The MISSE-9 Polymers and Composites Experiment Being Flown on the MISSE-Flight Facility

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Outline

• Introduction to the space environment
  – Examples of spacecraft damage

• Materials International Space Station Experiment (MISSE)
  – Overview of Glenn’s MISSE 1-8 polymers flight experiments

• MISSE-Flight Facility (MISSE-FF)
  – Introduction to MISSE-FF
  – Glenn’s MISSE-9 Polymers and Composites Experiment (PCE)
    o Ram, Wake & Zenith

• Polymers and Composites Experiment Summary
In low Earth orbit (LEO) environmental threats include:

- Solar radiation (ultraviolet (UV), x-rays)
- Charged particle radiation (electrons, protons)
- Cosmic rays (energetic nuclei)
- Temperature extremes & thermal cycling
- Micrometeoroids & orbital debris (space particles)
- Atomic oxygen (AO) (reactive oxygen atoms)
Atomic Oxygen (AO)

- AO is the predominant species in LEO (≈200-650 km)
- It is formed by photodissociation of molecular oxygen (O₂) by short wavelength energetic UV radiation
- At ram impact velocities (17,000 mph) the average impact energy is 4.5 eV
- AO oxidizes certain materials (such as polymers) with resulting gas formation - so the material erodes away...

⇒ AO is a serious threat to spacecraft survivability
Space Environment Induced Degradation

Long Duration Exposure Facility (LDEF)
5.8 years in space

AO erosion of Kapton blanket

Structural degradation

Impact site

Radiation induced darkening

Hubble Space Telescope (HST)

Radiation induced embrittlement & cracking of Teflon insulation (6.8 years in space)
The MISSE 1-8 missions consisted of a series of materials flight experiments flown in trays called Passive Experiment Containers (PECs), that were exposed to the space environment on the exterior of the International Space Station (ISS).

The PECs were positioned in *ram/wake* or *zenith/nadir* orientations providing different environmental exposures.

**Objective:**

To test the stability and durability of materials and devices in the space environment.
Flight Orientations & Environmental Exposures

**Ram:**

- Facing the direction of travel (i.e. forward pointing or leading edge)
- **Highest AO & moderate solar exposure**

**Wake:**

- Facing away from the direction of travel (i.e. aft pointing or trailing edge)
- **Very little AO & moderate solar exposure**

**Zenith:**

- Direction facing away from Earth (i.e. directly above)
- **Grazing AO & highest solar exposure**

**Nadir:**

- Direction facing towards Earth (i.e. straight down)
- **Grazing AO & lowest solar exposure**
# MISSE 1-8

## Mission Summary

<table>
<thead>
<tr>
<th>MISSE PEC</th>
<th>Launch Mission</th>
<th>Date Placed Outside ISS</th>
<th>Location on ISS</th>
<th>Tray Orientation</th>
<th>Retrieval Mission</th>
<th>Date Retrieved from Outside of ISS</th>
<th>LEO Exposure Duration (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 2</td>
<td>STS-105</td>
<td>8/16/2001</td>
<td>PEC 1: High Pressure Gas Tank (HPGT) PEC 2: Quest Airlock</td>
<td>Ram &amp; Wake</td>
<td>STS-114</td>
<td>7/30/2005</td>
<td>3.95</td>
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<tr>
<td>6A &amp; 6B</td>
<td>STS-123</td>
<td>3/22/2008</td>
<td>Columbus Laboratory</td>
<td>Ram &amp; Wake</td>
<td>STS-128</td>
<td>9/1/2009</td>
<td>1.45</td>
</tr>
</tbody>
</table>

* Deployed during Expedition 13
** Deployed during STS-135

**ORMatE-III R/W:** Optical Reflector Materials Experiment III Ram/Wake
## MISSE 1-8
### Polymer Experiments

### 6 experiments with 195 flight samples

<table>
<thead>
<tr>
<th>MISSE Mission</th>
<th>Experiment</th>
<th># Samples</th>
<th>Mission Orientation</th>
<th>Duration (yrs)</th>
<th>Experiment Objective</th>
<th>Active/Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Polymers Experiment (PEACE)</td>
<td>41</td>
<td>2 Ram</td>
<td>4.0</td>
<td>Determine the AO erosion yield ( (E_y) ) of a wide variety of polymers</td>
<td>P</td>
</tr>
<tr>
<td>6A &amp; 6B</td>
<td>Stressed Polymers Experiment</td>
<td>36</td>
<td>6A Ram</td>
<td>1.5</td>
<td>To determine if the AO ( E_y ) is dependent upon stress, plus evaluate thin film stacking effects on ( E_y )</td>
<td>P</td>
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<tr>
<td>7A &amp; 7B</td>
<td>Zenith Polymers Experiment</td>
<td>25</td>
<td>7A Zenith</td>
<td>1.5</td>
<td>To determine the effect of solar exposure on the AO ( E_y ) of fluoropolymers (high solar/low AO exposure)</td>
<td>P</td>
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<tr>
<td></td>
<td>Nadir Tensile Sample Experiment</td>
<td>6</td>
<td>7A Nadir</td>
<td>1.5</td>
<td>To determine the effect of LEO radiation (charged particle &amp; albedo radiation) on the embrittlement of Al-FEP</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Polymer Experiment</td>
<td>45</td>
<td>7B Ram 7B Wake</td>
<td>8A: 2.1 8B: 2.0</td>
<td>For AO ( E_y ) determination and to determine if AO erosion of high &amp; low ash containing polymers is dependent on fluence</td>
<td>P</td>
</tr>
<tr>
<td>8B &amp; 8A</td>
<td>Polymers Experiment</td>
<td>42</td>
<td>8B Ram 8B Wake 8A Zenith</td>
<td>8A: 2.1 8B: 2.0</td>
<td>To characterize the degradation of polymers &amp; other spacecraft materials flown in ram, wake &amp; zenith orientations</td>
<td>P</td>
</tr>
</tbody>
</table>
Objective: To determine the AO erosion yield ($E_Y$) of a wide variety of polymers exposed for an extended period of time to the LEO AO space environment.

**MISSE 2**
Deployed Aug. 16, 2001 (STS-105)
Retrieved July 30, 2005 (STS-114)
4 years of space exposure
**Atomic Oxygen**

**Erosion Yield** \( (E_y) \)

(Also called Reaction Efficiency or Recession Rate)

\( E_y \) is the volume loss per incident oxygen atom \((\text{cm}^3/\text{atom})\)

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**Erosion Yield** \( (E_y) \) of Sample

\[
E_y = \frac{\Delta M_s}{A_s \rho_s F_k}
\]

where:
- \( \Delta M_s \): Mass loss of polymer sample (g)
- \( A_s \): Area of polymer sample (cm\(^2\))
- \( \rho_s \): Density of sample (g/cm\(^3\))
- \( F_k \): AO fluence measured by Kapton H witness samples (atom/cm\(^2\))

**Atomic Oxygen Fluence**

\[
F_k = \frac{\Delta M_k}{A_k \rho_k E_k}
\]

where:
- \( \Delta M_k \): Mass loss of Kapton H witness (g)
- \( A_k \): Area of Kapton H witness (cm\(^2\))
- \( \rho_k \): Density of Kapton H sample (1.427 g/cm\(^3\))
- \( E_k \): Erosion yield of Kapton H (3.0 \( \times \) 10\(^{-24} \) cm\(^3\)/atom)
MISSE 2 Polymers Experiment

Pre-flight

Post-flight
Polyimide (PMDA)
Upilex-S
2-E5-32

Post-flight photos

In flight tray

Complete erosion
Partial erosion
No erosion

Flight
Control
11 layers (1 mil) 1 mil

Out of tray

Flight
Control
11 layers (1 mil) 1 mil
### MISSE 2 Polymers Erosion Yield Data

<table>
<thead>
<tr>
<th>Polymer Abbreviation</th>
<th>$E_y$ (cm$^3$/atom)</th>
<th>$E_y$ Uncertainty (%)</th>
<th>Polymer Abbreviation</th>
<th>$E_y$ (cm$^3$/atom)</th>
<th>$E_y$ Uncertainty (%)</th>
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</thead>
<tbody>
<tr>
<td>ABS</td>
<td>1.09E-24</td>
<td>2.7</td>
<td>PEI</td>
<td>&gt; 3.31E-24*</td>
<td>2.6</td>
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<tr>
<td>CA</td>
<td>5.05E-24</td>
<td>2.7</td>
<td>PA 6</td>
<td>3.51E-24</td>
<td>2.7</td>
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<tr>
<td>PPD-T (Kevlar)</td>
<td>6.28E-25</td>
<td>2.6</td>
<td>PA 66</td>
<td>1.80E-24</td>
<td>12.6</td>
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<tr>
<td>PE</td>
<td>&gt; 3.74E-24*</td>
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<td>PI (CP1)</td>
<td>1.91E-24</td>
<td>2.8</td>
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<tr>
<td>PVF (Tedlar)</td>
<td>3.19E-24</td>
<td>2.6</td>
<td>PI (Kapton H)</td>
<td>3.00E-24</td>
<td>2.7</td>
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<tr>
<td>PVF (White Tedlar)</td>
<td>1.01E-25</td>
<td>4.1</td>
<td>PI (Kapton HN)</td>
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<td>POM (Delrin)</td>
<td>9.14E-24</td>
<td>3.1</td>
<td>PI (Upilex-S)</td>
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<td>3.0</td>
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<td>PAN</td>
<td>1.41E-24</td>
<td>3.3</td>
<td>PI (PMR-15)</td>
<td>&gt; 3.02E-24*</td>
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<td>ADC (CR-39)</td>
<td>&gt; 6.80E-24*</td>
<td>2.6</td>
<td>PBI</td>
<td>&gt; 2.21E-24*</td>
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<td>PC</td>
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<td>PEO</td>
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<td>PBO (Zylon)</td>
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<td>EP</td>
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<td>ECTFE (Halar)</td>
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<td>PP</td>
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<td>ETFE (Tefzel)</td>
<td>9.61E-25</td>
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<td>PBT</td>
<td>9.11E-25</td>
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<td>FEP</td>
<td>2.00E-25</td>
<td>2.7</td>
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<td>PSU</td>
<td>2.94E-24</td>
<td>3.2</td>
<td>PTFE</td>
<td>1.42E-25</td>
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<td>PU</td>
<td>1.56E-24</td>
<td>2.9</td>
<td>PFA</td>
<td>1.73E-25</td>
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<td>PPPA (Nomex)</td>
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<td>2.9</td>
<td>AF</td>
<td>1.98E-25</td>
<td>2.6</td>
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<td>PG</td>
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<td>10.7</td>
<td>PVDF (Kynar)</td>
<td>1.29E-24</td>
<td>2.7</td>
</tr>
</tbody>
</table>

* $E_y >$ this value because sample stack was partially, or fully, eroded through

Ave. uncertainty: 3.30%
Stressed Polymers Experiment

MISSE 6A & 6B
Deployed March 22, 2008
Retrieved Sept. 1, 2009
1.45 years of space exposure
⇒ Flying the same polymer on various MISSE missions provides important information on erosion dependence on environmental exposure

⇒ An objective of MISSE-9 PCE is to obtain $E_y$ vs. AO fluence data for additional spacecraft polymers
MISSE 7
AI-FEP
% Elongation at Failure vs. Environmental Exposure

Parallel: Tensile samples sectioned parallel to the manufacture roll direction
Normal: Tensile samples sections normal to the manufacture roll direction

AI-FEP: Aluminized-Teflon fluorinated ethylene propylene
*Nadir ESH was estimated at 150 ESH (no direct solar exposure, albedo reflected only)
• **Excellent correlation of AO $E_y$ to ESH/AO fluence ratio:**
  ➢ *Shows the effect of solar radiation and/or heating due to solar exposure on erosion of FEP*

• **C-FEP ($170 \degree C$) has a significantly higher $E_y$ than Al-FEP (2 °C) for the same exposure:**
  ➢ *Heating has a major impact on the $E_y$ of FEP in the zenith orientation*

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**FEP:** Fluorinated ethylene propylene  
**C-FEP:** Carbon back-surface painted FEP  
**Al-FEP:** Aluminized-Teflon FEP  
**HST Al-FEP:** Hubble Space Telescope retrieved Al-FEP
Polymers and Composites Experiment (PCE)  
MISSE 9 inaugural mission of the MISSE-Flight Facility (MISSE-FF)
MISSE-FF will be a permanent external material science platform on the ISS that is modular and robotically serviceable
  - Express Logistics Carrier-2, Payload Site 3 (ELC-2 Site 3)
  - Provides ram, wake, zenith and nadir exposures
  - Launch aboard SpaceX-13 (Nov. 2017)

- Modular design allows MISSE Sample Carriers (MSCs) with experiments to be added/replaced at different times
  - Min. of 4 MSCs will be rotated every 6 months
  - MSC duration: 6 months - 3 years (1 year typical)

- Supports active experiments with downlink of data

- Active environmental sensors provides environmental data over time in each flight orientation
  - Standard: Temperature, contamination, UV (for NASA PI's)
  - Service Fee: AO, UV (non-NASA PI), TID

- High-resolution cameras provide monthly sample images
- Remotely controllable MSCs provide sample protection and on-demand picture data
Primary Objectives:
1. Determine the low Earth orbit (LEO) atomic oxygen (AO) erosion yield ($E_y$) of spacecraft polymers and composites as a function of solar irradiation and AO fluence
2. Determine optical and tensile property degradation of spacecraft polymers in LEO
3. Determine AO fluence and contamination for MISSE-9 ram, wake & zenith orientations
4. Use the flight data to improve AO predictive models (erosion and scattering)
5. Document the flight data, and provide for archiving in the MISSE MAPTIS database

Rationale for ISS Accommodations: Significant differences exist between LEO and ground-lab exposures (variations in AO species, AO energies, thermal & radiation exposures), therefore actual LEO exposure is necessary to determine accurate $E_y$ values and mechanical property degradation for spacecraft missions.

Experiment Description:
- Passive experiment with 138 samples flown in ram, wake & zenith orientations
  - 39 Ram, 52 Wake & 47 Zenith
- Pre-flight & post-flight data will be measured in ground-facilities

Expected Results:
- LEO $E_y$ values as a function of AO fluence, solar irradiation & inorganic content
- Changes in optical, thermal and tensile properties
- AO fluence and contamination data in ram, wake and zenith directions

Principal Investigator (PI): Kim de Groh (GRC)
Primary Collaborators: Bruce Banks (SAIC/GRC) & Hathaway Brown School
Sample Collaborators: Loredana Santo & Fabrizio Quadrini (University of Rome “Tor Vergata”), Jenny Devaud & John Fleming (Ball Aerospace), Larry Drzal (Michigan State University), Henry de Groh (NASA Glenn) & Maryann Meador (NASA Glenn)
# MISSE-9 PCE Ram Samples

<table>
<thead>
<tr>
<th>MISSE-9 ID</th>
<th>Material</th>
<th>Abbrev.</th>
<th># Layers</th>
<th>Total thickness (inch)</th>
<th>C or S</th>
<th>Size (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M9R-C1</td>
<td>Polyimide (PMDA) (Kapton H)</td>
<td>Kapton H</td>
<td>2</td>
<td>0.010</td>
<td>C</td>
<td>1</td>
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<tr>
<td>M9R-C2</td>
<td>Polyimide (PMDA) (Kapton H)</td>
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<td>0.010</td>
<td>C</td>
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<td>Kapton HN</td>
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<td>0.010</td>
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<td>M9R-C6</td>
<td>Alumina slide</td>
<td>Al₂O₃</td>
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<td>0.063</td>
<td>C</td>
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<td>C</td>
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<td>POM</td>
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<td>0.020</td>
<td>C</td>
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<td>0.020</td>
<td>C</td>
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<tr>
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<td>0.118</td>
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<td>M9R-C12</td>
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<td>ZnO-Epoxy</td>
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<td>0.125</td>
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<td>0.101</td>
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<td>M9R-C15</td>
<td>Fluorinated ethylene propylene (Teflon FEP)</td>
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<td>M9R-C16</td>
<td>Aluminized-Teflon (FEP/Al)*</td>
<td>Al-FEP</td>
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<tr>
<td>M9R-C17</td>
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<td>Ag-FEP</td>
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<tr>
<td>M9R-C18</td>
<td>Carbon painted (India Ink) Teflon (FEP/C/FEP)*</td>
<td>C-FEP</td>
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<td>M9R-C20</td>
<td>Polytetrafluoroethylene (Chemfilm DF 100)</td>
<td>PTFE</td>
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<td>0.005</td>
<td>C</td>
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<td>M9R-C21</td>
<td>Crystalline polyvinylfluoride, white pigment (white Tedlar)</td>
<td>PVF-W</td>
<td>1</td>
<td>0.002</td>
<td>C</td>
<td>1</td>
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<tr>
<td>M9R-C22</td>
<td>Highly Oriented Pyrolytic Graphite</td>
<td>HOPG</td>
<td>1</td>
<td>0.041</td>
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<td>Polyethylene terephthalate (Mylar)</td>
<td>PET</td>
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<td>PE</td>
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<td>M9R-C27</td>
<td>Magnesium Fluoride</td>
<td>MgF₂</td>
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<td>0.108</td>
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<td>Cyanate ester graphite fiber composite (RS3-M55J 6K)</td>
<td>RS3-M55J</td>
<td>1</td>
<td>0.062</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>M9R-C29</td>
<td>Sodium silicate/RS3-M55J 6K</td>
<td>Na₃Si₂O₅RS3-M55J</td>
<td>1</td>
<td>0.064</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>M9R-C30</td>
<td>Polyimide aerogel</td>
<td>Polyimide Aerogel</td>
<td>1</td>
<td>0.125</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>M9R-C31</td>
<td>Carbon nanotube (CNT) paper</td>
<td>Buckypaper</td>
<td>3</td>
<td>0.005</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>M9R-C32</td>
<td>Graphene nanoplatelets (GnP) paper</td>
<td>GnP paper</td>
<td>1</td>
<td>0.010</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>M9R-S1</td>
<td>Polyimide (PMDA) (Kapton H)</td>
<td>Kapton H</td>
<td>2</td>
<td>0.010</td>
<td>S</td>
<td>1</td>
</tr>
<tr>
<td>M9R-S2</td>
<td>Z307 (black paint)/aluminum</td>
<td>Z307/Al</td>
<td>1</td>
<td>0.035</td>
<td>S</td>
<td>1</td>
</tr>
<tr>
<td>M9R-S3</td>
<td>Ball Infrared Black (BIRB) paint/aluminum</td>
<td>BIRB/Al</td>
<td>1</td>
<td>0.100</td>
<td>S</td>
<td>1</td>
</tr>
<tr>
<td>M9R-S4</td>
<td>Carbon nanotube (CNT) coated SiC w/ 0.5 mil Kapton cover</td>
<td>Kapton H/ CNT/SiC</td>
<td>1</td>
<td>0.130</td>
<td>S</td>
<td>1</td>
</tr>
<tr>
<td>M9R-S5</td>
<td>Indium tin oxide coated Kapton HN/aluminum</td>
<td>ITO/Kapton HN/Al</td>
<td>1</td>
<td>0.002</td>
<td>S</td>
<td>1</td>
</tr>
<tr>
<td>M9R-S6</td>
<td>Indium tin oxide coated silver-Teflon</td>
<td>ITO/FEP/ Ag/Inconel</td>
<td>1</td>
<td>0.005</td>
<td>S</td>
<td>1</td>
</tr>
<tr>
<td>M9R-S7</td>
<td>Atomic Oxygen Scattering Chamber (30° angle)</td>
<td>AO Scatter Chamber</td>
<td>1</td>
<td>0.275</td>
<td>S</td>
<td>1</td>
</tr>
</tbody>
</table>

*FEP layer is space facing

39 Samples
- 32 Circular (C)
- 7 Square (S)
MISSE-9 PCE Ram Samples
39 samples: 32 circular (0.5 – 1-inch) & 7 square (1-inch)

Images courtesy of Alpha Space
Circular and Square Sample Assembly

Samples will be held inside the MSC deck, which is bolted to the carrier with a backing cover plate, spacers and wavy washers, similar to MISSE 1-8 sample trays.
Overview of PCE Ram Samples
(High AO & moderate solar exposure)

- Ram Samples:
  - Kapton H for MISSE-9 ram AO fluence determination
  - Al₂O₃ slides for MISSE-9 ram contamination determination
  - Samples for LEO AO $E_y$ and optical property durability:
    - Polymers
    - Composites
    - Black paint (BIRB & Z307) coated samples
    - Buckypaper & graphene nanoplatelets (GnP) paper
    - Carbon nanotube (CNT) coatings
    - Polyimide aerogel
    - MgF₂
    - ITO/FEP and ITO/Kapton HN (also for electrical property durability)
  - Samples of varying diameters to study the effect of the sample holder on $E_y$ (sample holder chamfer edge effect on $E_y$)
  - Samples with varying % of inorganic filler to determine filler effect on $E_y$
  - AO Scattering Chamber (30° angle base) for AO scattering characterization
  - Previously flown polymers for $E_y$ vs. AO fluence, $E_y$ vs. solar exposure and $E_y$ vs. ESH/AO fluence
  - C-FEP vs. Al-FEP to study passive heating effects on $E_y$ of radiation exposed FEP
# MISSE-9 PCE Wake
## 1-inch Samples
(14 Samples: 10 Circular & 4 square)

<table>
<thead>
<tr>
<th>MISSE-9 ID</th>
<th>Material</th>
<th>Abbrev.</th>
<th>Thickness (inch)</th>
<th>C or S</th>
</tr>
</thead>
<tbody>
<tr>
<td>M9W-C1</td>
<td>Polyimide (PMDA) (Kapton H)</td>
<td>Kapton H</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C2</td>
<td>Polyimide (PMDA) (Kapton HN)</td>
<td>Kapton HN</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C3</td>
<td>Alumina slide</td>
<td>Al₂O₃</td>
<td>0.063</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C4</td>
<td>Fluorinated ethylene propylene (Teflon FEP)</td>
<td>FEP</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C5</td>
<td>Aluminized-Teflon (FEP/Al)*</td>
<td>Al-FEP</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C6</td>
<td>Silver-Teflon (FEP/Ag/Inconel)*</td>
<td>Ag-FEP</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C7</td>
<td>Carbon painted (India Ink) Teflon (FEP/C/FEP)*</td>
<td>C-FEP</td>
<td>0.015</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C8</td>
<td>Polyvinyl chloride</td>
<td>PVC</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C9</td>
<td>Cosmic ray shielding (CRS) sample</td>
<td>CRS</td>
<td>0.039</td>
<td>C</td>
</tr>
<tr>
<td>M9W-C10</td>
<td>Shape memory composite (SMC) sample</td>
<td>SMC</td>
<td>0.236</td>
<td>C</td>
</tr>
<tr>
<td>M9W-S1</td>
<td>Indium tin oxide coated Kapton HN/aluminum</td>
<td>ITO/Kapton HN/Al</td>
<td>0.002</td>
<td>S</td>
</tr>
<tr>
<td>M9W-S2</td>
<td>Indium tin oxide coated silver-Teflon</td>
<td>ITO/FEP/Ag/Inconel</td>
<td>0.005</td>
<td>S</td>
</tr>
<tr>
<td>M9W-S3</td>
<td>Indium tin oxide coated silver-Teflon</td>
<td>ITO/FEP/Ag/Inconel</td>
<td>0.005</td>
<td>S</td>
</tr>
<tr>
<td>M9W-S4</td>
<td>Carbon nanotube (CNT) coated SiC</td>
<td>CNT/SiC</td>
<td>0.130</td>
<td>S</td>
</tr>
</tbody>
</table>

*FEP layer is space facing; C: Circular; S: Square
# MISSE-9 PCE Wake Tensile Samples (38)

<table>
<thead>
<tr>
<th>MISSE-9 ID</th>
<th>Material</th>
<th>Abbrev.</th>
<th>Thickness (inch)</th>
<th>Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>M9W-T1 to T5</td>
<td>Aluminized-Teflon (FEP/Al)* - Parallel</td>
<td>Al-FEP</td>
<td>0.002</td>
<td>5</td>
</tr>
<tr>
<td>M9W-T6 to T10</td>
<td>Aluminized-Teflon (FEP/Al)* - Normal</td>
<td>Al-FEP</td>
<td>0.002</td>
<td>5</td>
</tr>
<tr>
<td>M9W-T11 to T15</td>
<td>Aluminized-Teflon (FEP/Al)* - Parallel</td>
<td>Al-FEP</td>
<td>0.005</td>
<td>5</td>
</tr>
<tr>
<td>M9W-T16 to T20</td>
<td>Aluminized-Teflon (FEP/Al)* - Normal</td>
<td>Al-FEP</td>
<td>0.005</td>
<td>5</td>
</tr>
<tr>
<td>M9W-T21 to T24</td>
<td>Silver-Teflon (FEP/Ag/Inconel)* - Parallel</td>
<td>Ag-FEP</td>
<td>0.005</td>
<td>4</td>
</tr>
<tr>
<td>M9W-T25 to T29</td>
<td>Carbon painted (India Ink) Teflon (FEP/C)* - Parallel</td>
<td>C-FEP</td>
<td>0.002</td>
<td>5</td>
</tr>
<tr>
<td>M9W-T30 to T34</td>
<td>Carbon painted (India Ink) Teflon (FEP/C)* - Parallel</td>
<td>C-FEP</td>
<td>0.005</td>
<td>5</td>
</tr>
<tr>
<td>M9W-T35 to T38</td>
<td>Aluminized-Teflon (Al/FEP) - Parallel (Al space facing)</td>
<td>Al/FEP</td>
<td>0.002</td>
<td>4</td>
</tr>
</tbody>
</table>

*FEP is space facing

# Tensile Samples 38

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![Tensile Sample Diagram](image)

**ASTM D638-08 Type V Specimen Dimensions**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>W—Width of narrow section</td>
<td>3.18 mm (0.125 in.)</td>
</tr>
<tr>
<td>L—Length of narrow section</td>
<td>9.53 mm (0.375 in.)</td>
</tr>
<tr>
<td>WO—Width overall, min</td>
<td>9.53 mm (0.375 in.)</td>
</tr>
<tr>
<td>LO—Length overall, min</td>
<td>63.5 mm (2.5 in.)</td>
</tr>
<tr>
<td>G—Gage length</td>
<td>7.62 mm (0.300 in.)</td>
</tr>
<tr>
<td>D—Distance between grips</td>
<td>25.4 mm (1.00 in.)</td>
</tr>
<tr>
<td>R—Radius of fillet</td>
<td>12.7 mm (0.500 in.)</td>
</tr>
</tbody>
</table>
MISSE-9 PCE Wake Samples
52 samples: 38 tensile & 14 1-inch
MISSE-9 PCE Wake Tensile Sample Assembly

Images courtesy of Alpha Space
Overview of PCE Wake Samples
(Very little AO & moderate solar exposure)

- **Wake 1-inch Samples:**
  - Kapton H for MISSE-9 wake AO fluence determination
  - Al$_2$O$_3$ slides for wake contamination determination
  - Samples for optical property durability:
    - Polyvinyl chloride (PVC)
    - Carbon nanotube (CNT) coatings
    - ITO/FEP and ITO/Kapton HN (also for electrical property durability)
  - Cosmic ray shielding (CRS) sample for functionality and durability
  - Shape memory composite (SMC) sample for functionality and durability
  - FEP for $E_y$ vs. ESH/AO fluence
    - FEP, Al-FEP & Ag-FEP
  - C-FEP vs. Al-FEP to study passive heating effects on $E_y$ of radiation exposed FEP

- **Wake Tensile Samples:**
  - Tensile samples to study LEO radiation embrittlement
    - 2 mil vs. 5 mil Al-FEP to study film thickness effects on embrittlement
    - Al-FEP vs. Ag-FEP to compare mechanical property degradation
    - Effect of roll direction (parallel vs. normal) on embrittlement of FEP
    - C-FEP vs. Al-FEP to study passive heating effects on embrittlement of radiation exposed FEP
### MISSE-9 PCE Zenith
#### 1-inch Samples
**(23 Samples: 18 Circular & 5 square)**

<table>
<thead>
<tr>
<th>MISSE-9 ID</th>
<th>Material</th>
<th>Abbrev.</th>
<th>Thickness (inch)</th>
<th>C or S</th>
</tr>
</thead>
<tbody>
<tr>
<td>M9Z-C1</td>
<td>Polyimide (PMDA) (Kapton H)</td>
<td>Kapton H</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C2</td>
<td>Polyimide (PMDA) (Kapton HN)</td>
<td>Kapton HN</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C3</td>
<td>Alumina slide</td>
<td>Al₂O₃</td>
<td>0.063</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C4</td>
<td>Fluorinated ethylene propylene (Teflon FEP)</td>
<td>FEP</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C5</td>
<td>Aluminized-Teflon (FEP/Al)*</td>
<td>Al-FEP</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C6</td>
<td>Silver-Teflon (FEP/Ag/Inconel)*</td>
<td>Ag-FEP</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C7</td>
<td>Back-surface carbon painted Teflon (FEP/C/FEP)*</td>
<td>C-FEP</td>
<td>0.015</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C8</td>
<td>Ethylene-chlorotrifluoroethylene (Halar)</td>
<td>ECTFE</td>
<td>0.003</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C9</td>
<td>Polytetrafluoroethylene (Teflon PTFE)</td>
<td>PTFE</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C10</td>
<td>Chlorotrifluoroethylene (Kel-F)</td>
<td>CTFE</td>
<td>0.005</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C11</td>
<td>Ethylene-tetrafluoroethylene (Tefzel ZM)</td>
<td>ETFE</td>
<td>0.003</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C12</td>
<td>Polyvinylidene fluoride (Kynar)</td>
<td>PVDF</td>
<td>0.003</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C13</td>
<td>Polyethylene</td>
<td>PE</td>
<td>0.002</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C14</td>
<td>Polyvinylfluoride (clear Tedlar)</td>
<td>PVF</td>
<td>0.001</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C15</td>
<td>Crystalline polyvinylfluoride w/white pigment (white Tedlar)</td>
<td>PVF-W</td>
<td>0.002</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C16</td>
<td>Polyimide (BPDA) (Upilex-S)</td>
<td>Upilex-S</td>
<td>0.001</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C17</td>
<td>Shape memory composite (SMC) sample</td>
<td>SMC</td>
<td>0.236</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-C18</td>
<td>Magnesium Fluoride</td>
<td>MgF₂</td>
<td>0.108</td>
<td>C</td>
</tr>
<tr>
<td>M9Z-S1</td>
<td>Z307 (black paint)/aluminum</td>
<td>Z307/Al</td>
<td>0.035</td>
<td>S</td>
</tr>
<tr>
<td>M9Z-S2</td>
<td>Ball Infrared Black (BIRB) paint/aluminum</td>
<td>BIRB/Al</td>
<td>0.100</td>
<td>S</td>
</tr>
<tr>
<td>M9Z-S3</td>
<td>Carbon nanotube (CNT) coated SiC</td>
<td>CNT/SiC</td>
<td>0.130</td>
<td>S</td>
</tr>
<tr>
<td>M9Z-S4</td>
<td>EpoCNT (carbon nanotube in epoxy matrix)/aluminum</td>
<td>EpoCNT/Al</td>
<td>0.064</td>
<td>S</td>
</tr>
<tr>
<td>M9Z-S5</td>
<td>Indium tin oxide coated silver-Teflon</td>
<td>ITO/FEP/Ag/Inconel</td>
<td>0.005</td>
<td>S</td>
</tr>
</tbody>
</table>

*FEP layer is space facing; C: Circular; S: Square*
MISSE-9 PCE Zenith
Tensile Samples (24)

<table>
<thead>
<tr>
<th>MISSE-9 ID</th>
<th>Material</th>
<th>Abbrev.</th>
<th>Thickness (inch)</th>
<th>Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>M9Z-T1 to T4</td>
<td>Aluminized-Teflon (FEP/Al)* - Parallel</td>
<td>Al-FEP</td>
<td>0.002</td>
<td>4</td>
</tr>
<tr>
<td>M9Z-T5 to T8</td>
<td>Aluminized-Teflon (FEP/Al)* - Normal</td>
<td>Al-FEP</td>
<td>0.002</td>
<td>4</td>
</tr>
<tr>
<td>M9Z-T9 to T12</td>
<td>Aluminized-Teflon (FEP/Al)* - Parallel</td>
<td>Al-FEP</td>
<td>0.005</td>
<td>4</td>
</tr>
<tr>
<td>M9Z-T13 to T16</td>
<td>Aluminized-Teflon (FEP/Al)* - Normal</td>
<td>Al-FEP</td>
<td>0.005</td>
<td>4</td>
</tr>
<tr>
<td>M9Z-T17 to T20</td>
<td>Carbon painted (India Ink) Teflon (FEP/C)* - Parallel</td>
<td>C-FEP</td>
<td>0.002</td>
<td>4</td>
</tr>
<tr>
<td>M9W-T21 to T24</td>
<td>Aluminized-Teflon (Al/FEP) - Parallel (Al space facing)</td>
<td>Al/FEP</td>
<td>0.002</td>
<td>4</td>
</tr>
</tbody>
</table>

*FEP is space facing

ASTM D638-08 Type V Specimen Dimensions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>W—Width of narrow section</td>
<td>3.18 mm (0.125 in.)</td>
</tr>
<tr>
<td>L—Length of narrow section</td>
<td>9.53 mm (0.375 in.)</td>
</tr>
<tr>
<td>WO—Width overall, min</td>
<td>9.53 mm (0.375 in.)</td>
</tr>
<tr>
<td>LO—Length overall, min</td>
<td>63.5 mm (2.5 in.)</td>
</tr>
<tr>
<td>G—Gage length</td>
<td>7.62 mm (0.300 in.)</td>
</tr>
<tr>
<td>D—Distance between grips</td>
<td>25.4 mm (1.00 in.)</td>
</tr>
<tr>
<td>R—Radius of fillet</td>
<td>12.7 mm (0.500 in.)</td>
</tr>
</tbody>
</table>

# Tensile Samples 24
MISSE-9 PCE Zenith Samples
47 samples: 24 tensile & 23 1-inch

Images courtesy of Alpha Space
Overview of PCE Zenith Samples
(Grazing AO & high solar exposure)

- **Zenith 1-inch Samples:**
  - Kapton H for MISSE-9 zenith AO fluence determination
  - Al\(_2\)O\(_3\) slides for MISSE-9 zenith contamination determination
  - Shape memory composite (SMC) sample for functionality and durability
  - Samples for AO \(E_y\) and optical property durability:
    - \(MgF_2\)
    - Carbon nanotube (CNT) coatings
    - Black paint (BIRB & Z307) coated samples
    - ITO/FEP (also for electrical property durability)
  - Previously flown polymers for \(E_y\) vs. ESH/AO fluence:
    - Fluoropolymers
    - Upilex-S, Kapton HN, White Tedlar, PE
  - C-FEP vs. Al-FEP to study passive heating effects on \(E_y\) of radiation exposed FEP

- **Zenith Tensile Samples:**
  - Tensile samples to study LEO radiation embrittlement
    - 2 mil vs. 5 mil Al-FEP to study film thickness effects on embrittlement
    - Al-FEP vs. Ag-FEP to compare mechanical property degradation
    - Effect of roll direction (parallel vs. normal) on embrittlement of FEP
    - C-FEP vs. Al-FEP to study passive heating effects on embrittlement of radiation exposed FEP
The **Polymers and Composites Experiment (PCE)** has been selected for flight on MISSE-9, the inaugural mission of the MISSE-Flight Facility (MISSE-FF)

**Passive experiment:**
- 138 samples to be flown in ram, wake & zenith orientations:
  - **Ram (39):** 32 - circular (0.5” - 1.0”) & 7 - 1” square
  - **Wake (52):** 38 - tensile samples + 14 - 1” samples
  - **Zenith (47):** 24 - tensile samples + 23 - 1” samples
  - Pre-flight & post-flight data will be measured in ground-facilities

**Flight mission:** MISSE-9 manifested to launch on SpaceX-13 (Nov. 2017) for 1 year

**Expected results include:**
- Monthly high resolution on-orbit photographs of flight samples
- AO fluence and contamination data in ram, wake and zenith directions
- LEO AO $E_y$ values as a function of AO fluence, solar irradiation & inorganic content
- Changes in optical, thermal and tensile properties

**Expected impacts:**
*This experiment will provide critical space environmental durability data for LEO and low Mars orbit mission spacecraft enabling:*
- Improved predictions of materials and component lifetimes in space
- Improvements to Glenn's AO $E_y$ Predictive Tool and AO Monte Carlo Model
- A revision of NASA Technical Standards Spacecraft Polymers Atomic Oxygen Durability Handbook to include $E_y$ vs. AO fluence and $E_y$ vs. solar data for spacecraft polymers
Acknowledgements

Glenn’s MISSE research has been supported by various projects over the past 17 years including the ISS Research Program, the MISSE-X Project, the MISSE Informatics Project and currently Glenn Center Funds

We would like to thank to Bob Yang (HQ), Jessica Curry (JSC), Terry O’Malley (GRC), Andrew Keys (MSFC) and Craig Robinson (GRC) for their support of the MISSE-9 Polymers and Composites Experiment