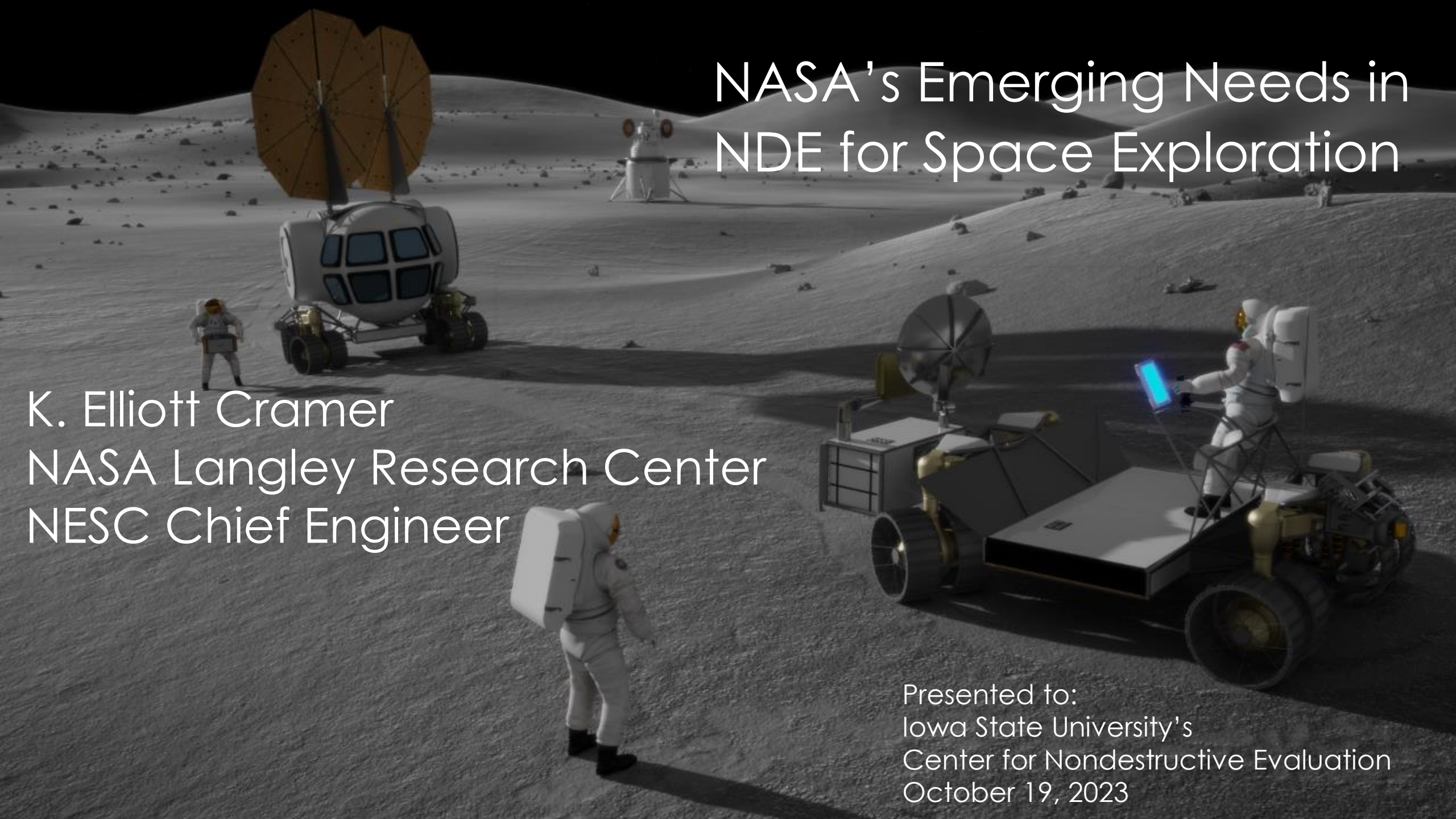


NASA's Emerging Needs in NDE for Space Exploration

K. Elliott Cramer
NASA Langley Research Center
NESC Chief Engineer

Presented to:
Iowa State University's
Center for Nondestructive Evaluation
October 19, 2023



THIS TALK WILL FOCUS ON NASA'S HUMAN SPACE FLIGHT MISSION AND THE GREATER ROLE NDE CAN PLAY

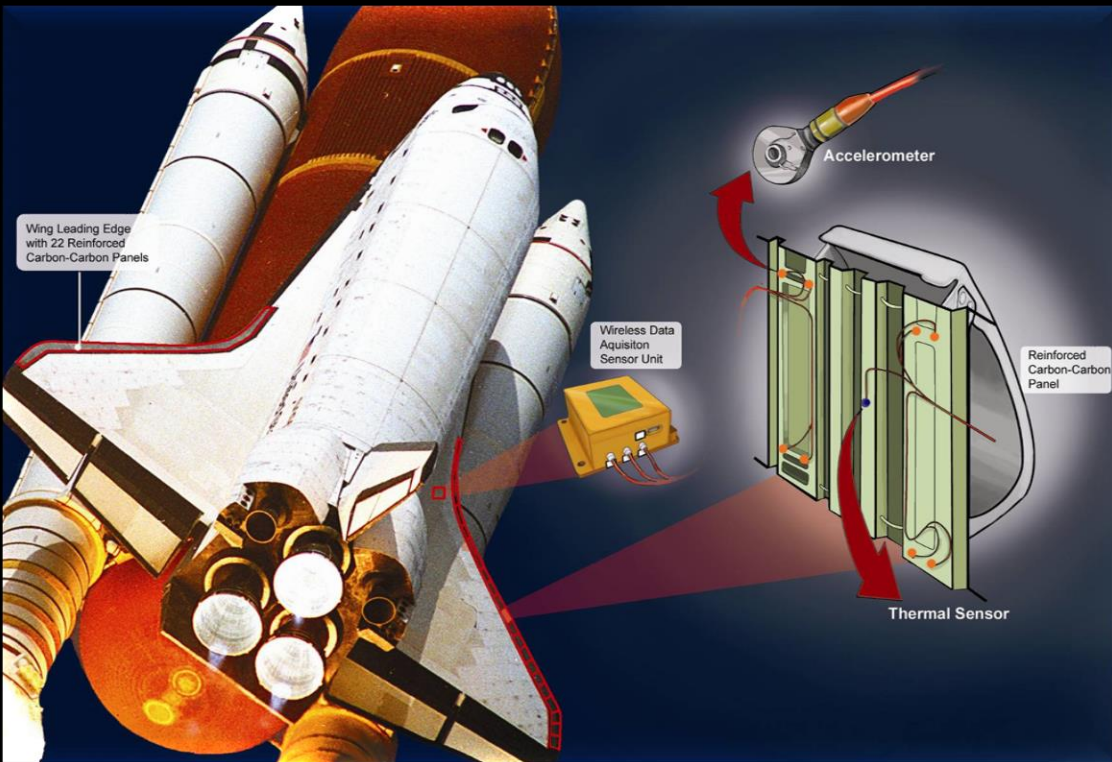


NDE's Unique Role in the Space Shuttle and ISS



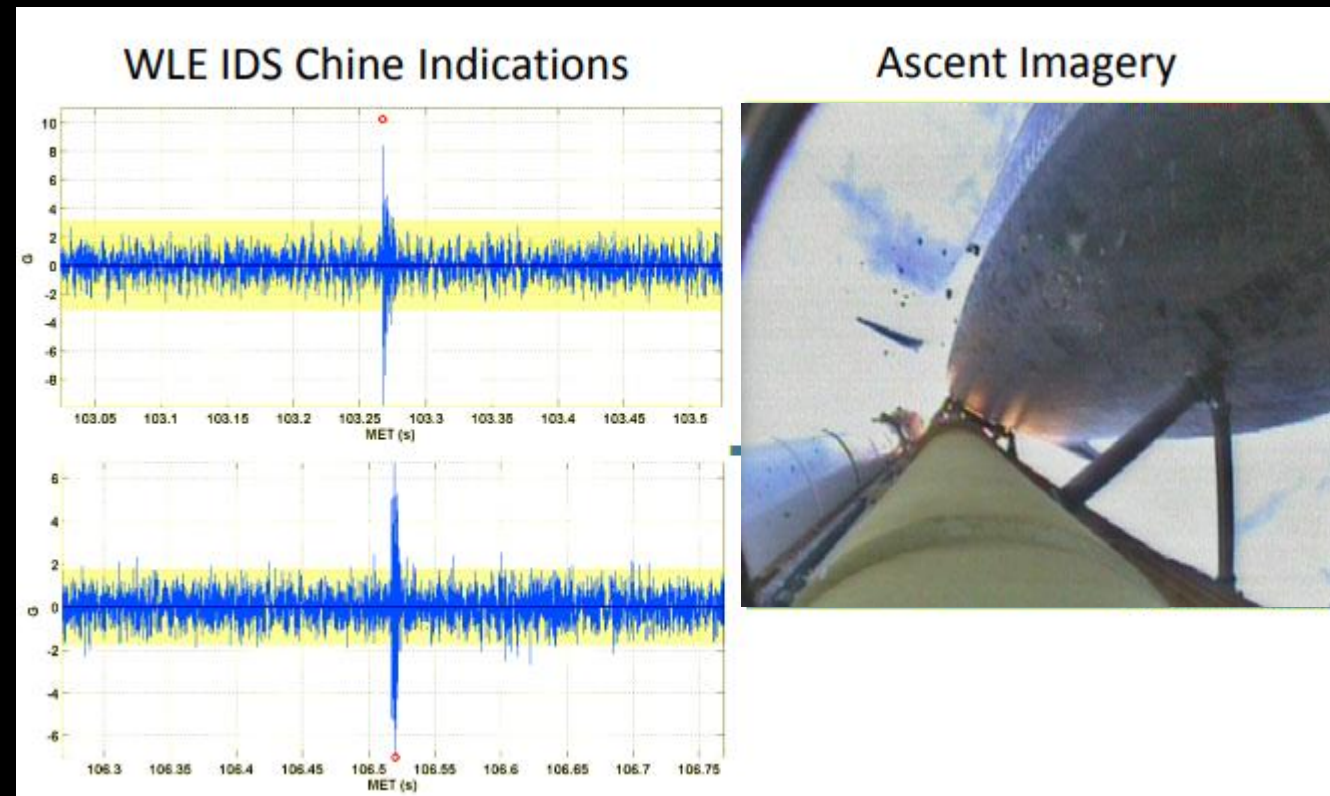
NDE's Role in Exploring the Moon, Mars and Beyond

COLUMBIA ACCIDENT LED TO THE DEVELOPMENT OF SHM FOR THE SPACE SHUTTLE WINGS



Shuttle Wing Leading Edge Impact Detection System (WLEIDS)

First WLEIDS ascent indication with corroboration from both debris and damage imagery
STS-127 – July 15, 2009

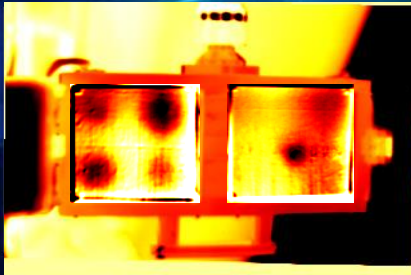


THE COLUMBIA ACCIDENT LED NASA TO PURSUE ON-ORBIT NDE

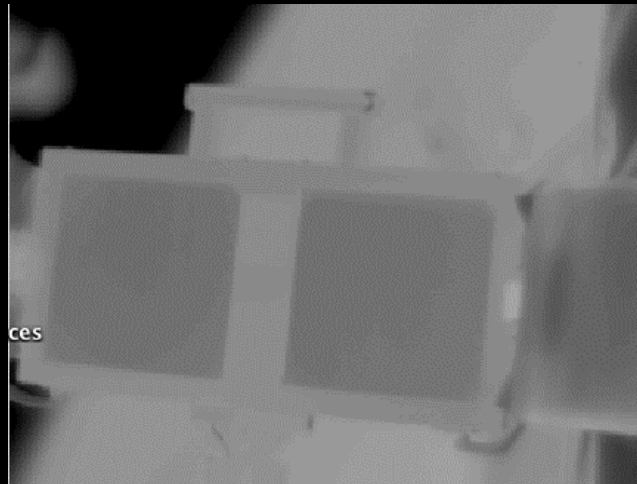
EVA IR Camera DTO – Objective #2



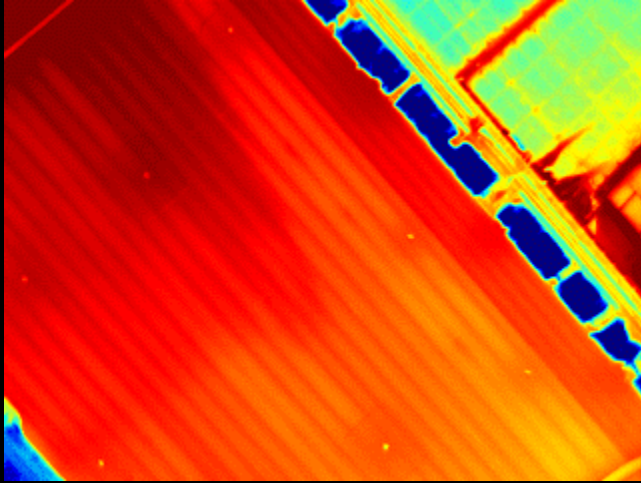
RCC Damaged
Sample Test Article



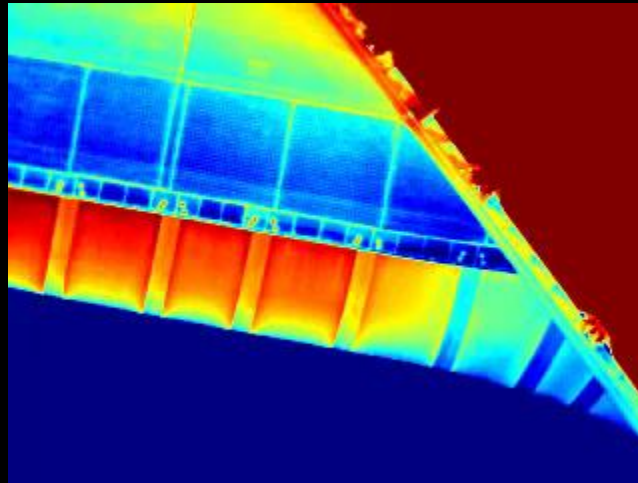
IR Camera



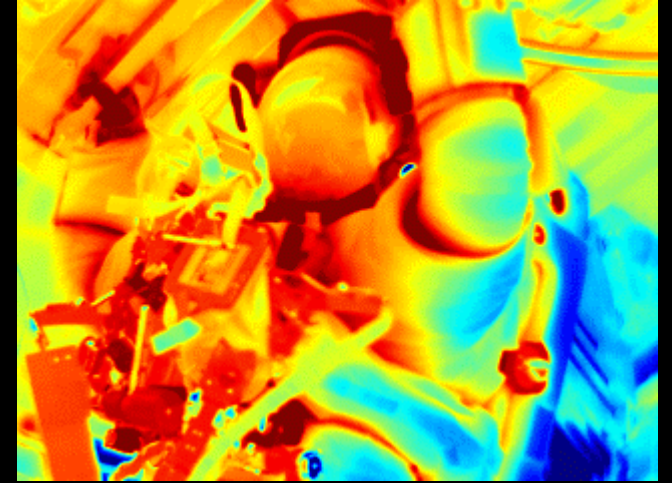
ONCE YOU HAVE THE CAPABILITY YOU FIND OTHER USES FOR IT



Space Shuttle Payload
Bay Doors / Radiators



Survey of Shuttle Wing
Leading Edges



Thermal Performance
of EVA Suits

CRACKING IN THE RUSSIAN FUNCTIONAL CARGO BLOCK (FBG) LED TO ON-ORBIT EDDY CURRENT AND ULTRASOUND



Zarya FBG Module prior to docking

Sonatest Veo3 ultrasonic phased array recently manifest to ISS



Inside the FBG

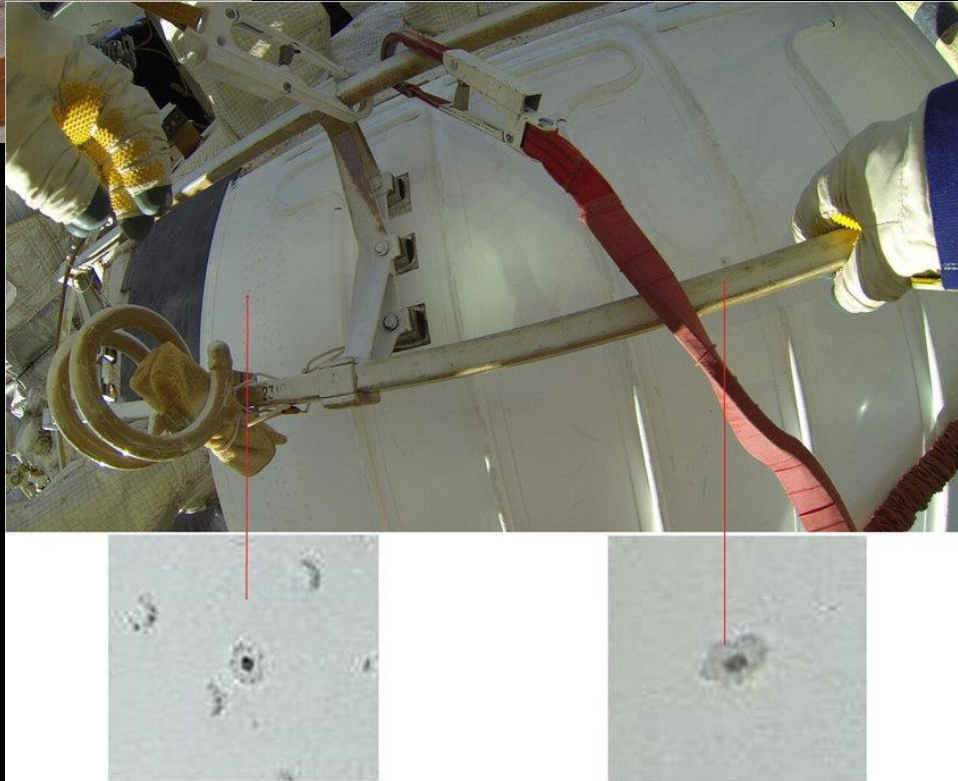


Using a Nortec 600D Eddy Current system on-orbit

SPACE ORBITAL DEBRIS HAS LED TO A DEMONSTRATION OF STRUCTURAL HEALTH MONITORING FOR ISS

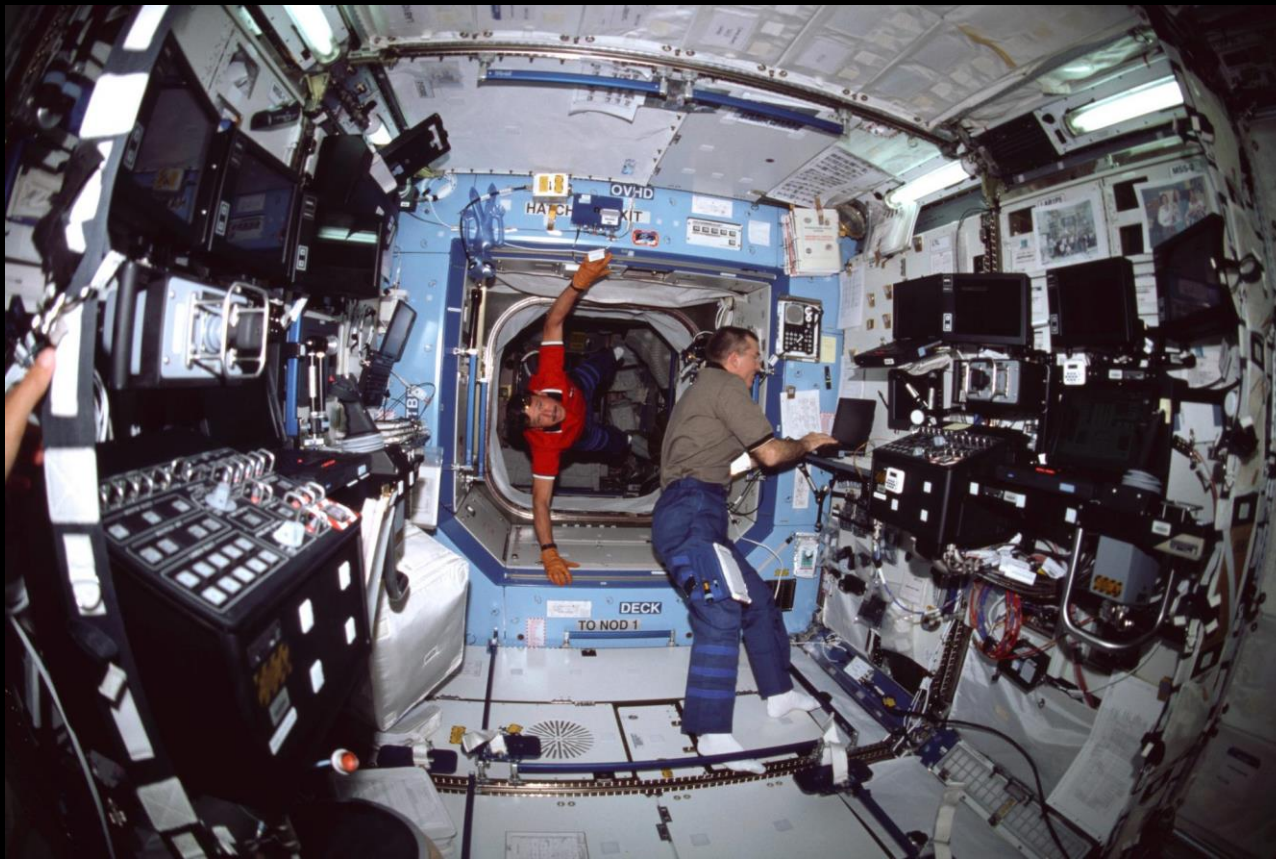


Examples of orbital debris impact to ISS

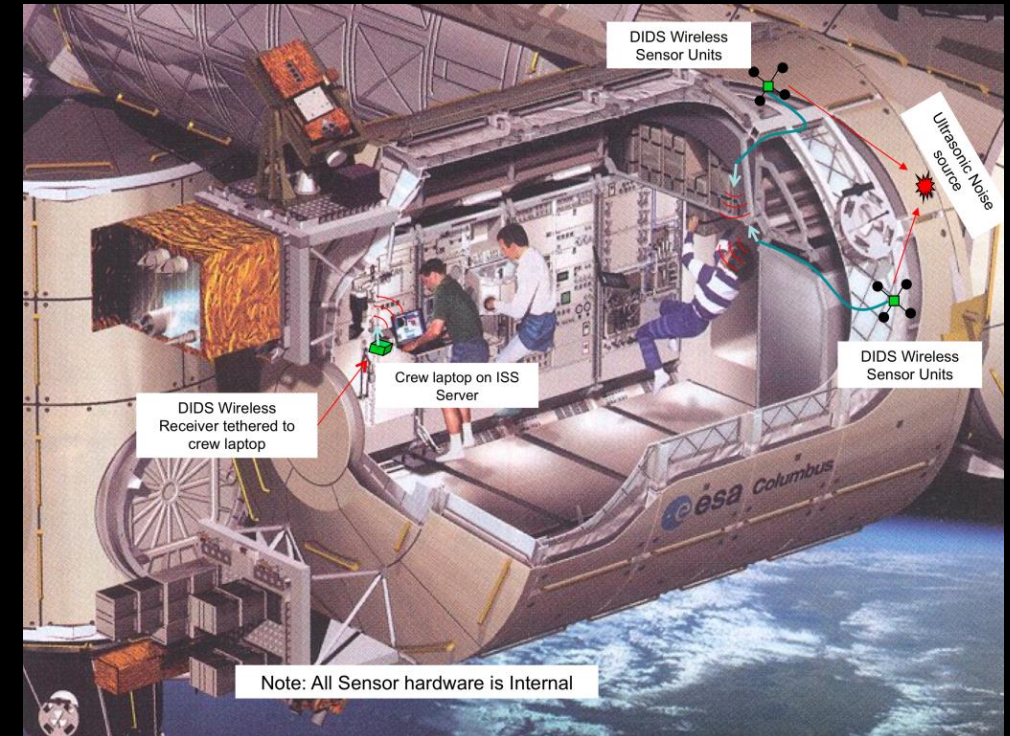


Canadian Space Agency astronaut Chris Hadfield, Expedition 34 Flight Engineer, installing SHM sensors behind a rack in the Destiny laboratory of the International Space Station.

CURRENTLY IT IS IMPRACTICAL TO INSTRUMENT THE ENTIRE ISS

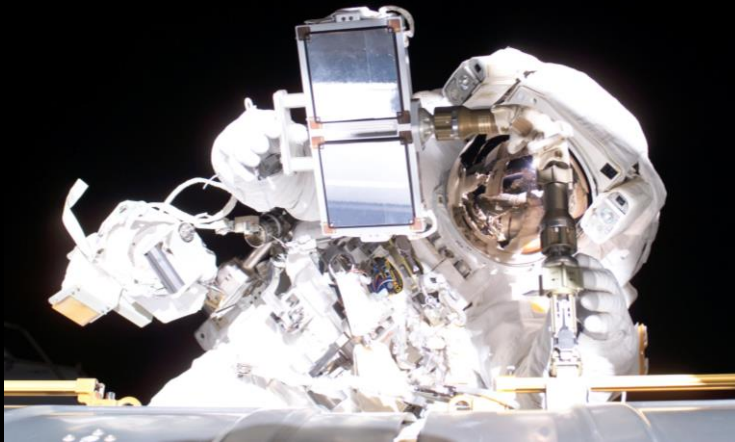


Interior view of ISS module showing the difficulty of accessing the structure



Demonstration of technology done with a limited number of sensors in one module

TO DATE THERE HAVE BEEN SEVERAL IN SPACE NDE AND SHM ACTIVITIES



EVA IR camera



Eddy Current for crack sizing



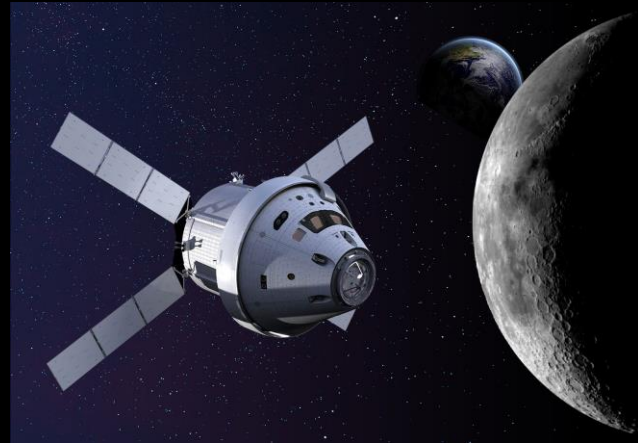
SHM for leak location

But what about going forward?

MOVING FORWARD TO MARS WILL PRESENT EVEN GREATER NDE CHALLENGES



Low Earth Orbit

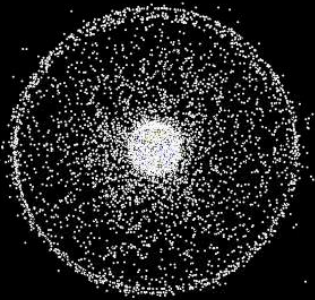


Cislunar Space

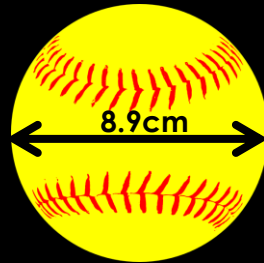


Living and working on
the moon/Mars

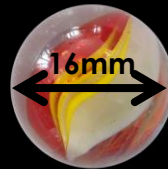
THE LOW EARTH ORBIT ENVIRONMENT PRESENTS A CHALLENGE TO SPACE STRUCTURES



Computer generated fly-thru
of objects in Earth orbit that
are currently being tracked.



23,000 pieces of debris larger than a softball
(3.5in dia.) orbiting the Earth.



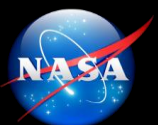
There are half a million pieces of debris the size of
a marble or larger (up to 0.4 in/1 cm dia.)



Typ. Salt Crystal
1mm

Approximately 100 million pieces of debris about
.04 inches (or one millimeter) and larger. There is
even more micrometer-sized (0.000039 of an inch
in diameter) debris.

Velocity up to 17,500 mph



COMMERCIAL USE OF LOW EARTH ORBIT WILL REQUIRE ADVANCED NDE AND SHM

Image Credit:
Axiom



Axiom concept
commercial space station

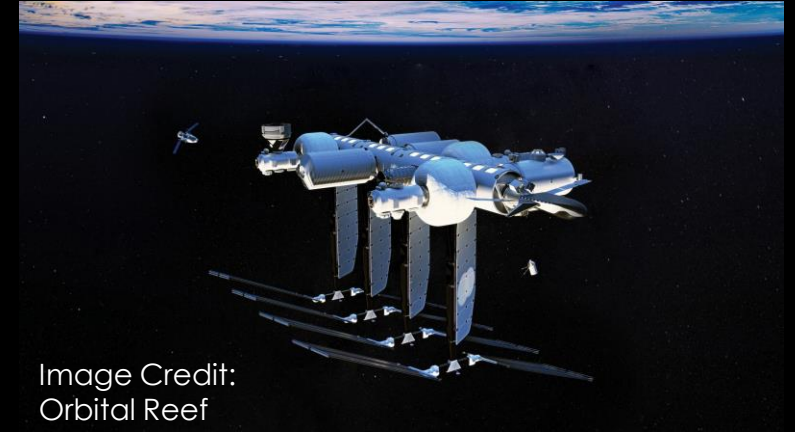


Image Credit:
Orbital Reef

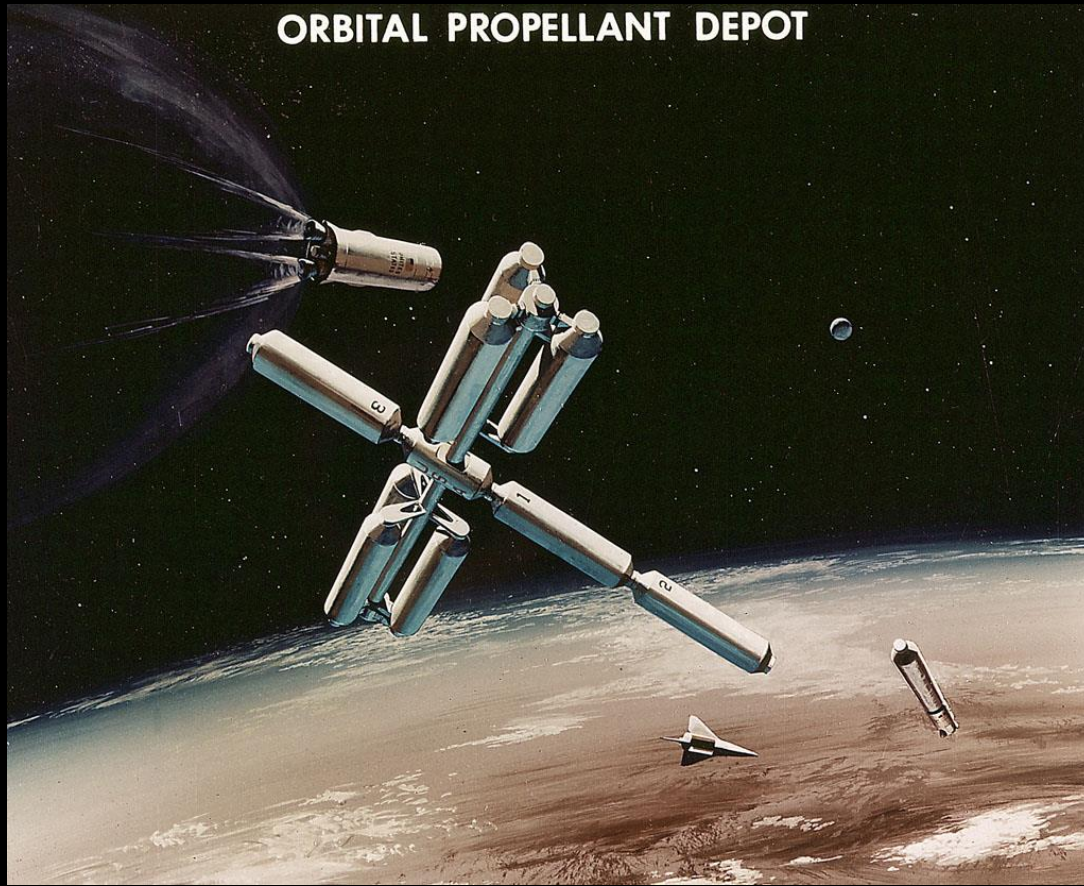
Orbital Reef concept
commercial space station



Image Credit:
Northrop Grumman

Northrop Grumman concept
commercial space station

LIKE A SPACE STATION ORBITAL FUEL DEPOTS WILL HAVE UNIQUE NDE AND SHM NEEDS



Orbital fuel depots will be unmanned for long periods of time in a space debris environment

Autonomous monitoring the structural health as well as the fuel storage integrity will be critical

Facilitating on-orbit maintenance through routine inspections and repairs will be key to the success of such structures

Concept orbital fuel depot

ORBITAL MANUFACTURING, ASSEMBLY AND SERVICING WILL HAVE NDE NEEDS



On-orbit autonomous inspection and repair



Concept on-orbit manufacturing with closed-loop, real-time, in situ inspection



Why the Moon?

LIVING AND WORKING ON THE MOON WILL PROVIDE OPPORTUNITIES FOR RESEARCH AND TECHNOLOGY DEVELOPMENT THAT WILL PREPARE HUMANS FOR FURTHER HUMAN EXPLORATION TO MARS AND BEYOND.



Human Civilization

Successful nations of yesterday dared to explore beyond their borders; successful nations of today will explore beyond our atmosphere. Successful nations of tomorrow will explore even further into our solar system.



Global Partnerships

Exploration will be most successful when the shared aspirations of the international community are realized. A global exploration strategy maximizes resources and talent, benefitting all of us in space and on Earth.



Economic Expansion

Space research results in applications that improve our daily lives. NASA has historically embraced close partnerships with commercial industry, and the future holds even more potential for commercial contributions to space exploration.



Scientific Knowledge

We can learn about the history of Earth and the solar system from the moon by studying its craters and regolith. This will provide clues about the origin and structure of the moon and planets and answer life's most fundamental questions.



Exploration Preparation

Lunar exploration provides opportunities to test new technologies, experience living on extraterrestrial surfaces and learn ways to use resources found in space – all with the goal of safely preparing crews for missions to Mars and beyond.



Public Engagement

Lunar exploration will inspire the next generation of explorers to learn real-life applications of science, technology, engineering and math. Learning these disciplines will lead to discoveries and innovations in space and here on Earth.

Artemis: Landing Humans On the Moon



Lunar Reconnaissance Orbiter: Continued surface and landing site investigation



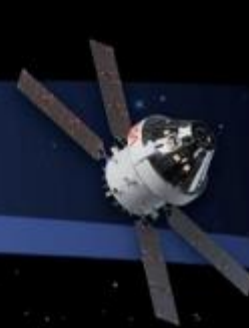
Artemis I: First human spacecraft to the Moon in the 21st century



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



Gateway begins science operations with launch of Power and Propulsion Element and Habitation and Logistics Outpost



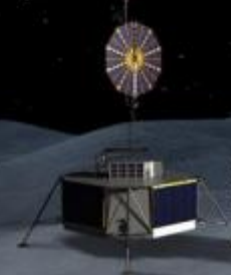
Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System



Early South Pole Robotic Landings
Science and technology payloads delivered by Commercial Lunar Payload Services providers



Volatiles Investigating Polar Exploration Rover
First mobility-enhanced lunar volatiles survey



Uncrewed HLS Demonstration



Humans on the Moon - 21st Century
First crew expedition to the lunar surface



Artemis Base Camp Buildup

First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface

Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities

Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions

Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets.

Lunar Terrain Vehicle (LTV)

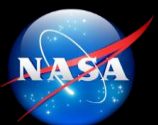
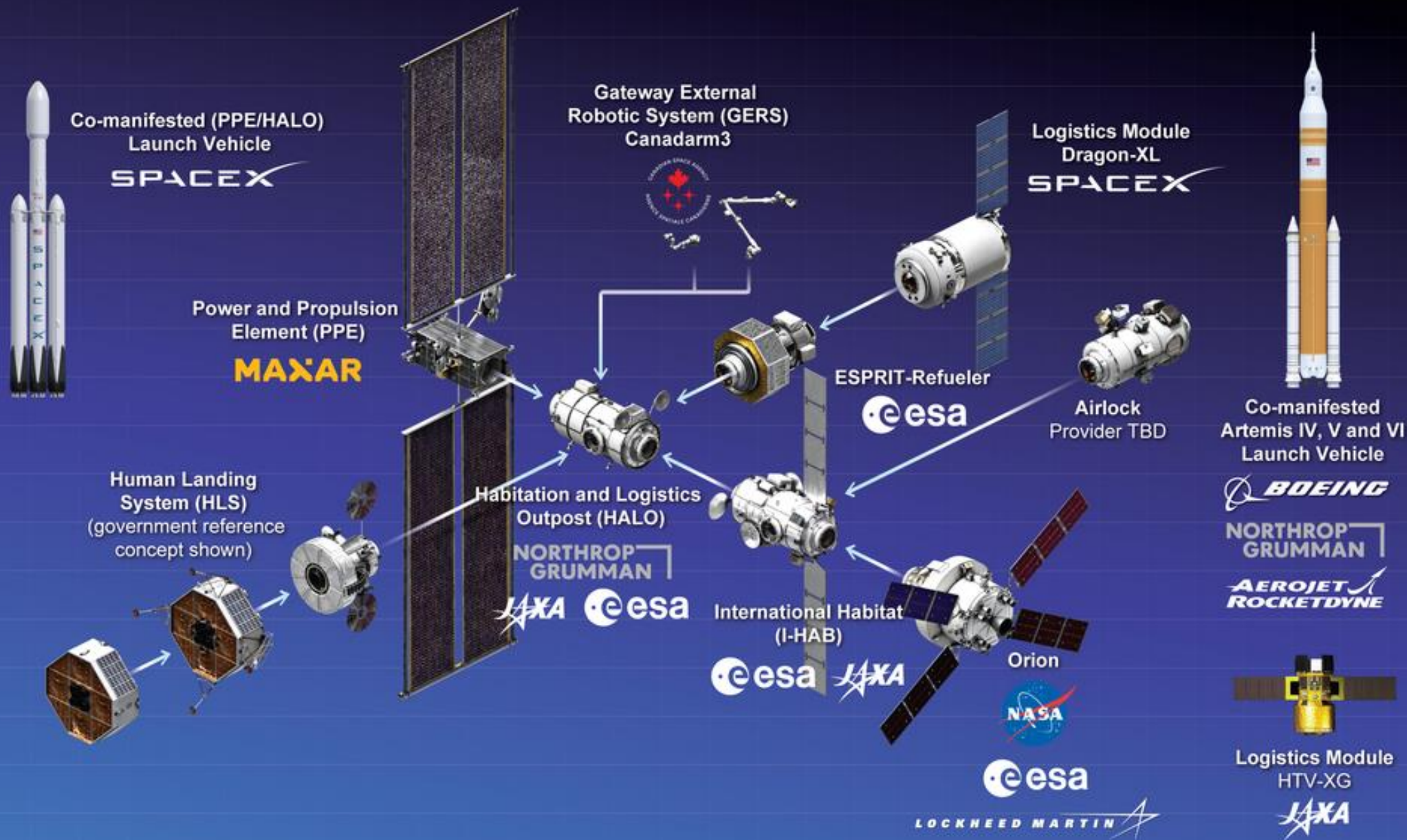
Crew
Landing
Services

Pressurized
Rover

Fission
Surface
Power

ISRU Pilot
Plant

Surface
Habitat

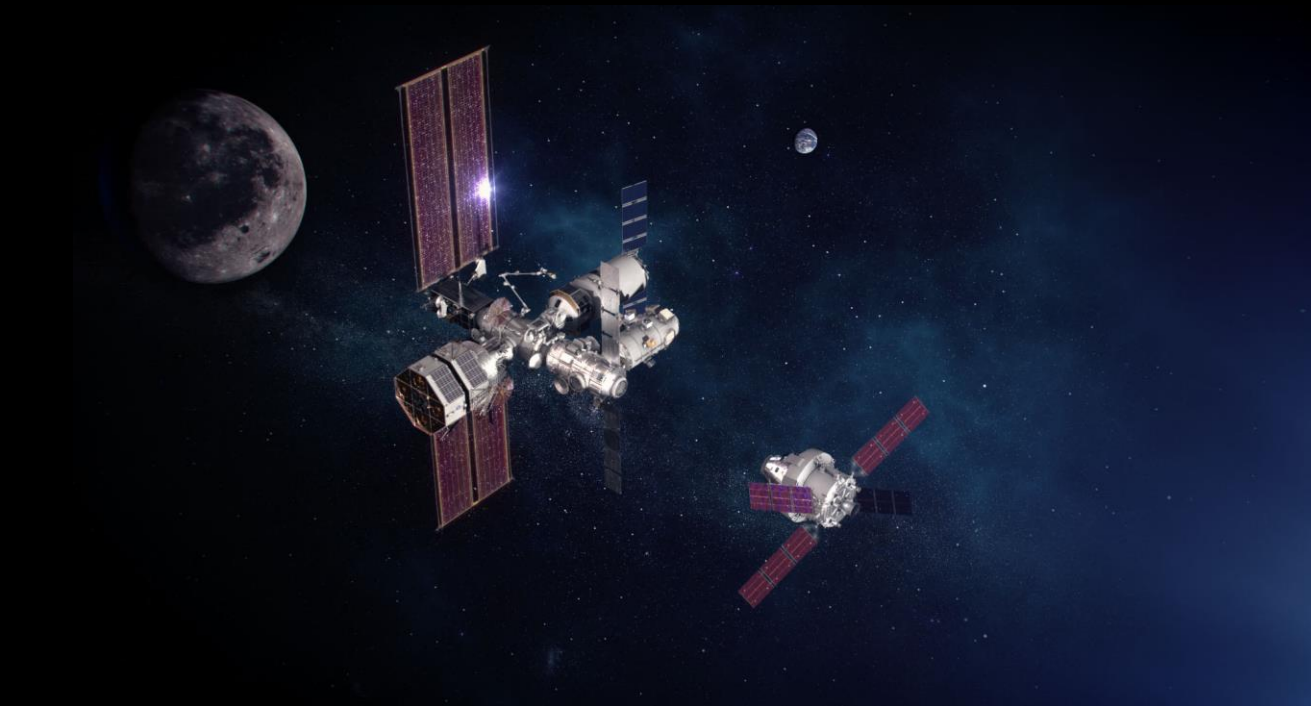


GATEWAY HAS UNIQUE CHALLENGES DUE TO HUMAN HABITATION

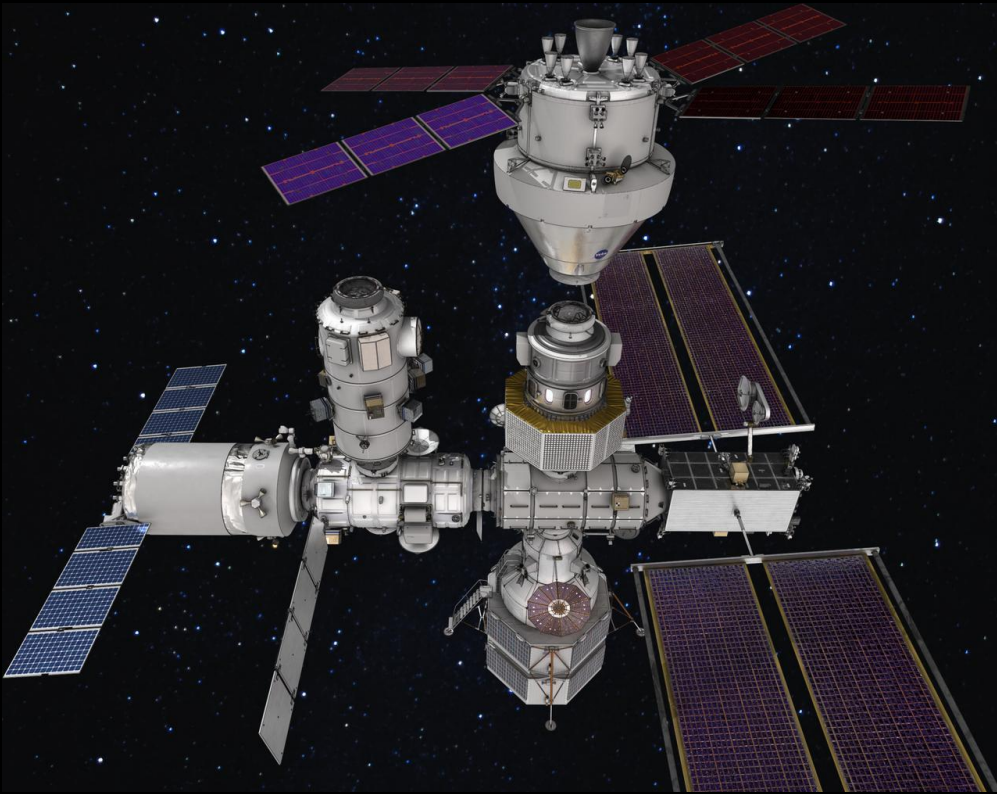
Gateway will serve as a multi-purpose outpost orbiting the Moon that provides essential support for long-term human return to the lunar surface and serves as a staging points for deep space exploration.

Autonomous monitoring the structural health will be critical to ensure astronaut health

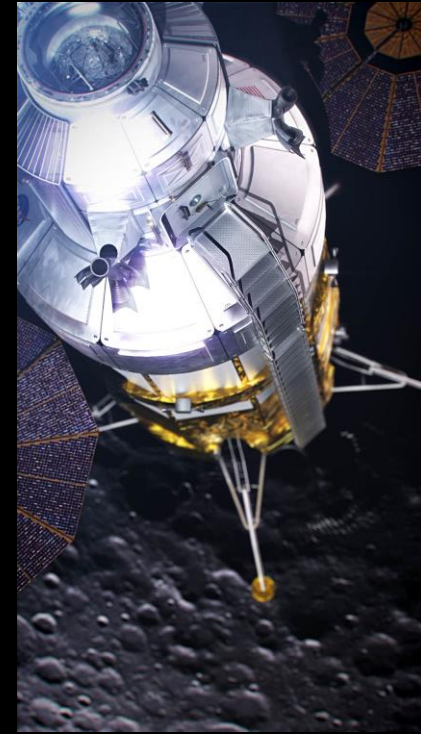
Facilitating automated on-orbit maintenance through routine inspections and repairs will be key to mission success



HUMAN LANDING SYSTEM REUSE REQUIRES INSPECTION CAPABILITIES

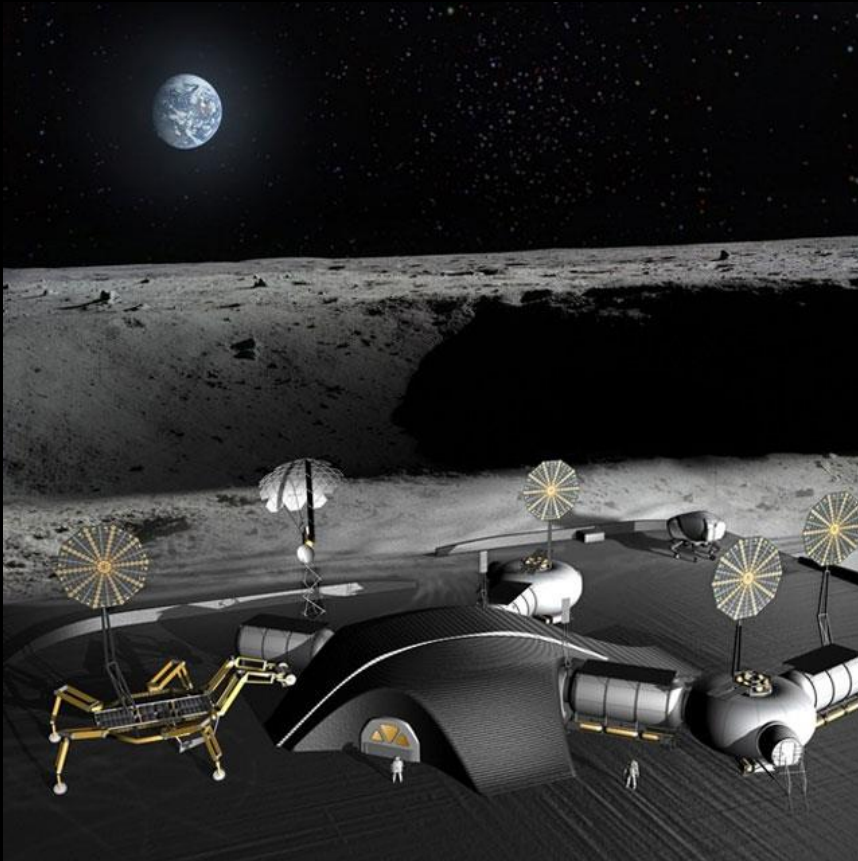


Gateway will serve as a solar-powered communication hub, science laboratory, and short-term habitation module for astronauts, as well as a docking station for HLS

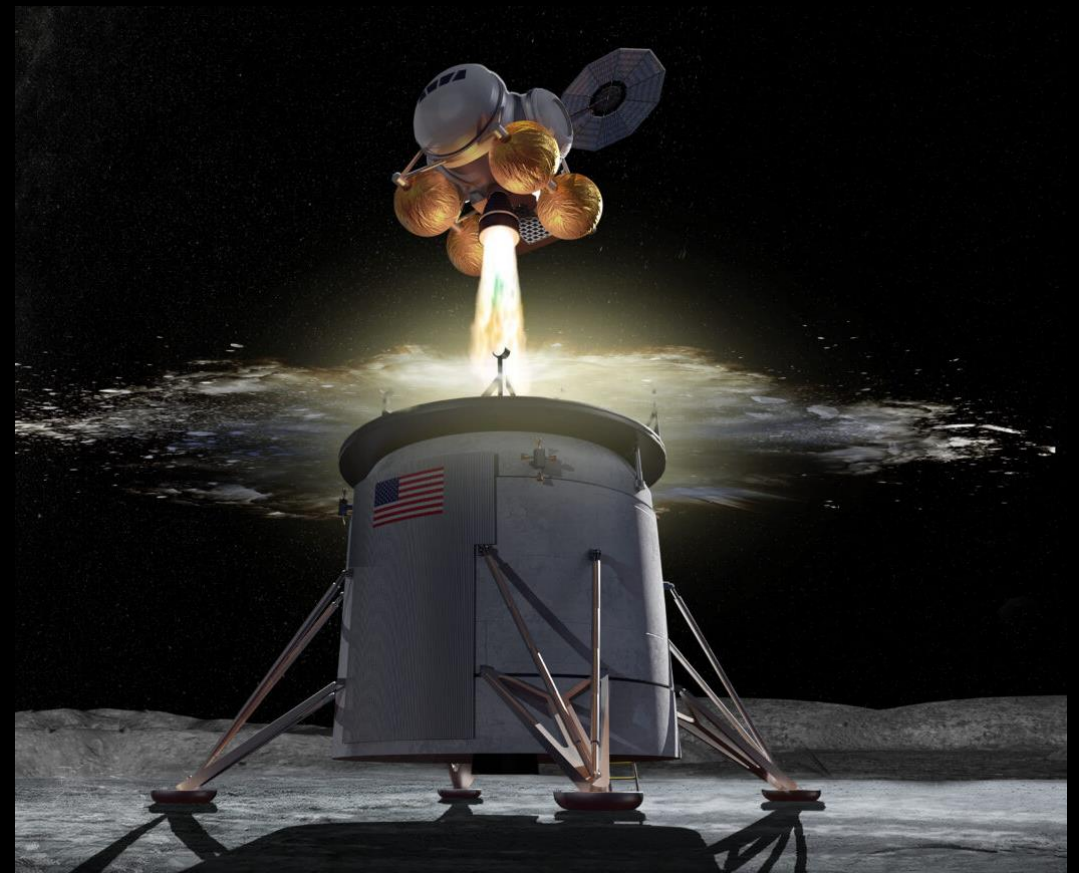


A reusable HLS will make multiple sorties between Gateway and the Lunar surface

HABITATS WILL REQUIRE ONGOING INSPECTION AND MAINTENANCE



Concept multi-purpose base camp



Concept habitat and landing pad

LANDERS CAN CREATE A LUNAR INFRASTRUCTURE MAINTENANCE ISSUE



NASA Morpheus concept
lander on a hard surface

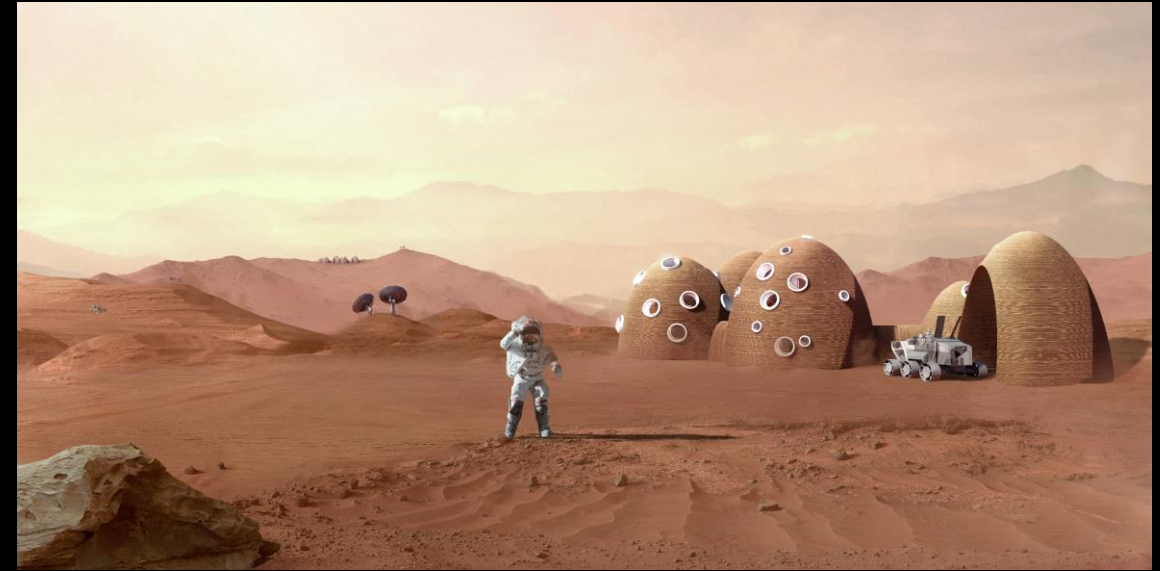


NASA Morpheus concept
lander on a soft surface

ADDITIVE MANUFACTURED STRUCTURES PRESENT MULTIPLE CHALLENGES



Concept regolith sintered
landing pad



Concept regolith sintered
habitats

Ensuring both the initial and ongoing
integrity of Lunar / Martian construction

HUMAN RATED LUNAR VEHICLES WILL ALSO HAVE SPECIAL NEEDS



Concept pressurize Rover



Concept un-pressurize Lunar Terrain Vehicle

VEHICLES AND HABITATS WILL BE A MIX OF CONVENTIONAL AND NON-CONVENTIONAL AEROSPACE MATERIALS

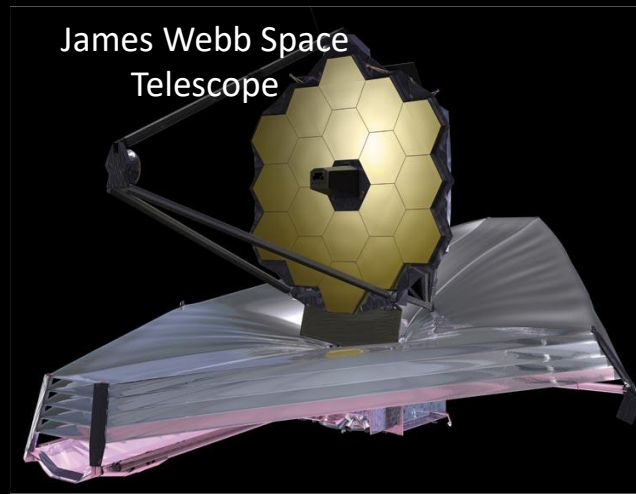


Composite
Crew Module

- Metallics and composites for structure
- Glass and plastics for windows and recyclability
- Fabrics for inflatables and deployables
- Unknown materials from in situ resources



Concept Lunar
Fabrication

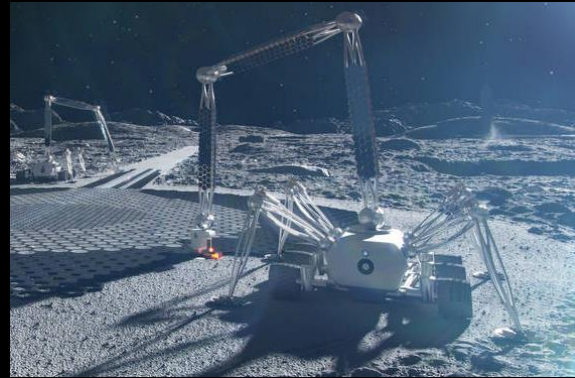
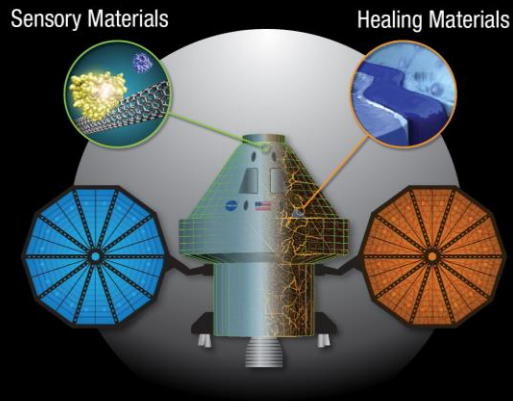


James Webb Space
Telescope

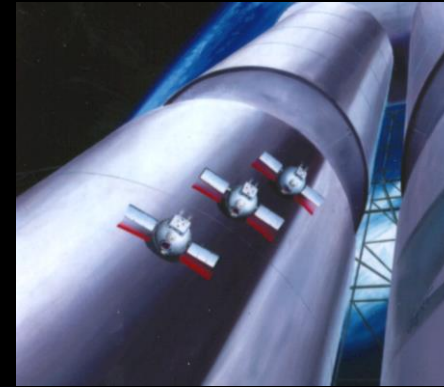
Concept Inflatable
Habitat



IN SUMMARY, THE DEMANDING MOON-TO-MARS MISSION REQUIRES NEW TECHNOLOGY

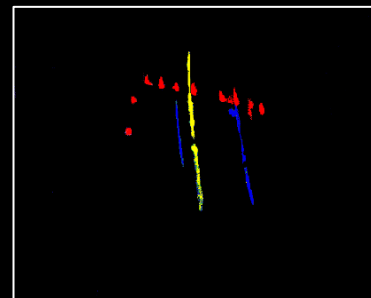


In situ inspection
during manufacturing

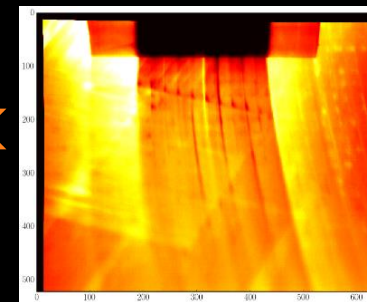


Simple to operate or
autonomous NDE
systems capable of
covering large areas

Novel autonomous SHM,
which could include
sensory and multi-
functional materials



Automatic Feature
Recognition



Raw Data

Automated data
analysis and defect
recognition



QUESTIONS?

