the federal missions in Tennessee Valley Corridor. This initiative works to encourage greater collaboration among the TVC community colleges and federal partners.

TVC RURAL INNOVATION INITIATIVE

The TVC Rural Innovation Initiative (RII) seeks opportunities to expand the expertise and innovation of our region throughout rural communities – providing economic opportunities to the entire Tennessee Valley Corridor.

TVC

AL • KY • NC • TN • VA

www.TennValleyCorridor.org

SPACE LAUNCH SYSTEM

Countdown to Launch

February 22, 2022

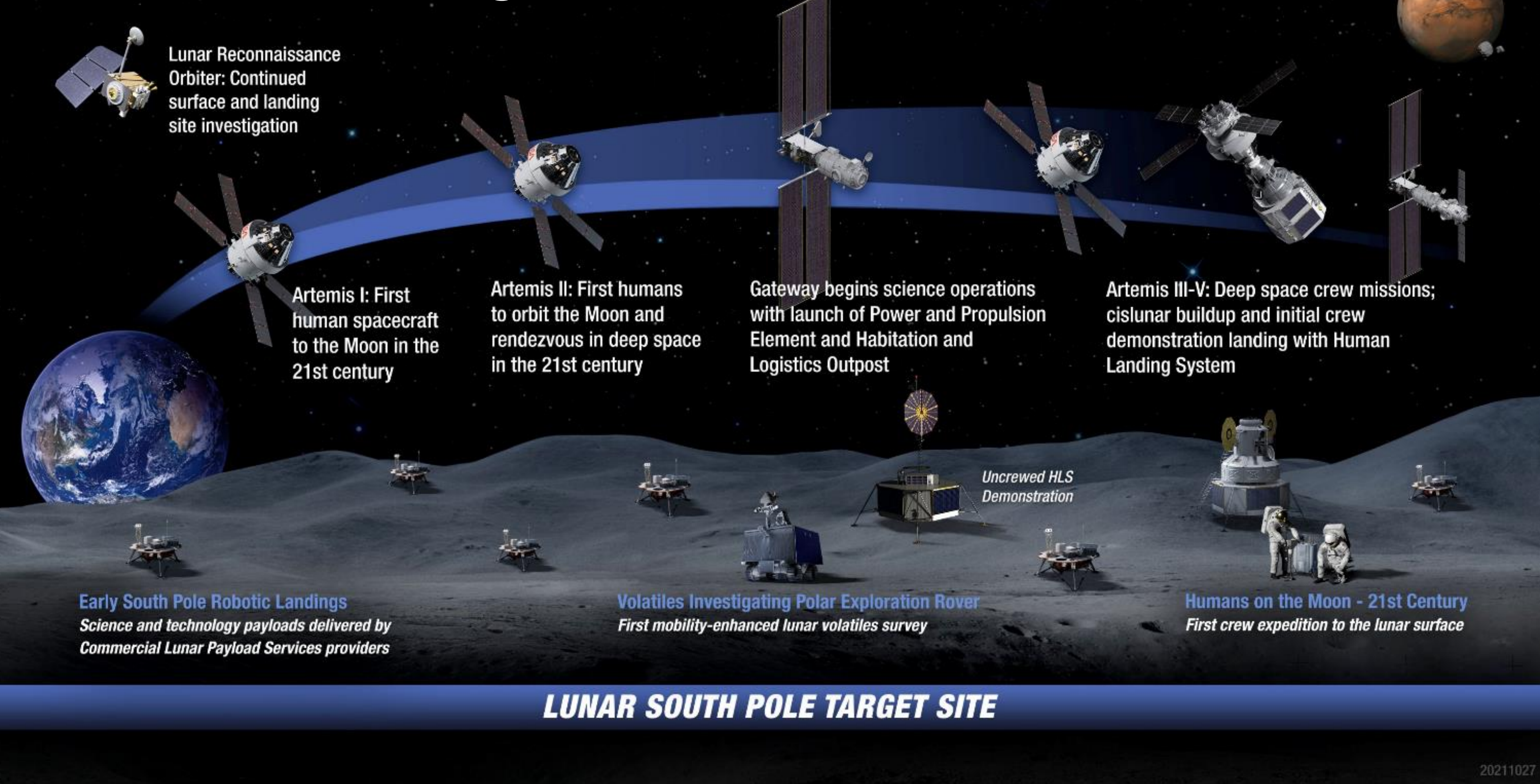
Trey Cate
Deputy Manager, Strategic Communication
Space Launch System Program

We go to the Moon to learn how to live on other worlds.

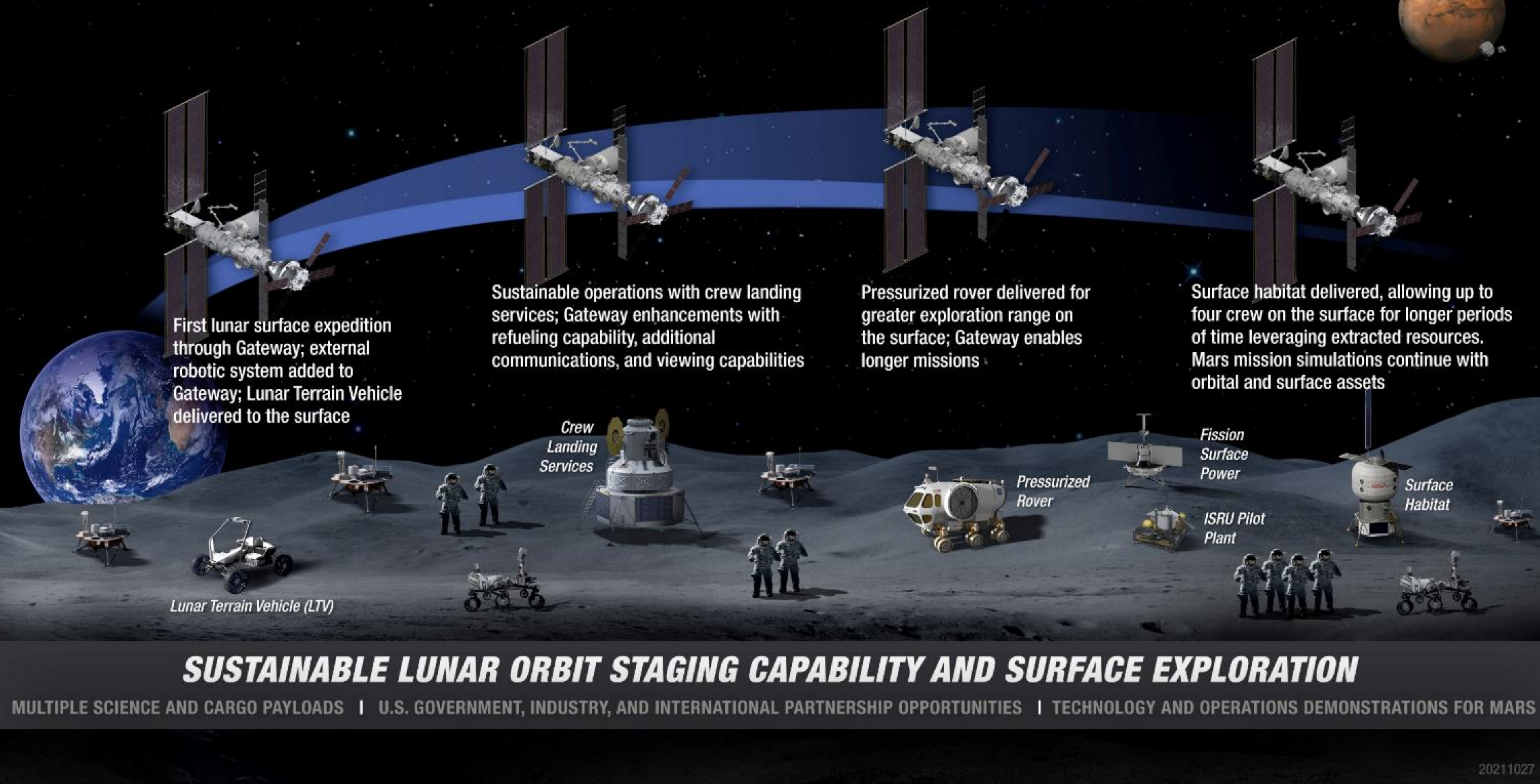
Image: Andrew McCarthy

Image: Andrew McCarthy

Artemis: Landing Humans On the Moon



Artemis Base Camp Buildup



NASA'S Space Launch System

Unparalleled Capability

The only rocket with the power and capability required to carry astronauts and/or large payloads to deep space.

Soft Power

Ensures American leadership in deep space exploration and sets the conditions for commercial markets to emerge.

Unique National Asset

The current and evolved versions of SLS along with Exploration Ground Systems ensure our Nation's access to deep space.

America's Rocket

Unlike privately built launchers, SLS belongs to the American taxpayer. Missions are transparent and benefit all.

THE POWER OF SLS

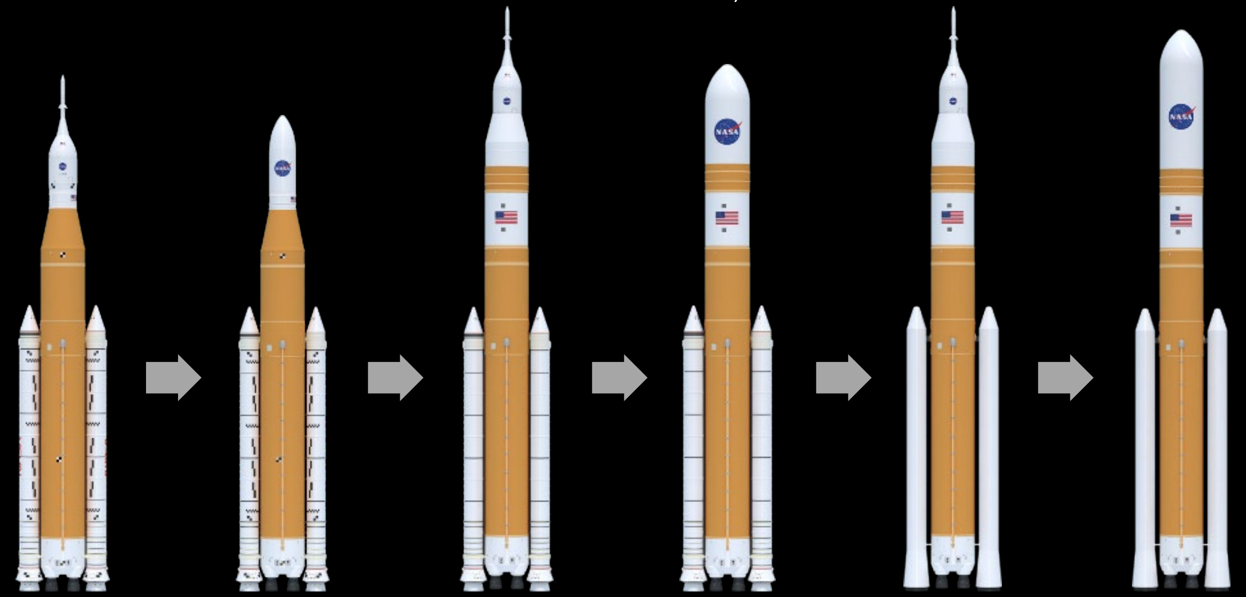
FOUNDATION FOR A GENERATION OF DEEP SPACE EXPLORATION

	SLS Block 1 Crew	SLS Block 1 Cargo	SLS Block 1B Crew	SLS Block 1B Cargo	SLS Block 2 Crew	SLS Block 2 Cargo
Payload to LEO	95 t (209.4k lbs)	95 t (209.4k lbs)	105 t (231.4k lbs)	105 t (231.4k lbs)	130 t (286.6k lbs)	130 t (286.6k lbs)
Payload to TLI/Moon	> 27 t (59.5k lbs)	> 27 t (59.5k lbs)	38 t (83.7k lbs)	42 t (92.5k lbs)	> 43 t (94.7k lbs)	> 46 t (101.4k lbs)
Payload Volume	516 ft³ (14.6 m³)	8,118 ft³ (229.9 m³)	10,100 ft³ (286 m³)**	21,930 ft³ (621.1 m³)	10,100 ft³ (286 m³)**	34,910 ft³ (988 m³)
Maximum Thrust	8.8 M lbs	8.8 M lbs	8.9 M lbs	8.9 M lbs	9.5 M lbs	9.5 M lbs

Low Earth Orbit (LEO) represents a typical 200 km circular orbit at 28.5 degrees inclination

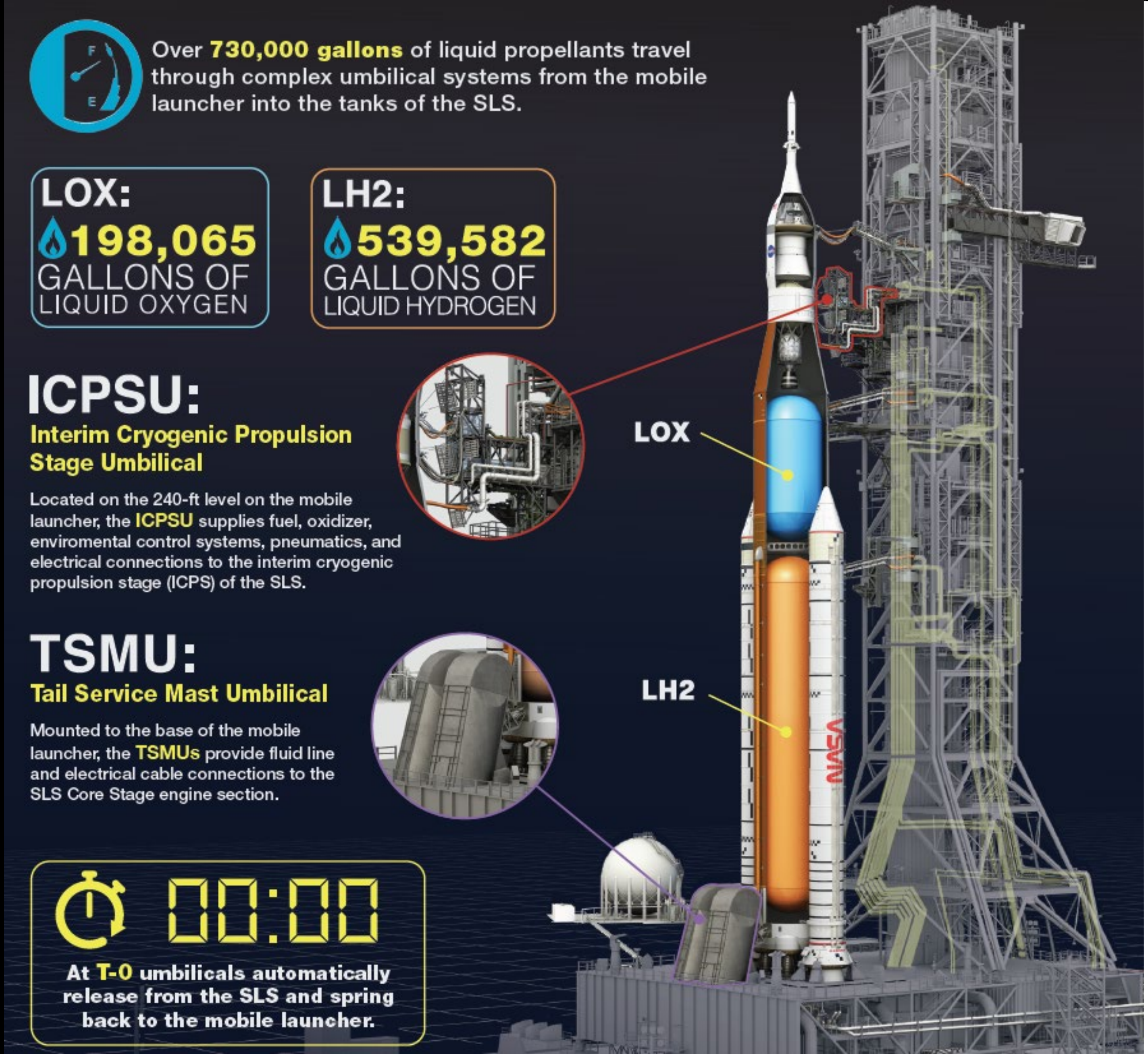
Trans Lunar Injection (TLI) is a propulsive maneuver used to set a spacecraft on a trajectory that will cause it to arrive at the Moon. A spacecraft performs **TLI** to begin a lunar transfer from a low circular parking orbit around Earth.

The numbers depicted here indicate the mass capability at the Trans-Lunar Injection point.



SLS Block 1 Crew — SLS Block 1 Cargo — SLS Block 1B Crew — SLS Block 1B Cargo — SLS Block 2 Crew — SLS Block 2 Cargo

** Not including Orion/Service Module volume



WET DRESS REHEARSAL

Last Major Test Before Launch

Launch readiness date for Artemis I flight will be set following a successful wet dress rehearsal

ARTEMIS I

The First Uncrewed Integrated Flight Test of NASA's Orion Spacecraft and Space Launch System Rocket

1. **LAUNCH**
SLS and Orion lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
With separation.
4. **PERIGEE RAISE MANEUVER**
5. **EARTH ORBIT**
Systems check with solar panel adjustments.
6. **TRANS LUNAR INJECTION (TLI) BURN**
Maneuver lasts for approximately 20 minutes.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL**
ICPS commits Orion to moon at TLI.
8. **OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS**
As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).
9. **OUTBOUND POWERED FLYBY (OPF)**
60 nmi from the Moon; targets DRO insertion.
10. **LUNAR ORBIT INSERTION**
Enter Distant Retrograde Orbit.
11. **DISTANT RETROGRADE ORBIT**
Perform half or one and a half revolutions in the orbit period 38,000 nmi from the surface of the Moon.
12. **DRO DEPARTURE**
Leave DRO and start return to Earth.
13. **RETURN POWERED FLYBY (RPF)**
RPF burn prep and return coast to Earth initiated.
14. **RETURN TRANSIT**
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere.
15. **CREW MODULE SEPARATION FROM SERVICE MODULE**
16. **ENTRY INTERFACE (EI)**
Enter Earth's atmosphere.
17. **SPLASHDOWN**
Pacific Ocean landing within view of the U.S. Navy recovery ship.

ARTEMIS I TEST OBJECTIVES

Rigorous checkout prior to crewed flights

- Test Orion’s heat shield at lunar re-entry velocities
  - 24,500 mph or Mach 32
  - Re-entry will be as hot as 5,000°F – half as hot as the surface of the Sun!
- Test all SLS, Orion systems in deep space environment
- Test recovery systems and retrieve Orion
- Test all ground processing and launch facilities
- Deploy secondary payloads (CubeSats)

SLS PROGRESS TOWARD ARTEMIS II


Orion Stage Adapter weldment complete


Booster motor segments complete


ICPS shipped to Cape Canaveral


Forward join complete


RS-25 engines complete

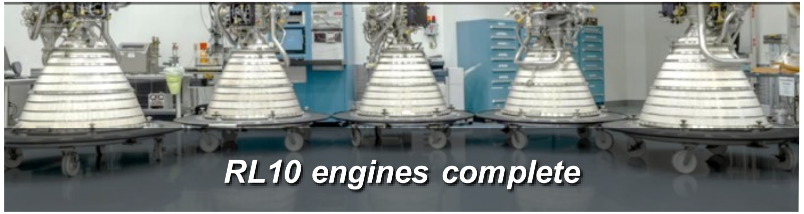

LVSA spray-on foam applied

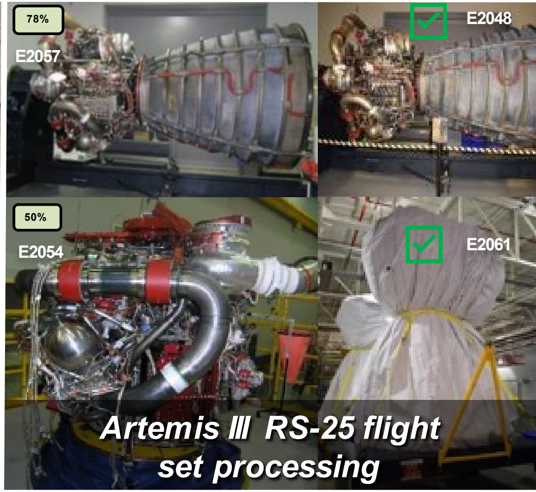
Liquid Hydrogen Tank

SLS PROGRESS TOWARD ARTEMIS III AND BEYOND


Artemis IV booster segment


Universal stage adapter manufacturing demonstration article

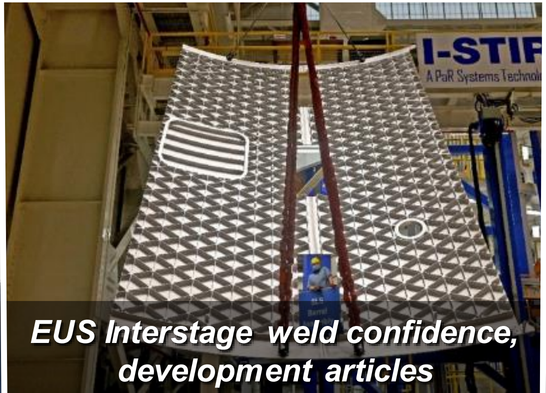

RL10 engines complete



Artemis III RS-25 flight set processing


Pathfinder composite case


Artemis III core stage LOX tank forward dome



EUS Interstage weld confidence, development articles


Exploration Upper Stage Umbilical

ARTEMIS I LAUNCH & SPLASHDOWN WATCH PARTY
AND
STEM LEARNING PATHWAY REGISTRATION

SCAN ME

Later this year, NASA will use the most powerful rocket ever built, the Space Launch System, to launch the Artemis I mission to send an uncrewed Orion spacecraft thousands of miles beyond the Moon – farther than any spacecraft built for humans as ever flown.

Do you want to share the excitement of Artemis I? **Join NASA to participate online for NASA's Artemis I mission. All resources, participation, and registration are FREE.** Registration will provide communications about launch schedule changes, information about launch related activities, and access to curated STEM resources.

Are you ready to sign up? **Scan the QR code** to register to let NASA know that you're hosting a watch party, virtually participating, or would like to receive the Artemis I STEM Learning Pathway, an add-on at the bottom of the registration page.

ARTEMIS

www.nasa.gov

@NASA_SLS

NASASLS

youtube.com/nasa

@NASAArtemis

National Aeronautics and
Space Administration

Workshop Overview

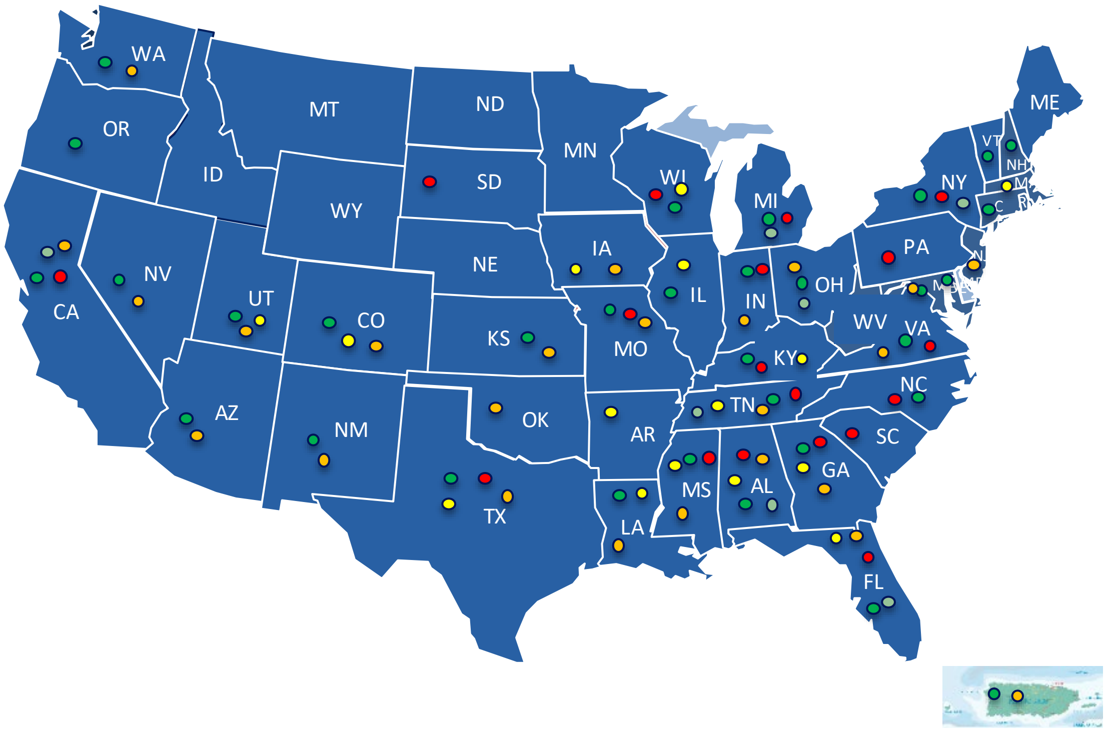
Jeramie Broadway
Senior Technical Assistant to the Associate Director, Technical

February 22, 2022

MARSHALL
SPACE FLIGHT CENTER

Marshall Space Flight Center

- Pathways Internships
- Educational Internships
- Space Act Agreements
- CANS
- Stakeholder Outreach



2020 Academic Partnerships at MSFC

Workshop survey and event feedback form

- Provide your institution's capabilities & expertise
- Your opportunity to tell us how Marshall can support you
- Online forms due March 11, 2022

Call to Action

Housekeeping

- Please place your questions in the chat
  - Time permitting, we will take questions after each presentation
  - If we do not answer your question, we will follow-up after the event
  - Media questions will be forwarded to our media relations organization
- Presentations will be distributed to those that have have registered

Thank you for being here!

Habitats and Advanced Environmental Control & Life Support Systems (ECLSS)

Robert Hickman

Exploration Formulation Manager

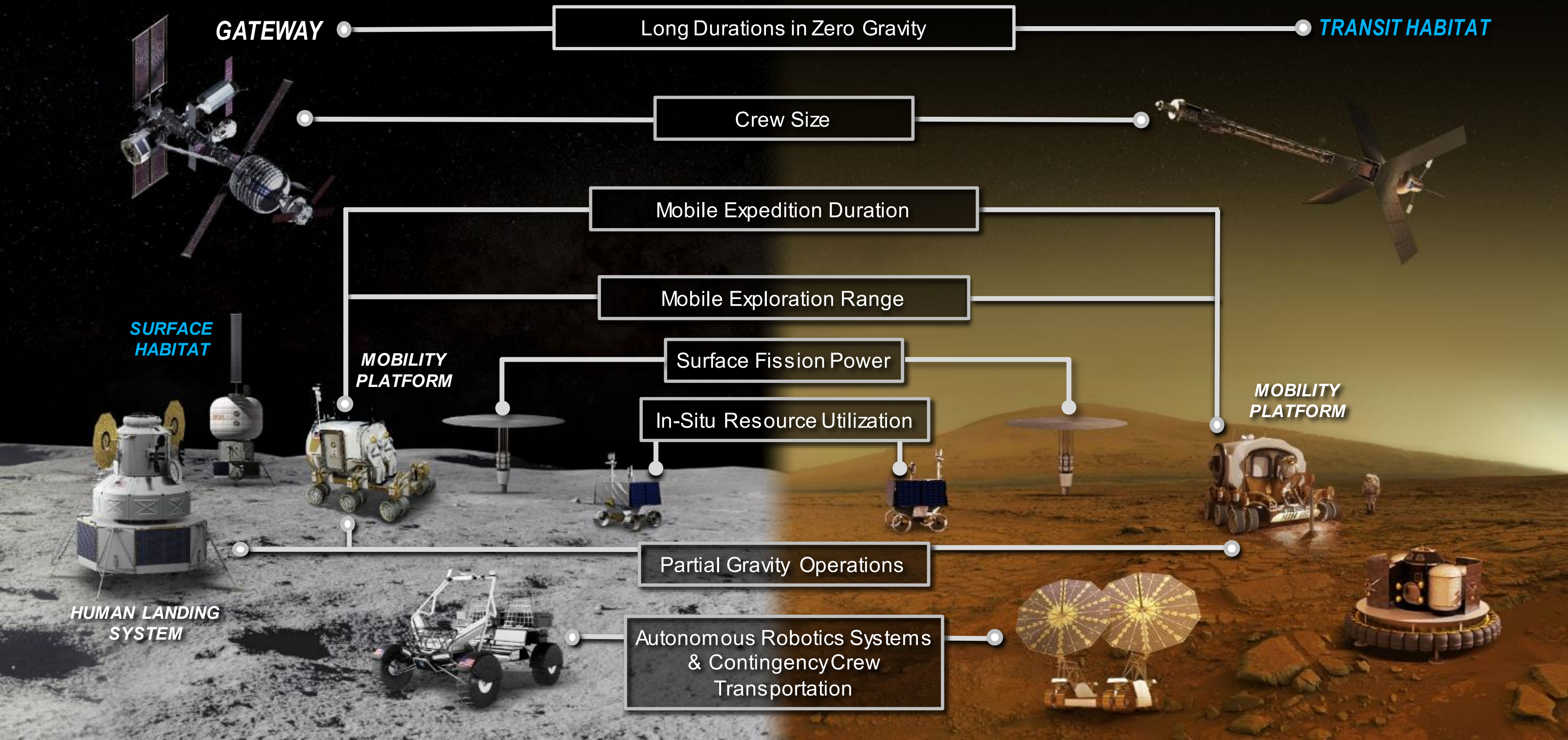
February 22, 2022

National Aeronautics and Space Administration

MARSHALL SPACE FLIGHT CENTER

MOON AND MARS EXPLORATION

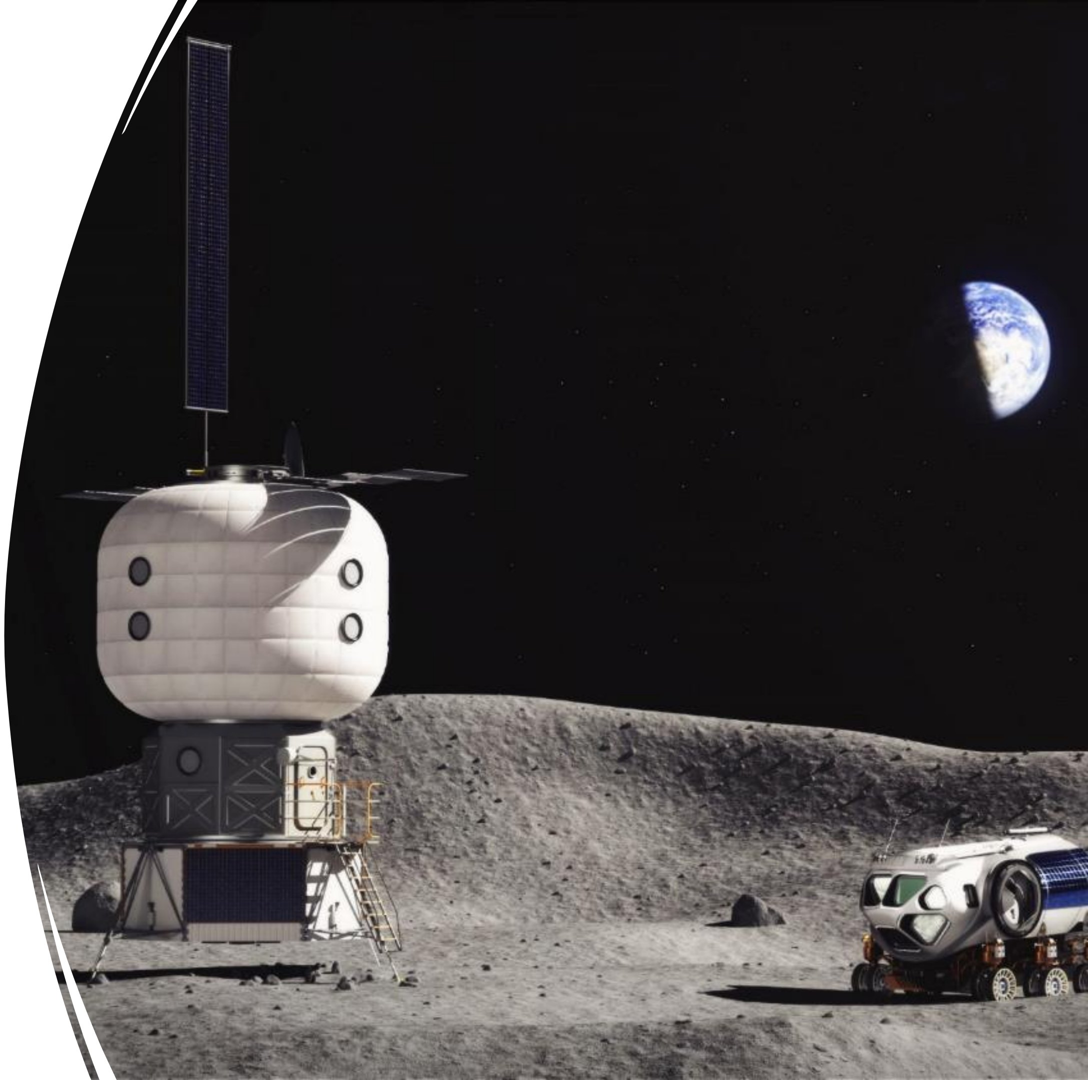
Operations on and around the Moon will help prepare for the first human mission to Mars



Surface Habitat

Capabilities:

- A primary asset to achieve a sustained lunar presence and serve as a platform for Mars mission preparations
- 2-4 crew – medical, exercise, galley, crew quarters, stowage
- 30-60 day capable habitat
- EVA capable via air lock with suit maintenance capability
- Power generation, recharge capability for surface assets
- Communication hub for surface assets



Surface Habitat | Challenges

- Delivery Mass
- Functional Volumes
- Outfitting
- Dust contamination
- Dormancy
- Survive the night thermal/power
  - Power conservation
  - Energy storage solutions with improved energy density
- Logistics transfer and loading
- Capability to maintain and repair external systems

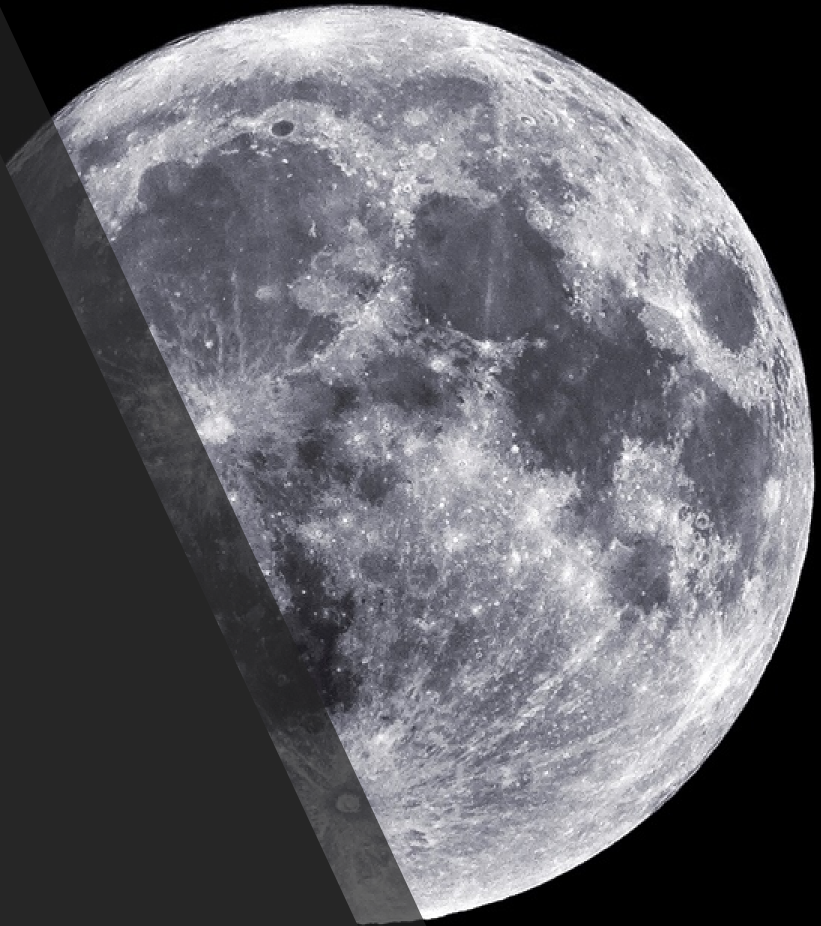


Chart courtesy of Tiffany Nickens (NASA Habitation Formulation Team)

MARS TRANSIT HABITAT

Capabilities:

- A primary asset to transport crew to and from Mars.
- Series of 4-crew Lunar-Mars Analog missions leading up to one 700-1110 -day Mars mission
- Docked at Gateway for initial deployment for shakedown
- Reused for multiple missions over 15-year lifetime

Chart courtesy of Tiffany Nickens (NASA Habitation Formulation Team)

Transit Habitat | Challenges

- No spares resupply chain during transit
- Logistics storage capacity for mission
- Waste management and trash management in transit
- Radiation & MMOD protection
- Communication delays
- Ability to recover from major habitation failures
- Autonomous avionics
- Human health and performance for long duration missions

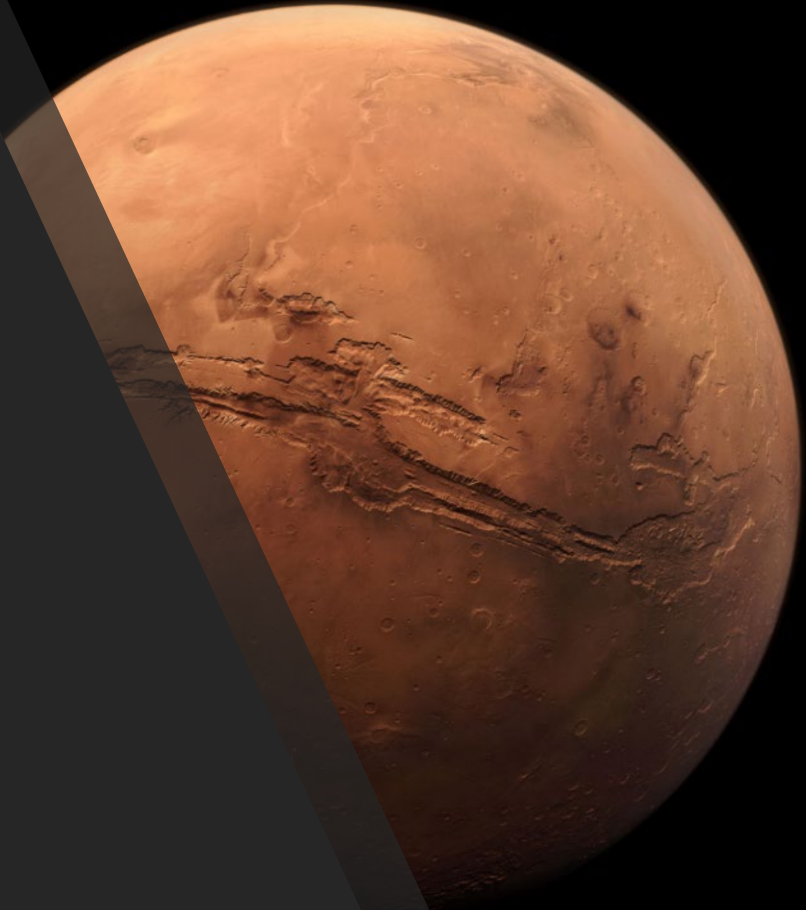


Chart courtesy of Tiffany Nickens (NASA Habitation Formulation Team)

Environmental Control & Life Support System (ECLSS) Capabilities

- Hab Sys capabilities keep astronauts healthy and productive while living in space and planetary vehicles
- Broadly characterized into vehicle Environmental Control and Life Support Systems (ECLSS) and Crew Health and Performance (CHP) Capability Areas

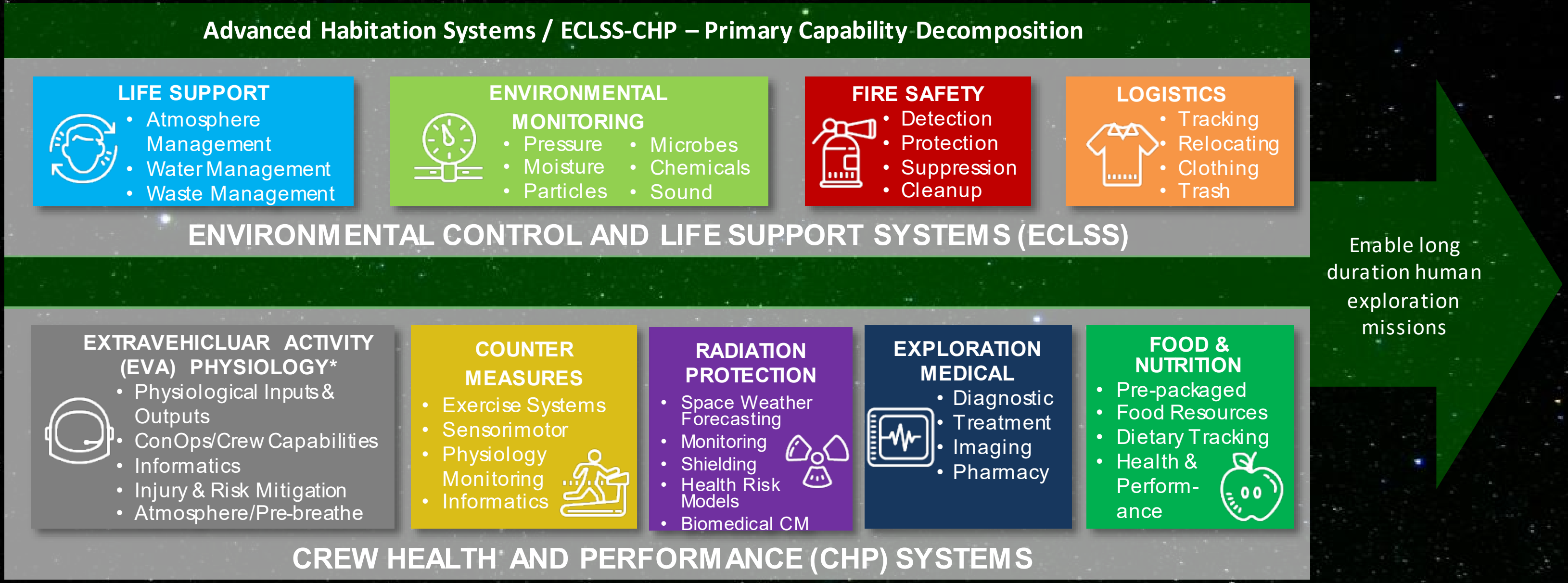
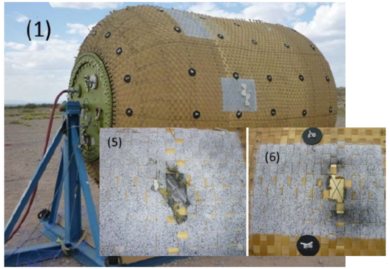


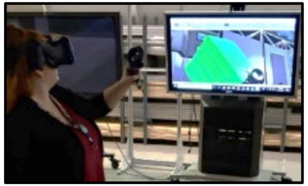
Chart courtesy of James Broyan (NASA Advanced Habitation Systems)

MSFC Habitation and ECLSS Development Needs

- Habitation
  - Softgoods materials development and testing
  - Outfitting and Human Systems Integration
  - In-Space Manufacturing (ISM)
  - Intra-Vehicular Robotics (IVR) and Autonomous Systems
- Advanced ECLSS
  - Oxygen recovery and high-pressure oxygen
    - Increase oxygen recovery from 50% to >70%
    - Develop system to deliver 3600 psi oxygen for EVA
  - Water recovery
    - Develop Urine recovery for low mass gravity system
    - Techniques for dormancy and controlling biofilms
    - Infusing new technology and modern manufacturing
  - Ground systems performance testing (spares/mass reduction)
    - Component and subsystem long duration performance and reliability
    - Performance verification in relevant environment (reduced pressure)
    - Integrated systems operations



Softgoods Development



Human Factors Analysis

ECLSS Development & Testing

Autonomous Systems & Robotics

National Aeronautics and
Space Administration

Lander Systems

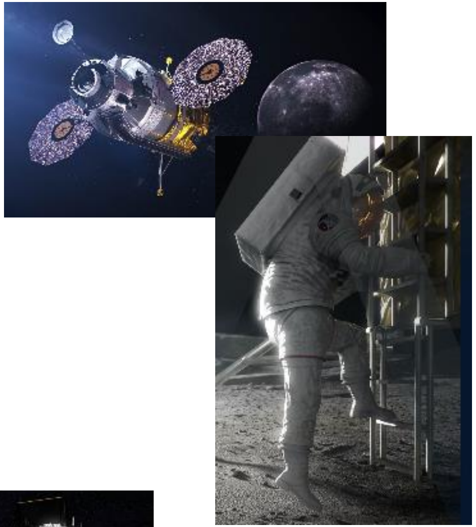
Robert Hickman
Exploration Formulation Manager
February 22, 2022

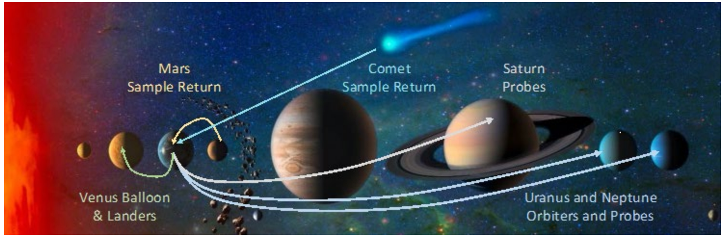
MARSHALL
SPACE FLIGHT CENTER

Landing Systems – Science, Robotic, and Human Exploration

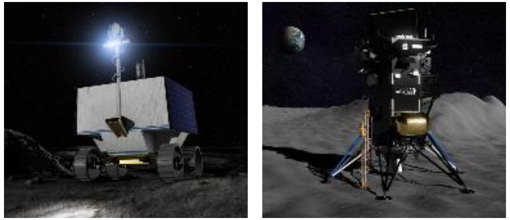
- ARTEMIS Moon to Mars
  - Human Landing System (HLS)
  - Lunar Exploration Transportation Services (LETS)
    - HLS and Cargo Lander
- Commercial Lunar Payload Services (CLPS)
  - Science and tech demo missions, Lunar Terrain Vehicle (LTV)
- Science Missions – Small Spacecraft to Flagship
  - Mars Sample Return Planetary Probes, Icy Moons,

Human Lunar Missions





Missions Across the Solar System

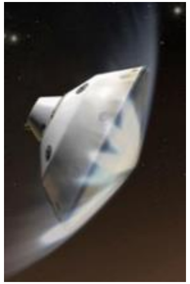


CLPS VIPER Rover and Nova-C Lander

HLS Vendor Concepts

Landing Systems – Science, Robotic, and Human Exploration

- Entry Descent & Landing (EDL)
  - High entry speed leads to high heat rates
  - Long atmospheric pass leads to high heat loads
  - Aerothermodynamic and Atmospheric uncertainties
  - 20-30x increase in delivered mass over SOA
  - Rigid sphere-cone aeroshells (constrained by the vehicle)
- Precision Landing & Hazard Avoidance (PL&HA)
  - Landings in treacherous terrains
  - Plume surface interactions
  - Guidance, navigation, and control (GN&C)
- Lunar capabilities that feed forward to Mars & Deep Space
  - Unique mission challenges and requirements

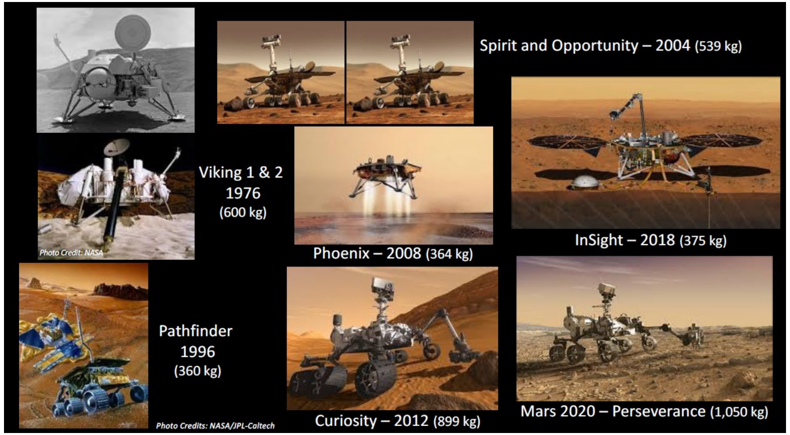

"E"ntry


"D"escent

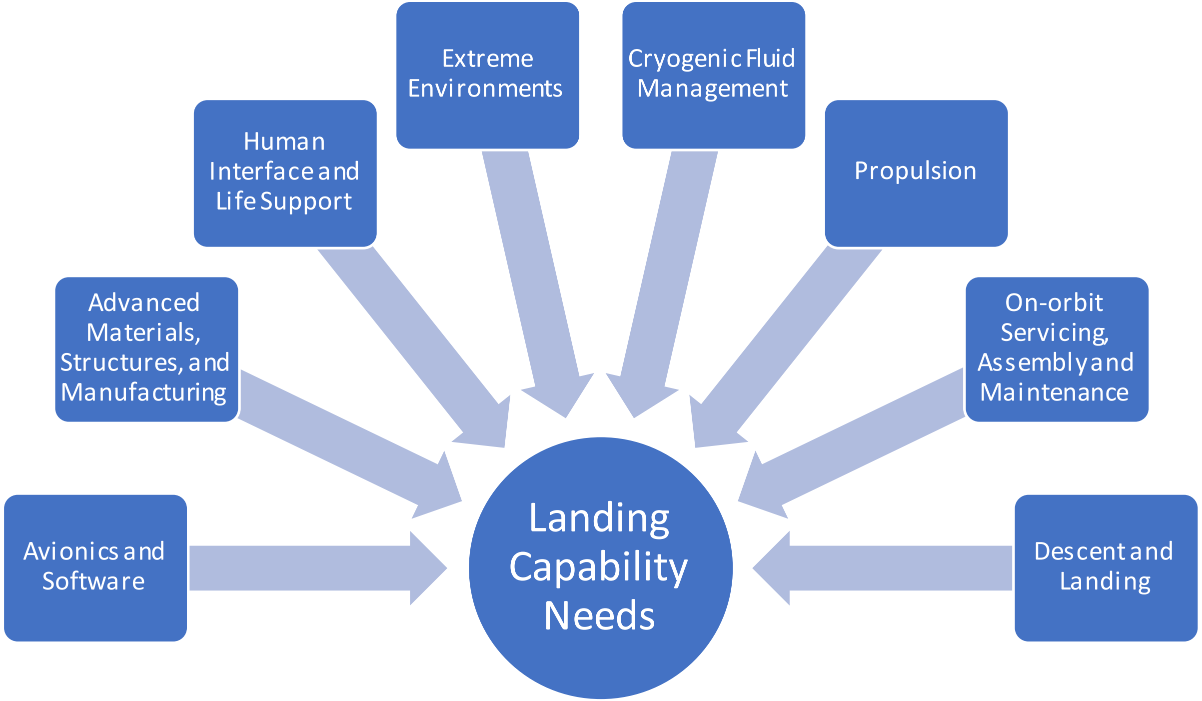

"L"anding

Landing System Challenges

- Mars 2020 Mission successfully landed the Perseverance rover within 7.7 x 6.6 km ellipse
  - 2012 Curiosity 25 x 20 km
- EDL System
  - Viking-style entry body and parachute
  - Apollo-based entry guidance
  - Camera-based Terrain Relative Navigation (TRN)
  - JPL Vision System and Doppler Radar (velocity/range)
  - JPL TRN used fused camera images and IMU data for precise position relative to a reconnaissance map
- Need investments for Entry Systems, PL&HA, Propulsion, and Foundational Modeling



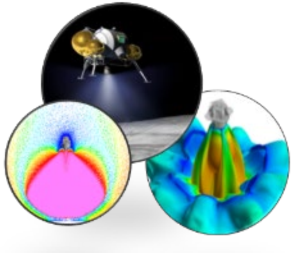
Landing System SOA



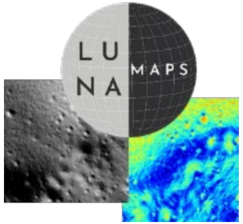
Landing Systems Capability Needs

Landing Systems Capability Needs

- Descent and Landing
  - Landing Accuracy <50M (5 year goal), <1M (10 year goal)
  - Hazard detection and avoidance
  - Regolith occultation mitigation
  - Self-leveling technologies
  - Landing pads
- Propulsion
  - Variable Thrust Descent Engines (Deep Throttling)
  - Integrated RCS
  - Electric Turbopump
  - Nuclear Electric, Nuclear Thermal



Plume Surface Interactions (models and validation)



Mapping Technologies (generation and imaging)

Sensors, Scanners, Cameras, Lidar, and SW for Terrain Relative Navigation

Retropropulsion (physics, GN&C vehicle control, CFD modeling, simulation, and testing)

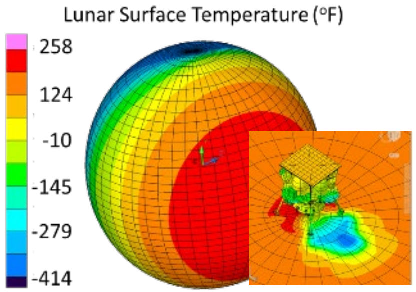
- Cryogenic Fluid Management (Active and Passive)
  - Cryocoolers
  - zero leakage couplers and valves
  - Fluid Mass Gauging
  - Liquefaction
  - Thermal isolation structures
- On Orbit Servicing, Assembly and Maintenance
  - Automated Refueling Technologies
  - On-orbit Additive Manufacturing
  - Automated Servicing
  - Docking Technologies
  - Rendezvous and Proximity Operations

Rendezvous and Docking, Refueling, and Servicing

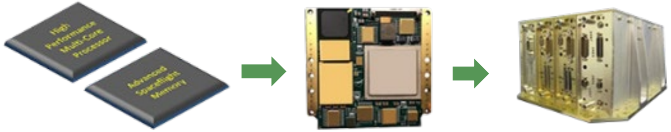
Landing Systems Capability Needs

- Mitigating exposure to extreme environments
  - Regolith abrasion and contamination
  - Lunar regolith properties and modeling
  - Radiation Tolerant Hardware
  - Wide ranging solar and thermal environments
  - Survival of lunar night (~230 hours duration)
- Avionics, Power, and Software
  - Cislunar Navigation Technologies
  - Concurrent and continuous RF Communications for multiple assets (Surface Assets, EVA, HLS, Gateway, Orion)
  - Remote Operations
  - Remote Cameras
  - High density battery technology

Lunar Coatings & Dust Mitigation



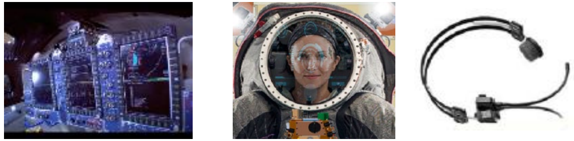
Survive The Night Technologies



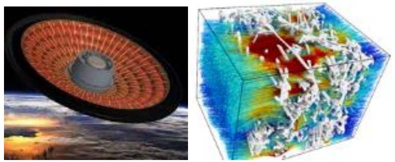
High Performance Spaceflight Computing

Landing Systems Capability Needs

- Human Interface and Life Support
  - Life Support Systems
  - Radiation Hardened Crew Displays, Controls, and Interfaces
  - Sensor Monitoring (Smoke, Dust)
  - 37% O2 atmosphere material selection (flammability)
- Advanced Material, Structures, and Manufacturing
  - Mass Reduction
  - On-orbit Additive Manufacturing
  - Thermal Isolation Structures
  - Thermal and abrasion resistant coating
  - Radiation Resistant Polymers



Crew Interfaces and Communications



Maturing new materials and systems to fill performance gaps

Landing Systems Capability Needs

Cryogenic Fluid Management (CFM) Propulsion

Zenia Garcia

In-Space Transportation Formulation Manager

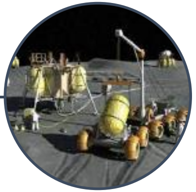
February 22, 2022

National Aeronautics and Space Administration

MARSHALL SPACE FLIGHT CENTER

CFM technology development is critical for meeting NASA's mission architecture for long duration mission

Tank and Feed Systems for In-Space applications



Surface Storage and Liquefaction of ISRU Propellant (Moon and Mars)

Long Term Propellant Storage Depot & Refueling/Transfer Operations

Mars Transit

Why CFM?

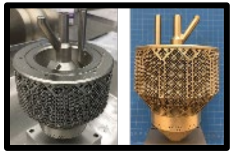
Demonstrate technologies enabling autonomous transfer and storage of cryogenic hydrogen, capable of scaling to tens of metric tons, with negligible losses for long duration in space and on the lunar surface.

Current CFM Technology Development, Enabling Future Mission Planning:

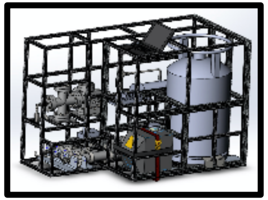
- Cryogenic thermal coatings
- Automated Cryo-couplers
- Propellant Densification
- High Vacuum Multi-Layer Insulation (IFUSI and CELSIUS)
- Unsettled liquid mass gauging
- Low Leakage Cryogenic Valves
- High Capacity Cryocooler (20K 20W)
- High Capacity Cryocooler (90K 150W)
- Storage of LH_2 Utilizing both 90K & 20K Cryocoolers (2-Stage Cooling)
- Leveraging Cryo-genic 'Demo's of Opportunity' & Tipping Point Technologies
  - CLPS Intuitive Machines Nova-C Lander (RFMG Flight & Data Buy)
  - Tipping Points (Lockheed, ULA, Eta Space, SpaceX)

Technology Gaps

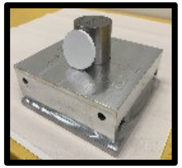
- LOX/Methane CFM - Zero Boil Off and Liquefaction (100's Watts @ 90K)
- Zero-g Long Duration Cryogenic Storage & Transfer (LO_2, LCH_4, LH_2)
- Advanced Cryocoolers
- Cryogenic Fluid Transfer Operations
- Zero-g Cryogenic Fluid Modeling



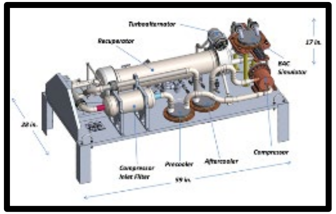
Thermo-dynamic Vent



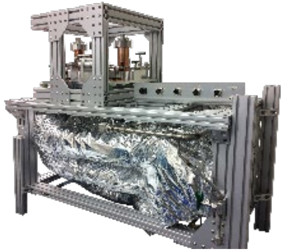
RGCT Transfer Line Chilldown Test



Solar White: One Inch Diameter Yttrium Oxide (Y2O3) Rigid Tile Sample Sitting on Sample Mold



150W/ 90K Cryocooler Conceptual Design



20W 20K Cryocooler Brassboard

Cryogenic Fluid Management (CFM)

Cross Cutting CFM Component

- ❖ High-pressure-ratio compressor for on-orbit gas transfer
- ❖ Flight-weight valves (reduced mass)
- ❖ Development of heat flux sensors
- ➢ Long Duration Low Leakage Valves & actuators: 2022 Dual Use Technology Development CAN (open Period 2, 7/13)
- ➢ Mass gauging:
  - ➢ Micro-G
  - ➢ Unsettled Mass Gauging
  - ➢ Development of Novel CFM Propellant Mass Gauging Technologies using Galactic Cosmic Radiation (GCR)
- ➢ Cryocoolers (both 20K and 90K)
- ➢ Automated cryocouplers
- ➢ Advanced cryogenic thermal coatings
- ➢ Propellant management devices \ Liquid Acquisition Devices (LADS)
- ➢ Thermodynamic vent systems

Cryogenic Fluid Management (CFM)

- ❖ 2022 NASA SBIR Phase I, Focus Area 1, Z10.01
- ➢ 2022 Dual Use Technology Development CAN (Open Period 2, 7/13)
- ✓ 2022 NASA STTR, Phase I, Focus Area 8

Predictive and validation computational modeling

- ❖ Sub-grid (CFD) of the film condensation process for 1g and low gravity
- ✓ Develop and implement computational methodology to enhance the evaluation of temperature and species gradients at the liquid/vapor interface in unsettled conditions

Active cooling

- ➢ Novel Integrated Active Cooling Features (inclusive of tube-on-tank and tube-on-broad area cooling (BAC)

Structures

- ➢ Development and testing of composite tanks and feedlines
- ➢ Low Permeability Structures
- ➢ Low Conductivity Structures
- ➢ Insulations: Both hard and soft vacuum

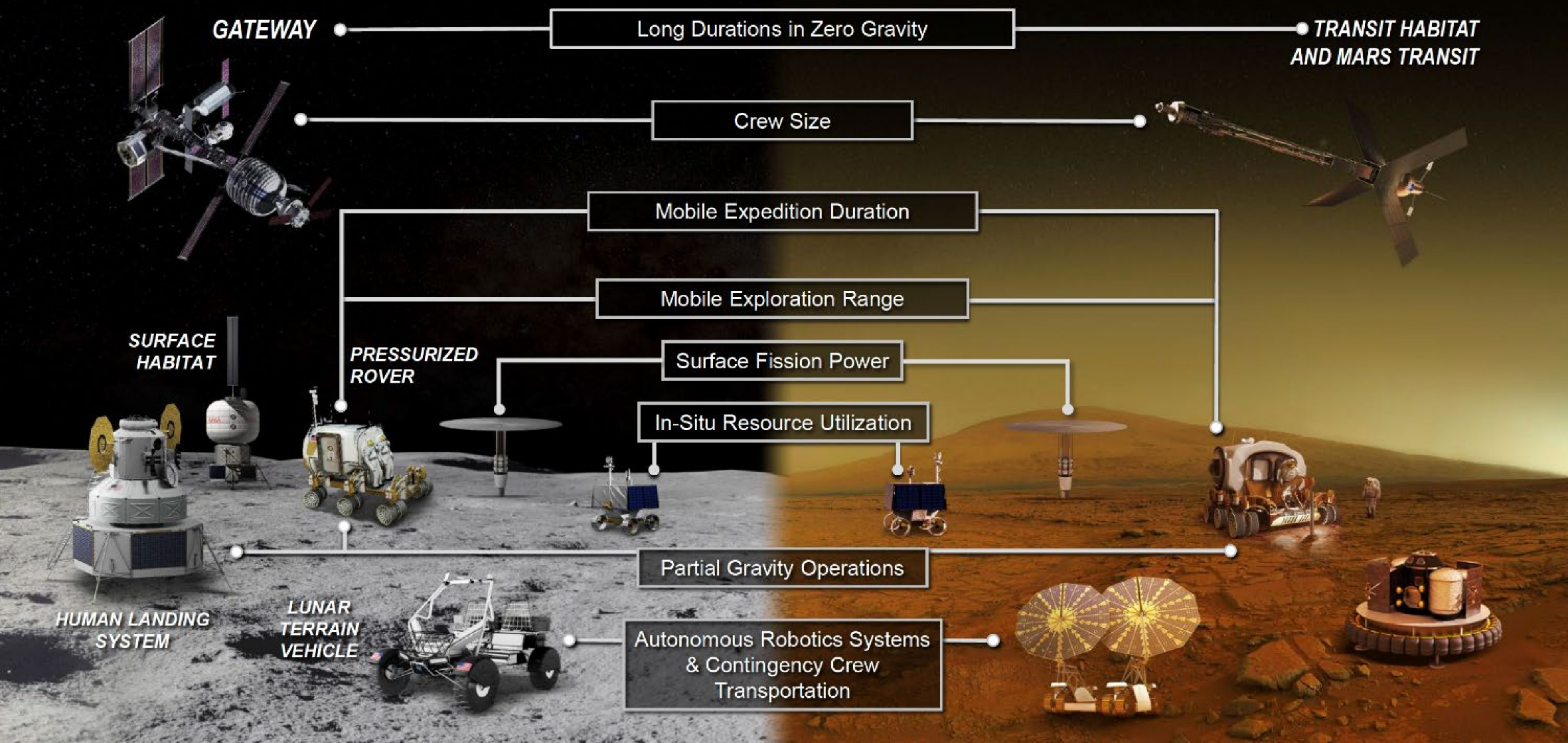
Technologies supporting in-space and surface propellant depot system for sustained Lunar and Martian presence

- ✓ In Situ cryogenic fluid liquefaction (hydrogen, oxygen, and methane)
- ✓ On Orbit Cryogenic Propellant Transfer: Cryogenic Propellant Storage (long term)
- ✓ Autonomous Transfer Operations
- ✓ Optimized Cryogenic Transfer Methods (line and tank chill and fill)

Cryogenic Fluid Management (CFM)

MOON AND MARS EXPLORATION

Operations on and around the Moon will help prepare for the first human mission to Mars



National Aeronautics and
Space Administration

Propulsion

Zenia Garcia
In-Space Transportation Formulation Manager
February 22, 2022

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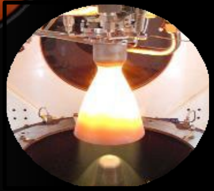
Go

Rapid, Safe, & Efficient Space Transportation

Solar Electric Propulsion (SEP)

Nuclear Propulsion Technologies

Thruster Advancement for Low-temperature Operations in Space (TALOS)



Cryogenic Fluid Management

Green Propellant Infusion Mission (GPIM)

Rapid Analysis and Manufacturing Propulsion Technology

- Develop nuclear technologies enabling fast in-space transits
- Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications.
- Develop advanced propulsion technologies that enable future science/exploration missions.

Why Propulsion?

Propulsion systems or component innovations in-space transportation, crew and cargo surface landers

Advancements in components and systems for engines and reaction control systems

- ❖ Liquid Oxygen (LOX)/Liquid Hydrogen (LH2)
- ❖ Liquid Oxygen (LOX)/Liquid Methane (LCH4)

Advancements in Rotating Detonation Rocket Engines (RDRE)

- ❖ Injector Response, Recovery, and Operation Dynamics
- ❖ Computational fluid dynamics modeling (CFD)
- ➢ Novel chamber and nozzle designs
- ➢ Tech Development using: Liquid propellant and Cryogenic Liquid

Solid propulsion technologies

- ✓ Lightweight, restartable ignition techniques for hybrid and solid rocket motors (SRM)
- ➢ Solid Hydrogen Gas generators for weight saving
- ➢ SRM and GG dual systems with system miniaturization
- ➢ 3D Printed casing and propellant liner
- ➢ Printed energetics

Propulsion

Propulsion systems or component innovations for launch, in-space transportation, and crew and cargo surface landers

Storable (Pump-fed) and electric pumps and related battery technology

- High-power and high-speed electric motors optimized for cryogenic and in-space applications
- E-pump storable engine – replacement for heavy pressure-fed deep space missions (in-space and landers)
- E-pump engine cycles powered via turbogenerator which is then used as power source upon landing

Innovative Attitude Control

- Reducing attitude control propellant and mass
- Extend attitude control device lifetime to support longer missions.

Green Propellant adoption and infusion

- Reduced Cost
- Expanded Thrust Range

Propulsion

National Aeronautics and Space Administration

Advanced Technology Systems

John A. Carr, Ph.D.
Advanced Technologies Formulation Manager
February 22, 2022

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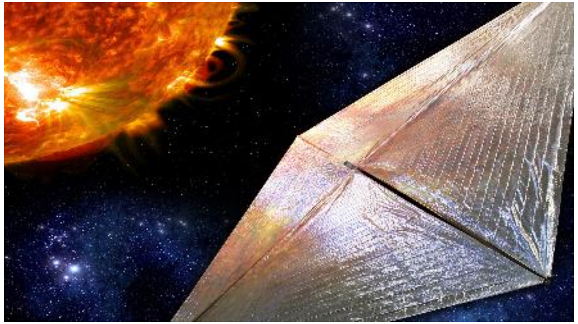
Advanced technology is broad and becoming a catch all for tech areas of high growth that support agency needs.

- These areas are disparate, however, several linked towards solar sails and lunar surface needs

- Expect disparate growth accordingly as MSFC moves forward in this portfolio

Introduction and Overview

Photon Sailing can enable new missions, enhance current missions, and supports both exploration and science goals.



State of the Art

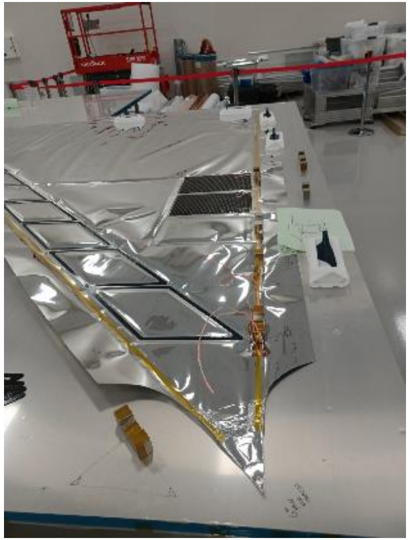
- NEAScout: 85m^2 Sail, 14kg to near earth Asteroid. Active Mass Translation. A_c = 0.07mm/s^2
- Solar Cruiser: 1,672m^2 sail, 111kg to non-ecliptic sunward side of L1. A_c = 0.12mm/s^2

Future Need and MSFC Interest

- Larger Sails: >5,000m^2 and more importantly, A_c >1.0mm/s^2
  - Advanced booms: Higher stiffness and lower mass
  - Spin Stabilization Systems
- Advanced Roll Control: Reflective Control Devices, Diffractive Sails, Articulated booms
- Embedded technologies: Thin-film solar power, Thin-film comm

Solar Photon Sails (Solar Sails)

Embedded Tech will enhance solar sailing missions and will enable new capabilities for non-sailing spacecraft – especially small spacecraft



State of the Art

- LISA-T: Lightweight Integrated Solar Array >350W/kg and >450kW/m^3
- LiDIA: Lightweight Deployable Integrated Antenna

Future Need and MSFC Interest

- Very large thin-film solar power
  - Thin, flexible UV resistant coatings (beyond polyimides and PMG)
  - Additive manufacturing of entire array, with path to *in situ* (lunar surface)
- Very large thin-film antenna arrays: >50dBi, >185dBi/kg

Sail Embedded Technologies

Electrostatic Solar Wind Sailing will enable fast transit to the heliopause and beyond.

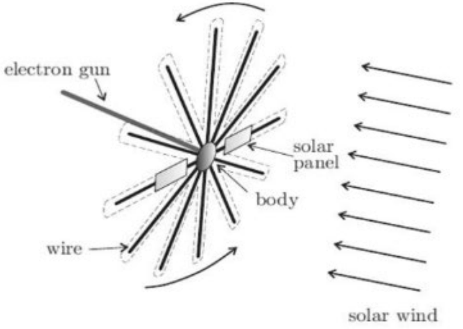


Figure 1: E-Sail Concept

State of the Art

- Voyager: 3.5AU/yr, Heliopause in ~35 years
- Modem Chemical: 4.4AU/yr, Heliopause in ~28 years
- E-Sail: HERTS; design work, low TRL tech dev for tethers, control systems, modeling, and electronics.

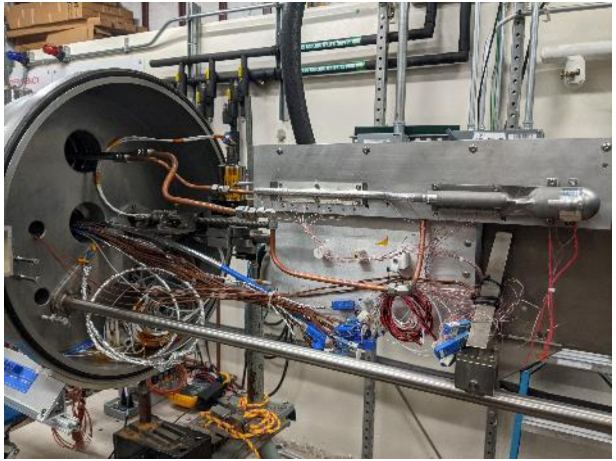
Future Need and MSFC Interest

- GN&C system design and modeling, Dynamics Modeling
- Thrust vector control design and modeling
- Tether deployment; Tether charging and charge control
- Hight voltage electronics, switching, electron emitters

Subsystem	TRL
GN&C / System dynamics	3
Thrust vector control	3
Tether Deployment	3
Plasma Acceleration / Charge Control	3
High Voltage Switching	3/4
Electron Emitter	4
High Voltage Power Supply	4
New Tether Materials State of Art (SOA) Tethers	4/5
Command, Control & Comm. (NEA Scout Heritage)	7+
Power Generation	7

Electrostatic Solar Sail (E-Sail)

Non-nuclear Thermal Control Systems will enable broad scale access to the lunar surface, Martian surface, and beyond.



State of the Art

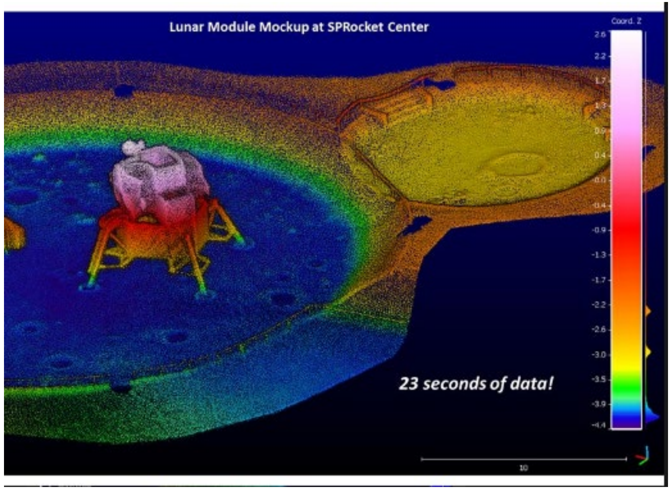
- Variable Heat Rejection: 3:1 (Human); 30:1 (Robotic)
- Advanced radiators: 19 kg/m^2 (Deployed); 6kg/m^2 (mounted)
- Thermal Control Coatings: α = 0.35, ε= 0.87 after 5 years
- ….. Dust tolerance, freeze tolerance, exchangers, fluids, modeling, etc.

Future Need and MSFC Interest

- High Variable Heat Rejection (>100:1)
- Dust Tolerant Thermal Systems
- Advanced Modeling and Analysis Techniques
- High Specific Power & Thermal Control Systems for Small Spacecraft

Extreme Thermal Control

Nav and Mapping solutions for GPS denied, dark environments will enable robust lunar terrain activities including PSRs and through the night.



State of the Art

- Mars Rovers: Navcam Hazcam, Pancam, wheel odometry, and Inertial Measurement Units, Autonav
- Lunar Roving Vehicle: directional gyros, odometers, a hybrid signal processor, and vehicle attitude, position, and speed indicating devices

Future Need and MSFC Interest

- Compact FMCW LiDAR (Frequency Modulated Continuous Wave)
- Space Hardening Designs
- Data handling (dedicated DPU, compression, etc.)

GPS Denied Navigation and Mapping

ISRU technology is key to enable long-term, sustained presence on the lunar surface, Martian surface, and beyond.

State of the Art

- Regolith-based volatiles resource acquisition and processing
- Regolith-based in-space manufacturing and construction
- Mars atmosphere-based resource acquisition and processing

Future Need and MSFC Interest

- Regolith Coatings: Fire retardant, insulation, etc.
- Metal extraction *via* ionic liquids and feedstock generation
- Mineral Separation and beneficiation
- *In-situ* propellant synthesis and liquification

In situ Resource Utilization (ISRU)

“I think dust is probably one of our greatest inhibitors to a nominal operation on the moon. I think we can overcome other physiological or physical or mechanical problems **…except dust**" *- Gene Cernan, Apollo 17*

State of the Art

- SOA too complex to summarize here: passive tech, active tech, wear metrics, seal metrics, bearings, valves, mechanisms, optical surfaces (solar, thermal, image, etc.)

Future Need and MSFC Interest

- Passive coating technologies
- Dust tolerant thermal systems
- Bearing and seal mitigations
- Dirty chamber testing (service MSFC can provide)

Dust Mitigation

Space Nuclear Propulsion

Kurt Polzin, Ph.D.

John A. Carr, Ph.D.

Feb 22nd 2022

National Aeronautics and Space Administration

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SNP Background

- Power source is <u>decoupled</u> from the propellant selection.
- HALEU designs (high-assay low enriched uranium (< 20% enrichment))
- Nuclear Thermal Propulsion (NTP)
  - Hydrogen flows through a nuclear reactor, which replaces the conventional chemical combustion process
  - Power from the reactor is transferred to the propellant, increasing the gas temperature
  - Gas is expanded through a nozzle to yield directed kinetic energy, generating thrust

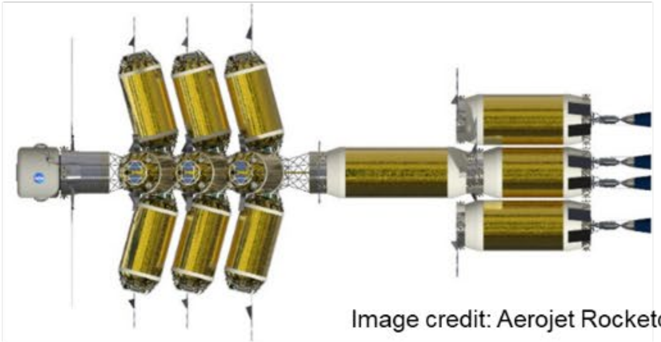


Image credit: Aerojet Rocketdyne

- Nuclear Electric Propulsion (NEP)
  - A nuclear reactor generates heat, which is converted to electricity through a dynamic power conversion system (e.g., closed-cycle Brayton)
  - Large radiators reject heat to space on the cold side of the power conversion thermodynamic cycle
  - Generated electricity powers electric thrusters, accelerating charged particles through the application of electromagnetic body forces

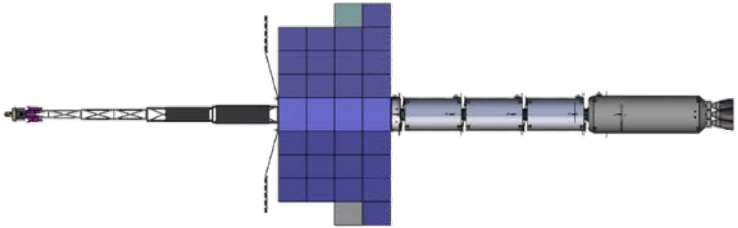
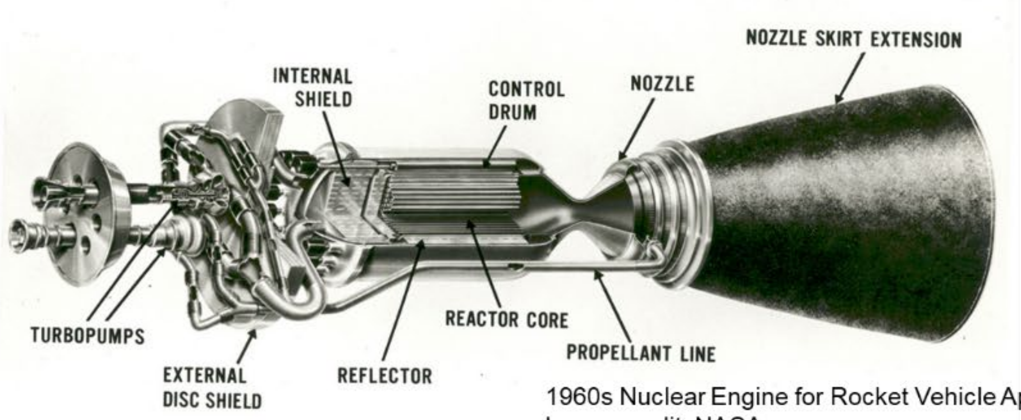


Image credit: COMPASS team, NASA-Glenn Research Center



1960s Nuclear Engine for Rocket Vehicle Application (NERVA) program image
Image credit: NASA

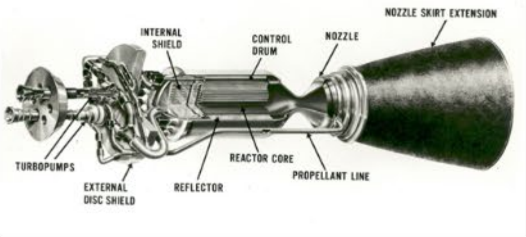
- Expander-cycle turbopumped engine
- For Human Mars mission
  - Performance targets of 900 s I_{sp}, 10s-100s of klbf thrust
  - Operates for ~ 10 cycles (burns) with each cycle lasting between 30-60 mins

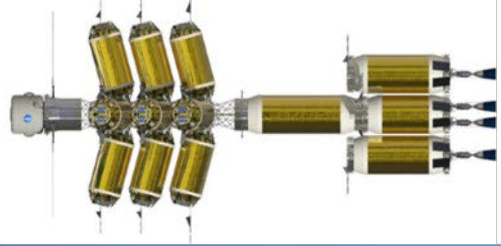
Development of a nuclear fuel form that can survive engine operating temperatures and cycling while exposed to the hot hydrogen environment and effectively transferring heat to the hydrogen propellant has been the #1 challenge for NTP since its inception

Nuclear Thermal Engine

Nuclear Thermal Challenges

- To achieve 900 s Isp, propellant must be heated to at least 2700 K (2427 deg C)
  - This leads to a required uranium fuel temperature of at least 2850 K
  - Well beyond the temperatures in terrestrial power reactors and nearing/above the melting point for some uranium alloys
    - Thermal energy must be transferred from the nuclear fuel into initially cryogenic LH_2 propellant
    - Heat transfer issues + need to avoid unmanageable thermal stresses (on start-up and cool-down)
- Neutron moderator material in reactor has significantly lower temperature limits
- Hot hydrogen is very reactive chemically and difficult to keep separated from the reactor materials
- Long-duration (multi-year) storage and usage of LH_2 propellant
  - low boil-off losses → long-term cryogenic fluid management at the 20 K level
  - use of multiple tanks/drop tanks necessitates a number of (potentially reusable) mating connections and liquid transfer seals, which will experience large temperature swings as LH2 flows through them
- Regulatory / Safety / Environmental – concerning operation of reactors, ground testability, and eventual launch approval

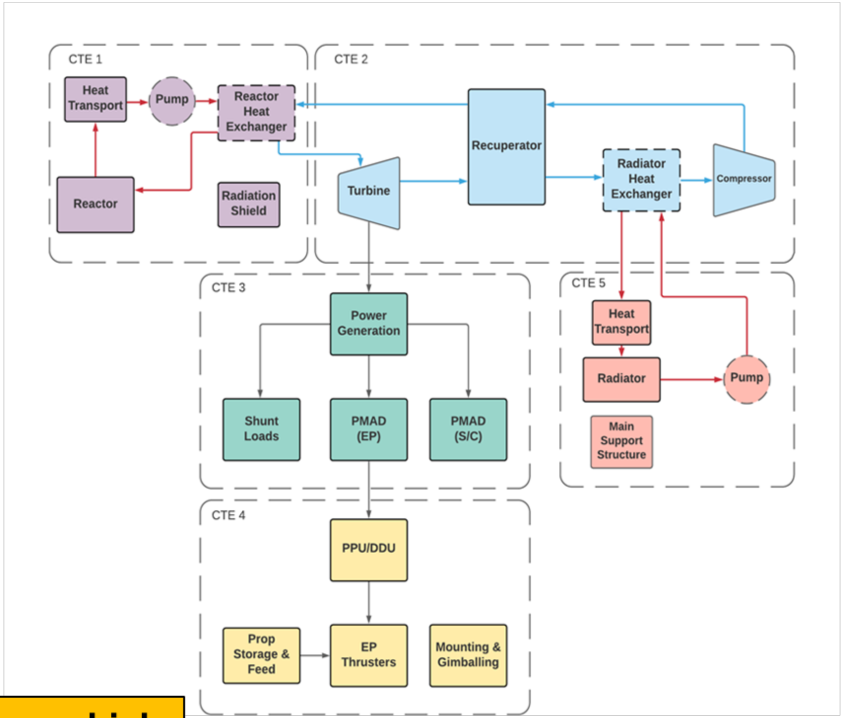




- Nuclear Reactor
- Power Conversion
- Thermal Management / Radiators
- Power Management and Distribution
- Electric Thruster System
- Cryogenic Storage of Propellants*
- Chemical Prop System*

* Possible if a hybrid NEP/Chem system is employed / challenges of chem system not discussed in this presentation

- For a human Mars mission
  - Multi-MW of electric power, 2000-7000 s Isp, 2-3 years of continuous operation



No experience integrating these CTEs into a space vehicle propulsion and power system. No real experience with ground test hardware at the power levels and in the environments of interest.

Functional block diagram of the critical technology elements (CTEs) comprising an NEP system

Nuclear Electric System

Nuclear Electric Challenges

Problems of limitations and availability

- Radiative heat rejection to space $P = \epsilon\sigma A\left(T_{rad}^4 - T_{background}^4\right)$
  - T_{rad} is limited by the power conversion cycle, not extremely hot for turbomachinery-based power generation (300-600 K, 'low quality' heat – hard to reject to space)
  - Drives to high radiator area A
  - Lead to radiators being the largest and most massive NEP components
- Desire power conversion cycle operation at hotter inlet temperatures (1200 K or greater) to conversion efficiency up and reduce radiator size
  - Material limits cap inlet temperature – means to increase inlet temp include use of different materials, coatings, and active cooling (all less mature for the NEP application)
  - Long duration use of turbomachinery without any servicing
- Thruster
  - No appreciable / long-duration electric thruster testing has been performed at MW power levels
  - Some thruster options require clustering of many smaller thrusters (mass, controllability)
  - Limitations (sometimes severe) on ground testing facility capabilities for MW-level thrusters (thruster size, plume dimensions, pumping speeds)
- Electrical and Electronic Components
  - Space-rated, rad-hardened components at high power levels not available and/or not qualified
  - Components for non-space use are heavy and not designed for the space environment

Project Prometheus Jupiter Icy Moons Orbiter NEP concept vehicle

Conclusions

- NTP and NEP each present a unique set of issues that must be addressed
  - NTP challenges involve extremes
    - Very hot nuclear fuel
    - Very cold, low boil-off cryogenic propellant
    - Significant thermal issues concerning the cooling of the reactor and the transfer of sufficient heat from the fuel to the propellant to support a 900 s I_{sp} performance point
  - NEP challenges involve limitations
    - Limitation on thermal radiation heat transfer drives radiators to very large sizes
    - Lack of maturity for high power conversion inlet temperature capability imposes constraints on the dynamic power conversion system
    - Limitations of propulsion system test experience and lack of facilities to operate thrusters for long durations at high power levels limit the ability to mature designs and quantify operational performance and failure modes
    - The long period of operation in a deep space environment imposes significant survivability and length-of-test requirements on multiple components of the system

National Aeronautics and Space Administration

Advanced Manufacturing

Justin Jackson
Advanced Manufacturing Formulation Manager
February 22, 2022

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Orion Crew Module

SLS Fuel Tank

RS25 Rocket Engine

Advanced Manufacturing at NASA is required to develop and mature innovative, low-cost and schedule improving manufacturing processes and products including: metallic joining, additive manufacturing, composites, and digital manufacturing.

Why Advanced Manufacturing?

Additive Manufacturing

State of the Art

- Revolutionary design flexibility, dramatic reductions in cost/schedule
- Ideal applications for complex components (e.g., liquid rocket engines)
- Large scale additive technologies are just being demonstrated
- Available materials are limited and not optimized for AM
- All empirical certification
- Variability is the achilles heel

Next Steps, Future Focus Areas and Investments

- Accelerate additive manufacturing certification (design/materials/processes)
- Materials for extreme environments (e.g., refractories for nuclear)
- New processes (e.g., additive friction stir, directed energy, sinter-based)
- Integrated large scale freeform applications
- NDE/Inspection, In situ monitoring and closed-loop control
- AM post-processing and surface enhancement techniques
- Technologies for non-propulsion structures (e.g., common bulkheads, tanks, domes, optical structures etc.)
- Advance modeling and simulation for optimal property predictions and material designs

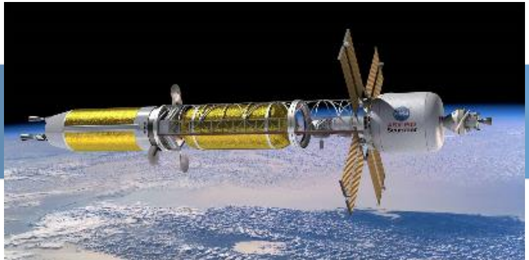
Advanced Composites

State of the Art

- Immediate 30% weight savings and 25% cost savings compared to SOA
- Very high “gear ratio” for Mars missions dramatically magnifies benefit
- Aluminum is most widely used in space vehicle structures
- Composites usage in space applications lags aviation and military applications (e.g., fuselage, wing, engine fan blades)
- Thermoplastic composites development is rapidly advancing
- Thermoset composites are de facto baseline and mechanical fastening is still primarily used (joints are the achilles heel)

Next Steps, Future Focus Areas and Investments

- Materials, design, analysis, manufacturing, and testing
- Digital/model-based discovery, characterization, and maturation
- Thermoplastic composites for space applications
- Tailorable properties offer new design possibilities
- Softgoods, hybrids, and interfaces/joints
- High temperature materials & structures
- New materials and space environmental effects on materials
- Accelerated analytical certification and failure mode approaches
- Adhesive bonding thermosets and welding thermoplastics



On-Orbit Servicing, Assembly, and Manufacturing (OSAM)/Space Manufacturing

National Aeronautics and Space Administration

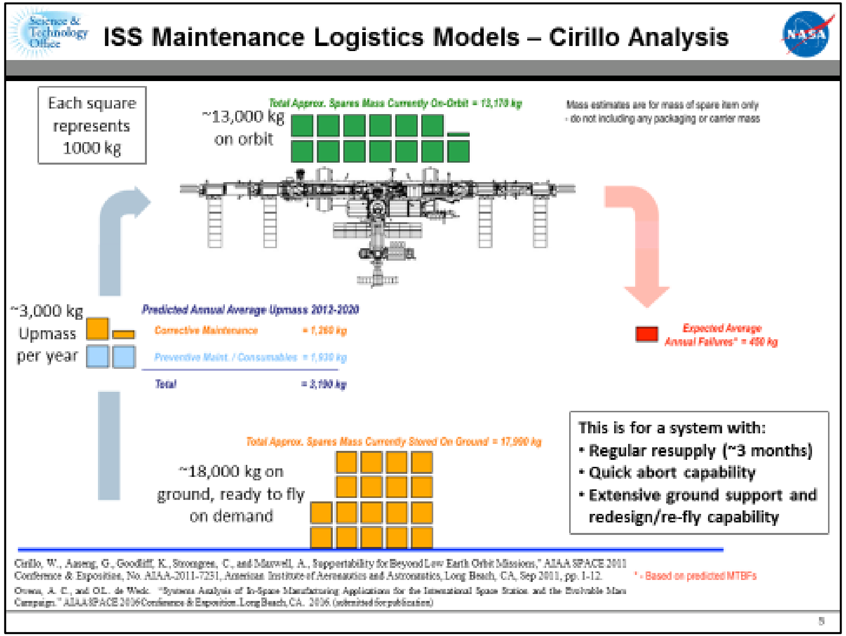
Justin Jackson

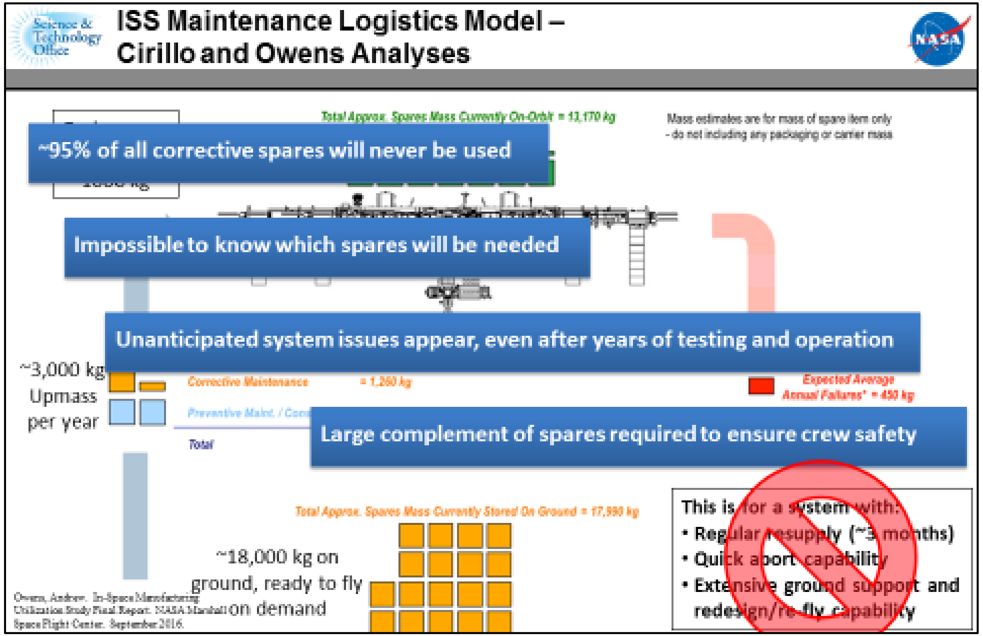
Advanced Manufacturing Formulation Manager

February 22, 2022

MARSHALL

SPACE FLIGHT CENTER





Current maintenance logistics strategy ***will not be effective*** for deep space exploration missions

The Case for ISM: Make it Don't Take it!

ISM/OSAM

State of the Art

- 20 years of ISS microgravity materials science research (SMD BPS)
- 3D Printer tech demo flown to ISS in 2014
- STMD GCD ISM project (FabLab prototype testing)
- HEOMD ISS commercial In Space Production Applications (InSPA)
- ISS National Lab/CASIS In-orbit materials/manufacturing
- OSAM-1 and OSAM-2
- ESA metal 3D printer on ISS, ~2022
- Materials International Space Station Experiment (MISSE)

Next Steps, Future Focus Areas and Investments

- On-demand manufacturing of metals, electronic components, recycling and reuse
- ISRU-derived materials for feedstocks – lunar and Martian
- Lunar surface manufacturing and outfitting with metals, polymers, and composites
- Physics-based models to predict processing and material properties
- In situ monitoring, closed-loop control, NDE/inspection, and repair is a top challenge
- Large scale additive manufacturing and welding in space
- Maximize use of ISS for demonstration

ISS - Demonstrate

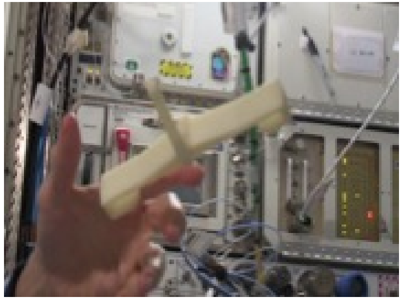
https://www.nasa.gov/mission_pages/station/images/index.html

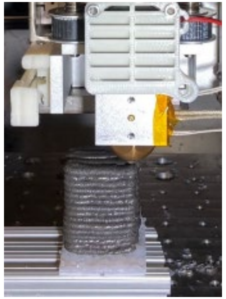
Gateway – Use (Small Scale)

https://www.nasa.gov/gateway/images

Habitat – Use (Large Scale)

https://www.nasa.gov/centers/marshall/news/releases/2020/nasa-looks-to-advance-3d-printing-construction-systems-for-the-moon.html
Credits: ICON/SEArch+





In-Space Manufacturing Prospects

National Aeronautics and Space Administration

NASA

Planetary Surface Construction

Justin Jackson

Advanced Manufacturing Formulation Manager

February 22, 2022

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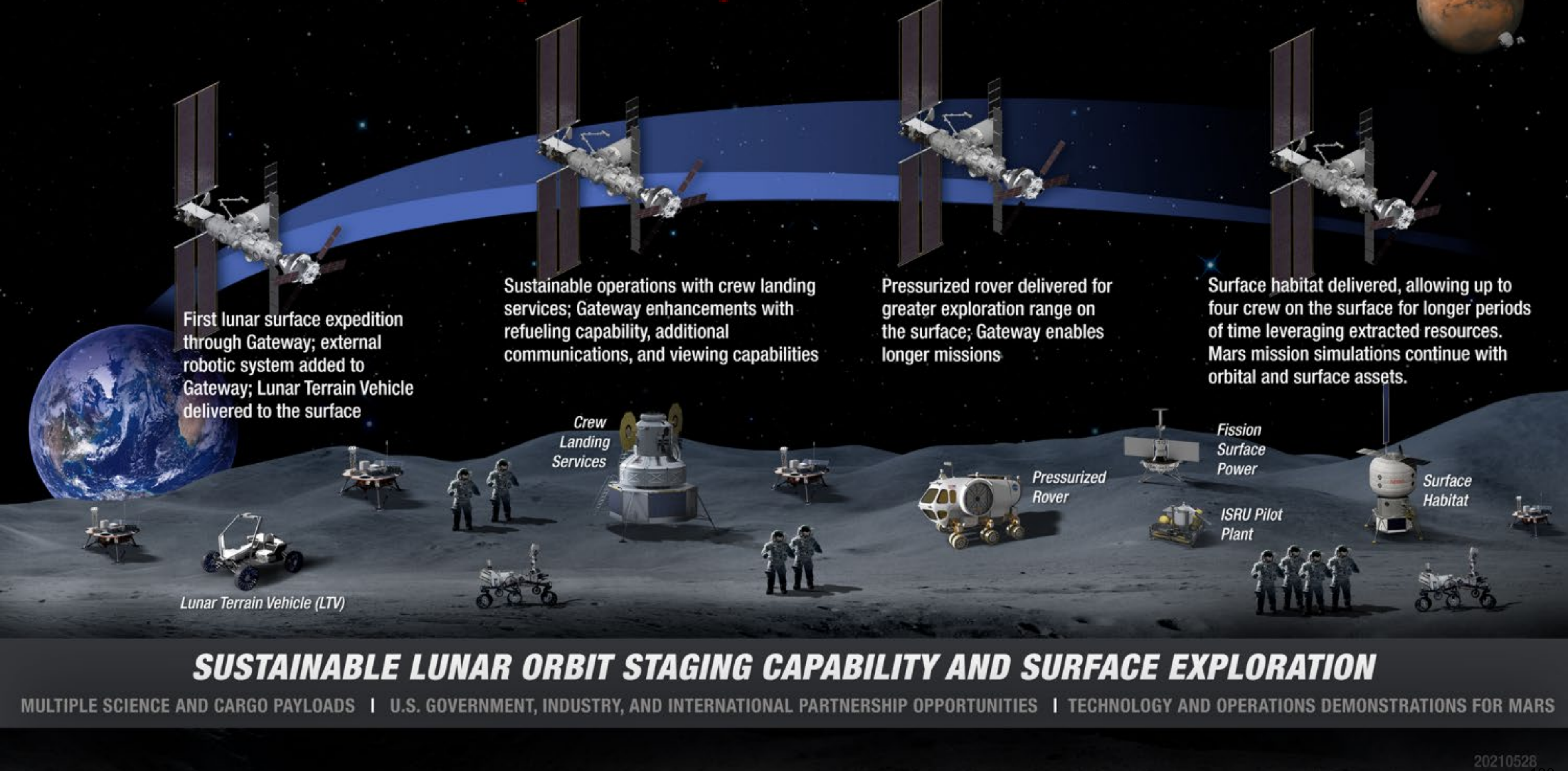
Artemis Base Camp Buildup

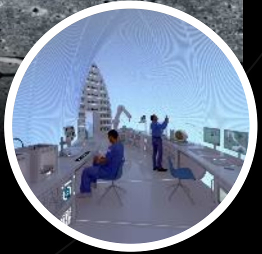


LIVE: Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities

Developing Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources

Excavation for ISRU-based Resource Production

- Site surveying, resource prospecting
- Ice mining & regolith extraction for 100’s to 1000’s metric tons of commodities per year



Excavation for Construction

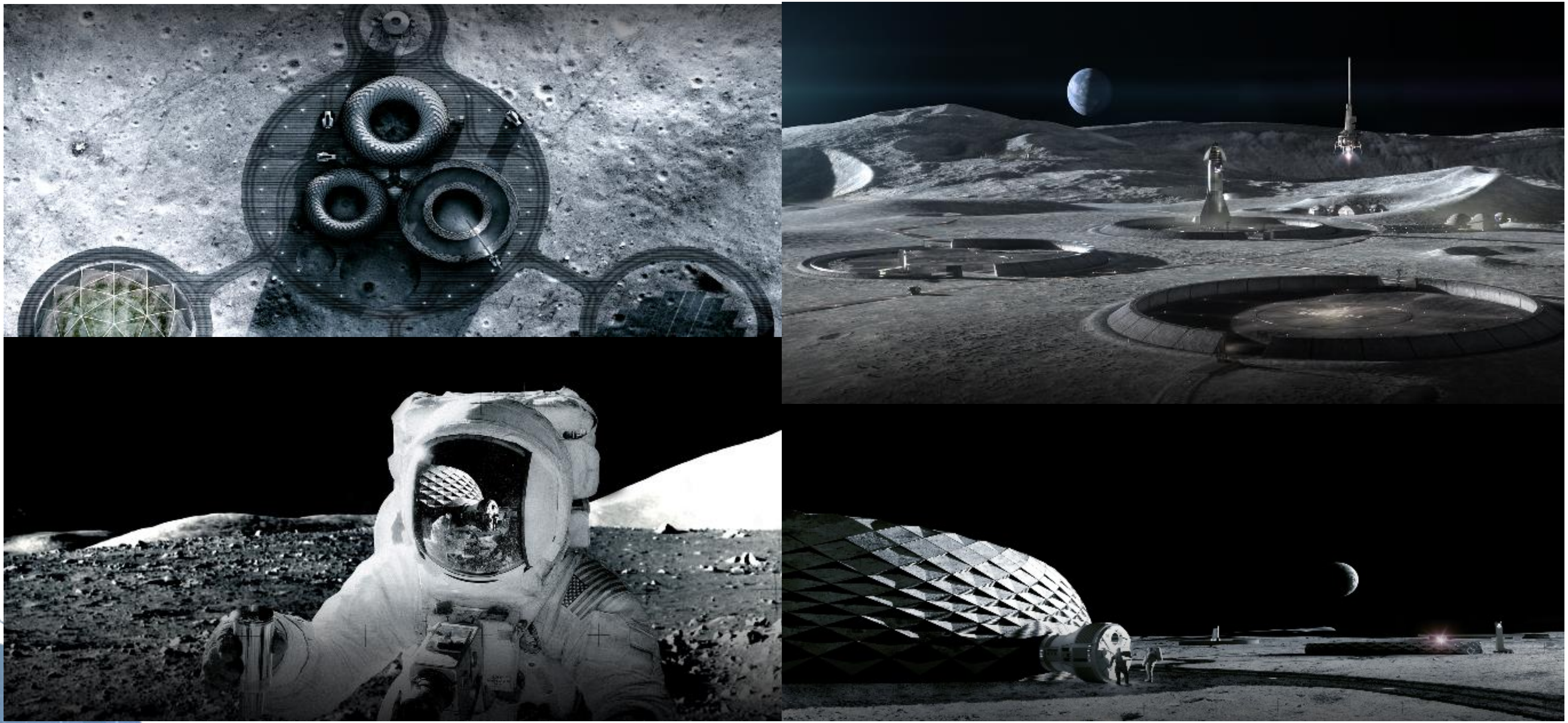
- Site preparation for construction: obstacle clearing, leveling & trenching
- Construction materials production utilizing in-situ resources
    - 100’s to 1000’s metric tons of regolith-based feedstock for construction projects
    - 10’s to 100’s metric tons of metals and binders

Construction and Outfitting

- Landing pad construction scaling to human lander capable landing pads
- Unpressurized structure scaling to single and then multi-level pressurized habitats
- Outfitting for data, power & ECLSS systems
- 100-m-diameter landing pads, 1 km-long roads, 1000’s m^3 habitable pressurized volume

Sustainable Off-Earth Living & Working

- Commercial autonomous excavation and construction of landing pads, roads and habitable structures
- Fully outfitted buildings to support a permanent lunar settlement and vibrant space economy
- Extensible to future Mars settlement



Vision for a Sustainable Lunar Base

Images courtesy of ICON, the Bjarke Ingels Group, and Space Exploration Architecture

National Aeronautics and
Space Administration

Digital Technologies

Scott B. Tashakkor, P.E.

February 22, 2022

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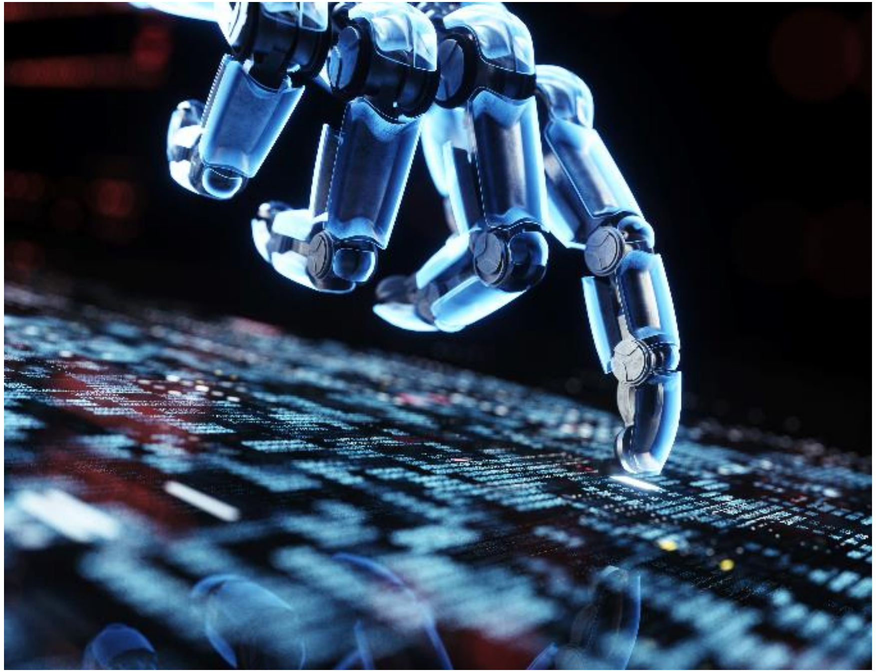
- Digital technologies
  - Limits on the topics
  - MSFC specific areas
  - Overlap between topics

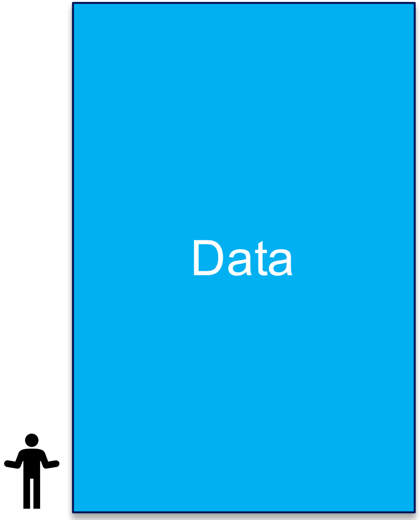


- Digital Twins
  - Methods and tools to create
  - Create from historical data
  - Integrate into processes

- Artificial Intelligence/Machine Learning (AI/ML)
  - Natural Language Processing
    - Processing of documents and requirements
  - Supervised/unsupervised learning
    - Tagging of data
    - Simplification
  - Deep Learning
    - Image recognition
    - Mission planning
  - Testing of AI/ML
    - Verification
    - Safety
    - Explain-ability

- Augmented Reality/Virtual Reality (AR/VR)
  - Operations
  - Training
- Automation
  - Robotics and Cyber Physical Systems
  - Industrial/Infrastructure Control
  - Additive (3-D) Manufacturing

- Big Data/Analytics
  - Analysis
    - Trends
    - Faults/Failures and off-nominals
  - Reduction
  - Visualization
    - 2-D, 3-D
  - Cloud and High-Performance Computing
    - Models/simulations



- Information technologies
  - Security
    - Containerization
    - Intrusion detection
  - Communication/Collaboration
    - Hybrid meetings
    - Automatic collection of metrics

Technologies Enabling Science Research in Astrophysics, Heliophysics, Earth and Planetary Sciences

National Aeronautics and Space Administration

Nicole Pelfrey

February 22, 2022

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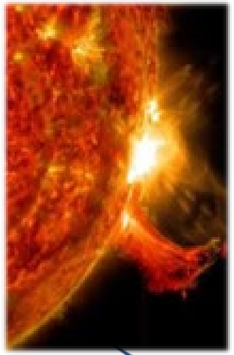
- Part of the Science & Technology Office at Marshall Space Flight Center (MSFC)
- 5 Branches: Astrophysics, Earth Science, Heliophysics & Planetary Science, Science Test Management, and Science Test.
- Located at the National Space Science and Technology Center (NSSTC) on the University of Alabama in Huntsville campus.
- Scientists, engineers, and contractors interacting with national and international counterparts in industry, academia, and with resident agencies such as NOAA-NWS, to perform cutting-edge research in the Space, Earth and Data sciences.
- Unique multi-institutional environment including large academic departments (e.g, Space, Earth Sciences), IT/Data Centers, labs, and offices enabling collaborative science instrument/tech development and research ranging from insights on the structure and evolution of the universe to understanding Earth's climate system.
- Science instrument development via collaborative use of NSSTC labs, offices, people and a robust space environments test capability resident on MSFC

Science Research and Projects Division (SRPD)

Astrophysics: ***Marshall builds on its successes to push astrophysics research into the future***

- Black Holes, Neutron Stars, Nebula, and Pulsars in the X-ray
- X-ray Grazing Incidence optics
- Gamma-ray Bursts, Time-Domain/Multi-Messenger
- Extreme-energy Particles and their Sources



Heliophysics: ***Enhancing our understanding of the Sun and its impact on the solar system.***

- Solar Transition Region and Magnetic Atmosphere
- Thermal Plasma/Plasmasphere Modeling, Analysis, and Instrument Development
- Ionospheric Disturbances
- Space Weather R2O/O2R

Science Across The Universe

Earth Science: ***Research to understand….Research to enable global societal applications***

- Weather, Energy and Water Cycle, Surface Processes, Atmospheric Modeling
- Lightning physics, processes, satellite, airborne and ground instrumentation
- Research to Applications (SPoRT, SERVIR, Disasters)
- Data Science and Informatics (IMPACT)

Planetary Science: ***MSFC Science to the Moon, Mars and beyond***

- Planetary Terrain Mapping and Navigation
- Planetary Surfaces and Interiors
- Science Integration with Exploration Capabilities

Science Test and Technology Development: ***Enabling the next generation science missions***

- X-ray and Cryogenic Test Facility (XRCF)
- Stray Light Test Facility (SLTF)
- Normal Incidence optics SME and tech development

Science Across The Universe

Assembly, integration, and environments test/metrology/cal services. Our skilled test engineers and technicians operate and maintain specialized equipment and facilities to enable technology maturation and pre-flight verification of science instruments and missions.

The X-ray and Cryogenic Facility (XRCF):

- World's largest x-ray optical test facility
- Provides evaluation and readiness testing for advanced telescope mirrors, video guidance systems, and other space structures in thermal environments to 20 Kelvin.

Technical Capabilities:

- Thermal Vacuum Chamber
- Thermal Environments
- Clean Rooms
- Illumination Beam Line Capabilities
- Beamline/Optical Shared In-Chamber Systems
- Beamline associated In-Chamber systems
- Optical Test Capabilities (Optical Test Window, Metrology Positioning /Alignment, Metrology Instruments, Optical Test Stability, Mirror Test Capability)

Science Test

Project management and oversight supporting numerous cutting-edge science missions, projects, and teams across the Division.

Science Project Management Capabilities

- Experience with multiple sizes/class of projects (early studies, ISS, sounding rockets, instruments, cube sats, SMEX, Flagship)
- Experience in all project phases from proposal development through Phase E
- Experience in non-flight project management (e.g., SERVIR, IMPACT, SNWG)
- Experience with International partners
- External Agency Customer experience and strong relationship with HQ stakeholders
- Large contract COR experience
- Agency-level Decadal Study experience
- Strong working relationship with core engineering and test teams

Chandra

Fermi-GBM

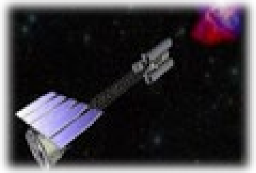
Hinode

IMPACT Interagency Implementation and Advanced Concepts Team

SERVIR

Hi-C, MaGIXS, CLASP/2.1….

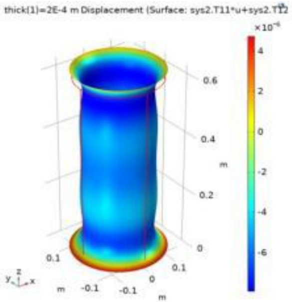
IXPE (12/9/21)



Science Project Management

Capabilities Needed For Continued Exploration

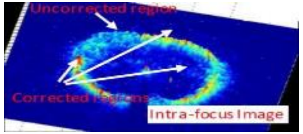
- Optical sensors and technology development to include multi-spectral gratings, for use in Astrophysics, Heliophysics
- Lightweight, high angular resolution X-ray optics
- Small pixel, low-noise, fast readout X-ray detectors
- Optomechanical design for spectrograph/telescope concepts and sensors

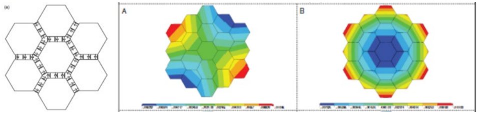


End-to-end research and implementation designed to achieve light-weight sub-arcsecond full-shell X-ray optics and to enhance the performance of segmented optics

- Mirror and module design
- Mandrel fabrication/polishing
- Mirror shell replication
- Mirror direct polishing
- Mounting and alignment
- Post figure-correction
- Metrology
- Thin-Film Research
- X-ray test and calibration

- MSFC's goal is to develop the next generation of light-weight, high angular- resolution mirrors and assemblies
- Technology developments are relevant to future X-ray missions that use either full-shell or segmented mirrors (e.g. Lynx)
- MSFC provides X-ray mirror capabilities across SMD divisions (Astrophysics & Heliophysics) and to other government entities (NIF, NIST, etc.)

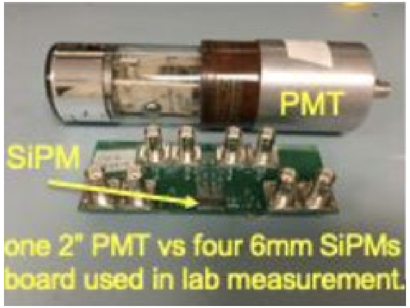


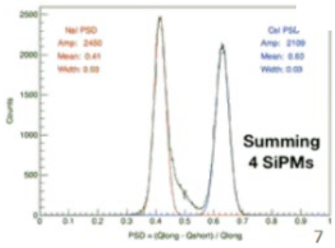


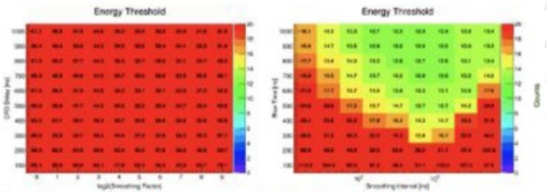
–Gamma ray detector technology development

Modernizing Gamma-ray Scintillation Detectors

- Laboratory work testing detectors in combination with new Silicon photomultipliers (SiPMs):
  - Optimize performance of phoswich detector configurations
    - Flown decades ago by NASA and recently by Moscow State University (Lomonosov), but now aiming for low mass configurations for GRB detectors
  - Reduce background, including spacecraft and atmospheric scattering
    - Improving sensitivity & GRB localization accuracy
  - Develop pulse shape discrimination circuits with modern electronics
  - Raise TRL to be useable for future NASA missions in LEO and deep space







Lowering CsI energy threshold with our pulse shape discrimination method.

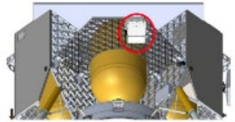
Capabilities Needed For Continued Exploration

Capabilities Needed For Continued Exploration

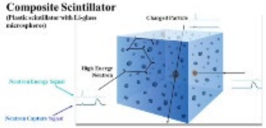
- High resolution, multi/hyperspectral, Visible to TIR sensors and physical parameter retrieval algorithms for terrestrial and Planetary/Lunar remote sensing
- Advanced technical systems EM radiation detection systems and sensors
- Instrumentation for remote or in situ measurements of ionospheric state, instabilities, scintillation
- Geophysical and geochemical measurements of planetary surfaces and interiors, including neutron detection, electron microscopy, x-ray spectroscopy and seismometry.
- Autonomous rovers for carrying Planetary/Lunar instruments
- Technologies that enable long term survival of instruments on the lunar surface (power, dust mitigation etc.)

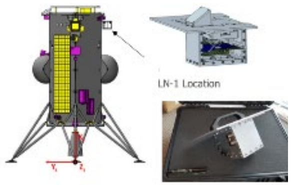
Planetary/Lunar Surface Processes and Interiors

- Measure optical signals in the night sky produced by high energy cosmic rays and neutrinos
- Instrument development for joint science and exploration purposes
- Develop neutron rate counters for the lunar surface and other NASA platforms
- Electomagnetic sounding of planetary ionospheres/magnetospheres and lunar surface magnetic features

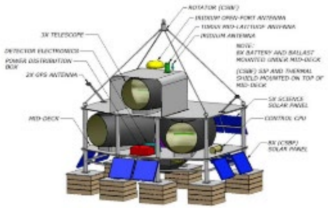


NMS-Lunar viewed from bottom of Peregrine lander





Intuitive Machines Nova-C Lander

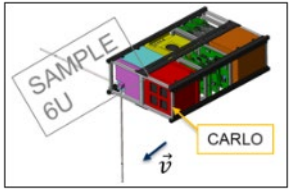


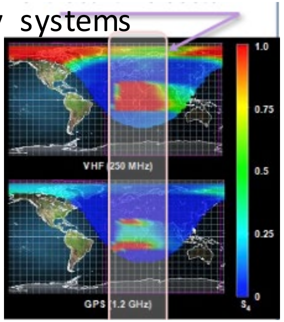
GONDOLA ASSEMBLY

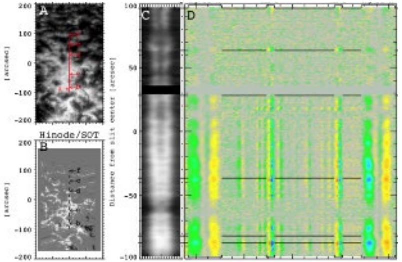
- High resolution (e.g., sub-arcsecond), radiation-hardened, high quantum efficiency CMOS or CCD imagers/cameras covering the soft X-ray to NIR spectrum
- Optomechanical design for spectrograph/telescope concepts and sensors
- Advanced technical systems EM radiation detection systems and sensors
- Advanced data processing and analysis algorithms adapted for flight software/on board processing.
- Instrumentation for remote or in situ measurements of ionospheric state, instabilities, scintillation
- Passive microwave remote sensor components (sub-orbital, orbital) to include low-noise multi-frequency antennas, front/back-end signal processing, on board data processing and retrieval algorithms, software
- Kilometer-scale electrodynamic tethering for precision multi-space positioning and control

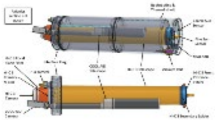
Solar Physics and Space Weather

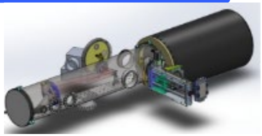
- Advancing understanding of the Sun's magnetic atmosphere and heliosphere
- Understanding space plasma environments, the physics processes that control them, and our ability to predict their dynamic behavior
- Enable missions to research ionospheric storms leading to outages of comm/nav systems

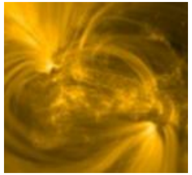










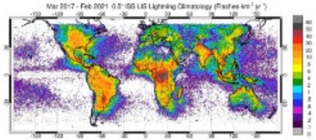


Capabilities Needed For Continued Exploration

- Earth and Space Weather research, products and approaches for transition of research to operational and societal application(s).
- Advanced data processing and analysis algorithms adapted/optimized for flight software and on board processing.
- Passive microwave remote sensor components (sub-orbital, orbital) to include low-noise multi-frequency antennas, on board signal processing, and geophysical variable retrieval algorithms
- High resolution, multi/hyperspectral Visible to TIR sensors and physical parameter retrieval algorithms for terrestrial and Planetary/Lunar remote sensing

Maximize the science and applications return of NASA's missions for science, decision makers, and society at large

- Detect, measure, monitor, and understand lightning and precipitation processes, weather and climate variability, Earth's surface heat and moisture fluxes
- Transition NASA Earth Science data and research results to operational stakeholders to improve decision-making processes.
- Harness technology advances in data and information systems to advance data informatics and mining activities for science discovery and societal applications.
- Create forward-looking data curation policies, tools, services and documentation. Lead the development of innovative open data systems to support rapidly evolving data production and management needs



Test camera with Lince5M CMOS sensor included in manufacturer evaluation kit

Capabilities Needed For Continued Exploration

Small Spacecraft Mission Enabling Capabilities for Science, Technology and Exploration

National Aeronautics and Space Administration

We Want You !

Joseph (Joe) Casas

Small Missions & DoD Formulation Manager

February 22, 2022

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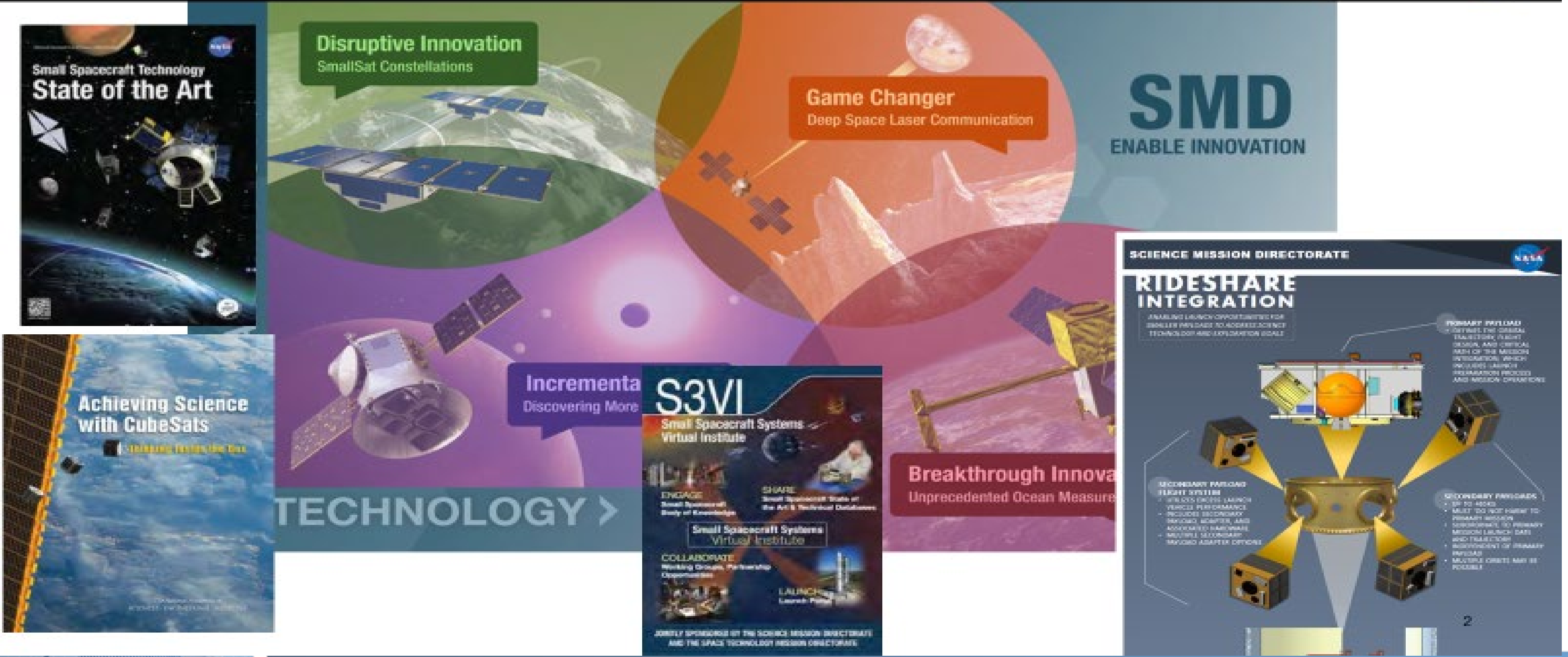
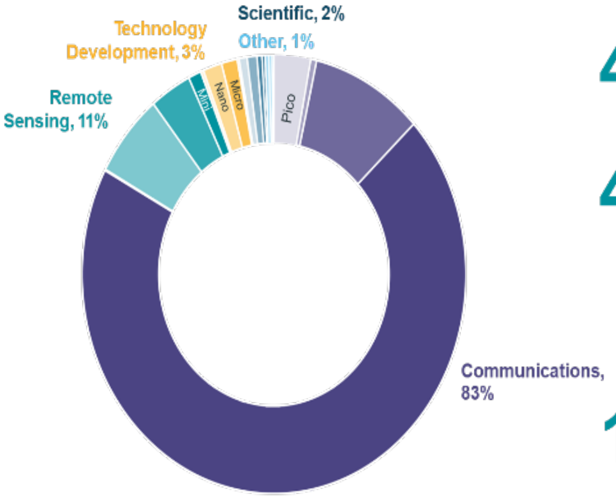
Science, Technology and Exploration Small Spacecraft Missions



Does NASA Have Small Spacecraft Mission Opportunities For You ?



40% of all smallsats launched in last 10 years launched in 2020

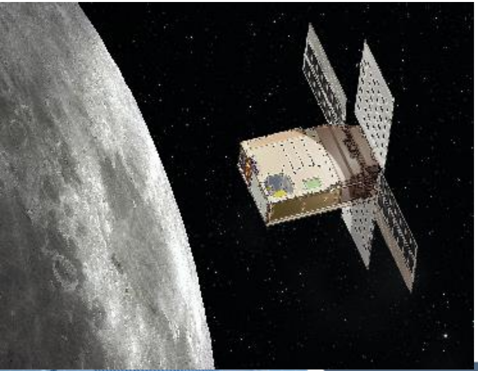
43% of total upmass represented by smallsats in 2020

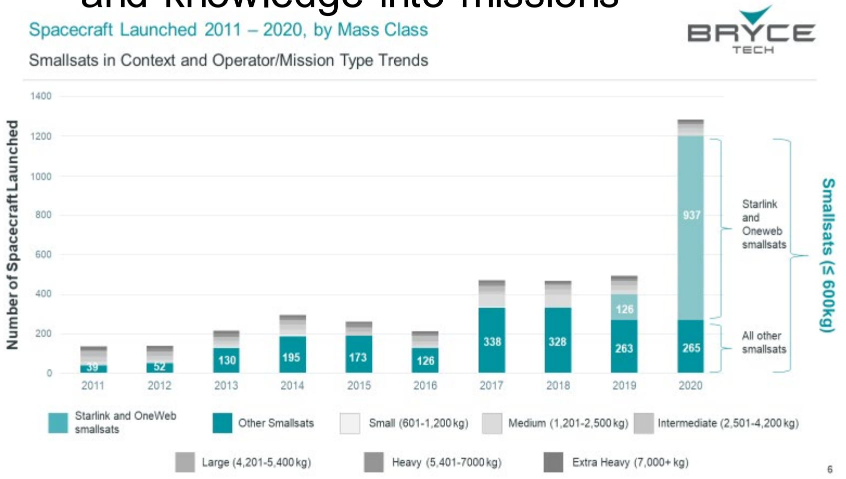
68 launches in 2020 carried smallsats

14% of smallsats launched on small/micro launch vehicles in 2020

What are Current and Future Needs :

- Innovation in research and technology development
- Training the future workforce
- STEM
- Faster infusion of emerging technologies and knowledge into missions





State of Demand for Small Spacecraft Mission Capability

Business Outcomes

Smallsat business ventures of all types continue efforts to prove both their business models and their ability to generate significant revenue. Financial outcomes of today's smallsat companies will impact the long-term smallsat market

Communications Constellations

Smallsat telecommunications operators dominated smallsat activity in 2020 and are continuing deployments in 2021. Launch of these large constellations will influence smallsat activity in the next few years

SmallSat Launch Options

Smallsat operators have an increasing number of launch options including small launch and rideshare. Dozens of new small launch vehicles (many <500kg capacity) are in development to launch smallsats. Launch providers, especially medium – super heavy are increasing rideshare opportunities/initiatives to capture demand fromsmallsat customers

Government use of Smallsats

Governments are increasingly seeking to leverage smallsats/including in architecture planning to augment existing capabilities

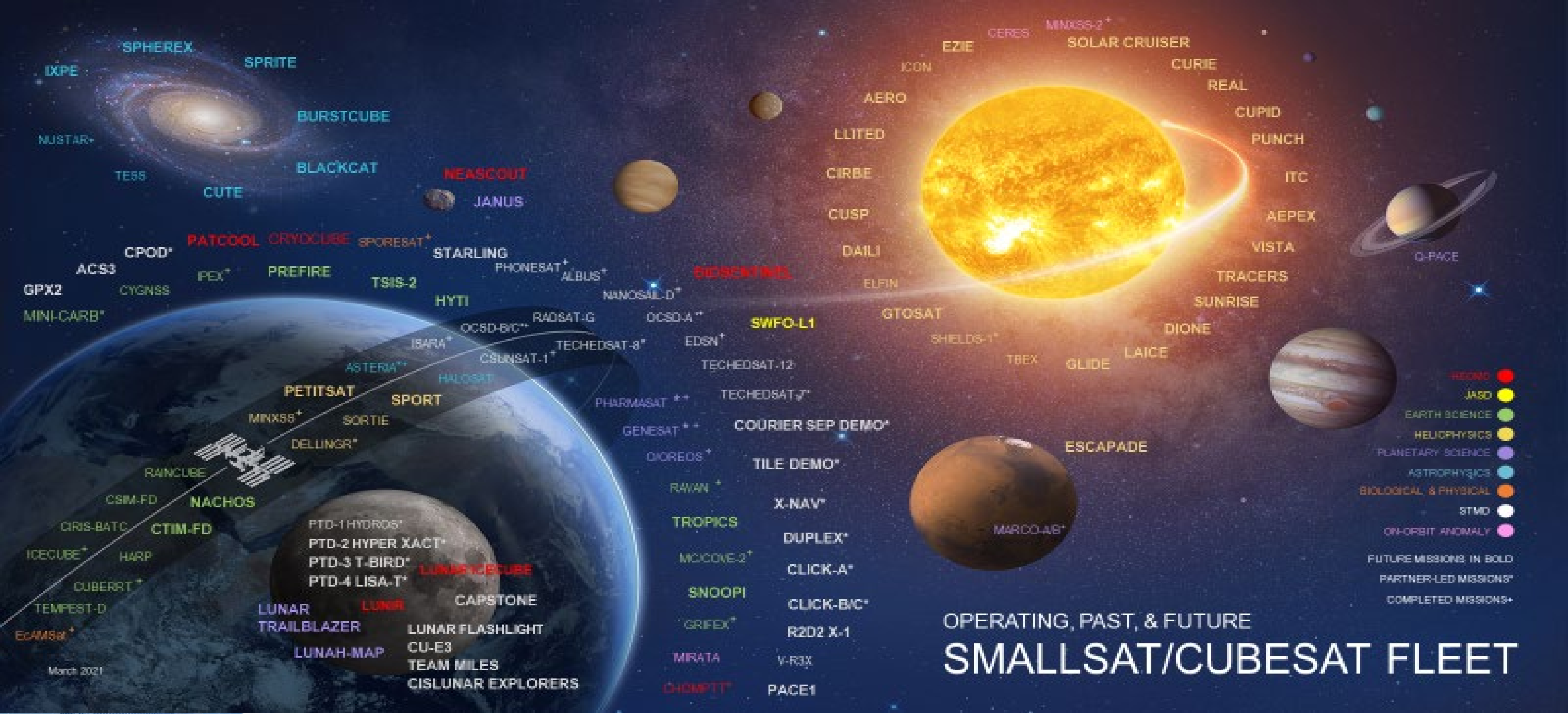
Looking Forward : What is NASA Doing?

Some Example Benefit to Organizations: YOU

- Enables students, teachers and faculty to obtain hands-on flight hardware development experience in a team building environment
- Advances the development of space technologies and innovation infusion at a faster pace
- Provides mechanism and collaborative opportunities to conduct scientific research, technology development and exploration engagement in the space environment
- Provides meaningful aerospace and educational experience

Some Example Benefit to NASA:

- Promotes and develops innovative public-private- academic partnerships
- Provides a mechanism for new innovative knowledge and low-cost technology development and scientific research addressing NASA Goals and Objectives supporting missions such as needed to address Lunar and Mars Strategic Knowledge and Capability Gaps
- Enables the acceleration of flight-qualified technology assisting NASA in raising the Technology Readiness Levels (TRLs)
- Strengthens NASA and the Nation's future STEM workforce



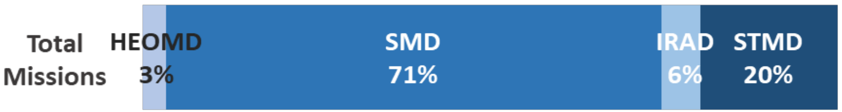
NASA : Science , Technology and Exploration Missions = Opportunities

NASA's SmallSat Missions at a Glance

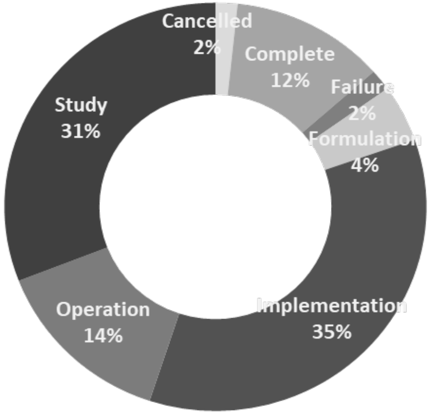
Inclusive of Missions and Studies

Data as of March 2021

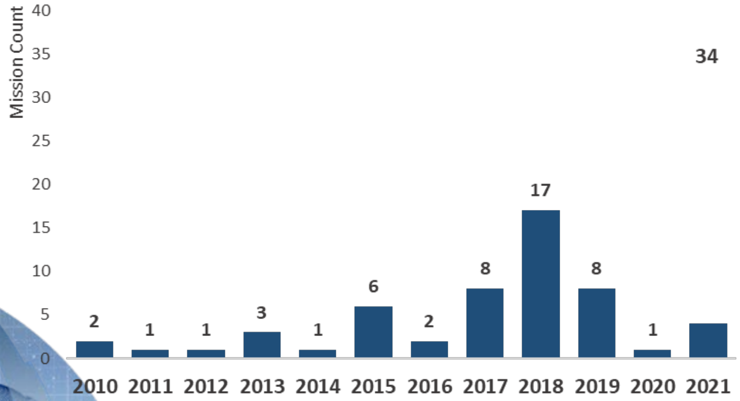
SmallSat/CubeSat Missions by Mission Directorate



Mission Phase and Satellite Size



Mission Launch Timelines



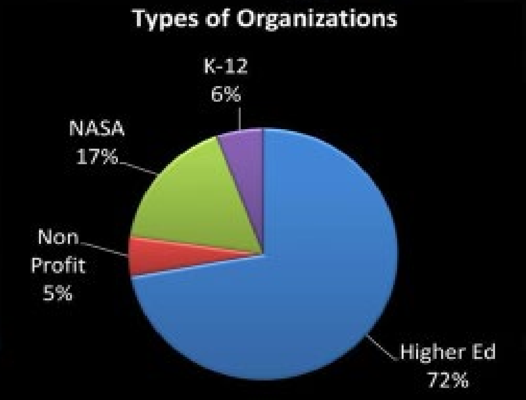
71 SmallSat Missions (99 Spacecrafts) in Formulation/ Implementation 2021 and beyond

NASA Science Mission Directorate

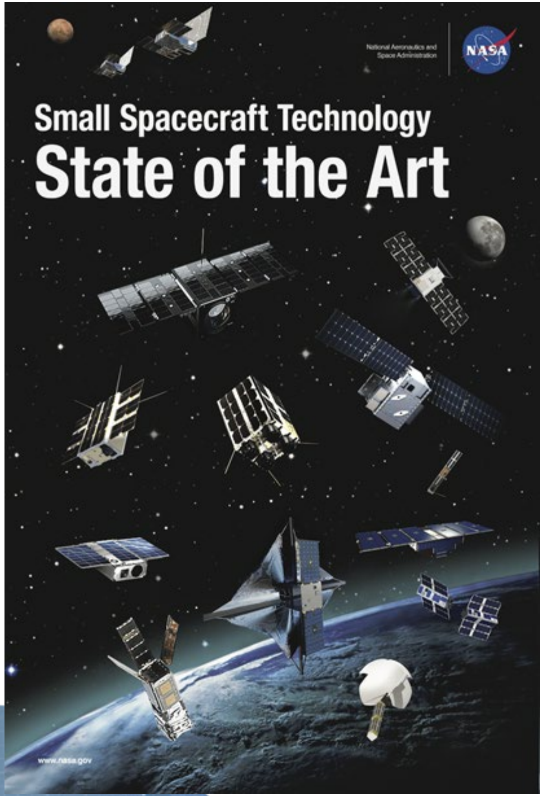
*Data inclusive of missions solicited from 2010-2021.

NASA's CubeSat Launch Initiative: Enabling Broad Access to Space

Educational Launch of Nanosatellites (ELaNa):



Just One of Many NASA Small Spacecraft Programs: Why Not You?

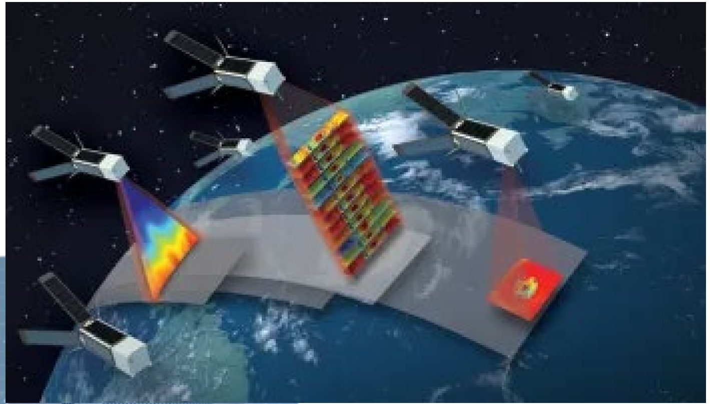


1. Integrated Spacecraft Platforms
2. Power
3. In-Space Propulsion
4. Guidance, Navigation, and Control
5. Structures, Materials, and Mechanisms
6. Thermal Control
7. Small Spacecraft Avionics
8. Communications
9. Integration, Launch, and Deployment
10. Ground Data Systems and Mission Operations
11. Identification and Tracking Systems
12. Deorbit Systems

Key Small Spacecraft Technology Areas

Autonomous Operations (Hardware systems, software/ algorithms, and modeling)

- Autonomous Spacecraft Control
- Autonomous Fault Management
- Operational Autonomy



Position, Navigation & Timing

- Weak or degraded terrestrial Global Navigation Satellite System compensation
- Cislunar Space Domain
- Near Lunar down to and on the surface
- XGEO

Example Small Spacecraft Enabling Capabilities (1)

Advance Manufacturing & Materials Selection

- Additive manufacturing of spacecraft subsystems to increase modularity

- Modular and Batch-Producible through the use of advanced engineering & MBSE

- Reduction of orbital space debris and deorbit time

Crosslinks & Networking

Autonomously configured space network allowing crosslink communications within constellations and among multipoint observation & measurements platforms

- Terrestrial platforms
- Cislunar platforms
- Near and on Lunar surface
- XGEO, to and from
- Space "traffic" awareness

Example Small Spacecraft Enabling Capabilities (2)

Educational Launch of Nanosatellites (ELaNa):
https://www.nasa.gov/mission_pages/smallsats/elana/index.html

NASA's CubeSat Launch Initiative(CSLI):
https://www.nasa.gov/directorates/heo/home/CubeSats_initiative

NASA Small Spacecraft Virtual Institute(S3VI):
https://www.nasa.gov/smallsat-institute

State-of-the-Art of Small Spacecraft Technology: Online home of the 2021 NASA State-of-the-Art Small Spacecraft Technology reports

https://www.nasa.gov/smallsat-institute/sst-soa

Useful Reference Links: Small Spacecraft Mission Capabilities

MAKE a Match

Successfully Partnering with NASA

Reggie Alexander
Manager for Partnerships and Formulation Office
Marshall Space Flight Center
www.nasa.gov/marshall

Engineering

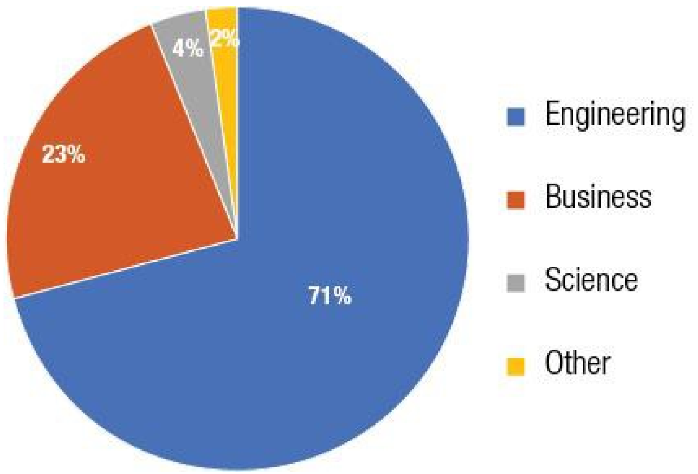
- Electrical
- Aerospace
- Software
- Chemical
- Computer
- Materials Science:
  - Bio Physics, Bio Materials, Space Physics, Space Science
- Mechanical
- Physics

Non-Engineering

- Business
- Communications
- Human Resources
- Science

Where could your students fit into our space?

2022 Workforce Needs



Partnerships Enriching Students

- Pathways Program (Co-op)
- Internships
  Spring, Summer, and Fall
- HUNCH: High School Students United with NASA to create Hardware
- Human Exploration Rover Challenge
- Student Launch Competition
- Space Technology Research Fellowship Program

NASA Pathways Programs

Intern Employment
Recent Graduate
Presidential Management Fellows

Marshall Summer Internships 2020

NASA Space Technology Research Fellowship Program (NSTRF)

- Graduate Students, Masters or Doctorate, US Citizens
- Training grants to US universities for pursuit of master or doctoral degree
- Faculty Advisor serves as Principal Investigator
- More info at NSPIRES

Partnerships Enriching Advanced Degrees and Faculty

on System, Tested through NASA's Flight Opportunities Program

Partnerships Enriching and Developing Institutions

Partnership Agreements

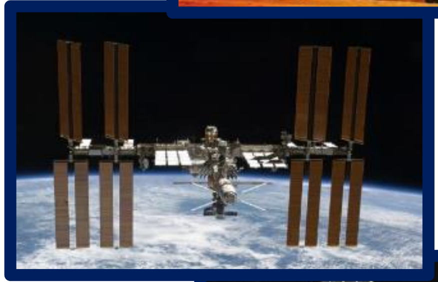
- Small Business Innovation Research
- Grants
- Cooperative Agreement Notice
- NASA Innovative Advanced Concepts
- Space Act Agreements

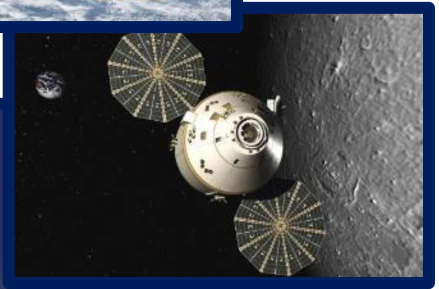
Competition-Based Prizes

www.nasa.gov/solve

www.nasa.gov/ntl

www.nasa.gov/challenges





- Curiosity Rover
  Six SBIR Companies produced technologies in use on the Rover

- 3D Printing onboard ISS
  First humans to carry out off-world manufacturing

- SBIR Technologies to Orbit on Orion
  Resin Transfer Molding (RTM) process is enabling the production of thick 3-dimensional composites for spaceflight applications

- Space Launch System (SLS)
  Fluid Dynamics Analysis Tools were developed in to assist in development of solid rocket motors and boosters

Small Business Technology Transfer Programs

2022 STTR Solicitation Phase 1 is open now.

Closes March 9 2022

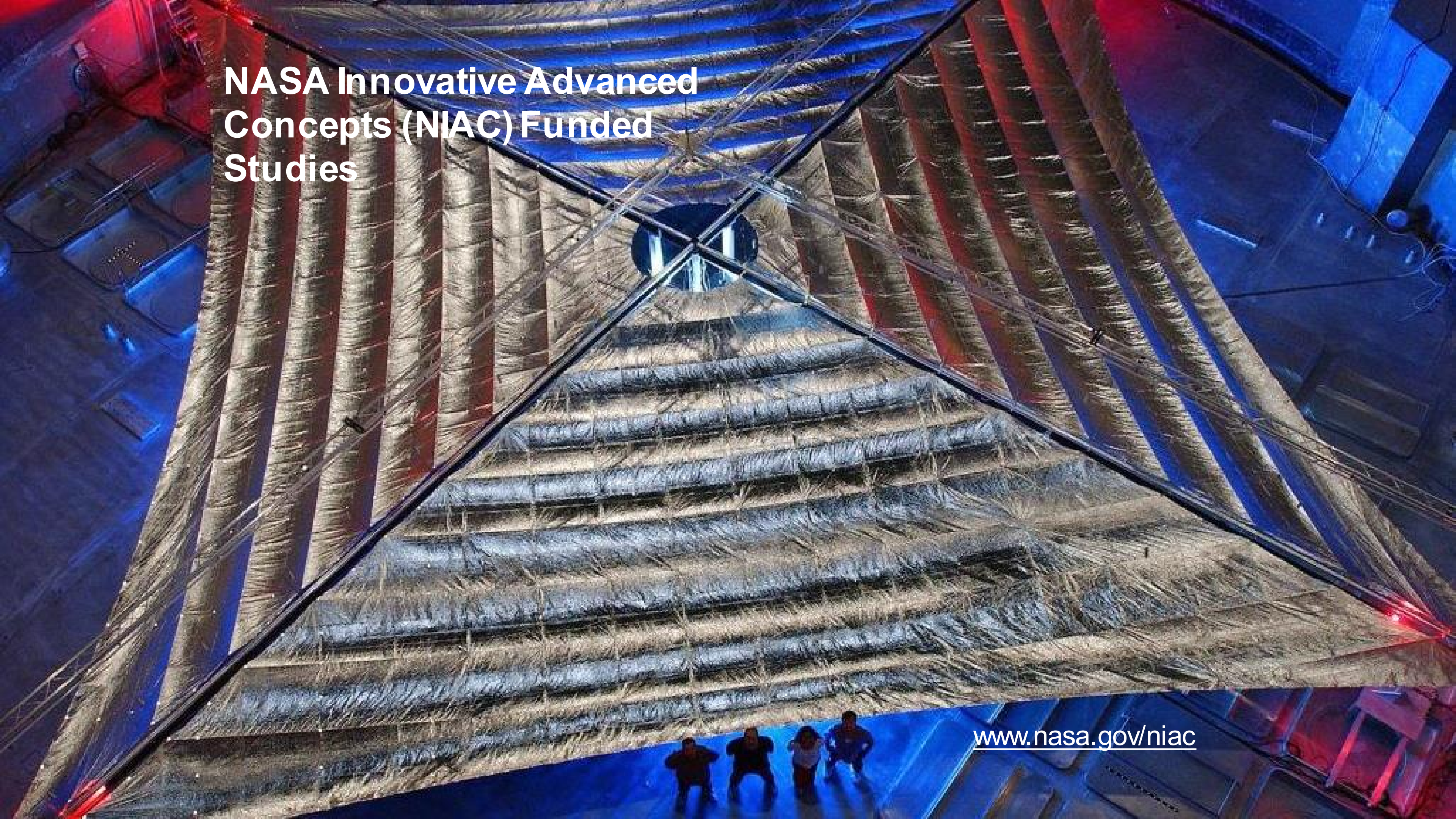
There are two separate anticipated 2022 CAN opportunities
Two-step process
1. White papers:
   - **Period 1 Due Date**: 19 January 2022
     Period 2 Due Date: 13 July 2022
     2. Selected white papers submit full proposals. Typically ~6 months from the White Paper due date to an awarded Cooperative Agreement project start.

- Posted on NASA NSPIRES under Open Solicitations and SAM.gov
- 2022 MSFC CAN released late October 15 2022

- Partnerships with business or university to advance technology with dual benefits to NASA and the partner
- $10K- $250K as cash or in-kind
- Partner matches resource contributions
- 12-month or less project duration

Cooperative Agreement Notice (CAN)

NASA Innovative Advanced Concepts (NIAC) Funded Studies



www.nasa.gov/niac

- Reimbursable agreements - Partner reimburses NASA full costs of NASA work for partner
  - Facility usage
  - Testing
  - Expertise

- Non-reimbursable agreements - no funds exchanged
- Provides mutual benefit to NASA and the Partner.

Space Act Agreements

Academia Partnering Opportunities

NASA Student Opportunities:

Pathways Employment Interns "path to employment"- similar to prior Federal Cooperative Education - a Federal-wide program for students enrolled in school pursuing a degree of interest to the agency. Find them at www.usajobs.gov/studentsandgrads

- **Internship Program:** Students enrolled in school pursuing a degree in business or science, technology, engineering and mathematics-related fields. Students must complete 640 hours of work experience, or approximately 16 weeks which can be broken into alternating semesters..
- **Recent Graduates:** Must apply within 2 years after graduation with exception for military active duty candidates who may have graduated up to 6 years prior.
- **Presidential Management Fellowship:** A flagship leadership development program at the entry-level for advanced degree candidates.

Education Interns: *(summer, fall, spring)*
Visit intern.nasa.gov

NASA Space Technology Research Fellowships Program:
Graduate Student Internships - calls come out in early September and proposals due early November.
FY 2016 Announcement. *Visit go.nasa.gov/1RNDsNC*

High school students United with NASA to Create Hardware:
HUNCH is instructional partnership between NASA and educational institutions. This partnership benefits both NASA and students. NASA receives cost-effective hardware and soft- goods, while students receive real-world hands-on experiences. Visit www.nasahunch.com

Human Exploration Rover Challenge:
(formerly NASA Great Moonbuggy Race)
Visit www.nasa.gov/roverchallenge

NASA Student Launch: Research-based, competitive, experiential exploration activity. Provides relevant, cost-effective research and development of rocket propulsion systems.
Visit education.msfc.nasa.gov/slp

NASA Partnership Opportunities:

Faculty Fellowships: NASA's Marshall Space Flight Center in Huntsville, Alabama, is offering fellowships for qualified science, technology, mathematics and engineering faculty at U.S. colleges and universities. This program provides a 10-week summer resi- dency at Marshall. *Visit go.nasa. gov/1RNAIoT*

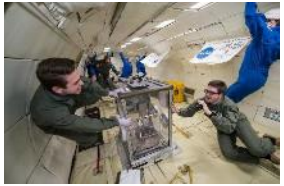
Grants/Cooperative Agreements:
Visit grants.gov and select "NASA."

Small Business Innovation Research:
Visit www.sbir.nasa.gov.

Small Business Technology Transfer Program:
Annual opportunity for universities to partner with small businesses to develop innovative technologies with commercial potential for NASA.
Visit sbir.nasa.gov/solicitations

Cooperative Agreement Notices:
Technology Development Opportunities to work with NASA on technologies of mutual interest.
Visit go.nasa.gov/1RNAbO6

Space Act Agreements: A contract vehicle for NASA entering into a partnership with various partners (e.g. Commercial Space, DoD, or academia). The work may be to utilize our unique goods, services, and facilities or it can be a partnership where both partners mutually benefit from the activity.
Visit partnerships.msfc.nasa.gov



Thank you!

Whitney Young
Academic & International Partnerships Manager

February 22, 2022

National Aeronautics and Space Administration

NASA

MARSHALL
SPACE FLIGHT CENTER