# The MISSE 7 Flexural Stress Effects Experiment After 1.5 Years of Wake Space Exposure


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## Abstract

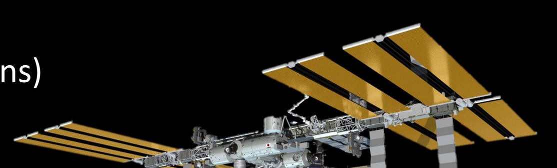

Low Earth orbit space environment conditions, including ultraviolet radiation, thermal cycling, and atomic oxygen exposure, can cause degradation of exterior spacecraft materials over time. Radiation and thermal exposure often results in bond-breaking and embrittlement of polymers, reducing mechanical strength and structural integrity. An experiment called the Flexural Stress Effects Experiment (FSEE) was flown with the objective of determining the role of space environmental exposure on the degradation of polymers under flexural stress. The FSEE samples were flown in the wake orientation on the exterior of International Space Station for 1.5 years. Twenty-four samples were flown: 12 bent over a 0.375 in. mandrel and 12 were over a 0.25 in. mandrel. This was designed to simulate flight configurations of insulation blankets on spacecraft. The samples consisted of assorted polyimide and fluorinated polymers with various coatings. Half the samples were designated for bend testing and the other half will be tensile tested. A non-standard bend-test procedure was designed to determine the surface strain at which embrittled polymers crack. All ten samples designated for bend testing have been tested. None of the control samples' polymers cracked, even under surface strains up to 19.7%, although one coating cracked. Of the ten flight samples tested, seven show increased embrittlement through bend-test induced cracking at surface strains from 0.70% to 11.73%. These results show that most of the tested polymers are embrittled due to space exposure, when compared to their control samples. Determination of the extent of space induced embrittlement of polymers is important for designing durable spacecraft.


## Space Environment

Materials on the exterior of the spacecraft are exposed to many environmental threats that can be harmful to the spacecraft and its operation

These threats include:

- Solar radiation (ultraviolet (UV), x-rays)
- Charged particle radiation (electrons, protons)
- Cosmic rays (energetic nuclei)
- Thermal cycling (hot & cold cycles)
- Micrometeoroids & debris impacts (space particles)
- Atomic oxygen (AO, single oxygen atom)



## MISSE Background

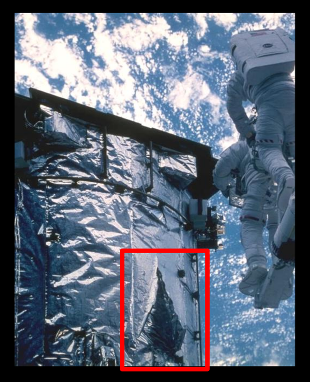
- MISSE stands for the Materials International Space Station Experiment
- MISSE is a series of materials flight experiments consisting of trays called Passive Experiment Containers (PECs) that were exposed to the space environment on the exterior of the International Space Station (ISS)
- The Flexural Stress Effects Experiment (FSEE) samples were flown in the wake orientation on the ISS from November 23, 2009 to May 20, 2011 for 1.49 years, and received 2,000 equivalent sun hours (ESH) of solar radiation (Ref 1)

## Flexural Stress Effects Experiment Background

Objective: To examine the role of surface flexural stress (two different levels) on space environment induced polymer embrittlement.

- Samples were flown bent over a mandrel in the wake orientation, which imposed surface flexural stress, so the role of surface flexural stress on polymer degradation could be examined
- Two different diameter mandrels (0.25" and 0.375" dia) were used so the effects of different stress levels on the polymers could be compared

An example of the effect of space exposure on polymer embrittlement can be seen on the Hubble Space Telescope, where the normally stretchy Teflon outer-layer of the multilayer insulation became brittle and cracked after only 5.8 years of space exposure.



Cracking of the Teflon insulation on the Hubble Space Telescope after 5.8 years of space exposure

MISSE 7B FSEE Sample Holder (Post-Flight)

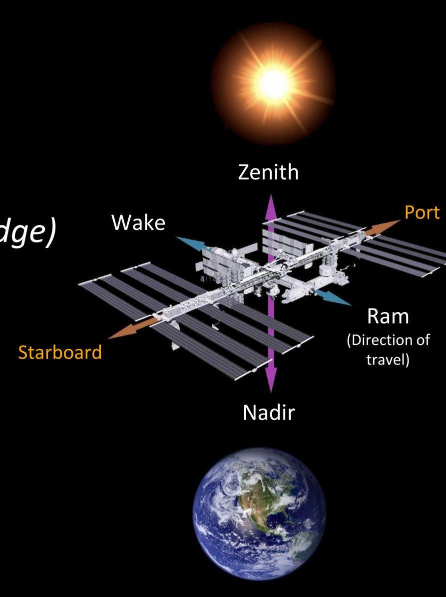
## Flight Orientations & Environmental Exposures

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

**Wake:**
- *Facing away from the direction of travel (i.e. trailing edge)*
- *Lowest AO & moderate solar exposure*

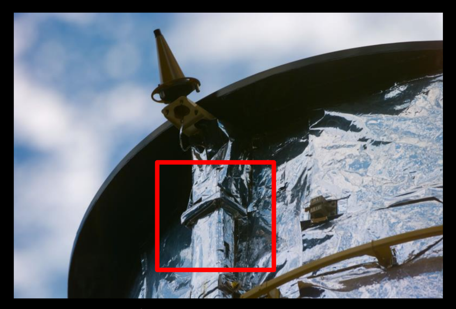
**Zenith:**
- *Direction facing away from Earth (i.e. directly above)*
- *Grazing AO & highest solar exposure*

**Nadir:**
- *Direction facing towards Earth (i.e. straight down)*
- *Grazing AO & lowest solar exposure*

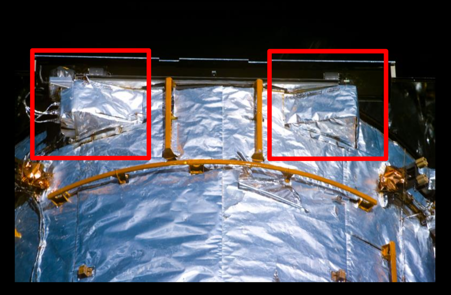



## Spacecraft Blanket Examples

- Pictured below are examples of how insulation blankets are bent while in flight
- Depicted in the image on the left is an example of a polymer insulation being bent around a corner on the Hubble Space Telescope (HST)
- In the image on the right, more bent polymer blankets can be seen on the HST during flight

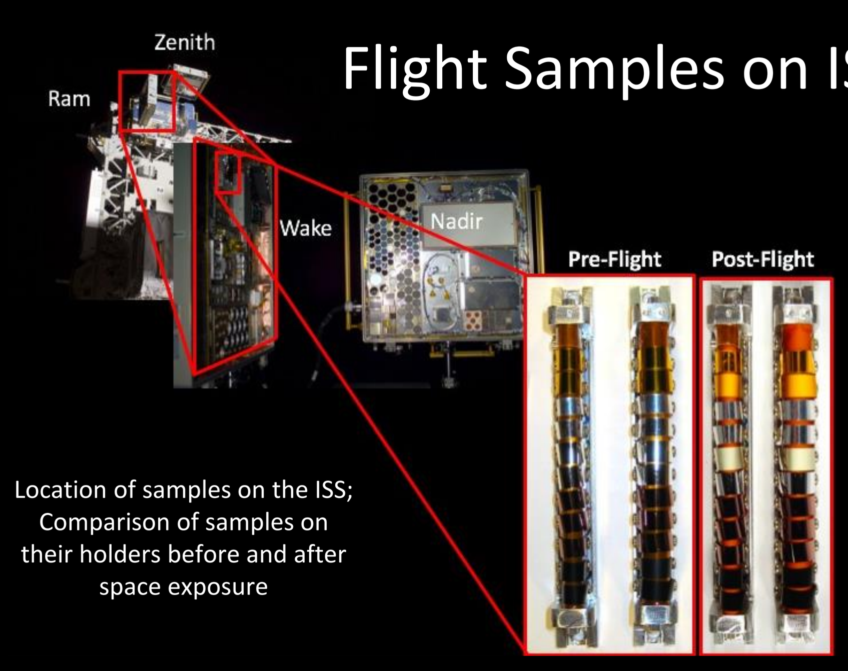


Spacecraft blanket wrapped about a corner on the HST

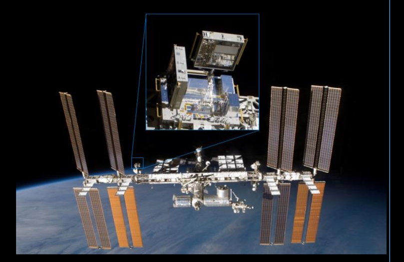


Teflon insulation blankets wrapped around the magnetometers on the HST

## Flight Samples on ISS




Location of samples on the ISS; Comparison of samples on their holders before and after space exposure



ISS flying above Earth with location of MISSE 7 PECs depicted

## FSEE Materials

| ID | | Material | Polymer Thickness | ID | | Material | Polymer Thickness |
|---|---|---|---|---|---|---|---|
| A-Mandrel (0.25 in dia) | MISSE ID | Sample length: 1.412 inch | | B-Mandrel (0.375 in dia) | MISSE ID | Sample length: 1.483 inch | |
| A-1 | N7-W-A1 | Kapton XC/Al | 1 mil | B-1 | N7-W-B1 | Kapton XC/Al | 1 mil |
| A-2 | N7-W-A2 | Kapton XC | 1 mil | B-2 | N7-W-B2 | Kapton XC | 1 mil |
| A-3 | N7-W-A3 | Si/Kapton E/ VDA*/Inconel/VDA | 2 mil | B-3 | N7-W-B3 | Si/Kapton E/ VDA/Inconel/VDA | 2 mil |
| A-4 | N7-W-A4 | Si/Kapton E/ VDA/Inconel/VDA | 2 mil | B-4 | N7-W-B4 | Si/Kapton E/ VDA/Inconel/VDA | 2 mil |
| A-5 | N7-W-A5 | Si/Kapton E/ VDA/Inconel/VDA | 2 mil | B-5 | N7-W-B5 | Si/Kapton E/ VDA/Inconel/VDA | 2 mil |
| A-6 | N7-W-A6 | VDA/CP1** | 1 mil | B-6 | N7-W-B6 | VDA/CP1 | 1 mil |
| A-7 | N7-W-A7 | CP1/VDA | 1 mil | B-7 | N7-W-B7 | CP1/VDA | 1 mil |
| A-8 | N7-W-A8 | FEP***/VDA | 2 mil | B-8 | N7-W-B8 | FEP/VDA | 2 mil |
| A-9 | N7-W-A9 | FEP/VDA | 5 mil | B-9 | N7-W-B9 | FEP/VDA | 5 mil |
| A-10 | N7-W-A10 | Kapton HN/VDA | 1 mil | B-10 | N7-W-B10 | Kapton HN/VDA | 1 mil |
| A-11 | N7-W-A11 | SiOx/Kapton HN/ SiOx/Al | 1 mil | B-11 | N7-W-B11 | SiOx/Kapton HN/ SiOx/Al | 1 mil |
| A-12 | N7-W-A12 | SLA****/DC93-500 (no backup) | 8 mil | B-12 | N7-W-B12 | SLA/DC93-500 (no backup) | 8 mil |

*VDA: Vapor deposited aluminum
**CP1: Clear polyimide
***FEP: Fluorinated ethylene propylene
****SLA: Stretched Lens Array

## Post-Flight Procedures

- Post-flight photo documentation
  - Photos of samples on holder
  - Photos of individual samples (off holder)
- The samples were divided into two groups: Group A and Group B
- Group A: Bend Test Samples
  - Prior to testing the actual samples, practice tests were performed on x-ray exposed samples
  - Bend testing determines the amount of strain required to produce surface cracks
- Group B: Tensile Test Samples
  - Tensile testing tests bulk embrittlement
  - Sample thicknesses will be measured prior to tensile testing

## Bend Test Procedures

- Half the samples are to be analyzed for space-induced embrittlement using a non-standard bend-test procedure in which the strain to induce surface cracking was determined
- Testing is conducted on a semi-suspended pliable surface held up with two supports to bend the samples without imposing a bulk tensile stress
- Successively smaller mandrels (cylindrical steel pieces) were used to apply surface strain to samples. There were 23 mandrels (dia. range: 1.253 cm to 0.052 cm), providing varying strains. As diameter of mandrel decreased, strain on sample surface increased

*E = % Strain*
*t = film thickness (cm)*
*d = mandrel diameter (cm)*

$$E = (t/(d+t)) \times 100$$

Figure 1

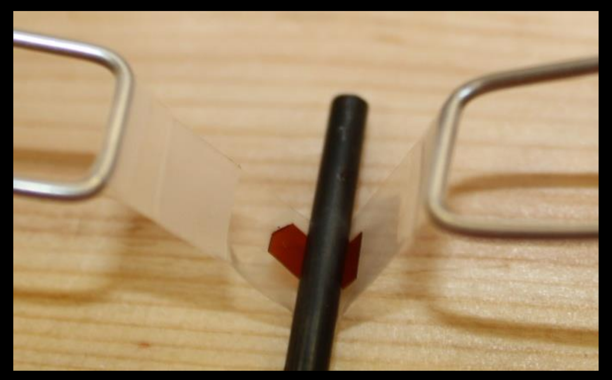


Figure 2

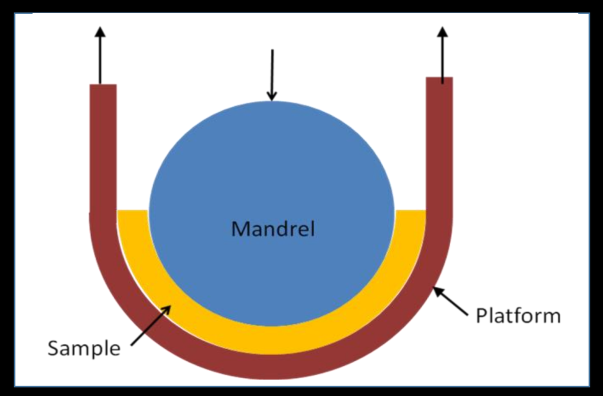


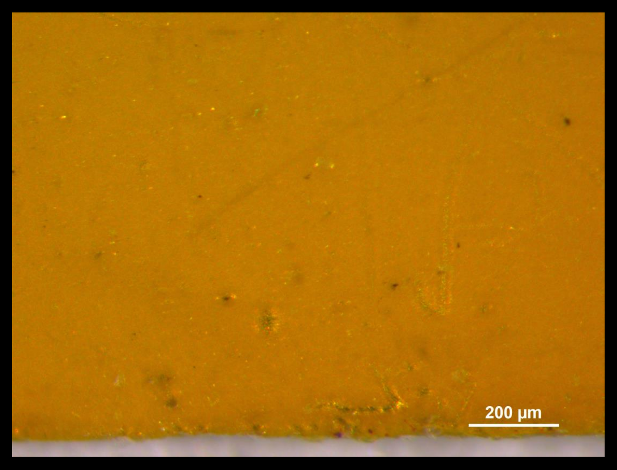

Figure 3

Figure 1: The bend test mechanism in its idle state; the polymer being tested rests atop the Kapton stretched across the center

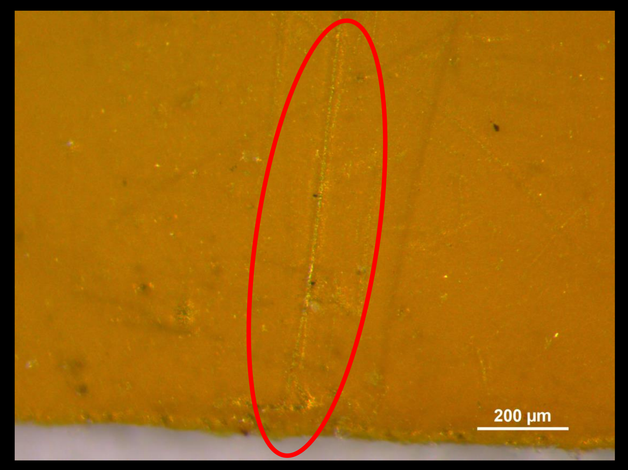
Figure 2: The bend test mechanism in its testing state; the polymer being tested wraps around the circumference of the mandrel with the space exposed surface in tension

Figure 3: Cross sectional illustration of bend testing procedure

## Post-Bend Cracking




Kapton HN/VDA sample before being bend tested




Kapton HN/VDA sample after being bend tested to 4.49% surface strain. Bend test induced crack is highlight with the red circle.

All ten flown polymers designated for bend testing have been tested. Of those ten, seven exhibited some level of cracking. Depicted above, is a Kapton HN/VDA (B-10) sample before and after being bend tested. After undergoing 4.49% surface strain, the sample began to crack. The other lines seen in the right photo are scratches, not cracks.

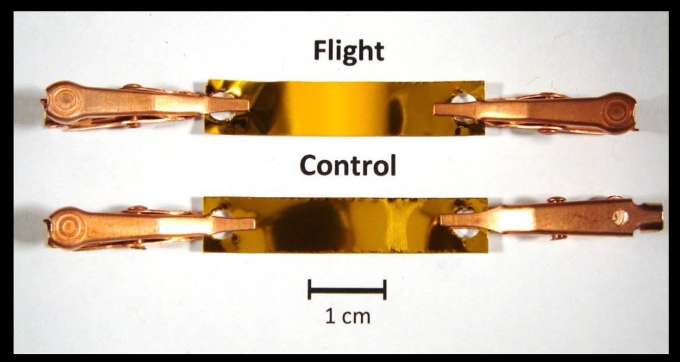
## Results

| Sample ID | Mandrel Diameter (in) | Material | Thickness (mil) | Diameter at Which Sample Cracked (in) | % Strain |
|---|---|---|---|---|---|
| A-1 | 0.25 | Kapton XC/Al | 1 | Did Not Crack (DNC) | |
| A-3 | | Si/Kapton E/ VDA/Inconel/VDA | 2 | 0.071 | 2.75% |
| A-7 | | CP1/VDA | 1 | 0.107 | 0.93% |
| A-9 | | FEP/VDA | 5 | 0.038 | 11.73% |
| A-10 | | Kapton HN/VDA | 1 | DNC | |
| B-1 | 0.375 | Kapton XC/Al | 1 | DNC | |
| B-3 | | Si/Kapton E/ VDA/Inconel/VDA | 2 | 0.107 | 1.84% |
| B-7 | | CP1/VDA | 1 | 0.143 | 0.70% |
| B-9 | | FEP/VDA | 5 | 0.355 | 1.39% |
| B-10 | | Kapton HN/VDA | 1 | 0.021 | 4.49% |

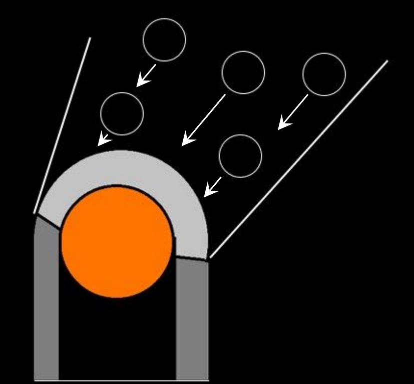
Since the polymers are being tested with steel mandrels, it is hard to ensure that they will remain unmarked, thus scratches will most likely appear. It is important to make sure scratches are not mistaken for cracks, as they can often be difficult to tell apart. Additionally, when the 0.375 diameter holder was returned, it was discovered that sample B-12 was missing from the holder. It is assumed that it broke off during flight. As a result of this, testing cannot be performed on the sample.

## Unexpected Atomic Oxygen

The samples were flown in the wake orientation with the intent of exposing them to very little AO. Ideally the only variable would be the fact that they were wrapped around different diameter mandrels while in flight. Upon observation, however, it was evident that the samples had in fact received some AO exposure (AO fluence of 2.9 x $10^{20}$ atoms/cm$^2$ (Ref. 1)). The ISS was rotated during a part of the mission causing the samples to be flown temporarily in the ram orientation. Calculations to determine the AO arrival angle will be performed based on the measurements of erosion texture on the samples.




Kapton HN/VDA before and after being exposed to the space environment. AO degradation can be seen in the flight sample.



Cross section illustration of AO hitting a sample

## Summary and Conclusion

Of the 10 FSEE flight samples tested, seven show increased embrittlement through bend-test induced cracking at surface strains from 0.70% to 11.73%, as compared to the control samples which did not crack. The more embrittled a sample is, the less post-flight strain is necessary to induce post-flight cracking. The samples under less stress on-orbit (B samples, 0.375 in. dia.) cracked under less strain with post-flight bend-testing than the same samples under greater stress on-orbit (A samples, 0.25 in. dia.). These results show that the more stress undergone during flight, the more strain needed for the material to crack post-flight. The CP1/VDA samples (A and B) were most embrittled and cracked under the smallest strain. The Kapton XC/Al samples were the least embrittled, and neither the A nor the B sample cracked post-flight.

## Future Work

In the future, the flight and control samples designated for tensile testing will be tested to determine mechanical property degradation. The tensile results will be compared to the surface embrittlement bend test data to help determine which materials are most sensitive to space induced embrittlement and to see if surface embrittlement correlates with bulk embrittlement.


Ref 1: de Groh, K. K. et al, NASA TM 2016-219167, March 2017.