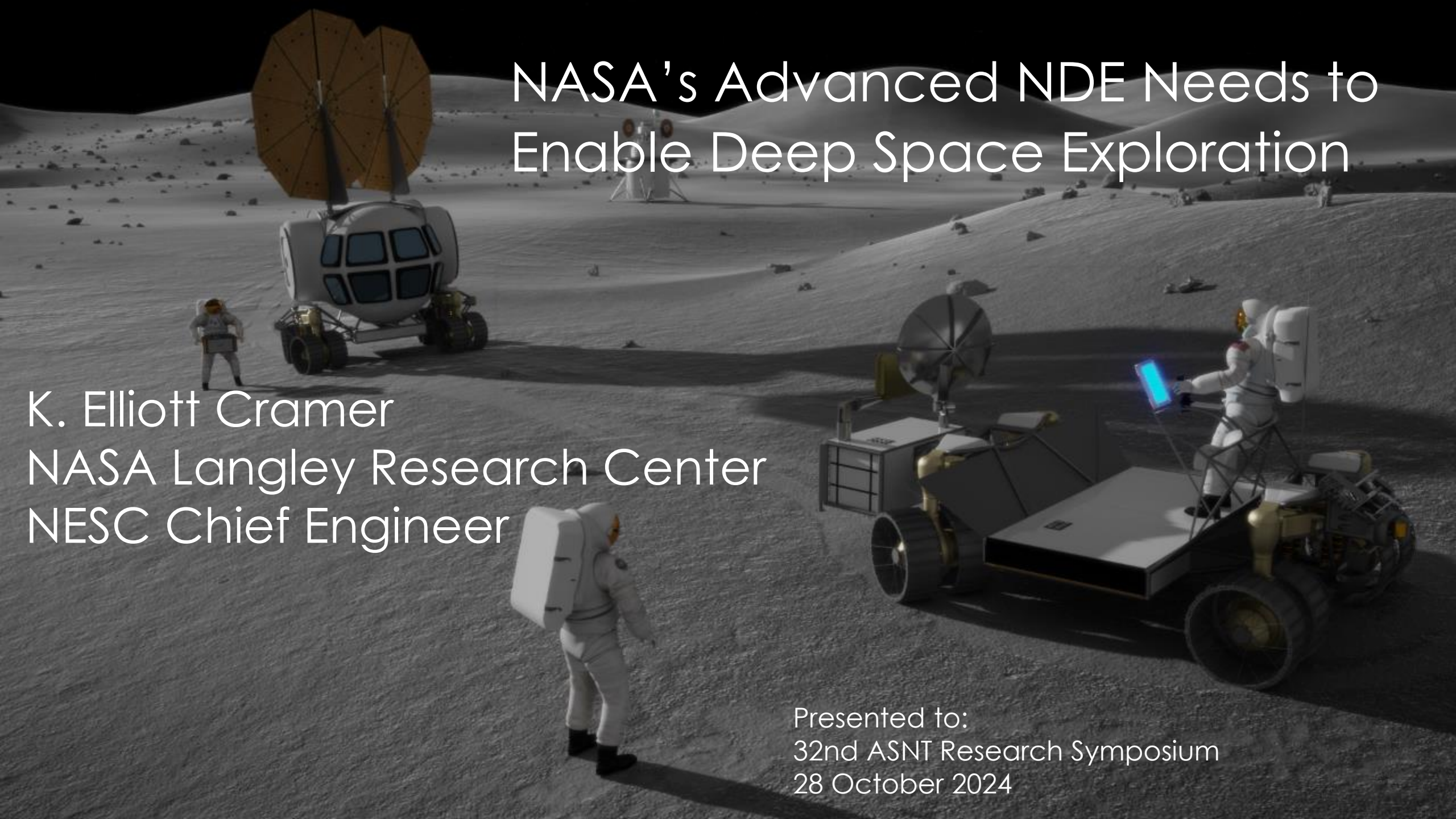


NASA's Advanced NDE Needs to Enable Deep Space Exploration

A detailed illustration of a lunar surface exploration mission. In the foreground, an astronaut in a white spacesuit with a large white backpack walks towards the left. To the right, a four-wheeled rover is equipped with a large parabolic dish antenna and a flat solar panel. Another astronaut is seated on the rover, operating a control panel that glows with a blue light. In the background, a larger rover with a prominent orange parabolic antenna is parked. The lunar landscape is characterized by rolling hills, scattered rocks, and a dark, featureless sky.

K. Elliott Cramer
NASA Langley Research Center
NESC Chief Engineer

Presented to:
32nd ASNT Research Symposium
28 October 2024

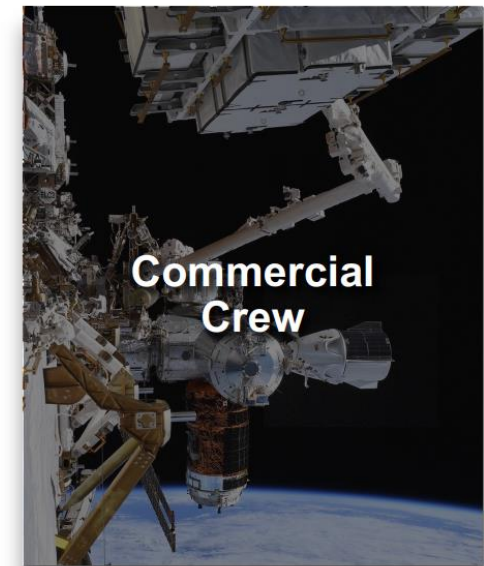
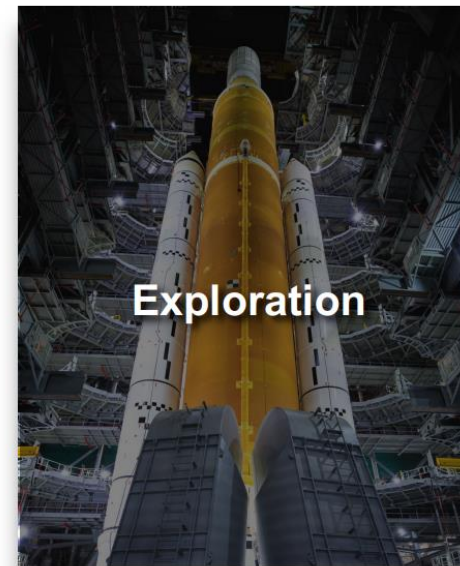
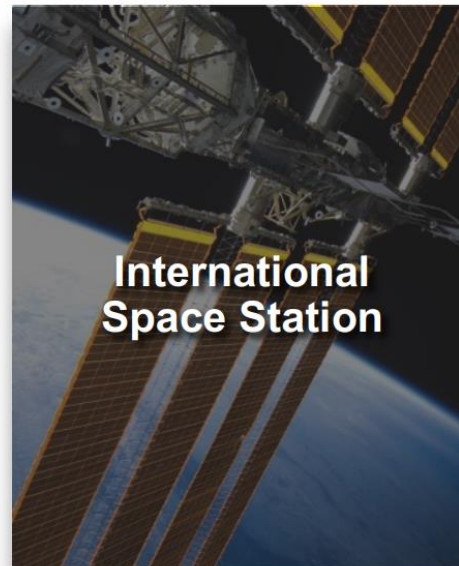
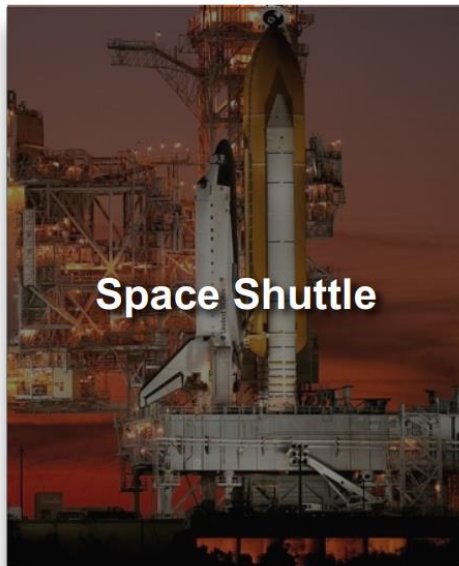
JULY 2003 – NASA ENGINEERING AND SAFETY CENTER (NESC) ESTABLISHED

Established in July 2003 in response to the Columbia accident.

NESC highlights NASA's traditional safety philosophy.

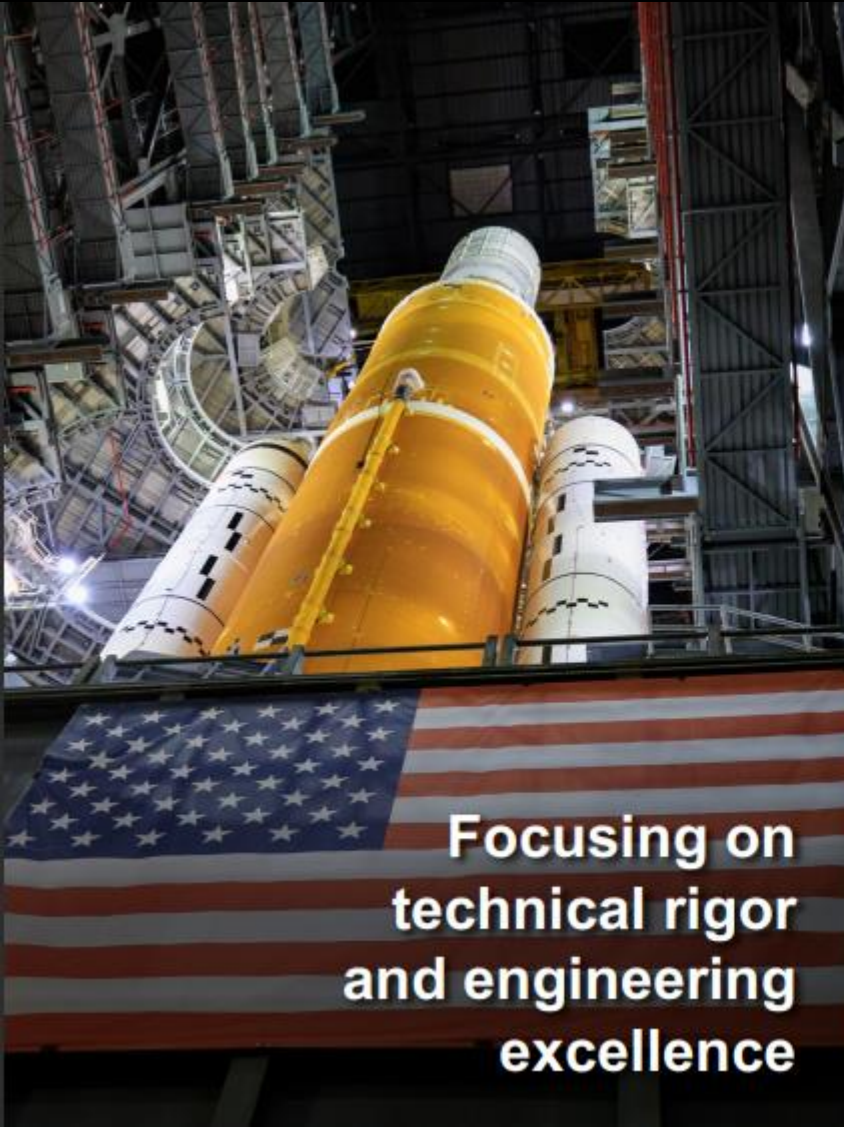
Strong In-Line Checks & Balances • Healthy Tension Between Organizational Elements • Value-Added Independent Assessment

Provides independent assessment of technical issues for NASA programs/projects and addresses national needs.



The NESC is cultivating a safety culture focused on engineering and technical excellence, while fostering an open environment and attacking challenges with unequalled tenacity.

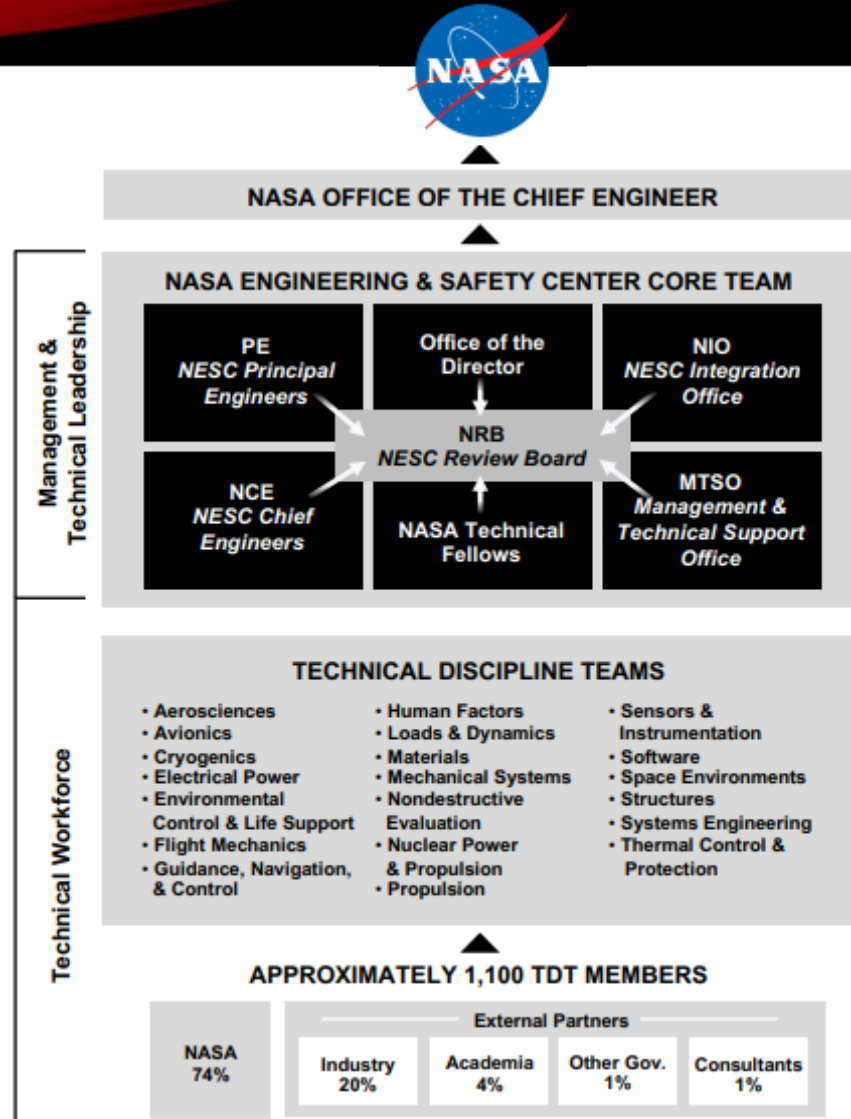
NESC MODEL



**Focusing on
technical rigor
and engineering
excellence**

- Institutionalized “Tiger Team” approach to solving problems, assessing risks, and informing decision makers
- Agency-recognized NASA Technical Fellows provide technical expertise leveraged through their Technical Discipline Teams (TDTs)
 - Experts from across NASA, industry, academia and other government agencies
 - Diverse, expert technical teams provide robust technical solutions
- NESC priority focus is on the Agency’s highest-risk and most complex issues
- Degree of NESC involvement varies depending on task at hand
 - Support to reviews
 - Augmentation of project teams
 - Problem solving through program-independent test and analysis
 - Development of new analysis tools and techniques
 - Exploration of alternate design concepts
- Strong Systems Engineering and Integration function for proactive trending and identification of problem areas before failures occur

NESC ORGANIZATION



Data as of May 10, 2024

- NESC has 65 full-time employees from across the Agency.
- Principal Engineers provide leadership for complex multi-discipline assessments
- NESC Chief Engineers at each Center provide technical insight and act as liaisons
- 19 NASA Technical Fellows are recognized experts in their respective engineering fields.
- 20 Technical Discipline Teams create a network of more than 1,100 engineers available for matrix support.
- More than 200 TDT members are intentionally drawn from industry, academia and other government agencies to prevent insularity.
- Participation on NESC teams provides value to home organizations.
 - Valuable problem-solving experience
 - Broad Agency-wide perspective
 - Engage next generation of engineers

THIS TALK WILL FOCUS ON NASA'S HUMAN SPACE FLIGHT MISSION AND THE NDE NEEDS AND CHALLENGES



Unique challenges in the
Space Shuttle and ISS – Low
Earth Orbit

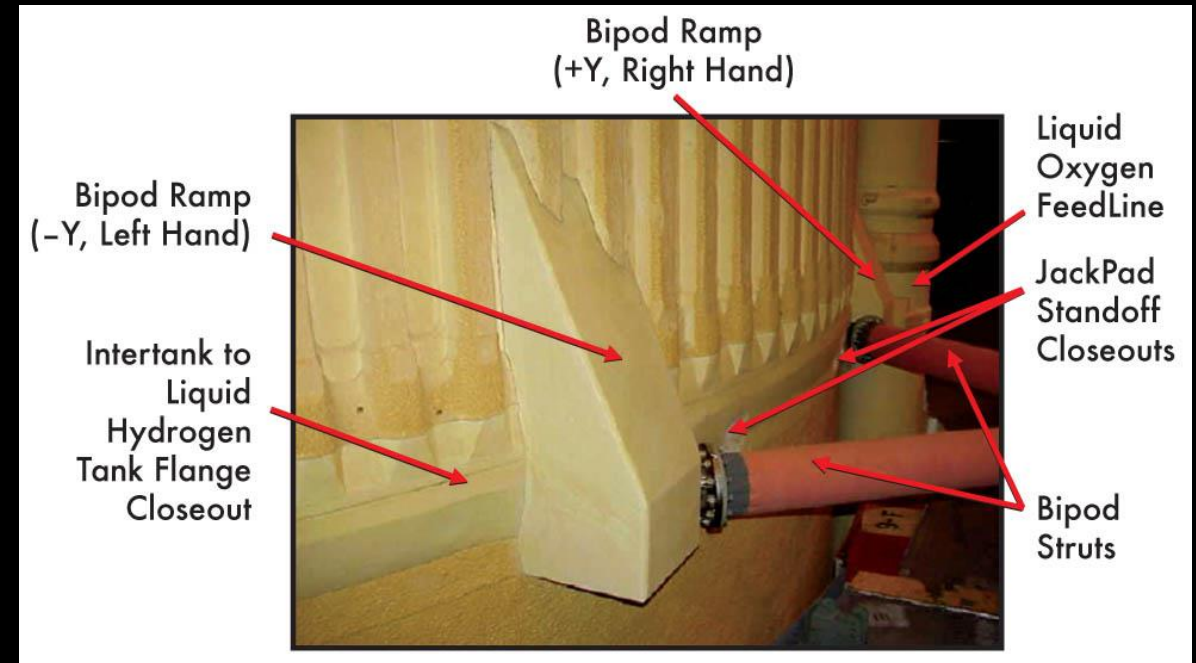


Exploring the Moon, Mars
and Beyond

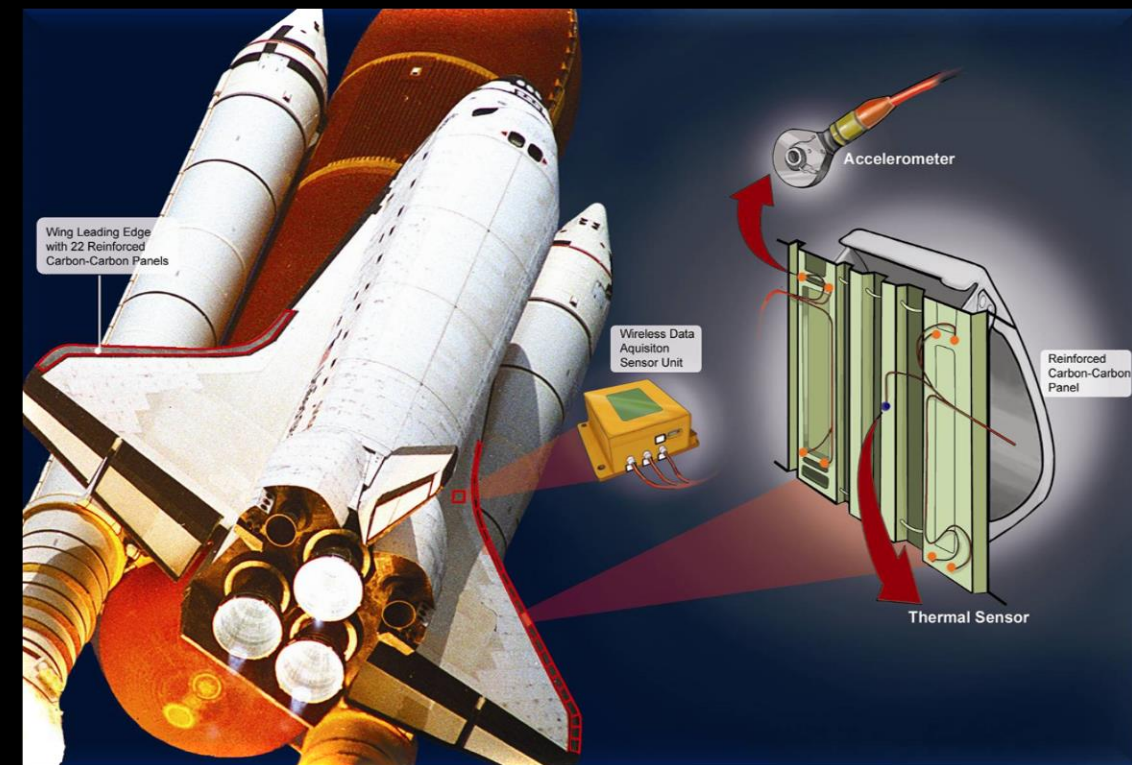
THE COLUMBIA ACCIDENT CHANGED NASA'S APPROACH TO SAFETY



STS-107 Launch
January 16, 2003
Columbia

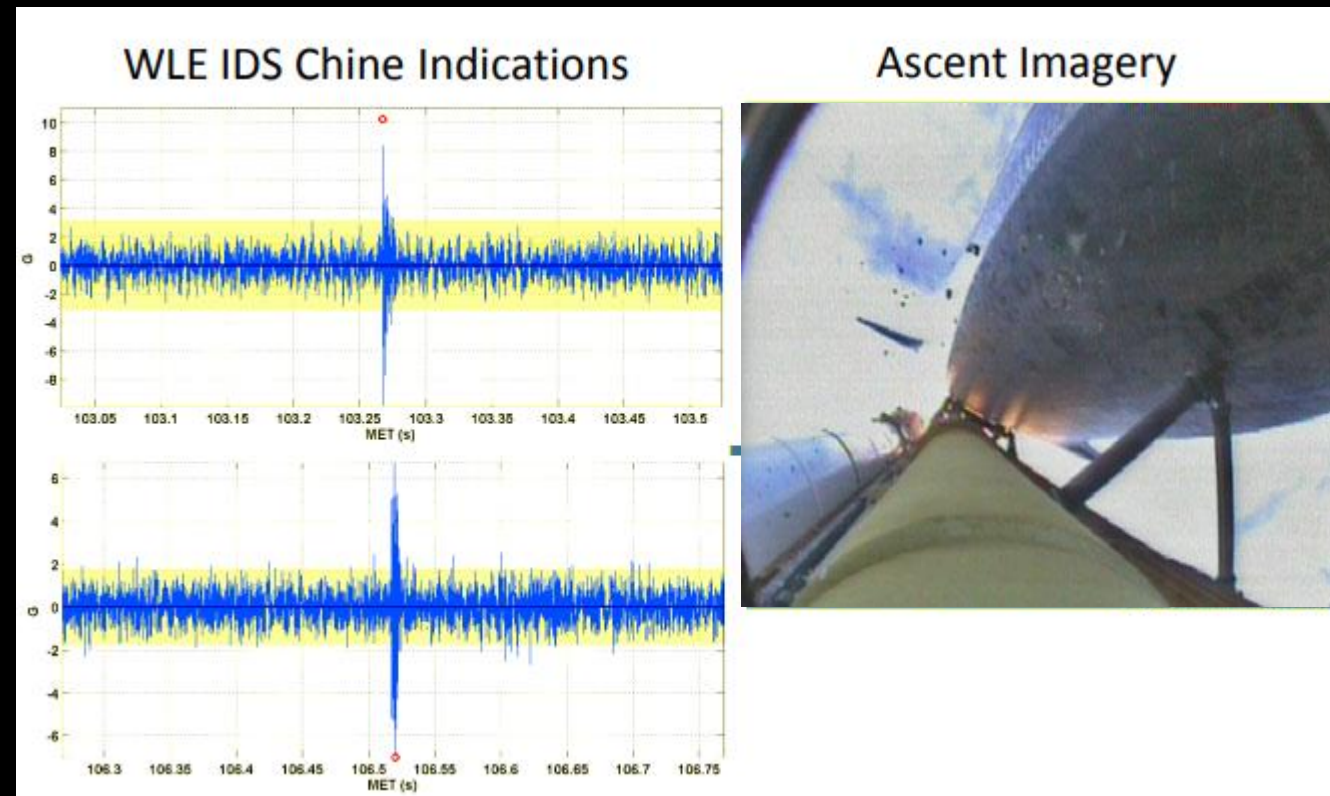


LED TO THE DEVELOPMENT OF AUTOMATED IMPACT SENSING FOR THE SPACE SHUTTLE WINGS



Shuttle Wing Leading Edge
Impact Detection System
(WLE IDS)

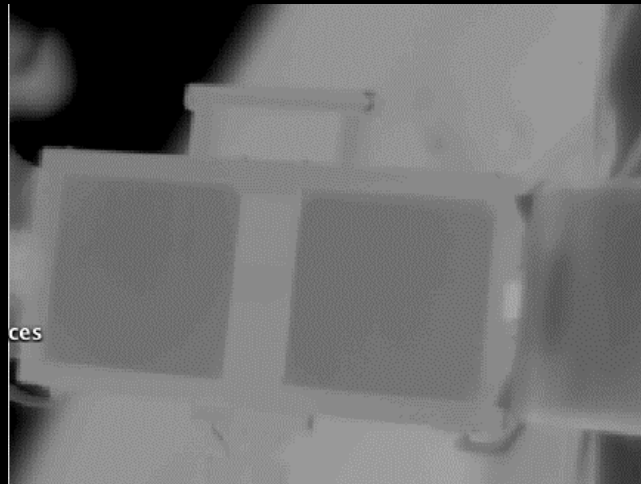
First WLE IDS ascent indication with corroboration
from both debris and damage imagery
STS-127 – July 15, 2009



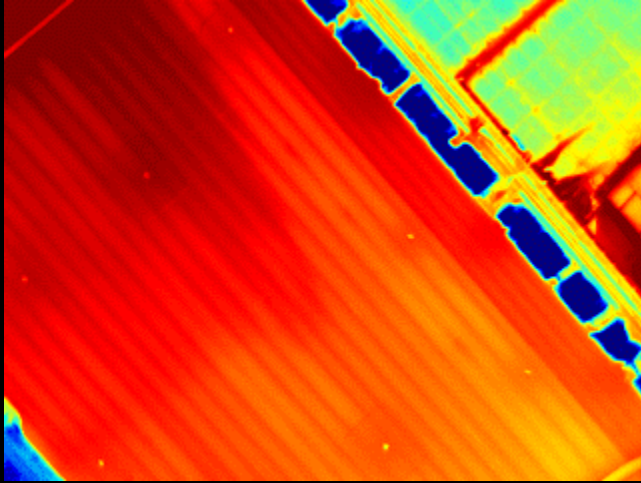
THE COLUMBIA ACCIDENT LED NASA TO PURSUE ON-ORBIT INSPECTION SYSTEMS



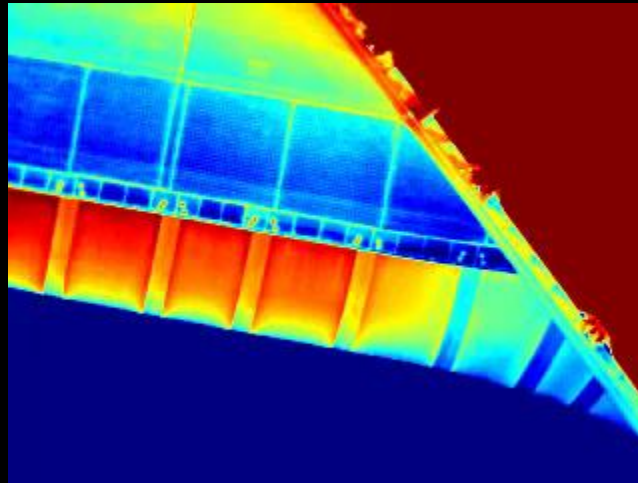
IR Camera



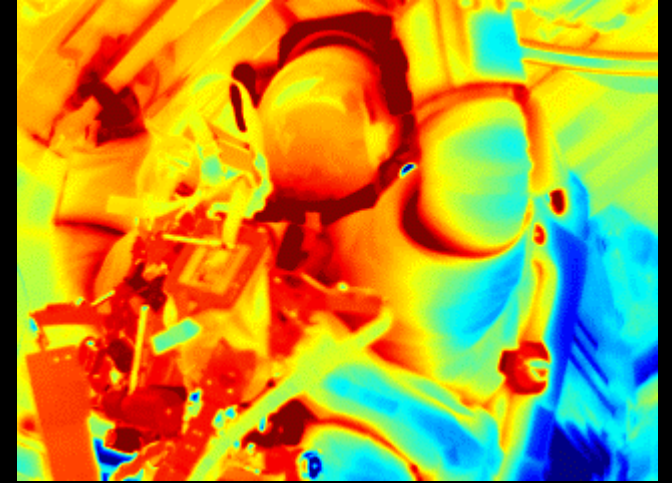
ONCE YOU HAVE THE CAPABILITY YOU FIND OTHER USES FOR IT



Space Shuttle Payload
Bay Doors / Radiators



Survey of Shuttle Wing
Leading Edges



Thermal Performance
of Space Suits

CRACKING IN THE RUSSIAN FUNCTIONAL CARGO BLOCK (FBG) LED TO MODIFYING COMMERCIAL INSPECTION SYSTEMS FOR ON-ORBIT USE



Zarya FBG Module
prior to docking



Inside the FBG



Using a Nortec 600D Eddy
Current system on-orbit

MODELING REQUIRED TO SUPPORT PAUT TESTING ON ISS

Modeling of Ultrasound inspection near a



Small stand-off

Geometry signal
 Flaw signal

Large stand-off

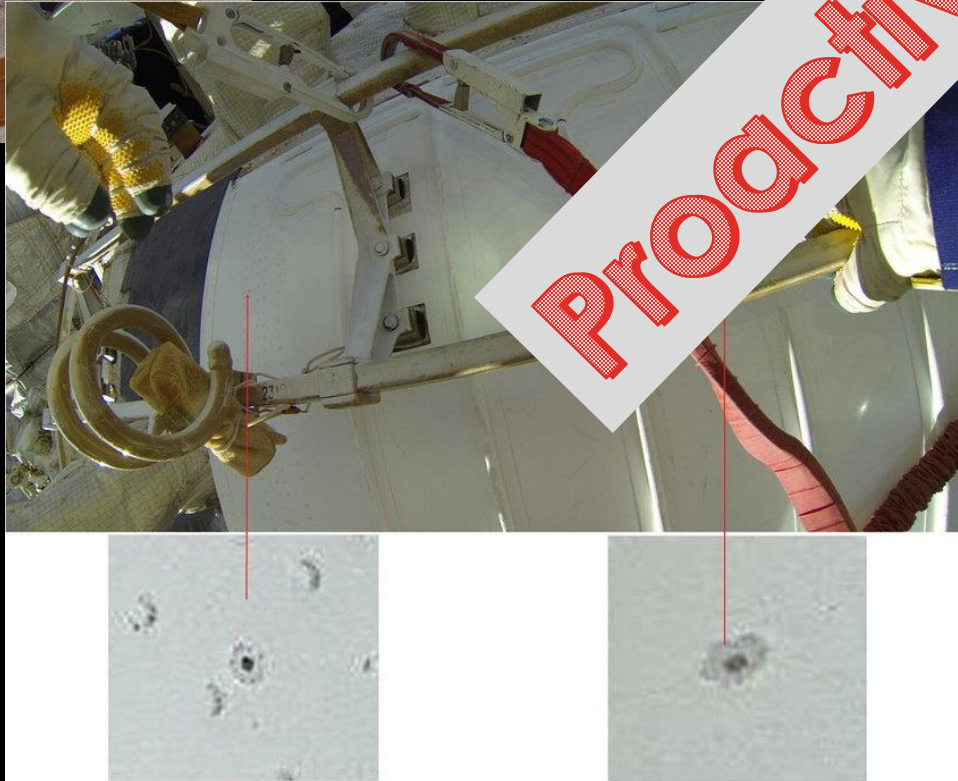
Sonatest Veo3 ultrasonic phased array recently manifest to ISS



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

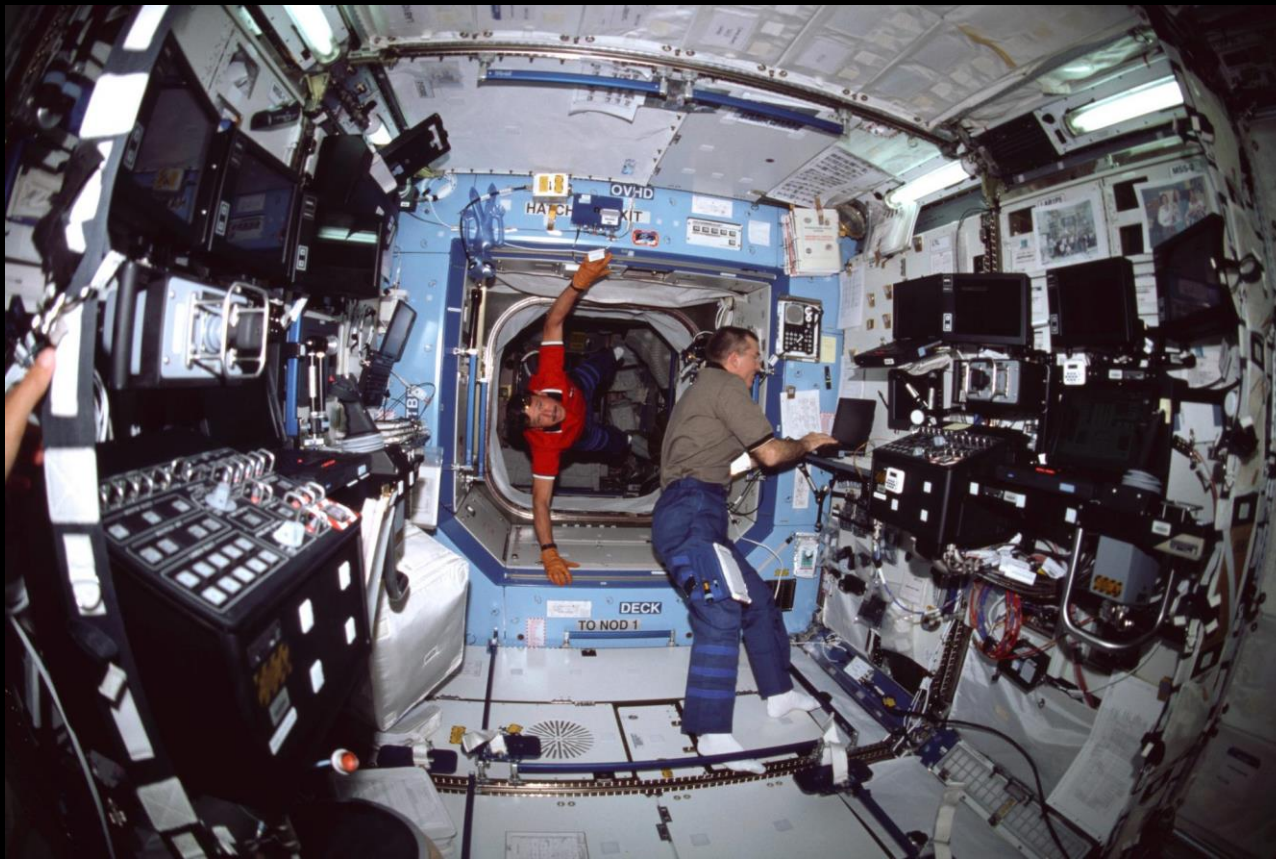


Examples of orbital debris impact to ISS

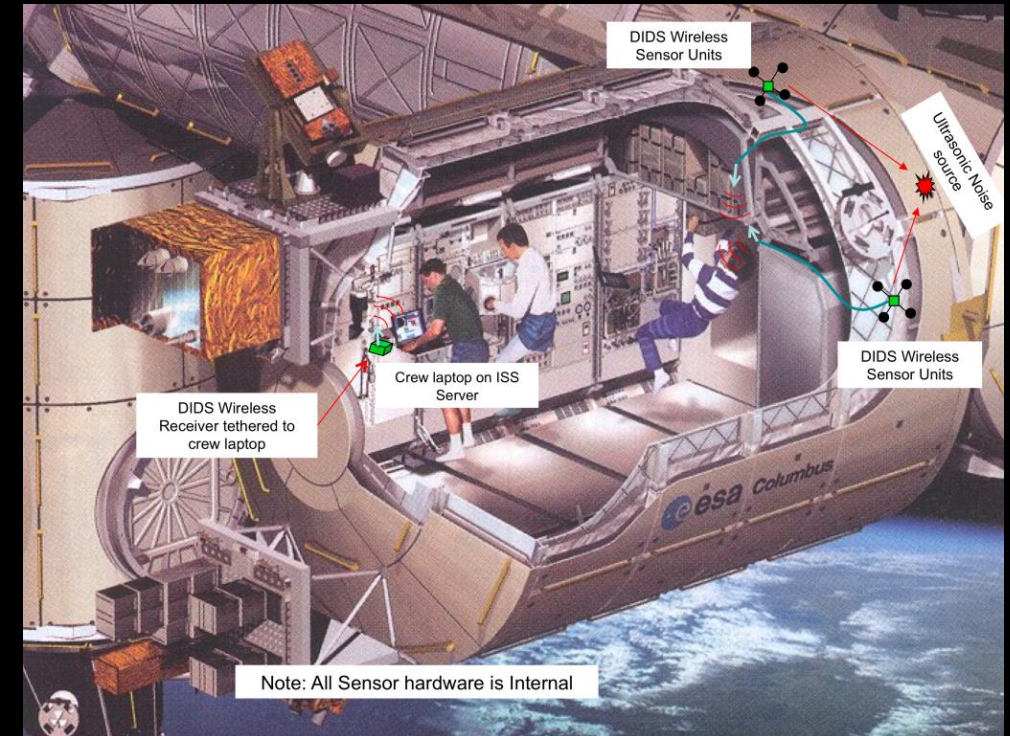


Canadian Space Agency astronaut Chris Hadfield, Expedition 34 Flight Engineer, installing SHM sensors behind a rack in the Destiny laboratory of the International Space Station.

CURRENTLY IT IS IMPRACTICAL TO INSTRUMENT THE ENTIRE ISS

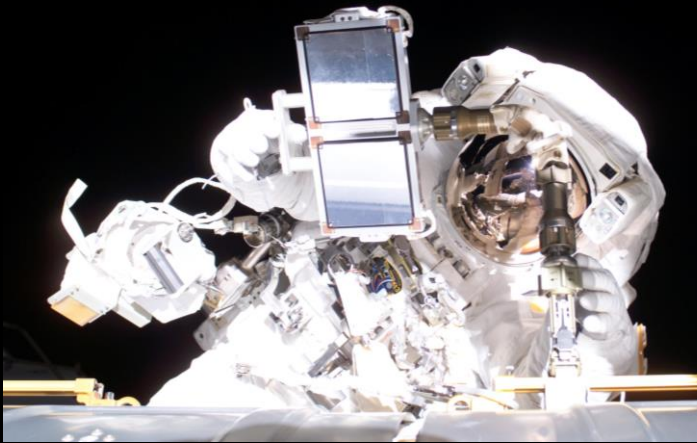


Interior view of ISS module showing the difficulty of accessing the structure

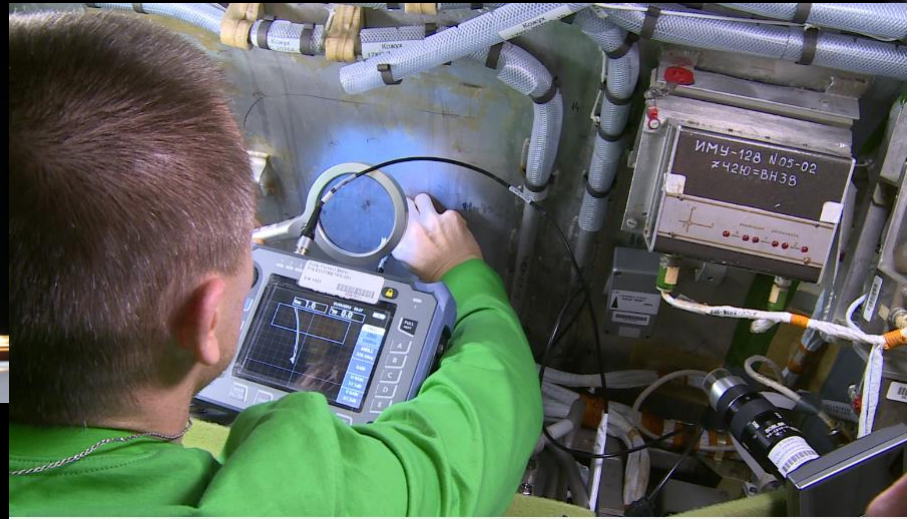


Demonstration of technology done with a limited number of sensors in one module

TO DATE THERE HAVE BEEN SEVERAL IN-SPACE NDE/SHM ACTIVITIES



On-orbit IR camera



Eddy Current for crack sizing



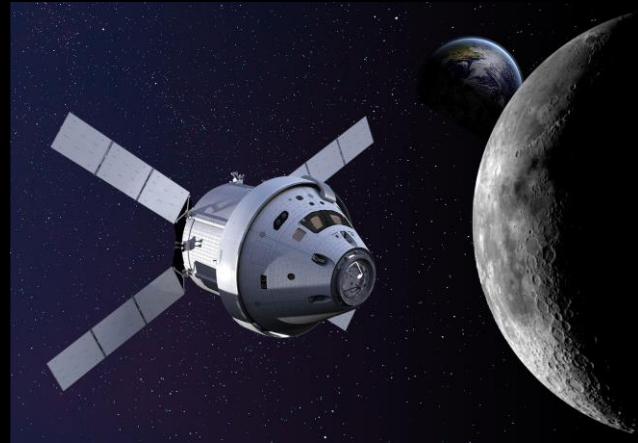
SHM for leak location

Astronauts were basically level 1 technicians
But what about going forward?

MOVING FORWARD TO MARS WILL PRESENT EVEN GREATER CHALLENGES



Low Earth Orbit



Cislunar Space



Living and working on
the moon/Mars

COMMERCIAL USE OF LOW EARTH ORBIT WILL REQUIRE ADVANCED INSPECTION AND MAINTENANCE CAPABILITIES

Image Credit:
Axiom



Axiom concept
commercial space station

There are half a million pieces of debris the size of a marble or larger (up to 0.4 in/1 cm dia.) with velocities up to 17,500 mph



Image Credit:
Northrop Grumman

Northrop Grumman concept
commercial space station

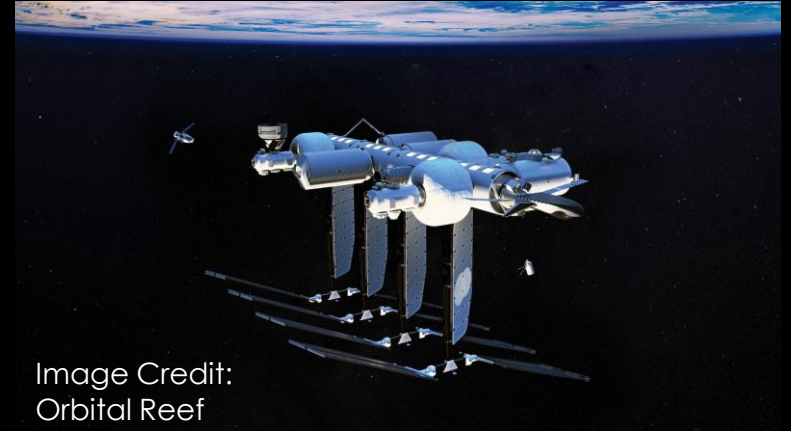
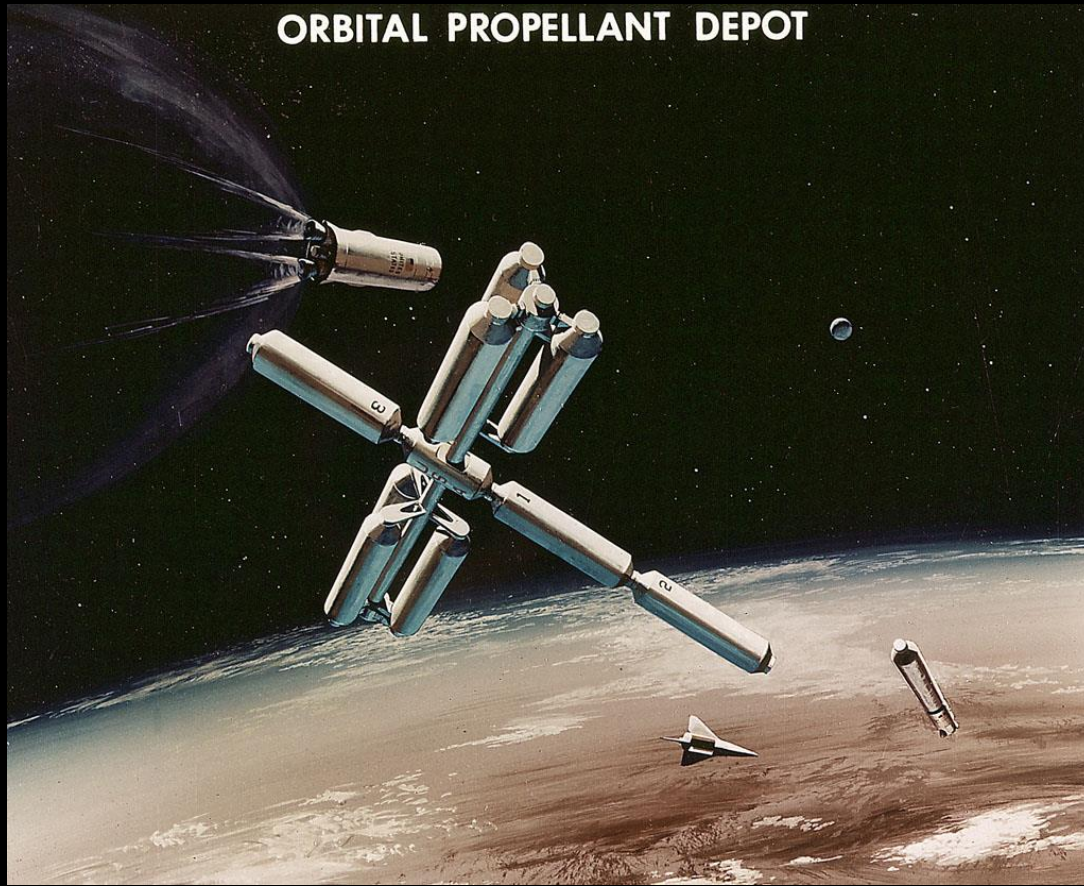


Image Credit:
Orbital Reef

Orbital Reef concept
commercial space station

LIKE A SPACE STATION ORBITAL FUEL DEPOTS WILL HAVE UNIQUE STRUCTURAL 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 UNIQUE NEEDS



Concept on-orbit
autonomous inspection
and repair



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



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



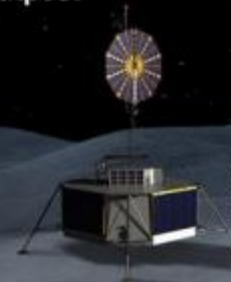
Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System



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

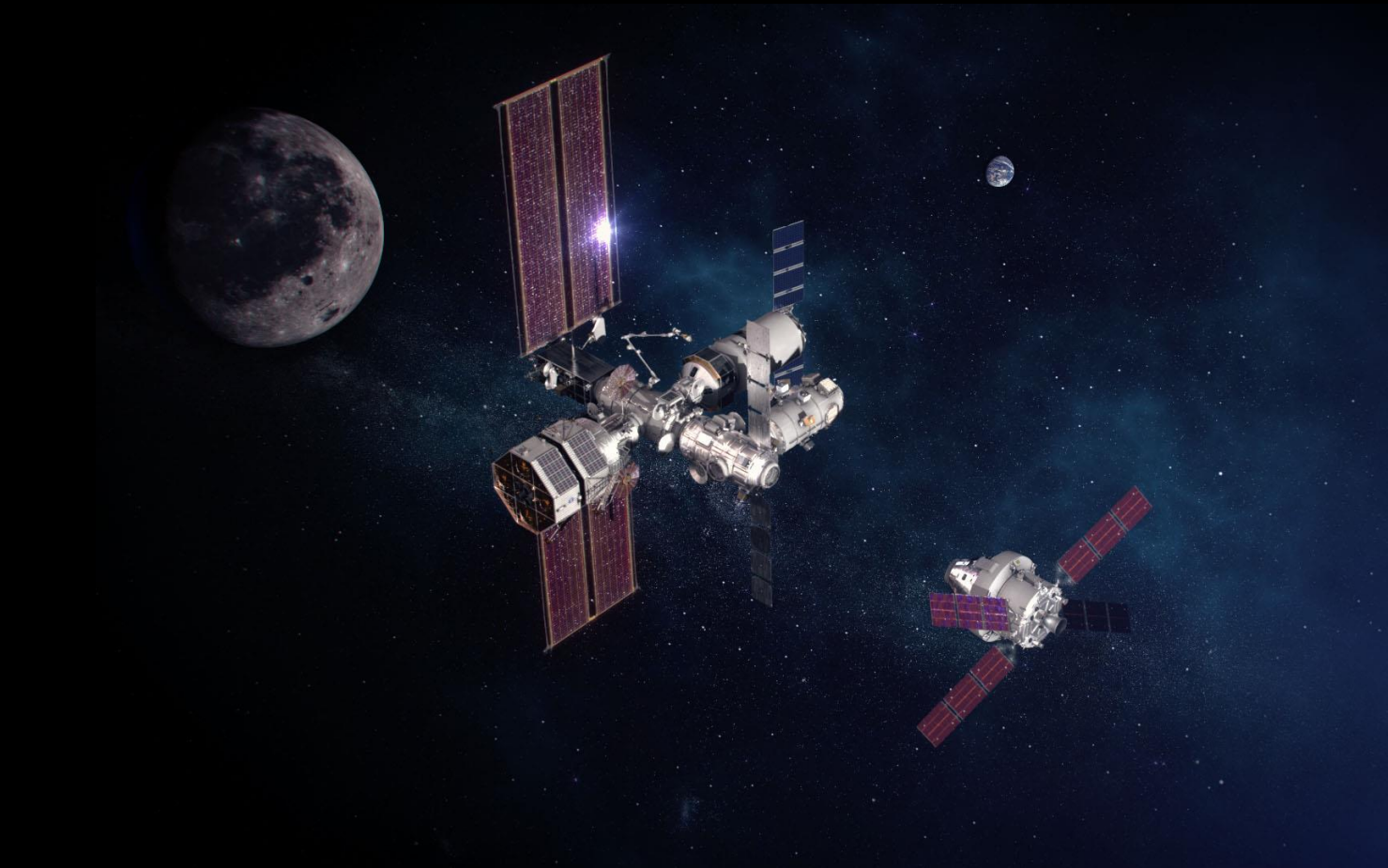
Surface
Habitat

GATEWAY HAS UNIQUE CHALLENGES DUE TO HUMAN HABITATION

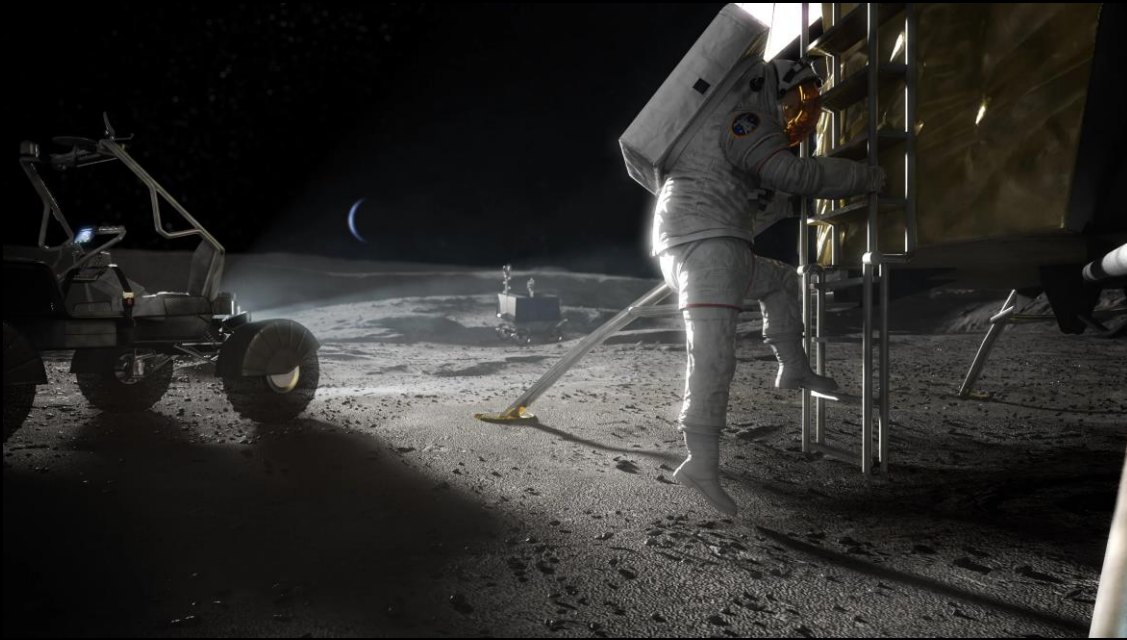
Gateway will serve as a multi-purpose outpost orbiting the Moon that provides essential support for long-term human return to the lunar surface and serves as a staging points for deep space exploration.

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

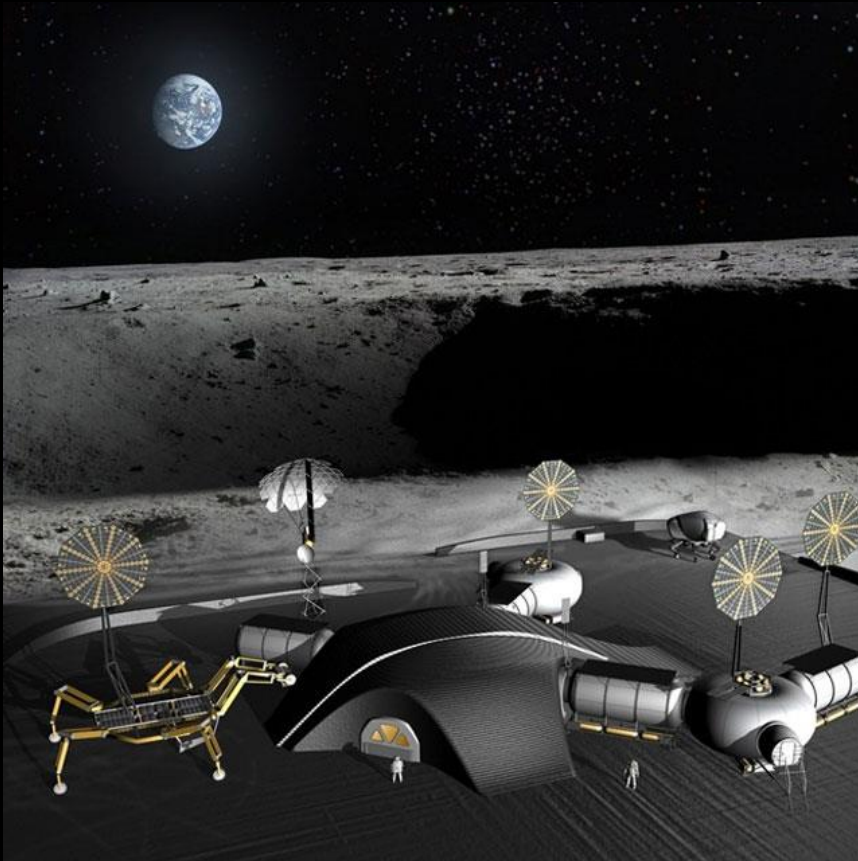


HUMAN LANDING SYSTEM REUSE REQUIRES INSPECTION CAPABILITIES

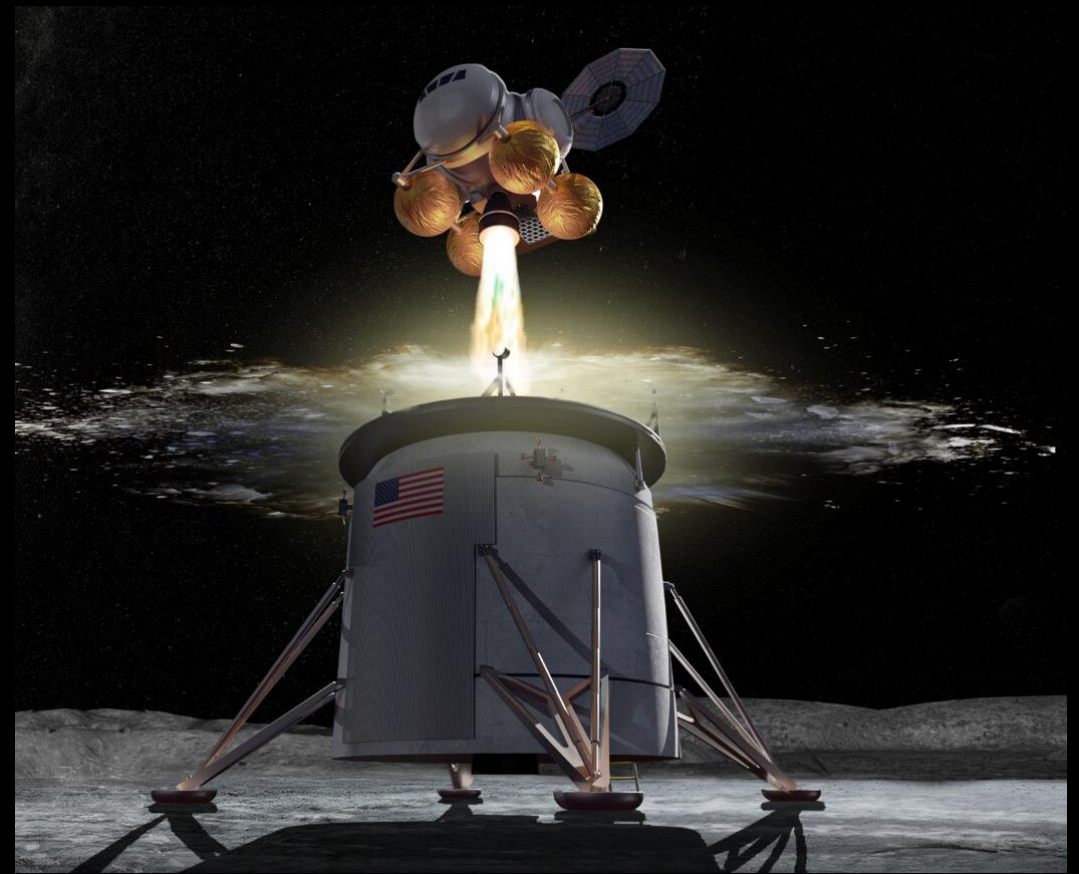


A reusable HLS will make multiple sorties between Gateway and the Lunar surface requiring routine maintenance

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

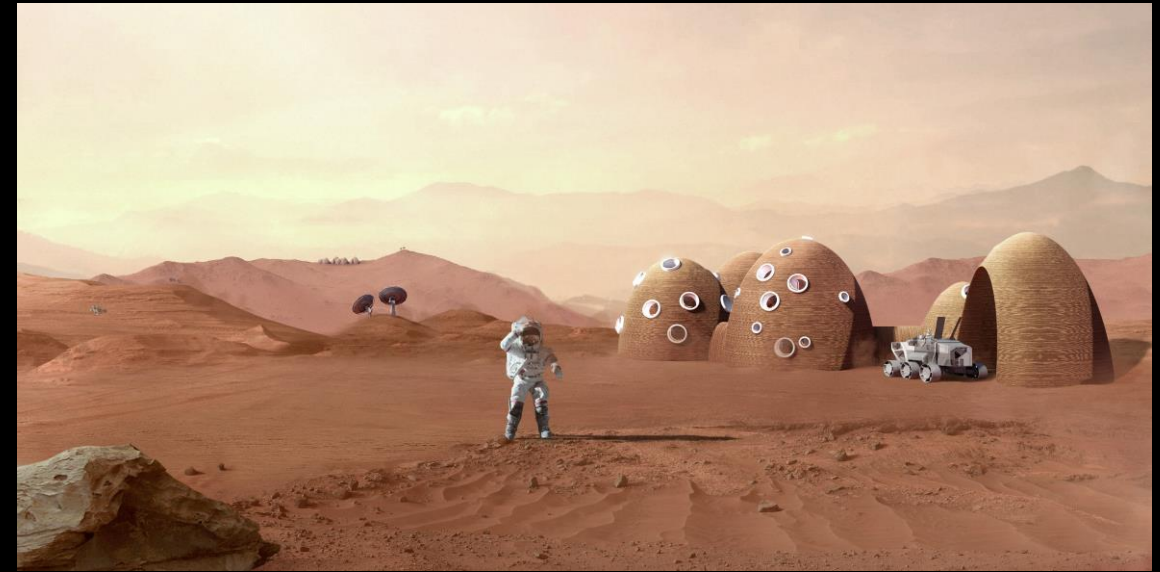


NASA Morpheus concept
lander on a soft surface

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

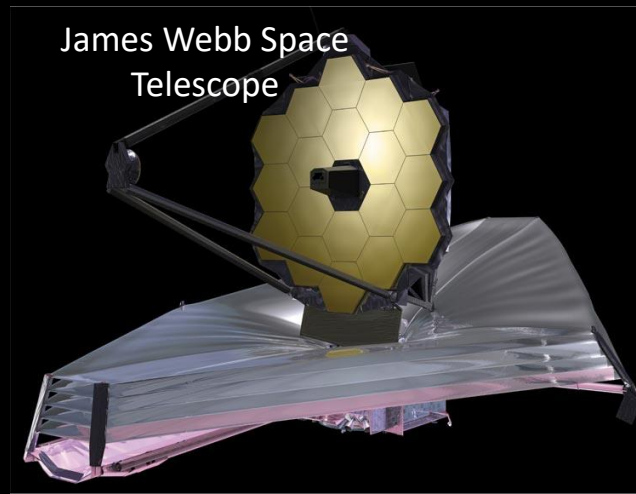


Composite
Crew Module

- 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

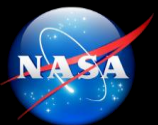
COMMUNICATION LIMITATIONS DRIVING EARTH INDEPENDENCE



The Moon is about 240,000 miles (384,000 km) away; therefore, the delay of a one-way radio signal from the Earth to the Moon is about 1.28 seconds.

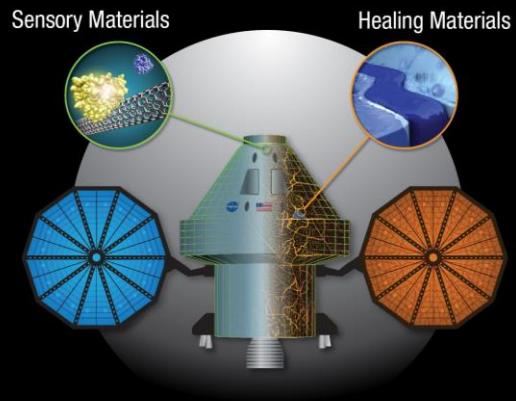


Mars is between 33.9 million miles (54.6 million kilometers) and 250 million miles (402 million kilometers). It takes between 6 and 21 minutes for a one-way radio signal to reach Mars.

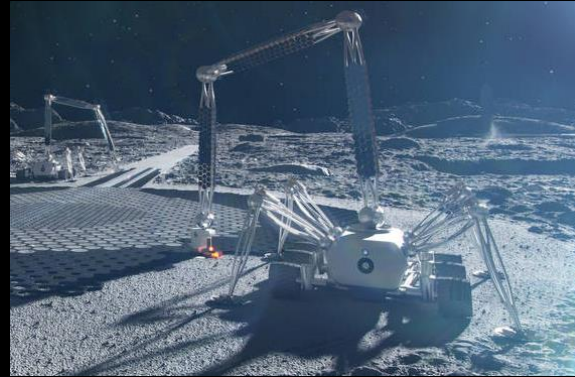


Deep Space Network X-Band Bandwidth < 25 Mbps

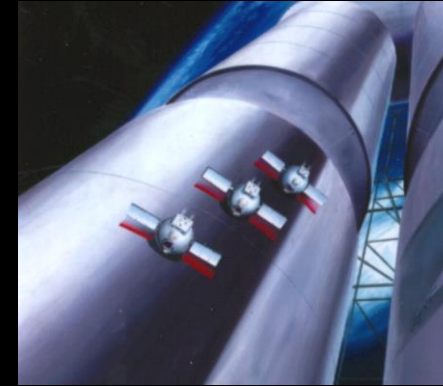
EARTH INDEPENDENCE LEADS TO UNIQUE NDE NEEDS



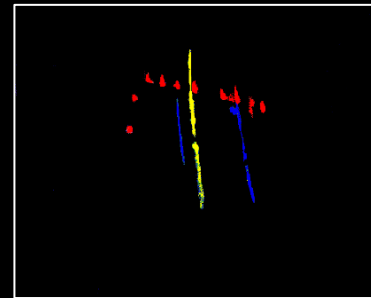
Novel autonomous SHM,
which could include
sensory and multi-
functional materials



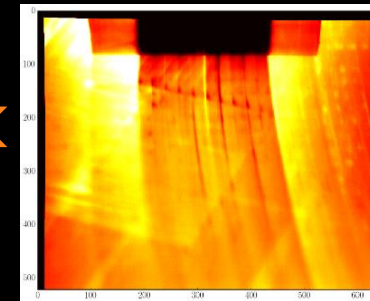
In situ inspection
during manufacturing



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



Automatic Feature
Recognition

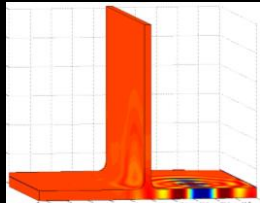


Raw Data

Automated data
analysis and defect
recognition

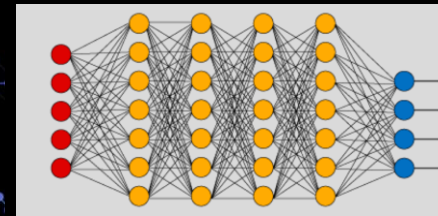
MOVING NDE FROM A TOOL KIT TO AN INTELLIGENT SYSTEM

Modeling

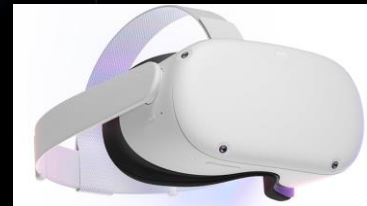


NDE Hardware

Robotics / Automation



Advanced
Data Analysis



Data Visualization



QUESTIONS?

