

# MISSE-X: An ISS External Platform for Space Environmental Studies in the Post-Shuttle Era

Sheila A. Thibeault, sheila.a.thibeault@nasa.gov, 757-864-4250, M. S. 226  
Stuart A. Cooke, stuart.a.cooke@nasa.gov, 757-864-7087, M. S. 434  
Melissa P. Ashe, melissa.p.ashe@nasa.gov, 757-864-7292, M. S. 432  
Rudolph J. Saucillo, rudolph.j.saucillo@nasa.gov, 757-864-7224, M. S. 462  
Douglas G. Murphy, murphy@ama-inc.com, 757-865-0944, M. S. 462  
NASA Langley Research Center  
Hampton, VA 23681

Kim K. de Groh, kim.k.degroh@nasa.gov, 216-433-2297, M. S. 309-2  
Donald A. Jaworske, donald.a.jaworske@nasa.gov, 216-433-2312, M. S. 309-2  
Quang-Viet Nguyen, quang-viet.nguyen@nasa.gov, 216-433-6147, M. S. 309-2  
NASA Glenn Research Center  
21000 Brookpark Road  
Cleveland, Ohio 44135

*Abstract*—Materials International Space Station Experiment-X (MISSE-X) is a proposed International Space Station (ISS) external platform for space environmental studies designed to advance the technology readiness of materials and devices critical for future space exploration. The MISSE-X platform will expand ISS utilization by providing experimenters with unprecedented low-cost space access and return on investment (ROI). As a follow-on to the highly successful MISSE series of ISS experiments, MISSE-X will provide advances over the original MISSE configurations including incorporation of plug-and-play experiments that will minimize return mass requirements in the post-Shuttle era, improved active sensing and monitoring of the ISS external environment for better characterization of environmental effects, and expansion of the MISSE-X user community through incorporation of new, customer-desired capabilities. MISSE-X will also foster interest in science, technology, engineering, and math (STEM) in primary and secondary schools through student collaboration and participation.<sup>1,2</sup>

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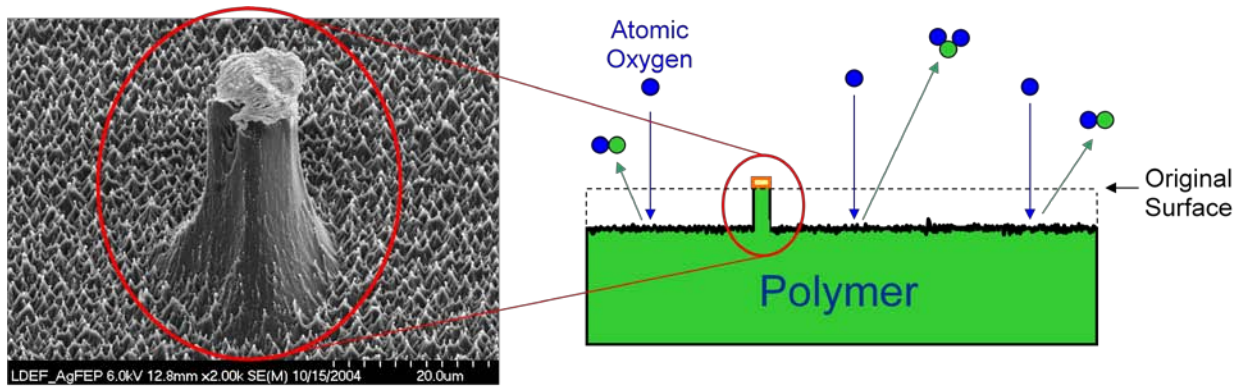
## 1. INTRODUCTION

The space environment presents specific threats to all crewed and robotic space exploration missions. Spacecraft damage resulting from these threats can have very serious implications, especially for the extended-duration missions to destinations including near-Earth objects, the Martian moons and Mars currently under study by NASA.[1] Therefore, for mission reliability and safety, space environmental effects on spacecraft materials and devices must be considered as a crucial part of NASA exploration program technology development activities.

In the low-Earth orbit (LEO) environment, space environmental threats include atomic oxygen (AO), vacuum, ultraviolet (UV) radiation, charged particle radiation, x-rays, thermal cycling, and micrometeoroid and orbital debris (MMOD). As an example, AO is predominant in LEO and is present in other planetary orbital environments including low-Mars orbit. At spacecraft velocities, AO is energetic enough to cause chemical bond cleavage and subsequent oxidation of many spacecraft materials. The oxidation products of most polymers and some metals are gaseous species. Extensive material erosion can occur as a result of this oxidation process.[2] Undercutting erosion is a mechanism of AO degradation that can also be a serious threat to component survivability. This occurs when defects in a material's protective surface coating provide pathways for atomic oxygen attack. As another example of space environmental effects, radiation-induced polymer degradation has severely embrittled the multilayer insulation (MLI) blankets covering the Hubble Space Telescope (HST) resulting in cracking and curling of the outer layer of insulation. Analysis of this material retrieved from HST servicing missions indicate that irradiation of this commonly used spacecraft thermal control material results in deep-layer embrittlement and that thermal cycling further contributes to this degradation.[3] Figure 1 illustrates AO-induced erosion, AO undercutting degrada-

<sup>1</sup> U.S. Government work not protected by U.S. copyright.

<sup>2</sup> IEEEAC paper #1708, Version 2, Updated October 24, 2010.



(a) AO erosion of Teflon fluorinated ethylene propylene around a protective particle after 5.8 years in LEO.[2]



(b) ISS retro-reflectors prior to launch (top) and after atomic oxygen undercutting erosion on the ISS (bottom).[4]



(c) Large radiation-induced cracks in multilayer insulation on HST as observed during Servicing Mission 2, after 6.8 years in space.[3]

**Figure 1. Examples of materials degradation in the LEO environment.**

tion on the ISS, and radiation-induced degradation on the HST. In addition to damage on the HST, radiation damage to MISSE polymer materials has also been reported.[5]

Ground-based durability testing is commonly used for spacecraft environmental durability prediction. However, accelerated ground laboratory testing does not ideally replicate in-space degradation, making actual long-duration spaceflight durability data essential. The ISS, as an orbital research facility, is an excellent platform for conducting long-duration space environmental exposure experiments to assess the durability of spacecraft materials and devices, and provide fundamental degradation data applicable to many spacecraft missions.

The original MISSE project, that began flights as an ISS external payload in August 2001, has provided a wealth of information on the long-term durability of hundreds of polymers, coatings, thin films, seals, solar cells, thermal control paints, components and devices.[6-10] Yet, as space environmental durability researchers learn from each of the flown MISSE experiments, additional analyses and the assessment of newly developed materials and devices are still needed.

To continue in-space durability testing after the near-term retirement of the Space Shuttle, a follow-on to the original MISSE design (Figure 2) is necessary since experimenters will likely have little opportunity to retrieve significant experiment hardware after experiment completion with any of the planned space transportation vehicles. The primary MISSE-X advances over the original MISSE design include:

- Active plug-and-play experiments that facilitate robotic operations and minimize return mass requirements in the post-Shuttle era.

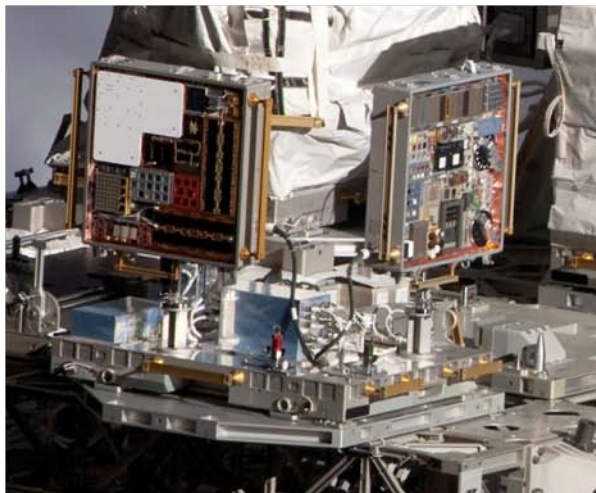
- Improved active sensing and monitoring of the ISS external environment, including near real-time data distribution, for better characterization of environmental effects on materials and devices over time.
- Expansion of the MISSE/ISS user community by responding to customer needs including daily photographing of experiments.

The MISSE-X concept was proposed jointly by NASA Langley Research Center (LaRC), NASA Glenn Research Center (GRC), NASA Johnson Space Center (JSC) and the Department of Defense Space Test Program (DoD STP) in response to a NASA Headquarters-sponsored call for ISS utilization technology research, development, test and evaluation (RDT&E) concepts. This proposal was requested by the NASA Office of the Chief Technologist (OCT) after an initial down selection process and was submitted in July 2010. Evaluation results of this call are anticipated in early 2011. The MISSE-X development timeline through pre-shipment review is approximately 36 months from the beginning of project funding.

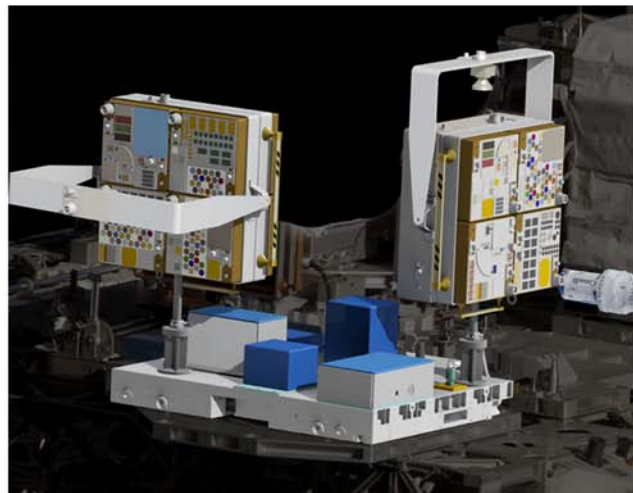
## 2. OBJECTIVES

Specific MISSE-X objectives include:

- To advance the technology readiness level (TRL) of new spacecraft materials and devices critical to future space exploration.
- To conduct experiments that measure performance, reliability, and durability of materials and devices (Figure 3 provides pre- and post-flight images of the Polymer Erosion and Contamination Experiment [PEACE] flown on MISSE 2).



(a)



(b)

Figure 2. (a) MISSE 7A and 7B on ISS photographed during STS-130; (b) the MISSE-X concept.



(a)



(b)

**Figure 3. The MISSE 2 PEACE Polymers experiment tray, (a) pre-flight, and (b) post-flight.[7, 10]**

- To implement new, customer-driven capabilities such as expanded active accommodations and near real-time experiment monitoring including daily photographing.
- To develop a plug-and-play mechanical and avionics system that reduces the cost and time required to fly experiments, while reducing return mass to ~10% of the launch mass.
- To develop accurate models to correlate ground- and space-based data, and to scale LEO results with other space environments.
- To foster interest in STEM in primary and secondary schools through student collaboration and participation.

These objectives directly support the larger goal of maturing the transformative technologies required to meet NASA's Grand Challenges as outlined by the NASA OCT, including advancement of spacecraft safety and reliability, and establishing conditions for permanent human presence in space. Success in meeting these challenges, and others as well, will rely in part on the proper operation and endurance of the many materials and devices comprising our future vehicles, habitats, and tools. As the ISS moves from the assembly phase into full-scale operation as a resource for experimentation, MISSE-X presents an ideal opportunity to

make this resource more accessible and affordable to the space community.

### 3. ISS ACCOMMODATION

The ISS presents a unique facility ideally suited for meeting the needs of MISSE-X experimenters in four key areas:

- (1) **Facilitating low-cost access to the space environment.** By providing a common platform that leverages ISS infrastructure to support the power and communication needs of active experiments, MISSE-X will allow researchers to focus their resources on the actual experiment development. On MISSE 1 through 4, only 5% of experiments were active. MISSE 5, 6 and 7 each contained 50% or more active experiments. Anticipating the demand based on this trend, and leveraging lessons learned about power and data systems requirements from previous missions, MISSE-X will accommodate up to 90% active experiments.
- (2) **Enabling MISSE-X to be serviced on orbit.** The capability of the MISSE-X platform to be serviced on ISS directly supports the plug-and-play objective.

Where previous designs required the entire MISSE configuration to be installed and retrieved as a single unit, MISSE-X will enable individual modules to be replaced on orbit. Allowing completed experiments to be replaced with new ones greatly improves the efficiency and ROI of the platform.

- (3) **Enabling the return of samples in the post-Shuttle era.** MISSE-X will allow the disassembly and retrieval of modular experiments or individual sample holders, greatly reducing the mass and volume of returned items.
- (4) **Providing long-duration exposure to the space environment.** Although ground testing is used for predicting the effects of exposure to AO, radiation, and other potential harms to spacecraft systems, accelerated ground-laboratory testing does not always replicate in-space degradation.[11] The synergistic effects of the space environment and the effects of long exposure low dose-rate radiation are two critical effects that can only be achieved on orbit.

MISSE-X would be a follow on to the extremely successful MISSE project. Over 4,000 samples from approximately 80 organizations from government, industry and academia have been flown as part of MISSE. Table 1 provides a summary of the partnerships and experiments for MISSE flights 1 through 7.[12] Examples of the type of materials flown on MISSE include polymers, ceramics, composites, coatings (protective, thermal, & optical), beta cloth, adhesives, foams, and dielectrics. Special applications materials include radiation shields, inflatables, markers,

labels, optics and gossamer films. Example components include switches, sensors (radiation, temperature, UV, AO and contamination), solar cells, semiconductors, mirrors, optical filters, optical diodes, optical modulators, and tethers. Also included were biological samples (seeds, spores, and bacteria) for long-duration microgravity effects studies.

MISSE experiments have greatly benefited the U.S. space program. The MISSE 2 polymer erosion results have had a direct impact on material design choices for numerous spacecraft including WorldView-2, Operational Land Imager, Global Precipitation Measurement-Microwave Imager, and the Space Test Program's Standard Interface Vehicle.[7] In addition, MISSE 2 PEACE polymer erosion data has been used to develop an Atomic Oxygen Erosion Yield Predictive Tool which allows the LEO atomic oxygen erosion yield of new and non-flown polymers to be predicted based on chemistry and physical properties.[13] MISSE 2 PEACE data is currently being use to write a NASA Technical Standards Handbook to be entitled "Spacecraft Polymers Atomic Oxygen Durability Handbook." MISSE data has also been used to determine correlation factors between ground-laboratory facilities such as plasma ashers, and space exposure, enabling more accurate performance predictions based on ground-testing.[14] Similarly, ground-to-space correlation factors were determined for coated Kapton flown on MISSE 2, which were then used for durability prediction of aluminized Kapton insulation blankets on HST. The resulting analysis helped determine extravehicular activity (EVA) priorities for the 5<sup>th</sup> HST servicing mission.[7] The Forward Technology Solar Cell Experiment on MISSE 5

**Table 1. Representative MISSE 1 - 7 Partnerships and Experiments.**

Partnerships	Experiments
<b>NASA</b>	
GRC & Hathaway Brown School	MISSE 2 PEACE Polymers Experiment. Data used for STEM education, predictive tool development, spacecraft design decisions and a NASA Technical Standards Handbook being written at GRC.
LaRC	Thin films and Crew Exploration Vehicle thermal protection system materials, radiation shielding materials (MISSE 1 - 6 experiments).
GRC	MISSE 7B Thermal Control Paints Experiment (next generation thermal control paints for Fission Surface Power applications).
GRC	MISSE 6 & 7 Low Impact Docking System (LIDS) Docking Seal Experiments.
<b>DoD</b>	
Naval Research Laboratory (NRL)	MISSE 5 Forward Technology Solar Cell Experiment.
Air Force Research Laboratory (AFRL)	Thin film polymers, coatings, and optical samples (MISSE 6 experiments).
Air Force Office of Scientific Research	Coatings, fibers and thin films (MISSE 6 experiments).
<b>Industry</b>	
Lockheed and TRW	Solar cells, cover glasses, special coatings (anti-reflection), inter-connectors (MISSE 1 - 4 experiments).
AZ Technology, Boeing & AFRL	Advanced multi functional coating candidates for variable thermal control and variable surface electrical conductivity.
Boeing	Fiber optics samples for space-based radar systems.
<b>Academia</b>	
University of Pittsburg, University of Chicago	Metal oxides and semiconductor materials; Conductive samples with electric field switching (Multidisciplinary University Research Initiative efforts).
North Dakota State	Ceramic materials (MISSE 6 experiments).
Montana State University and others	Shape memory composites, ceramic materials, coatings & electronic parts, and polymer-coated quartz crystal microbalance (Montana Space Grant Consortium).

provided mission critical in-space solar cell performance data for 39 advanced solar cell samples.[7] Over 200 publications have resulted from the MISSE research and development data; a few examples are referenced.[5-10, 13-17]

To estimate the economic value of MISSE, Boeing performed a first cut analysis of MISSE missions from 2001 through 2010.[18] In this analysis, the cost of the samples were compared with estimates for direct outcome value and indirect outcome value. Results of this analysis show that the direct and indirect total economic impact of MISSE has exceeded \$2.9 billion dollars. These totals reflect a direct return of 88 to 1 and an indirect return of 230 to 1. Based on this analysis, MISSE has delivered one of the highest tangible returns on investment in all the years of manned spaceflight. [19]

#### 4. TECHNICAL AND PHYSICAL CHARACTERISTICS

MISSE-X will utilize a highly modular design that provides maximum utility and flexibility for a variety of experiments. Figure 4 shows the main components of the MISSE-X system which include:

- (1) A common base plate referred to as the *Adapter Plate Assembly (APA)* used to interface with the ISS.
- (2) A pair of double-sided *Portable Experiment Containers (PECs)* that provides a modular platform for mounting and exposing samples to the ram, wake, nadir, or zenith direction.
- (3) Up to 16 individual *Modular Experiment Containers (MECs)* that contain the actual materials and devices to be exposed to the space environment.
- (4) *Active Experiment Sites (AESs)* that provide up to four locations for mounting larger non-directionally oriented experiments.
- (5) An *Experiment Controller (EC)* that manages command, data, and power distribution for the active components.

**Adapter Plate Assembly:** The APA provides a mechanical and electrical interface between MISSE-X and the ISS. The specific hardware used will depend on the specific ISS location chosen for MISSE-X. For example, an Express Logistics Carrier (ELC) location will require an Express Payload Adapter to be used as the APA. Power, command and data lines for MISSE-X will connect to the ISS via this adapter and the EC that resides on it.

**Portable Experiment Containers:** Two PECs mounted on the APA will serve as platforms for the plug-and-play MECs. Each PEC contains two opposing trays (55 cm. x 55 cm.). Each tray holds up to 4 MECs each, nominally in a

2x2 array. One PEC will be oriented to face the ISS ram/wake direction, and the other will face nadir/zenith. The differences in the space environmental properties provided by these orientations are of interest to investigators and will inform the selection of the desired PEC for a given MEC. A 2x2 array was chosen to provide sufficient experimental space for MISSE-historical sample holder dimensions, and also to provide sufficient space for the electronic circuit boards in each MEC. For experimenters requiring more space, a larger MEC can be developed to utilize multiple locations such as a 1x2 or an 'L-shaped' 1x3 MEC. Each PEC face also contains external ISS environmental sensors for monitoring temperature, AO, UV, and particulate radiation. The PEC hardware includes mechanical guides and blind mate connectors to support robotic servicing of the MECs. The PEC also regulates 28 VDC power coming from the EC, providing 5 VDC and 28 VDC voltage levels and a bidirectional serial data interface for the MECs. A removable cover on each PEC will protect the MECs from being exposed to the environment until deployment.

**PEC Camera:** The robotically serviceable PEC camera system is designed to deploy for daily picture taking sessions, but will remain stowed and out of view of the samples the majority of the time (Figure 2b, PEC cameras shown in deployed and stowed positions). Images will have a resolution of 0.2 mm/pixel or better to document progressive deterioration of the samples mounted on the MECs.

**Modular Experiment Containers:** A MEC is a standardized unit comprised of:

- A mechanical housing.
- A communication interface with the PEC.
- A power regulation system.
- A data acquisition system (DAQ).
- User-supplied experiments connected to the DAQ system for active experiments.

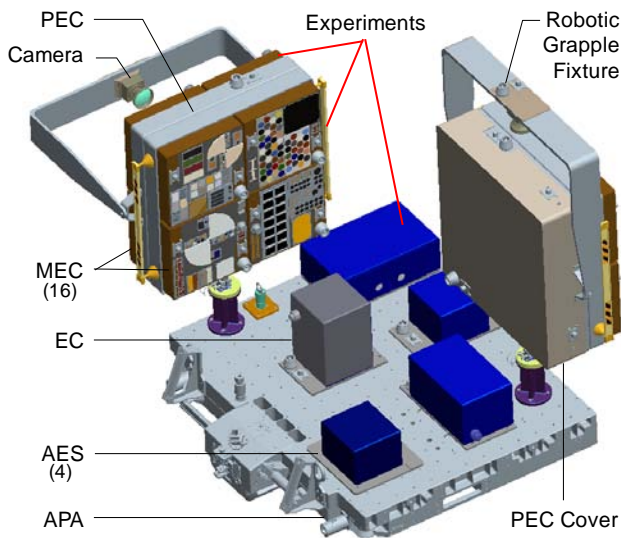
The materials and devices in a MEC will be mounted according to the desired space exposure. Experience on previous MISSE missions has shown that a large number of materials and devices can be tested in the available space. The sample mounts will be designed to allow the sample holders to be removed on orbit from the MEC to provide the ability to return samples with minimum down mass after completion of the experiment. The radiation-tolerant DAQ system provides high-precision, programmable sampling rate analog inputs, high-speed digital event counters, and digital-to-analog outputs for user-supplied experiments. A preliminary concept of the DAQ system provides up to 16 differential-input analog measurement channels to accommodate slow speed (several samples per day) and high speed (several mega-samples/sec) sample rates. A few channels are reserved for MEC health monitoring including temperature and system voltage. The DAQ system will provide about 0.3 mV resolution over a 5 V analog input signal range. This resolution will accommodate anticipated

future experiments where precise analog values are critical, including optical absorbance/transmission and spectroscopy, sensitive stress-strain measurements, Fourier transform-based measurements of an analog input, analog electronic component testing, and atomic force microscopy.

**Active Experiment Sites:** For experiments not required to be oriented in a specific direction, the AESs provide a mount directly on the APA rather than on a PEC. Like the MECs, the AES units will be replaceable on orbit. AES units will contain power, data and sensor systems specific to an experiment, and will also be managed by a common interface via the EC. MISSE 7 included a variety of active experiments mounted on the adapter plate.

**Experiment Controller:** The EC hosts the electrical interfaces between ISS and MISSE-X, providing control of the experiments and camera system, data collection, and power regulation and distribution. The 1553 system can be used for command and control, and Ethernet for payload telemetry. The EC also provides isolation from the ISS power supply and regulates it for use by the PECs and AES units.

**Robotic Servicing:** MISSE-X assembly is designed to accommodate robotic handling during all phases of the life cycle, including installation of the APA to the ISS, installation of the PECs onto the APA, and replacement of the MECs and AES units. The design leverages the Orbital Replacement Unit concept currently in use on ISS. Robot end-effector grapple fittings and camera targets are attached to each serviceable unit. Blind mate connectors and mechanical guides will facilitate the mate and demate process. EVA operations will be supported as an alternative.



**Figure 4. The MISSE-X hardware supports a variety of experiment mounting locations and contains an on-board camera system.**

## 5. FLIGHT EXPERIMENTS

Technologies to be investigated will include materials, coatings, sensors, solar cells, actuators, mirrors, optical components, and avionics. The planned observations and tests for MISSE-X and their relevance to specific OCT elements are shown in Table 2. [20]

The initial MISSE-X core experiments are shown in Table 3. To identify these, a questionnaire was sent to potential NASA and DoD customers. These core experiments were selected for their anticipated high ROI and their potential to meet national space technology needs. To solicit additional, cost-shared experiments, a formal call will be released to industry, academia, and other government agencies after MISSE-X receives funding for development. The Experiment Selection Committee, to be comprised of the MISSE-X Project Office and discipline leads, will select experiments based on OCT and MISSE-X technology objectives. Small Business Innovative Research (SBIR) companies have been identified as core experiment providers and will also be included in the formal call.

Understanding the space environment that these samples will encounter while on MISSE-X is crucial to understanding the performance and durability of these materials and devices. Therefore, MISSE-X will include environmental monitoring devices on each of the PEC surfaces that will provide an unprecedented wealth of environmental data. The atomic oxygen fluence monitors will monitor the amount of AO present at the site of the samples. Previous versions of this monitor have flown on MISSE 6 and MISSE 7. This monitor is critical for determining the resistance of the experimental materials to AO (i.e., the AO erosion yield) as a function of the AO exposure. Another environmental monitoring device will be the Compact Reconfigurable Environment and Assurance Monitor. A previous version of this flew on the Clementine spacecraft. This device contains a suite of sensors including a space environmental effects monitor, radiation-sensing field-effect transistor dosimeters, electromagnetic interference monitor, spacecraft charging monitor, UV radiation monitor, and an AO monitor.

## 6. OPERATIONS CONCEPT

MISSE-X can support a variety of scenarios for successful operations through all phases of the mission life cycle. All robotic operations can be accomplished alternatively via EVA. Experiments being returned after completion of the mission can be removed as a subassembly (e.g., a single MEC or AES unit) or a component (e.g., a sample holder) to dramatically reduce the return mass. Disassembly and bagging of MECs or sample holders will occur in the airlock or ISS glove box to prevent incidental environmental exposure.

**Table 2. MISSE-X Technology Focus, Observations and Tests, Linked to OCT Elements.**

Technology/Discipline	Observations and Tests	NASA Office of the Chief Technologist Elements and Grand Challenges
<b>Advanced Spacecraft Materials</b> <ul style="list-style-type: none"> <li>Polymers, composites, coatings, metals, ceramics.</li> </ul>	Time-lapse photo-documentation, in-situ mechanical, optical and thermal property measurements; post-flight erosion yield measurements, characterization of passive samples.	<b>Early Stage Innovation</b> <ul style="list-style-type: none"> <li>Improve spacecraft safety and reliability.</li> </ul> <b>Game Changing Technology</b> <ul style="list-style-type: none"> <li>Establish conditions for permanent humans in space.</li> </ul>
<b>Electronic Components and Devices</b> <ul style="list-style-type: none"> <li>Printed circuit boards, resistors, capacitors, integrated circuits, oscillators, rad-hard avionics.</li> </ul>	In-situ measurements of transient (high-speed) analog or digital signal response to excitation function or external stimulus to quantify performance degradation.	<b>Game Changing Technology</b> <ul style="list-style-type: none"> <li>Improve spacecraft safety and reliability.</li> <li>Develop routine satellite servicing.</li> </ul>
<b>Optical Components and Devices</b> <ul style="list-style-type: none"> <li>Imaging satellite windows, lenses, mirrors.</li> </ul>	In-situ optical transmittance or spectral measurements and time-lapse photo-documentation to quantify optical degradation as result of space environment.	<b>Game Changing Technology</b> <ul style="list-style-type: none"> <li>Discover life beyond Earth.</li> <li>Engineer the tools of scientific discovery.</li> </ul>
<b>Sensors and Instrumentation</b> <ul style="list-style-type: none"> <li>Opto-electronics, spectral imagers, cameras.</li> </ul>	In-situ measurements of opto-electronic devices such as photodiodes and charge-coupled devices over time to quantify changes in responsivity of elements or image pixels.	<b>Early Stage Innovation</b> <ul style="list-style-type: none"> <li>Manage climate change.</li> <li>Forecast natural disasters.</li> <li>Engineer the tools of scientific discovery.</li> </ul>
<b>Thermal Management Technology</b> <ul style="list-style-type: none"> <li>Radiator coatings, multilayer insulation blankets, heat pipes.</li> </ul>	In-situ measurements of analog temperatures, typically as transient (low-speed) analog signals in response to stimulus or excitation; time-lapse photography.	<b>Crosscutting Capability Demo</b> <ul style="list-style-type: none"> <li>Make space access economical.</li> <li>Improve spacecraft safety and reliability.</li> </ul>
<b>Radiation Protection Technology</b> <ul style="list-style-type: none"> <li>High-Z and low-Z materials and composites, UV radiation coatings.</li> </ul>	In-situ measurements of radiation and particle shielding effectiveness over time through digital event counters from scintillation detectors.	<b>Crosscutting Capability Demo</b> <ul style="list-style-type: none"> <li>Establish conditions for permanent humans in space.</li> <li>Protect astronaut health.</li> </ul>

MISSE-X will be robotically installed at an available ISS site such as the ELC, the Columbus module, or the Japanese Experiment Module. Experimentation begins with camera deployment and system checkout. Command and control, sensor data and image data will be routed through the ISS communications system and ground payload operation center at MSFC. Once the experiments on a particular MEC or AES are complete, that unit can be replaced on orbit with a new experiment. The old unit may be discarded, returned as a complete assembly, or partially disassembled to return only the sample holder. The system is expected to enable mission success with only 10% of the total launch mass returned. Unreturned mass at the mission end of life may be disposed of using a resupply vehicle for destructive re-entry, or remain on the ISS until the end of the ISS life cycle.

**7. PARTNERS, ROLES AND RESPONSIBILITIES**

MISSE-X is a multi-center and multi-agency proposal with experiment providers across the space community. LaRC will serve as the Project Lead, GRC will serve as the Science Lead, DoD STP will manage DoD payloads, and

JSC will provide ISS and launch vehicle certification and integration.

DoD STP will select, coordinate, qualify, and support integration of all DoD payloads including experiments from AFRL, NRL and the United States Naval Academy.

**8. RISKS AND RISK MITIGATION**

The previous successes of multiple MISSE flights mitigate most technical risks associated with MISSE-X, and provide a cost and schedule history that lends confidence to the accuracy of both the cost estimate and schedule. Consequently, the risk of a significant cost overrun or major schedule increase during project execution is low.

Inherent project risks remain in any project regardless of the number of past successes. Additionally, MISSE-X introduces new incremental risks that stem from differences between the MISSE-X operations concept and the previous MISSE flight experience. Table 4 shows MISSE-X techni-



**Table 3. MISSE-X Core Experiments and Associated TRLs.**

Experiment	TRL
Erosion of Polymers and Composites	3
International Low Impact Docking System (iLIDS) Docking Seals	4
Advanced Polymer Nanocomposite Materials	3
Radiation Shielding Materials	3
Electrodynamic Dust Shield	4
Compact Reconfigurable Environment & Assurance Monitor	5
Atomic Oxygen Fluence Monitors	5
Advanced Mirror Coatings and Substrates	4
Educational Outreach	3
High Efficiency, Low-Mass Solar Cell Systems	4
Embedded Instrumentation for Thermal Protection Systems	3
Active Environmental Exposure Experiment	3
Macro Fiber Composite Actuator	4
Galactic Cosmic Ray Shielding Materials	3
Environmentally Induced Polymer Strain	3
Advanced Avionics	5
Climate Absolute Radiance and Refractivity Observatory (CLARREO) IR Instrument Calibrated Thermometry	4
Inflatable Composites	3
High Efficiency, Low-Mass Solar Cell Systems	4

cal, cost and schedule risks and the associated risk mitigation strategies.

### 9. SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS EDUCATION

MISSE has a rich history of education outreach. For example, seeds (basil, cotton, prairie, etc.) flown on early MISSE missions were distributed to students for study. High school and college students have participated with principal investigators (PIs) in the preparation and analysis of samples with great success. High school students have earned over \$80K in scholarships at science fairs for their MISSE research.[7] Figure 5 shows high school students explaining a MISSE 6 flight experiment to their local television news station. A comprehensive STEM outreach structure is planned for MISSE-X.

The MISSE-X project will support STEM outreach in four ways:

- Work with NASA GRC’s External Programs Division to coordinate MISSE STEM experiments.
- Provide space on the MISSE-X platform for STEM-funded experiments suitable for primary and secondary education.

- Utilize the Internet to provide teachers with selected camera images and other MISSE-X data for curriculum development.
- Encourage broad participation in STEM outreach as part of the individual experiments.

### 10. SUMMARY

The space environment presents a number of threats that impact the functionality and survivability of spacecraft. These include: AO, vacuum, UV radiation, charged particle radiation, x-rays, thermal cycling, and MMOD. To mitigate these threats for the extended duration human and robotic missions that NASA is planning, space environmental testing is critically important.

The ISS is an ideal platform to conduct space environmental testing and has been used to support the MISSE series of missions since 2001. Research and development output from these missions have greatly benefited the end-user community in NASA, DoD, academia and industry. The economic value of the MISSE missions has been excellent. An analysis of the direct and indirect total economic value of MISSE to date showed that MISSE has delivered one of the highest tangible returns on investment in the history of the U.S. space program.

MISSE-X is a concept for an ISS external platform for environmental testing which has been proposed as a follow-on to MISSE. The advanced capabilities of MISSE-X include: active plug and play experiments that facilitate robotic operations and that will minimize return mass requirements in the post-Shuttle era, improved sensing and monitoring of the ISS external environment to better characterize environmental effects, and incorporation of customer-desired functions including daily photography of experiments. Similar to the MISSE flights, MISSE-X will provide experimenters with the option of locating their samples on the ISS ram, wake, nadir or zenith directions since the differences in the space environmental properties provided by these orientations are of significant interest.

MISSE-X core experiments have been identified utilizing a questionnaire sent to potential NASA and DoD customers. These core experiments were selected for their anticipated high ROI and their potential to meet national space technology needs. Additional cost-shared experiments will be solicited via a formal call that will be released to industry, academia, and other government agencies after MISSE-X receives funding for development.

The proposed MISSE-X project will continue MISSE’s rich history of education outreach. Space will be provided on the MISSE-X platform for STEM-funded experiments suitable for primary and secondary education. Additionally, the Internet will be utilized to provide teachers with selected

**Table 4. The MISSE-X Risk Mitigation Strategies Effectively Address Risks.**

Risk	Occurrence Likelihood	Consequence	Mitigation
<b>Technical Risks</b>			
Inability to achieve environmental hardening and long term reliability for cameras. Failure of camera(s) after launch.	Moderate	Moderate	Planned for early procurement and testing of cameras to establish mean time between failure (MTBF) metrics and quantify sparing plan. Selected cameras have been designed for 5 years in geosynchronous orbit and are orbital replaceable units (ORUs).
Communication (uplink, ISS to PEC to ISS, downlink) compatibility or comm. failures: DAQ to MEC, MEC to PEC, or PEC to EC.	Low	Low	Well-defined ISS communication interface and infrastructure documents with ISS. End-to-end testing prior to launch. Most mission goals can be achieved via contingency plan for imaging experiment samples.
Late-notice ISS mounting location change or launch vehicle change.	Low	Moderate	Remaining reserves/margin may mitigate some risk of having to perform additional technical tasks to ensure compatibility.
Inability to remove PEC cover(s) robotically.	Low	Moderate	Trade study to select cover removal system. Contingency EVA or robotics procedure will be used to remove stuck cover.
ISS robotics not capable of performing planned tasks or ISS robotics failure.	Low	Moderate	Design features utilizing successful in-space demonstrated hardware will enable robotic operations. Pre-mission end-to-end testing for robotic procedures to ensure operations is robotics compatible. EVAs for operations deemed beyond robotic capability. EVA contingency for failed operations.
<b>Cost Risks</b>			
Launch delays.	High	Low	MISSE-X has no high-cost storage requirements during launch delays. Personnel will be assigned to other projects if there is a lengthy delay.
<b>Schedule Risks</b>			
International Traffic in Arms Regulations (ITAR) restrictions associated with flying on non-U.S. vehicles.	Low	Low	Remove ITAR concerns from MISSE-X experiments; wait for U.S. launcher; ITAR restrictions may ease or apply for exception.
Delayed delivery of space qualified electronic, electrical, and electromechanical (EEE) parts.	Low	Moderate	Long lead item procurements are planned early in the schedule. Specify procurement of pre-qualified electronics.
Experimenters fail to deliver their samples on time or fail to meet Interface Control Document (ICD) requirements.	Moderate	Low	Late experiments can be de-manifested. Alternative, mission ready experiments, can be flown in their place, as done on previous MISSE flights.
Delays in non-Shuttle launch vehicle integration.	Low	Moderate	Availability of documentation for launch vehicle environments and integration requirements for ISS payloads. Early emphasis on launch vehicle selection and acquisition of team member with experience integrating payloads with that launch vehicle.
Unavailability of launch vehicle with unpressurized capacity.	Moderate	Moderate	MISSE-X can be flown on the existing H-II Transfer Vehicle or stored until space is available. New U.S. commercial vehicle, Orbital's Taurus II / Cygnus, will have unpressurized capacity.
Launch delays.	High	Low	MISSE-X can be stored for an extended period of time prior to launch. Component analysis will identify limited life item list.

camera images and other MISSE-X data for curriculum development.

The MISSE-X concept was proposed jointly by NASA LaRC, NASA GRC, NASA JSC and DoD STP in response to a NASA Headquarters-sponsored call for ISS utilization technology RDT&E concepts. This proposal was requested by the NASA Office of the Chief Technologist after an initial down selection process and was submitted in July 2010. Assuming selection and funding in early 2011, MISSE-X will be ready for flight in early 2014.



**Figure 5. News coverage of high school students explaining their MISSE 6 experiment.**

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## BIOGRAPHIES



**Sheila Thibeault** has been a civil servant researcher at NASA LaRC since 1966. Since 1981, she has focused her research on the development of space durable materials and radiation shielding materials. From 2006 - 2009, she was the Task Lead for the Radiation Shielding Task, under the Exploration Technology

Development Program (ETDP). Her current position is Senior Research Physicist, Advanced Materials and Processing Branch, Research Directorate. She is the author or co-author of over 200 formal publications and referenceable presentations. She has received many professional awards, including the NASA Exceptional Service Medal in 2000 "For Outstanding Service in Advancing Space Materials for NASA Missions." She has been directly involved with MISSE since its inception in 1999. She is the Langley PI for MISSE 1, 2, 3, 4, 5, 6A, and 6B. Since 2008, she has been the Project PI for MISSE 6A and 6B. Sheila has a Bachelor of Science degree in Physics from the College of William and Mary. She has Master of Science and Ph.D. degrees in Physics from North Carolina State University.



**Stuart Cooke** has over 18 years of increasing technical and leadership responsibility with NASA LaRC. Additionally, he has four years experience with industry where he led multi-center, multi-discipline technical teams. Stuart worked on the AV-8B Harrier Program & EOS SAFIRE as a design engineer, HSR F-16XL-Supersonic Laminar Flow

Control Project as a Technical Project Engineer and the B757 Sim-to-Flight Project as a Lead ECS Subsystem Manager. Stuart successfully led engineering teams in the design, qualification, analyses, testing, fabrication, and implementation of these projects. Stuart also served as the Deputy Technology Manager of Airframe, Materials & Structures for the HSR Program Office where he provided level two oversight for LaRC and industry teams. Stuart served as the Systems Assurance Work Package Leader for the AGATE Program where he provided level two oversight, technical management and technology integration across seven technical work packages led by system engineering leads, entrepreneurs, and aviation experts in industry, academia, and non-profits. Stuart was the Transportation Systems Analysis & Assessment Lead for the SATS Program where he led a multi-discipline, multi-organizational team of senior transportation and systems analysts in the development of a comprehensive suite of analytical tools designed to evaluate the SATS concept. Stuart also served as the Project Chief Engineer for the Ares I-X Crew Module & Launch Abort System project where he successfully

ensured that all engineering resolutions, designs, analyses and deliverables were in compliance with all applicable standards and specifications. Stuart received his Bachelor of Science degree in Mechanical Engineering from the University of Tennessee.



**Melissa Ashe** has thirteen years of experience including nine years of mechanical design with teaming NASA contractors and three years of dedicated systems engineering experience with NASA LaRC. Melissa has participated in various NASA team projects ranging from wind tunnel models, the Shuttle External Tank ET PAL Ramp

Removal project, Boeing 757 projects to the Crew Exploration Vehicle (CEV) Orion Heat Shield Thermal Protection System (TPS) Advanced Development Project (ADP). Most recently, she executed several key roles for the CEV Orion Heat Shield TPS ADP. Her responsibilities included serving as the LaRC TPS ADP Systems Engineer, Interface Systems Lead, LaRC TPS ADP Project Manager as well as briefly contributing as the TPS ADP Flight Systems Deputy/Technical Authority. She has received numerous team and performance awards including special commendations for her outstanding contributions and commitments to the TPS ADP. Melissa received her Bachelor of Science degree in Engineering Science and Mechanics from Virginia Tech in 1997.



**Rudy Saucillo** currently serves as a Systems Analysis Lead in the Space Mission Analysis Branch at the NASA LaRC. In this role, Rudy initiates and leads LaRC and multi-center systems studies of human and robotic space exploration architectures, including transportation vehicle and surface element conceptual

designs and operations concepts. He also serves as the ISS Utilization Lead for the NASA Langley Space Technology and Exploration Planning Team. Previously, he was a technical lead and an engineering project manager with the Boeing Company. His responsibilities included directing a NASA Langley technical support contract responsible for the systems engineering and analysis of advanced space and atmospheric systems. He has a Bachelor of Science degree in Aerospace Engineering from Texas A&M University and a Master of Science degree in Aerospace Engineering from the University of Michigan.



**Doug Murphy** is an engineering manager at Analytical Mechanics Associates, Inc. in Hampton Virginia, and has worked on the development of aerospace simulation and visualization tools at NASA LaRC since 2000. His involvement with ISS includes work on interactive virtual environments and trade studies

for contingency planning. Previously, he was a Propulsion Operations Project Manager at Hughes Space and Communications Company in El Segundo California, supporting the design, production and launch of commercial satellites. He has a Bachelor of Science degree in Aerospace Engineering from the University of Michigan and a Master of Science degree in Electrical Engineering from the University of Southern California.



**Kim de Groh** is a senior materials research engineer in the Space Environment and Experiments Branch at NASA GRC where she has conducted research and mentored students for the past 21 years. Kim is internationally known as a technical leader in areas relating to the space environmental durability of

spacecraft materials. Kim has participated in Long Duration Exposure Facility (LDEF), shuttle and Russian Space Station Mir spaceflight experiments. She is the PI for the MISSE Science Project at Glenn Research Center and the PI for 13 MISSE 1-8 experiments, including seven collaborative experiments with high school girls. Kim has authored 101 technical publications, including a book chapter "Degradation of Spacecraft Materials" in the Handbook of Environmental Degradation of Materials (2005). She is currently writing a NASA Technical Standards handbook entitled "Spacecraft Materials Atomic Oxygen Durability Handbook" based on her MISSE 2 flight data. Kim received her Bachelor of Science and Master of Science degrees in Materials Science from Michigan State University.



**Don Jaworske** has been with NASA GRC for over 26 years. His areas of research include electron beam and ion beam sputter deposited coatings, cermet coatings, optical and thermal properties characterization, and most recently, heat pipes for space radiators. Don was a 2007 recipient of a NASA Fellowship on

Engineer/Scientist as Manager at the University of Tennessee, and has received a Space Flight Awareness Award and a Silver Snoopy Award for his work on MISSE. He is currently the Heat Rejection Risk Reduction Lead for

the Fission Surface Power Project and Project Manager for MISSE Science in the Space Environment and Experiments Branch at NASA GRC. Don received his Bachelor of Science degree in Chemistry from Heidelberg College and his Ph.D. degree in Chemistry from the University of Maryland.



**Quang-(Viet) Nguyen** is the Chief of the Space Environment & Experiments Branch at NASA GRC. The Space Environment & Experiments Branch conducts evaluations, predictions, and demonstrations of space environmental durability technologies to meet NASA as well as other U.S. commercial and governmental

needs for spacecraft and satellites. Flight experiments, ground-based space simulation facilities, and computational modeling are used to provide long-term space durability data, and to validate the performance and durability projections of spacecraft materials and components. Research is focused on the development and transfer of new technology for both space and terrestrial applications. Viet is currently serving as a program executive in the Joint Agency Satellite Division in the Science Mission Directorate at NASA Headquarters. Viet received his Ph.D. in Mechanical Engineering from the University of California, Berkeley.