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

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2017 International Space Station Research and Development Conference
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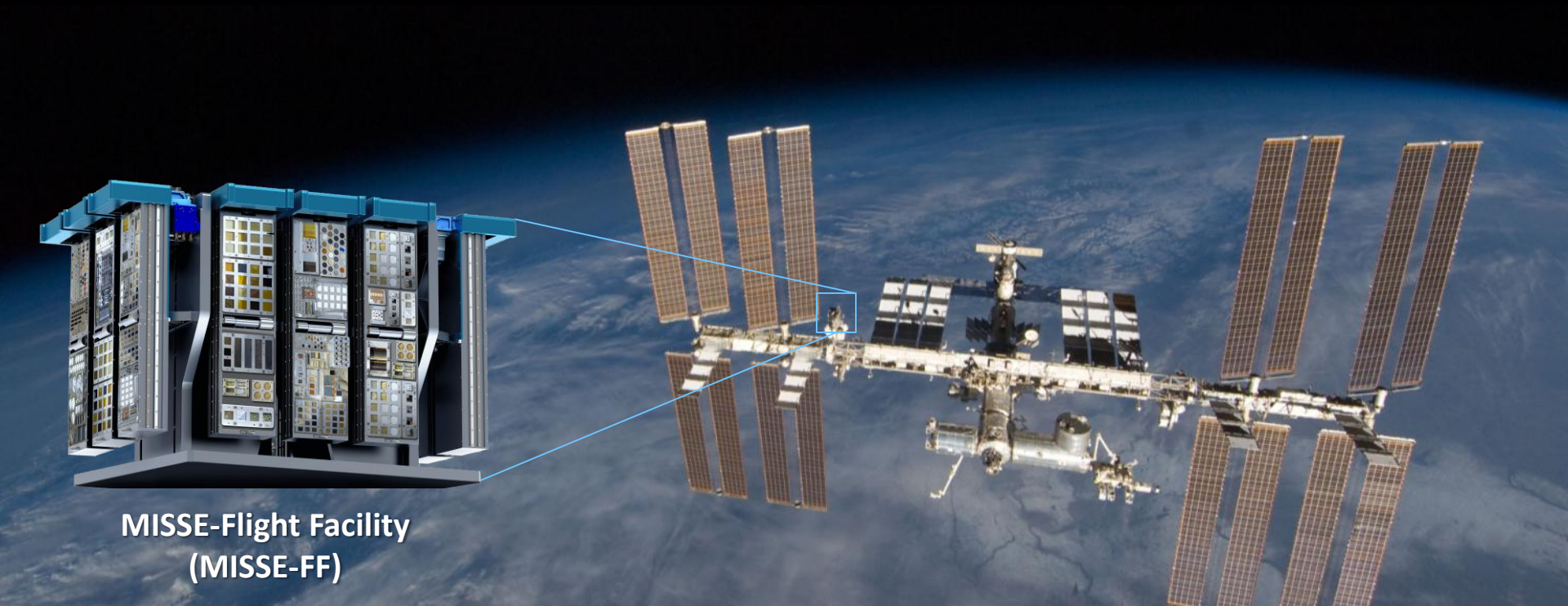
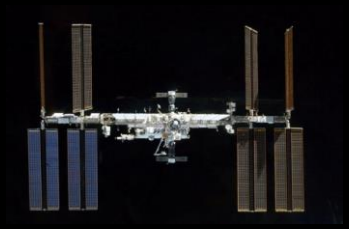
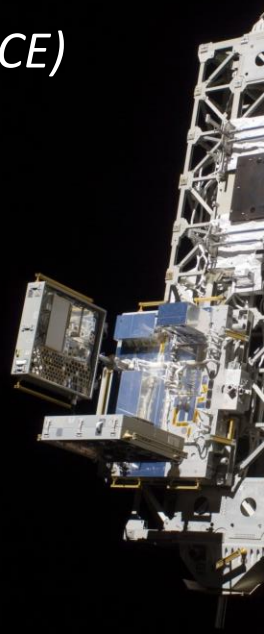


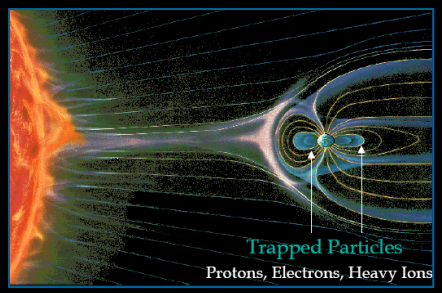
MISSE-Flight Facility (MISSE-FF)



Outline

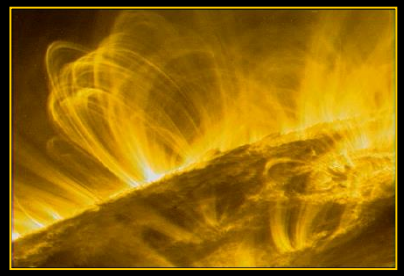
- Introduction to the space environment
  - *Examples of spacecraft damage*
- Materials International Space Station Experiment (MISSE)
  - *Overview of Glenn's MISSE 1-8 polymers flight experiments*
- MISSE-Flight Facility (MISSE-FF)
  - *Introduction to MISSE-FF*
  - *Glenn's MISSE-9 Polymers and Composites Experiment (PCE)*
    - *Ram, Wake & Zenith*
- Polymers and Composites Experiment Summary





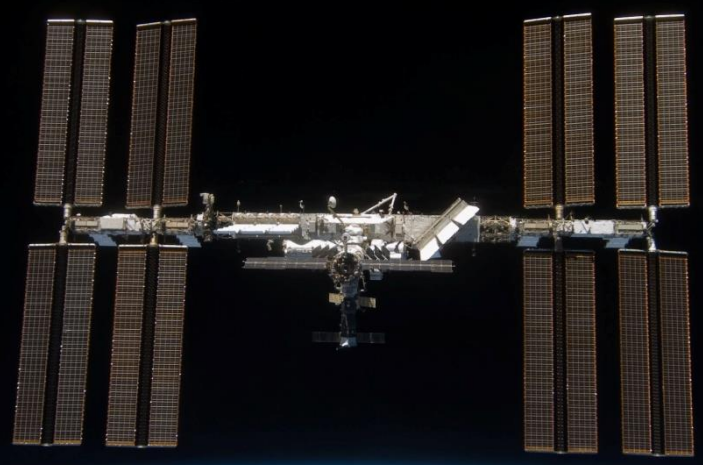
Materials on the exterior of spacecraft are exposed to many harmful environmental threats

The Space Environment

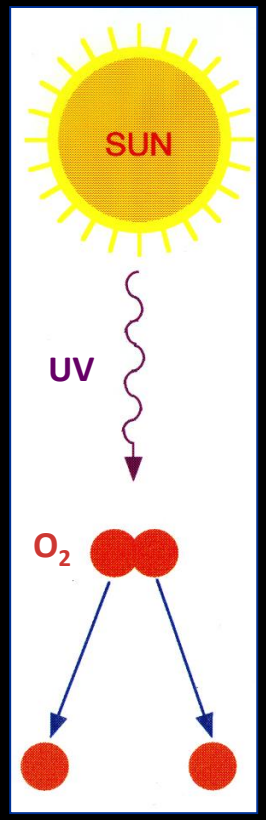


In low Earth orbit (LEO) environmental threats include:

- 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)

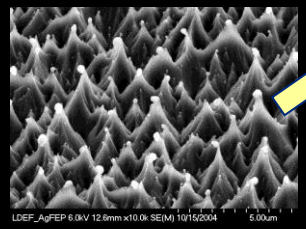


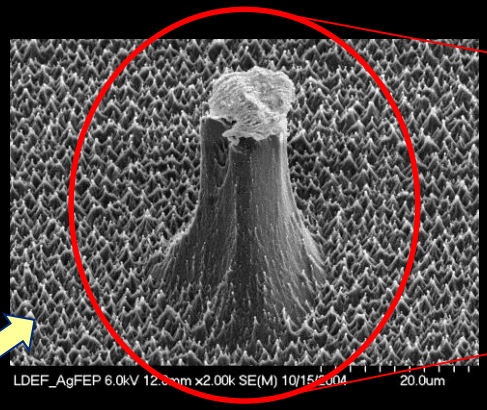
Atomic Oxygen

- AO is the predominant species in LEO (≈200-650 km)
- It is formed by photodissociation of molecular oxygen (O_2) 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*

Ram AO erosion causes "cone" formation





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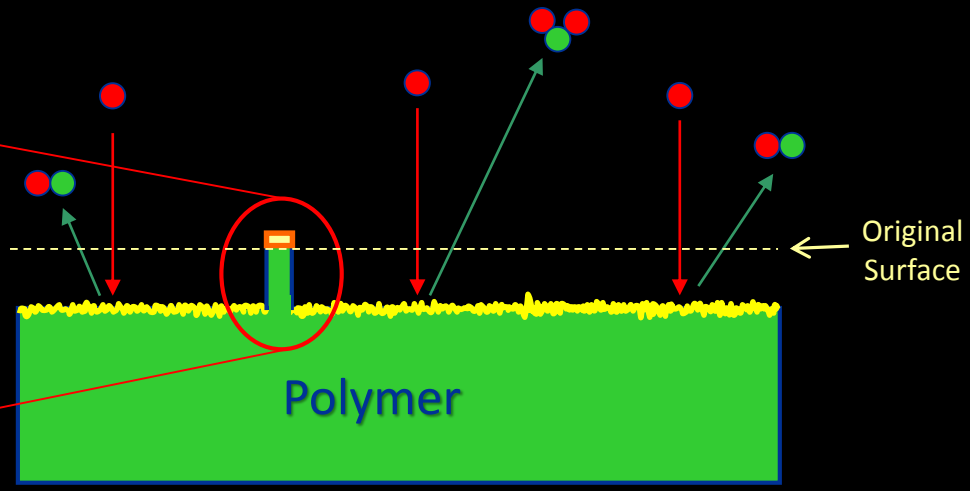
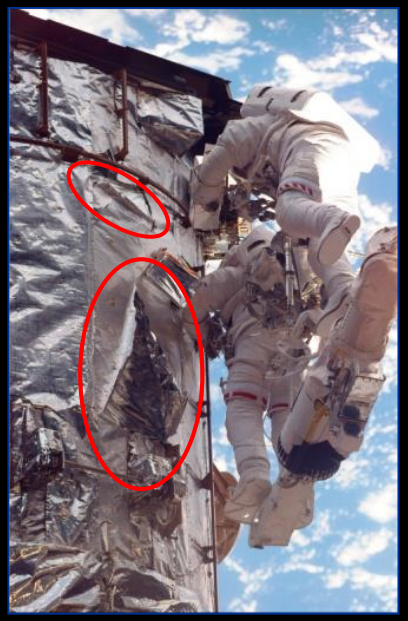


Space Environment Induced Degradation

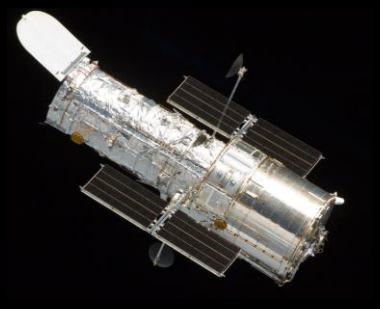
Pre-flight

Post-flight

AO erosion of Kapton blanket



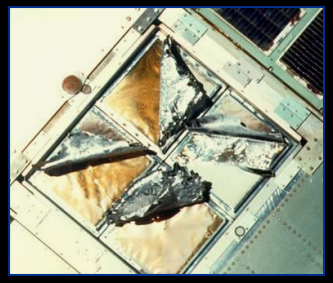
Radiation induced embrittlement & cracking of Teflon insulation (6.8 years in space)



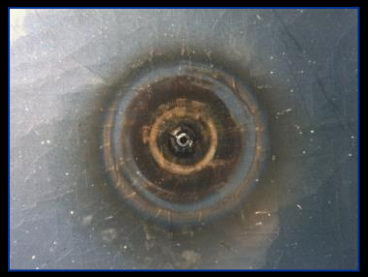
Hubble Space Telescope (HST)

Long Duration Exposure Facility **(LDEF)**

5.8 years in space



Structural degradation



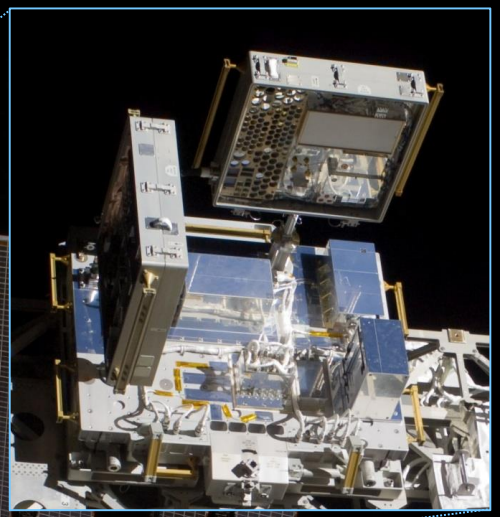
Impact site

Radiation induced darkening

Materials International Space Station Experiment (MISSE)

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

MISSE 7A & 7B
November 2009
STS-129

Flight Orientations & Environmental Exposures

Ram:

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

Wake:

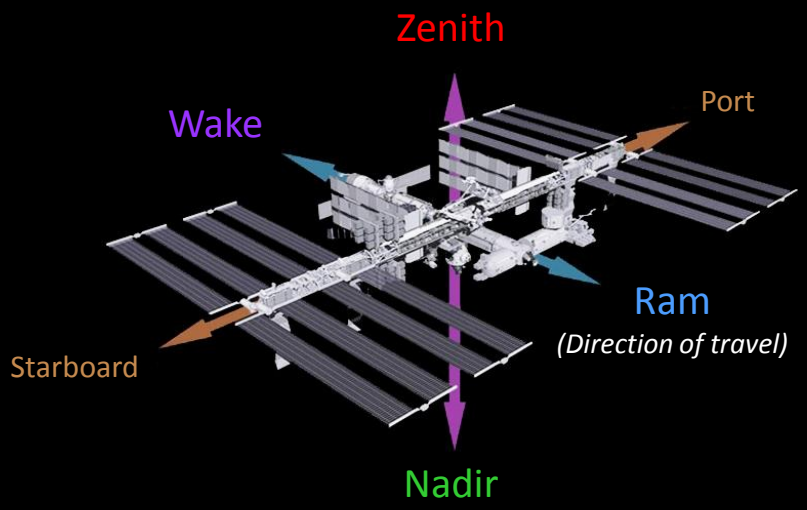
- *Facing away from the direction of travel (i.e. aft pointing or trailing edge)*
- *<u>Very little AO</u> & moderate solar exposure*

Zenith:

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

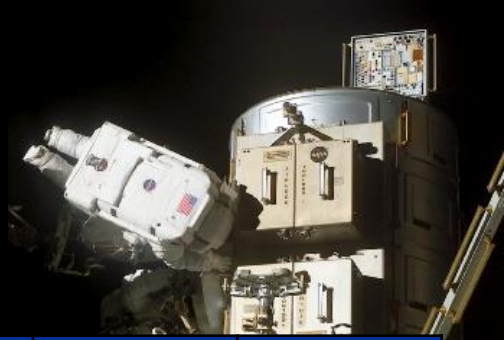
Nadir:

- *Direction facing towards Earth (i.e. straight down)*
- *Grazing AO & <u>lowest solar exposure</u>*



MISSE 1-8

Mission Summary



MISSE PEC	Launch Mission	Date Placed Outside ISS	Location on ISS	Tray Orientation	Retrieval Mission	Date Retrieved from Outside of ISS	LEO Exposure Duration (years)
1 & 2	STS-105	8/16/2001	PEC 1: High Pressure Gas Tank (HPGT) PEC 2: Quest Airlock	Ram & Wake	STS-114	7/30/2005	**3.95**
3 & 4	STS-121	8/3/2006*	PEC 3: HPGT PEC 4: Quest Airlock	Ram & Wake	STS-118	8/18/2007	**1.04**
5	STS-114	8/3/2005	Aft P6 Trunion Pin Handrail	Zenith & Nadir	STS-115	9/15/2006	**1.12**
6A & 6B	STS-123	3/22/2008	Columbus Laboratory	Ram & Wake	STS-128	9/1/2009	**1.45**
7A & 7B	STS-129	11/23/2009	EXPRESS Logistics Carrier 2 (ELC 2) on the S3 Truss	7A: Zenith & Nadir 7B: Ram & Wake	STS-134	5/20/2011	**1.49**
8 & ORMatE-III R/W	STS-134	8: 5/20/2011 ORMatE-III R/W: 7/12/2011**	EXPRESS Logistics Carrier 2 (ELC 2) on the S3 Truss	8: Zenith & Nadir ORMatE-III R/W: Ram & Wake	SpaceX-3 Dragon	7/9/2013	MISSE 8: **2.14** ORMatE-III: **2.00**

** Deployed during Expedition 13*

*** Deployed during STS-135*

ORMatE-III R/W: Optical Reflector Materials Experiment III Ram/Wake

MISSE 1-8

Polymer Experiments

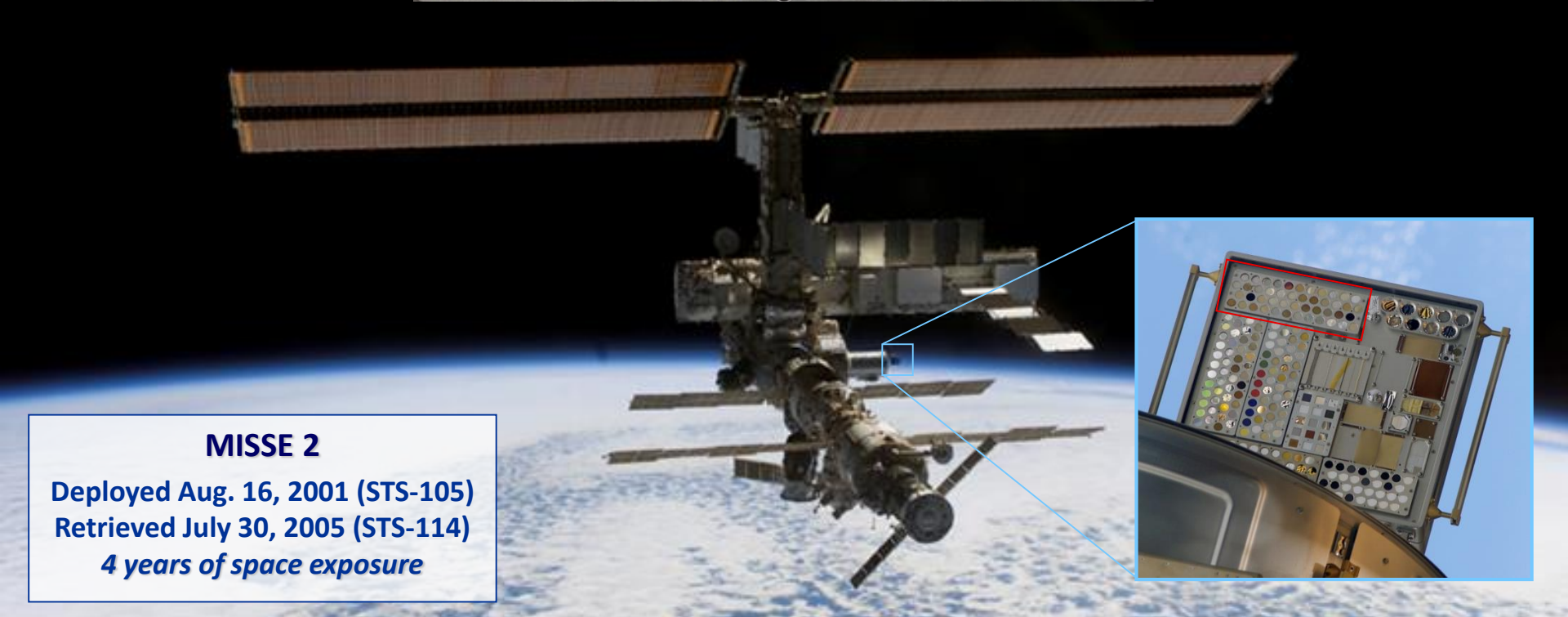
6 experiments with 195 flight samples

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

The MISSE 2 Polymers Experiment

Objective: To determine the AO erosion yield (Ey) of a wide variety of polymers exposed for an extended period of time to the LEO AO space environment

Pre-flight



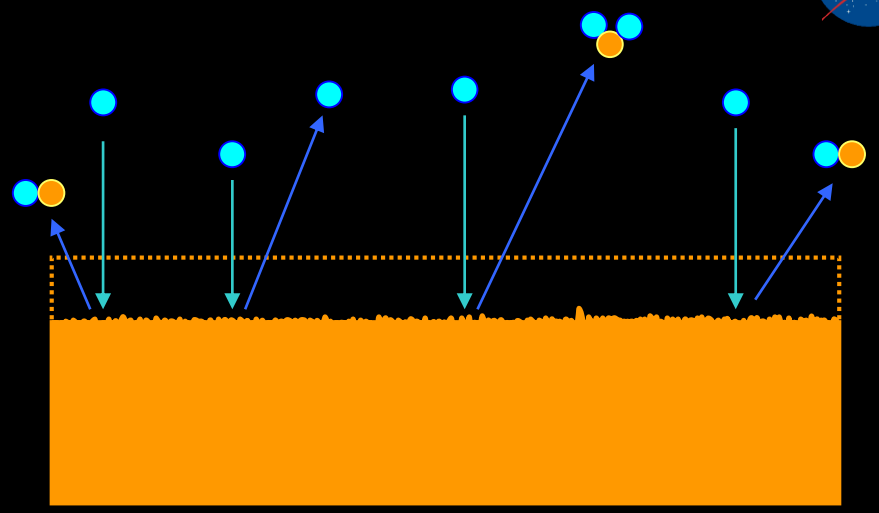
MISSE 2

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 (cm^3/atom)



Ey based on Mass Loss Measurements

Erosion Yield (E_y) of Sample

$$E_y = \frac{\Delta M_s}{A_s \rho_s F_k}$$

where:
- ΔM_s = Mass loss of polymer sample (g)
- A_s = Area of polymer sample (cm^2)
- ρ_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:
- ΔM_k = Mass loss of Kapton H witness (g)
- A_k = Area of Kapton H witness (cm^2)
- ρ_k = Density of Kapton H sample (1.427 g/cm^3)
- E_k = Erosion yield of Kapton H (3.0×10^{-24} cm^3/atom)

MISSE 2 Polymers Experiment

Pre-flight

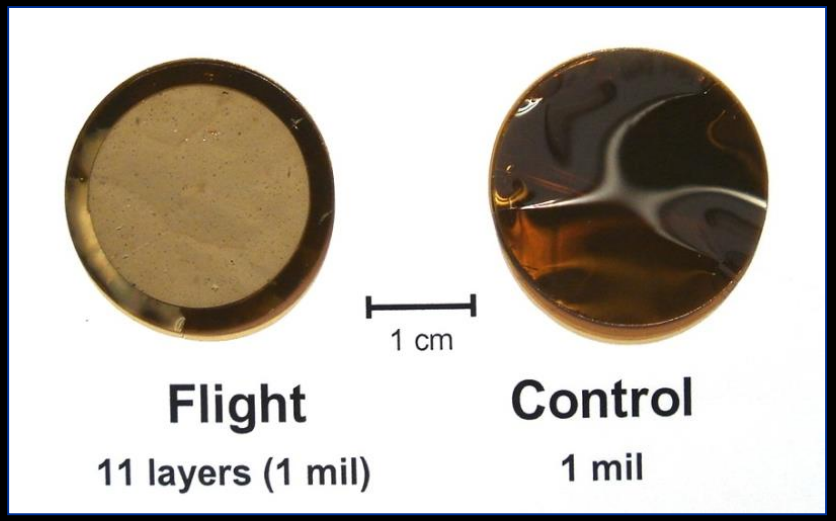
Post-flight

Polyimide (PMDA)
Upilex-S

2-E5-32

Post-flight photos

In flight tray

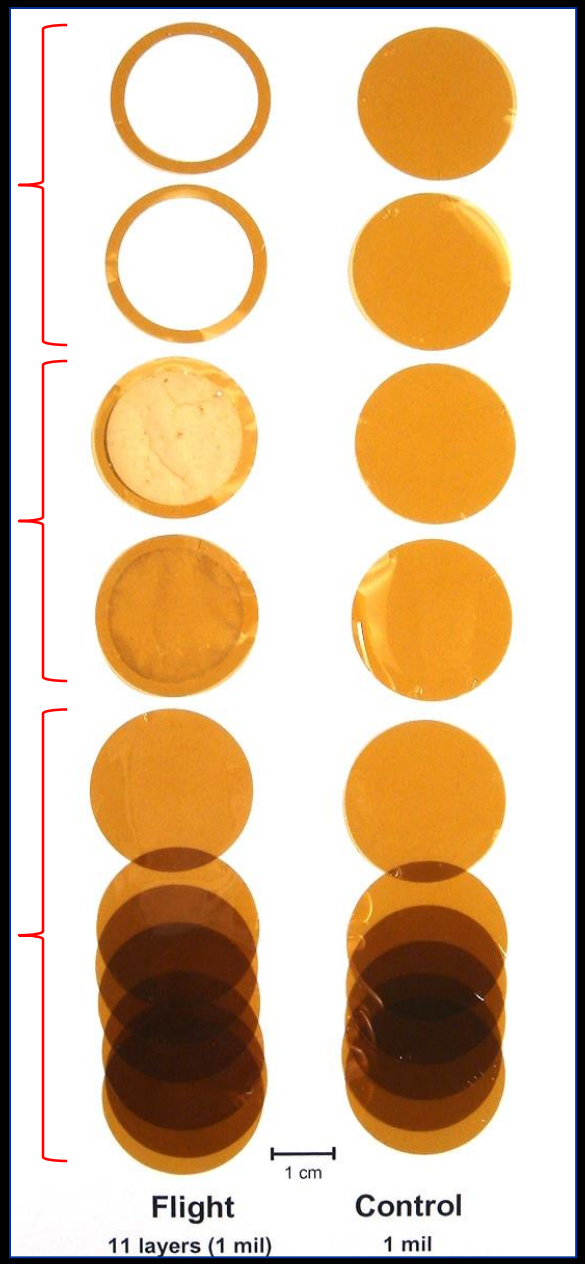


Out of tray

Complete erosion

Partial erosion

No erosion

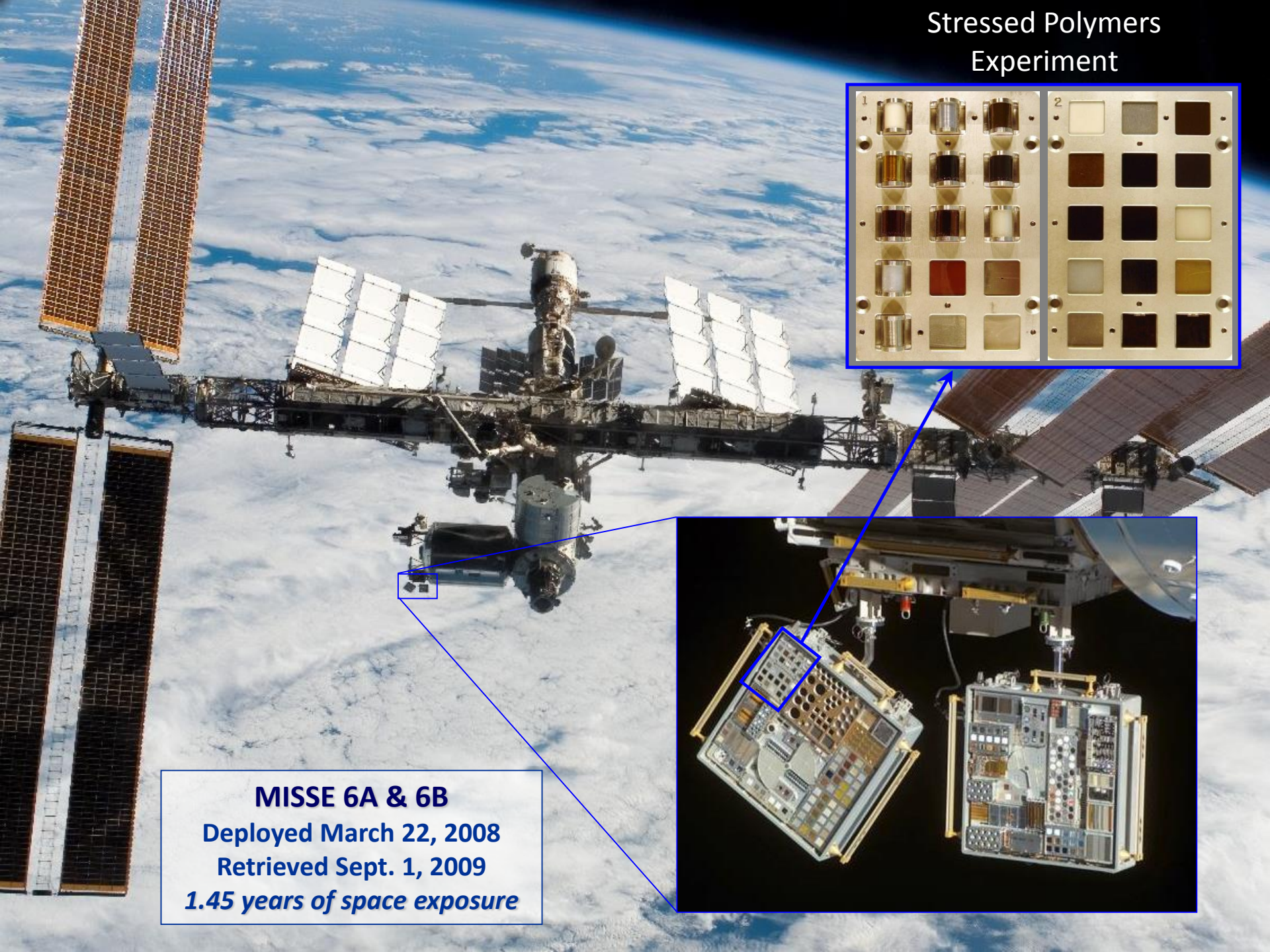


MISSE 2 Polymers Erosion Yield Data

Polymer Abbreviation	E_y (cm^3/atom)	E_y Uncertainty (%)	Polymer Abbreviation	E_y (cm^3/atom)	E_y Uncertainty (%)
ABS	1.09E-24	2.7	PEI	*> 3.31E-24**	2.6
CA	5.05E-24	2.7	PA 6	3.51E-24	2.7
PPD-T (Kevlar)	6.28E-25	2.6	PA 66	1.80E-24	12.6
PE	*> 3.74E-24**	2.6	PI (CP1)	1.91E-24	2.8
PVF (Tedlar)	3.19E-24	2.6	PI (Kapton H)	3.00E-24	2.7
PVF (White Tedlar)	1.01E-25	4.1	PI (Kapton HN)	2.81E-24	2.6
POM (Delrin)	9.14E-24	3.1	PI (Upilex-S)	9.22E-25	3.0
PAN	1.41E-24	3.3	PI (PMR-15)	*> 3.02E-24**	2.6
ADC (CR-39)	*> 6.80E-24**	2.6	PBI	*> 2.21E-24**	2.6
PS	3.74E-24	2.7	PC	4.29E-24	2.7
PMMA	*> 5.60E-24**	2.6	PEEK	2.99E-24	4.5
PEO	1.93E-24	2.6	PET (Mylar)	3.01E-24	2.6
PBO (Zylon)	1.36E-24	6.0	CTFE (Kel-f)	8.31E-25	2.6
EP	4.21E-24	2.7	ECTFE (Halar)	1.79E-24	2.6
PP	2.68E-24	2.6	ETFE (Tefzel)	9.61E-25	2.6
PBT	9.11E-25	2.6	FEP	2.00E-25	2.7
PSU	2.94E-24	3.2	PTFE	1.42E-25	2.6
PU	1.56E-24	2.9	PFA	1.73E-25	2.7
PPPA (Nomex)	1.41E-24	2.9	AF	1.98E-25	2.6
PG	4.15E-25	10.7	PVDF (Kynar)	1.29E-24	2.7

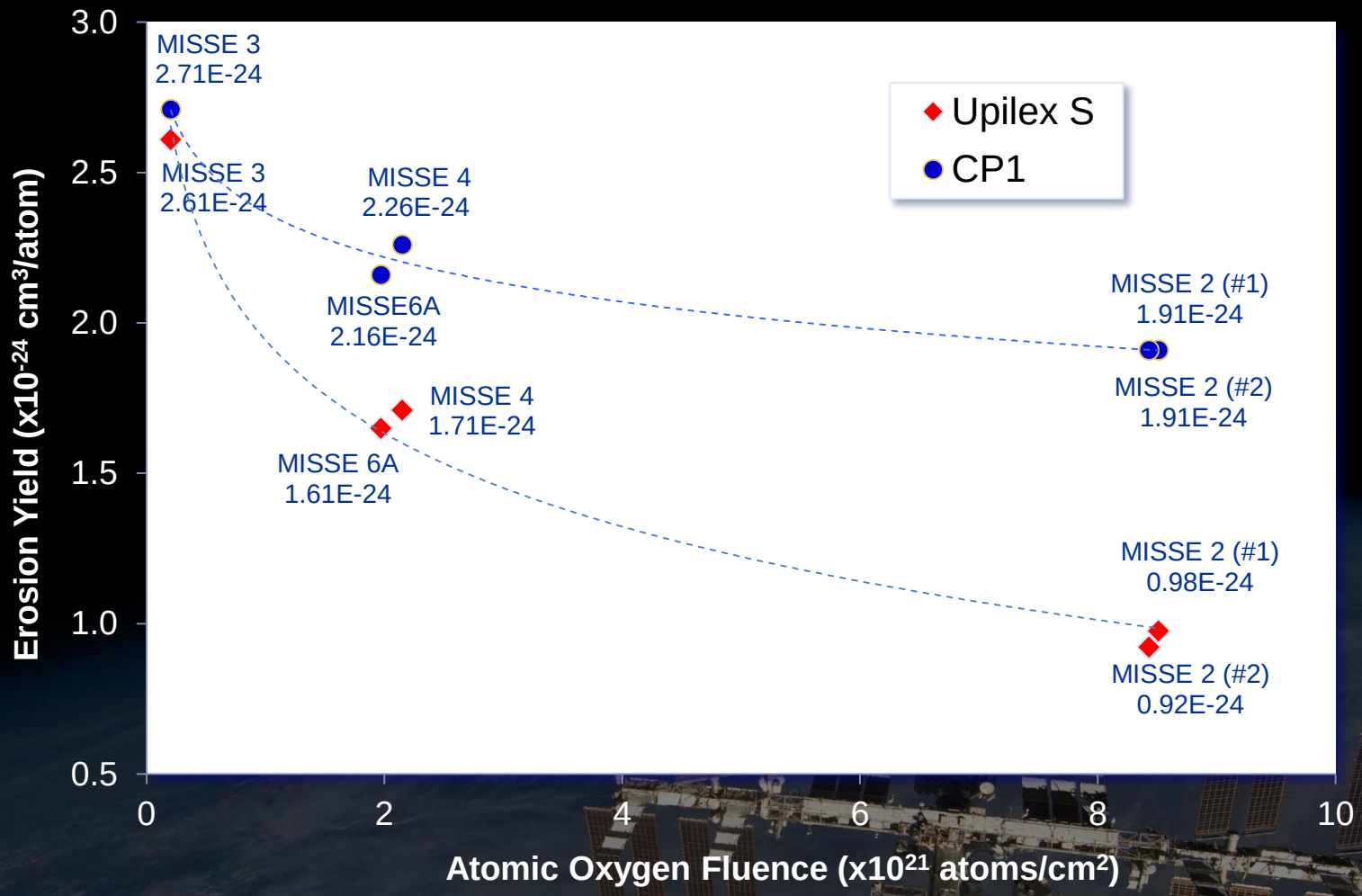
*E_y > this value because sample stack was partially, or fully, eroded through

Ave. uncertainty: 3.30%


Stressed Polymers Experiment
MISSE 6A & 6B
Deployed March 22, 2008
Retrieved Sept. 1, 2009
1.45 years of space exposure

Upilex-S and CP1 (Clear Polyimide)

Erosion Yield Vs. AO Fluence



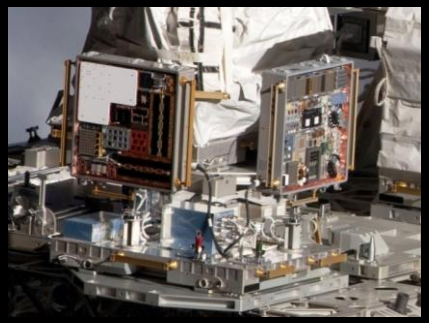
⇒ *Flying the same polymer on various MISSE missions provides important information on erosion dependence on environmental exposure*

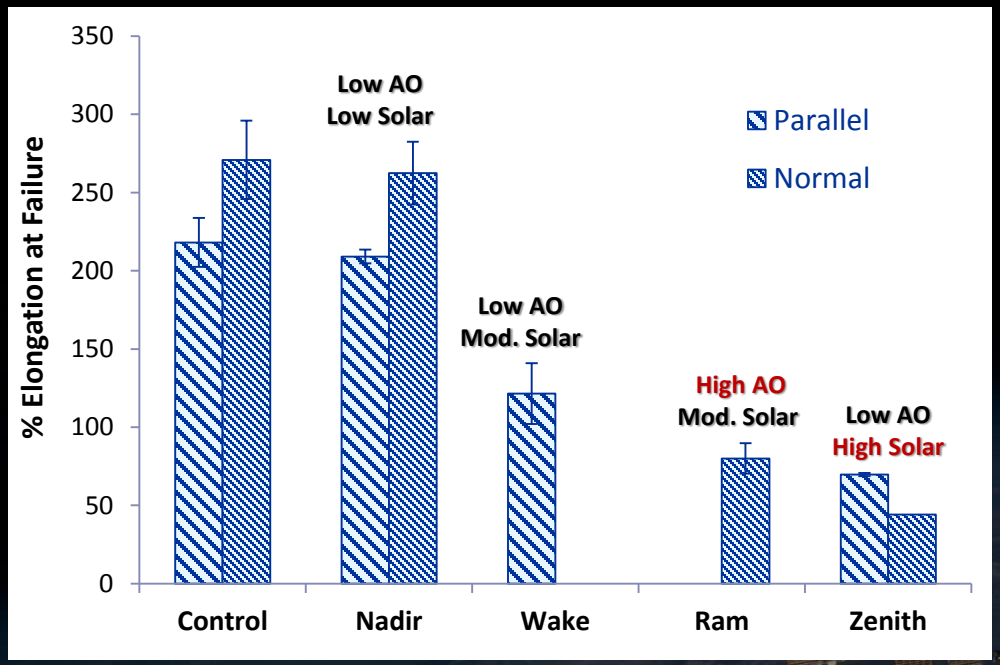
⇒ *An objective of MISSE-9 PCE is to obtain E_y vs. AO fluence data for additional spacecraft polymers*

MISSE 7

Al-FEP

% Elongation at Failure vs. Environmental Exposure



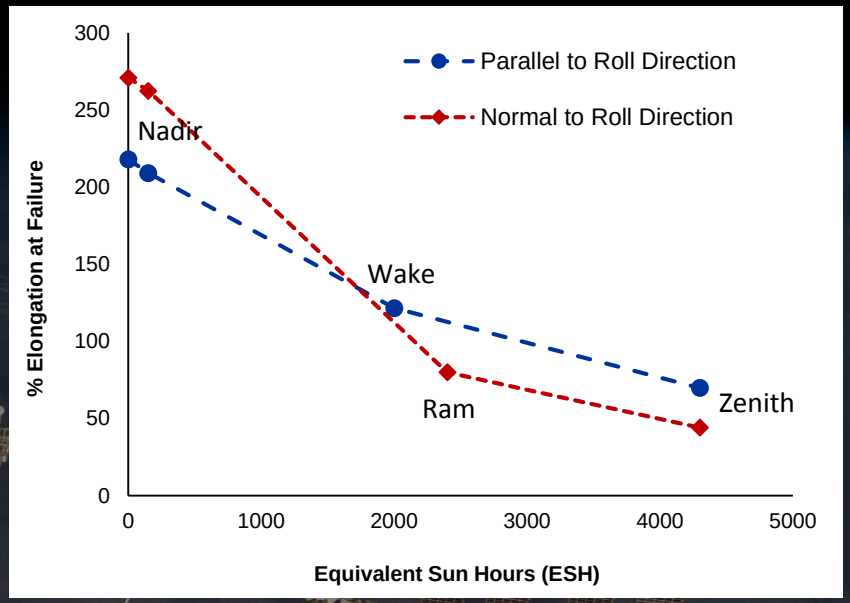


Nadir
150 ESH*
AO F= ~1.6×10^{20} atoms/cm^2

Ram
2,400 ESH
AO F= 4.2×10^{21} atoms/cm^2

Wake
2,000 ESH
AO F= 2.9×10^{20} atoms/cm^2

Zenith
4,300 ESH
AO F= 1.6×10^{20} atoms/cm^2



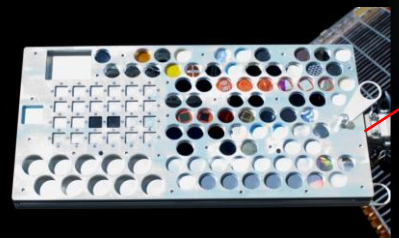
Parallel: *Tensile samples sectioned parallel to the manufacture roll direction*
Normal: *Tensile samples sections normal to the manufacture roll direction*

Al-FEP: Aluminized-Teflon fluorinated ethylene propylene

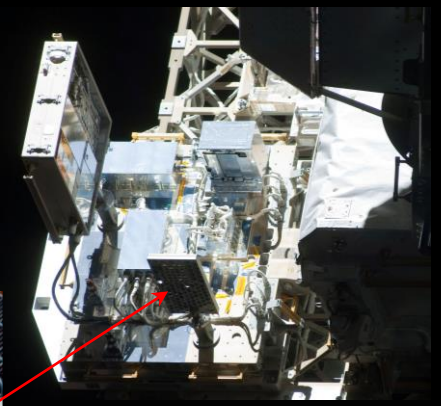
**Nadir ESH was estimated at 150 ESH (no direct solar exposure, albedo reflected only)*

MISSE 8

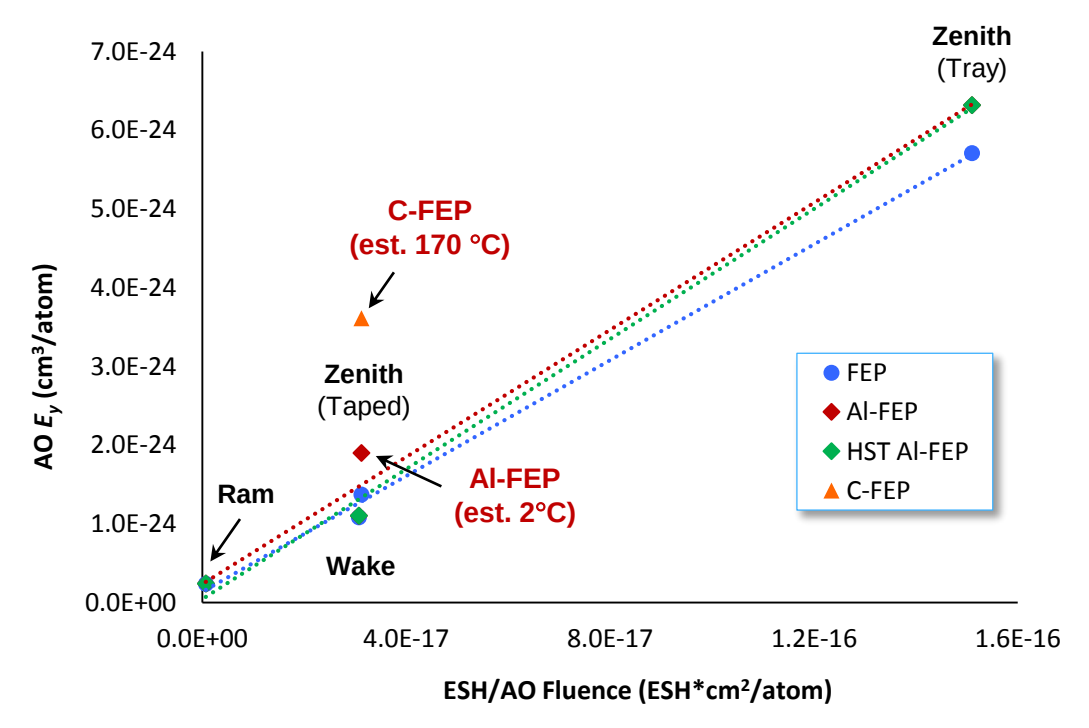
Teflon FEP AO E_y vs. Equivalent Sun Hours (ESH)/AO Fluence



ORMatE-III
Wake Surface



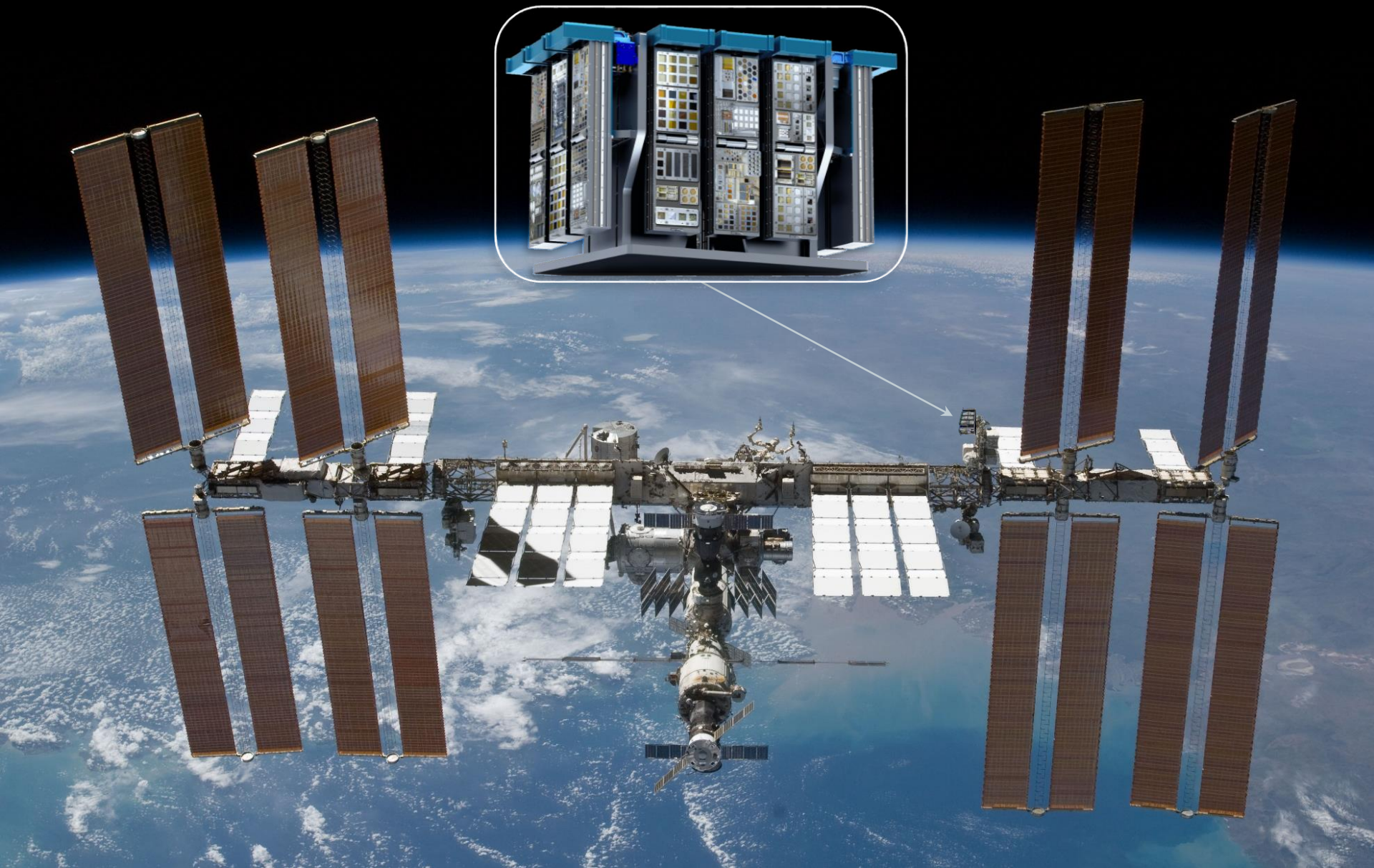
- *Excellent correlation of AO E_y to ESH/AO fluence ratio:*
  - *Shows the effect of solar radiation and/or heating due to solar exposure on erosion of FEP*
- *C-FEP (170 ℃) has a significantly higher E_y than Al-FEP (2 ℃) for the same exposure:*
  - *Heating has a major impact on the Ey of FEP in the zenith orientation*



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)

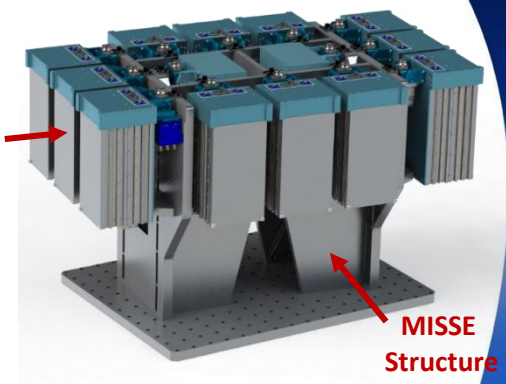


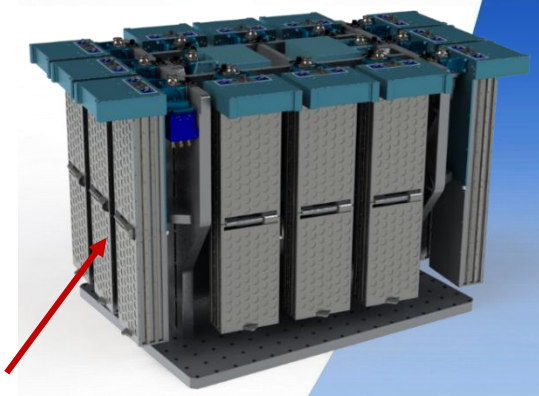
Materials International Space Station Experiment-Flight Facility (MISSE-FF)

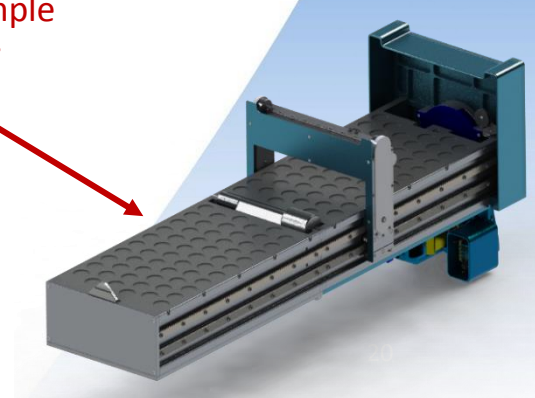
Alpha Space Test & Research Alliance, LLC

http://www.alphaspace.com/

- 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







Images courtesy of Alpha Space

MISSE-9
Polymers and Composite Experiment (PCE)

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)

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:

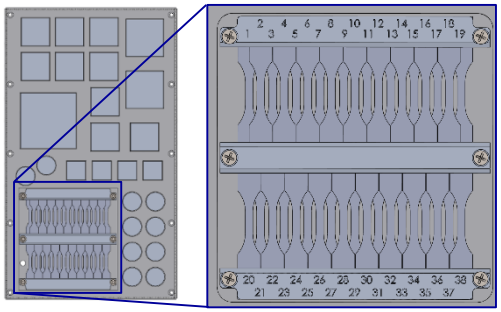
- Passive experiment with 138 samples flown in ram, wake & zenith orientations
  - 39 Ram, 52 Wake (38 tensile) & 47 Zenith (24 tensile)
- Pre-flight & post-flight data will be measured in ground-facilities

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

PCE (138 flight samples)

39 Ram, 52 Wake & 47 Zenith



Images courtesy of Alpha Space

MISSE-9 PCE Ram Samples

MISSE-9 ID	Material	Abbrev.	# Layers	Total thickness (inch)	C or S	Size (inch)
M9R-C1	Polyimide (PMDA) (Kapton H)	Kapton H	2	0.010	C	1
M9R-C2	Polyimide (PMDA) (Kapton H)	Kapton H	2	0.010	C	0.8
M9R-C3	Polyimide (PMDA) (Kapton H)	Kapton H	2	0.010	C	0.65
M9R-C4	Polyimide (PMDA) (Kapton H)	Kapton H	2	0.010	C	0.5
M9R-C5	Polyimide (PMDA) (Kapton HN)	Kapton HN	2	0.010	C	1
M9R-C6	Alumina slide	Al_2O_3	1	0.063	C	1
M9R-C7	Polyoxymethylene (Delrin acetal)	POM	2	0.020	C	1
M9R-C8	Polyoxymethylene (Delrin acetal)	POM	2	0.020	C	0.8
M9R-C9	Polyoxymethylene (Delrin acetal)	POM	2	0.020	C	0.65
M9R-C10	Polyoxymethylene (Delrin acetal)	POM	2	0.020	C	0.5
M9R-C11	Epoxy (Locktite Heavy Duty)	Epoxy	1	0.118	C	1
M9R-C12	2.9% ZnO powder filled epoxy (Locktite)	ZnO-Epoxy	1	0.125	C	1
M9R-C13	6.3% ZnO powder filled epoxy (Locktite)	ZnO-Epoxy	1	0.125	C	1
M9R-C14	9.78% ZnO powder filled epoxy (Locktite)	ZnO-Epoxy	1	0.101	C	1
M9R-C15	Fluorinated ethylene propylene (Teflon FEP)	FEP	1	0.005	C	1
M9R-C16	Aluminized-Teflon (FEP/Al)*	Al-FEP	1	0.005	C	1
M9R-C17	Silver-Teflon (FEP/Ag/Inconel)*	Ag-FEP	1	0.005	C	1
M9R-C18	Carbon painted (India Ink) Teflon (FEP/C/FEP)*	C-FEP	1	0.015	C	1
M9R-C19	Polyimide (PMDA) (Kapton H)	Kapton H	2	0.010	C	1
M9R-C20	Polytetrafluoroethylene (Chemfilm DF 100)	PTFE	1	0.005	C	1
M9R-C21	Crystalline polyvinylfluoride, white pigment (white Tedlar)	PVF-W	1	0.002	C	1
M9R-C22	Highly Oriented Pyrolytic Graphite	HOPG	1	0.041	C	1
M9R-C23	Polyimide (BPDA) (Upilex-S)	Upilex-S	2	0.002	C	1
M9R-C24	Polyimide (CP1)	CP1	2	0.006	C	1
M9R-C25	Polyethylene terephthalate (Mylar)	PET	4	0.008	C	1
M9R-C26	Polyethylene	PE	5	0.010	C	1
M9R-C27	Magnesium Fluoride	MgF_2	1	0.108	C	1
M9R-C28	Cyanate ester graphite fiber composite (RS3-M55J 6K)	RS3-M55J 6K	1	0.062	C	1
M9R-C29	Sodium silicate/RS3-M55J 6K	$Na_2Si_3O_7$/RS3-M55J 6K	1	0.064	C	1
M9R-C30	Polyimide aerogel	Polyimide Aerogel	1	0.125	C	1
M9R-C31	Carbon nanotube (CNT) paper	Buckypaper	3	0.005	C	1
M9R-C32	Graphene nanoplatelets (GnP) paper	GnP paper	1	0.010	C	1
M9R-S1	Polyimide (PMDA) (Kapton H)	Kapton H	2	0.010	S	1
M9R-S2	Z307 (black paint)/aluminum	Z307/Al	1	0.035	S	1
M9R-S3	Ball Infrared Black (BIRB) paint/aluminum	BIRB/Al	1	0.100	S	1
M9R-S4	Carbon nanotube (CNT) coated SiC w/ 0.5 mil Kapton cover	Kapton H/ CNT/SiC	1	0.130	S	1
M9R-S5	Indium tin oxide coated Kapton HN/aluminum	ITO/Kapton HN/Al	1	0.002	S	1
M9R-S6	Indium tin oxide coated silver-Teflon	ITO/FEP/ Ag/Inconel	1	0.005	S	1
M9R-S7	Atomic Oxygen Scattering Chamber (30° angle)	AO Scatter Chamber	1	0.275	S	1

*FEP layer is space facing

39 Samples

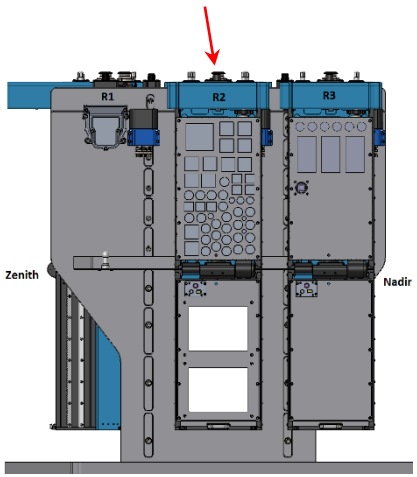
- 32 Circular (C)
- 7 Square (S)

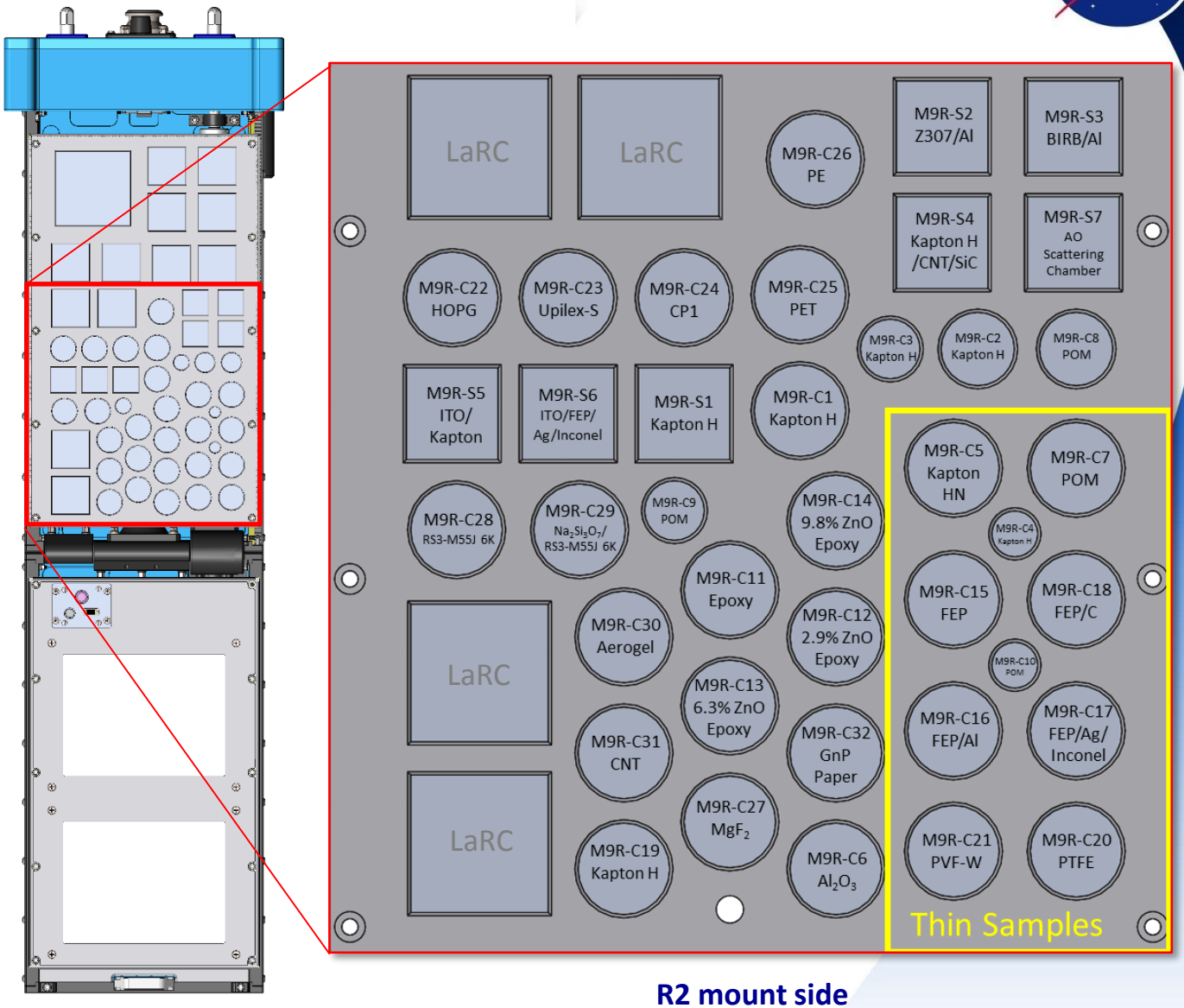
MISSE-9 PCE Ram Samples

39 samples: 32 circular (0.5 – 1-inch) & 7 square (1-inch)

MISSE-9

MISSE Sample Carrier (MSC) R2



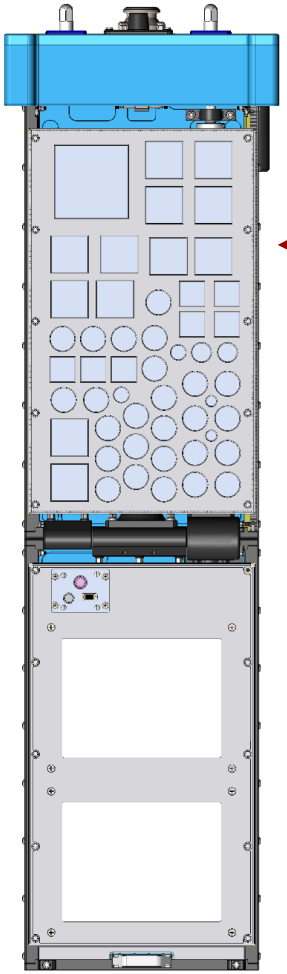


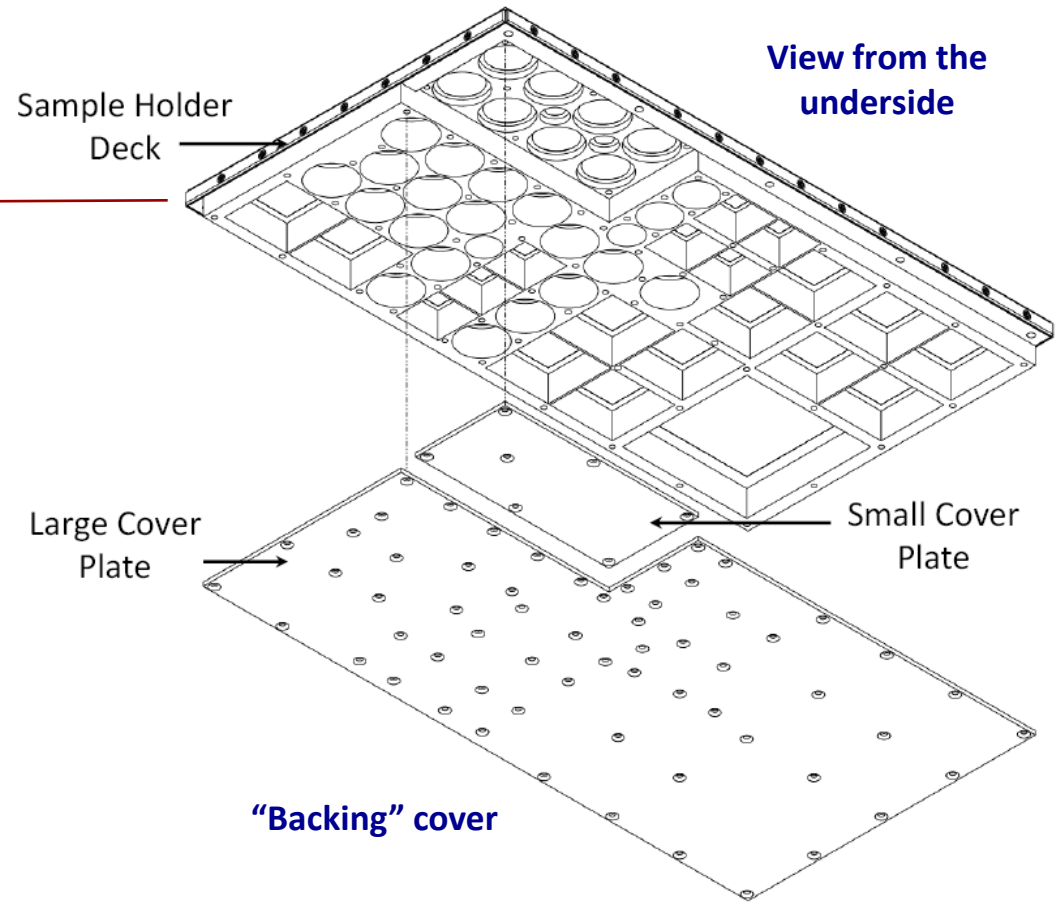
R2 mount side

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



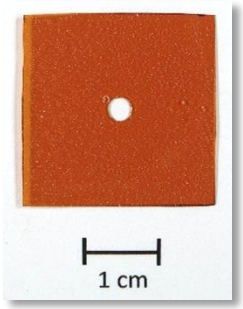


Images courtesy of Alpha Space

Overview of PCE Ram Samples

(High AO & moderate solar exposure)

- **Ram Samples:**
  - Kapton H for MISSE-9 ram AO fluence determination
  - Al_2O_3 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*
    - *MgF_2*
    - *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



AO Scattering Chamber NaCl/Kapton H

Blue: Environment data
Black: New sample data
Green: AO E_y vs. environment data
Red: Heating effects data

MISSE-9 PCE Wake
1-inch Samples

(14 Samples: 10 Circular & 4 square)

MISSE-9 ID	Material	Abbrev.	Thickness (inch)	C or S
M9W-C1	Polyimide (PMDA) (Kapton H)	Kapton H	0.005	C
M9W-C2	Polyimide (PMDA) (Kapton HN)	Kapton HN	0.005	C
M9W-C3	Alumina slide	Al_2O_3	0.063	C
M9W-C4	Fluorinated ethylene propylene (Teflon FEP)	FEP	0.005	C
M9W-C5	Aluminized-Teflon (FEP/Al)*	Al-FEP	0.005	C
M9W-C6	Silver-Teflon (FEP/Ag/Inconel)*	Ag-FEP	0.005	C
M9W-C7	Carbon painted (India Ink) Teflon (FEP/C/FEP)*	C-FEP	0.015	C
M9W-C8	Polyvinyl chloride	PVC	0.005	C
M9W-C9	Cosmic ray shielding (CRS) sample	CRS	0.039	C
M9W-C10	Shape memory composite (SMC) sample	SMC	0.236	C
M9W-S1	Indium tin oxide coated Kapton HN/aluminum	ITO/Kapton HN/Al	0.002	S
M9W-S2	Indium tin oxide coated silver-Teflon	ITO/FEP/Ag/Inconel	0.005	S
M9W-S3	Indium tin oxide coated silver-Teflon	ITO/FEP/Ag/Inconel	0.005	S
M9W-S4	Carbon nanotube (CNT) coated SiC	CNT/SiC	0.130	S

*FEP layer is space facing; C: Circular; S: Square

MISSE-9 PCE Wake Tensile Samples (38)

MISSE-9 ID	Material	Abbrev.	Thickness (inch)	Number of Samples
M9W-T1 to T5	Aluminized-Teflon (FEP/Al)* - Parallel	Al-FEP	0.002	5
M9W-T6 to T10	Aluminized-Teflon (FEP/Al)* - Normal	Al-FEP	0.002	5
M9W-T11 to T15	Aluminized-Teflon (FEP/Al)* - Parallel	Al-FEP	0.005	5
M9W-T16 to T20	Aluminized-Teflon (FEP/Al)* - Normal	Al-FEP	0.005	5
M9W-T21 to T24	Silver-Teflon (FEP/Ag/Inconel)* - Parallel	Ag-FEP	0.005	4
M9W-T25 to T29	Carbon painted (India Ink) Teflon (FEP/C)* - Parallel	C-FEP	0.002	5
M9W-T30 to T34	Carbon painted (India Ink) Teflon (FEP/C)* - Parallel	C-FEP	0.005	5
M9W-T35 to T38	Aluminized-Teflon (Al/FEP) - Parallel (Al space facing)	Al/FEP	0.002	4
			# Tensile Samples	38

*FEP is space facing

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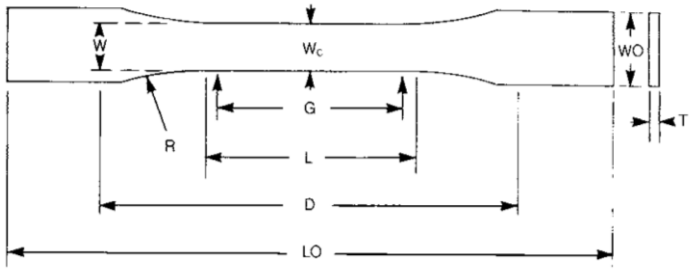


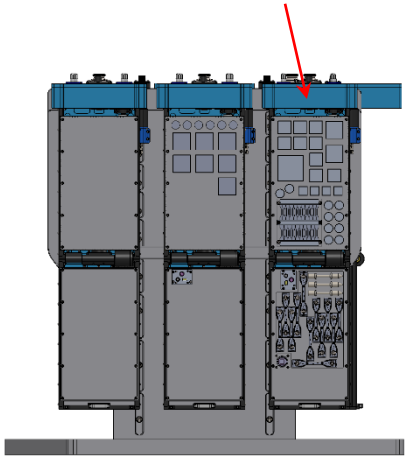
TYPES I, II, III & V

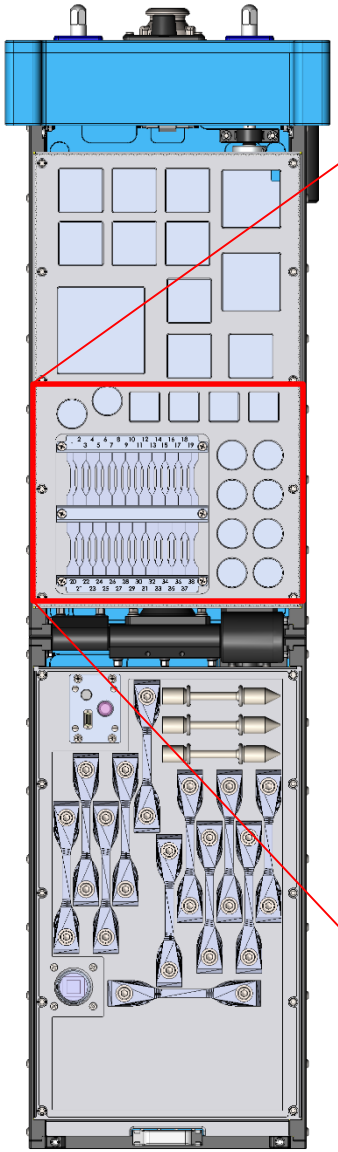
ASTM D638-08 Type V Specimen Dimensions	
W—Width of narrow section	3.18 mm (0.125 in.)
L—Length of narrow section	9.53 mm (0.375 in.)
WO—Width overall, min	9.53 mm (0.375 in.)
LO—Length overall, min	63.5 mm (2.5 in.)
G—Gage length	7.62 mm (0.300 in.)
D—Distance between grips	25.4 mm (1.00 in.)
R—Radius of fillet	12.7 mm (0.500 in.)

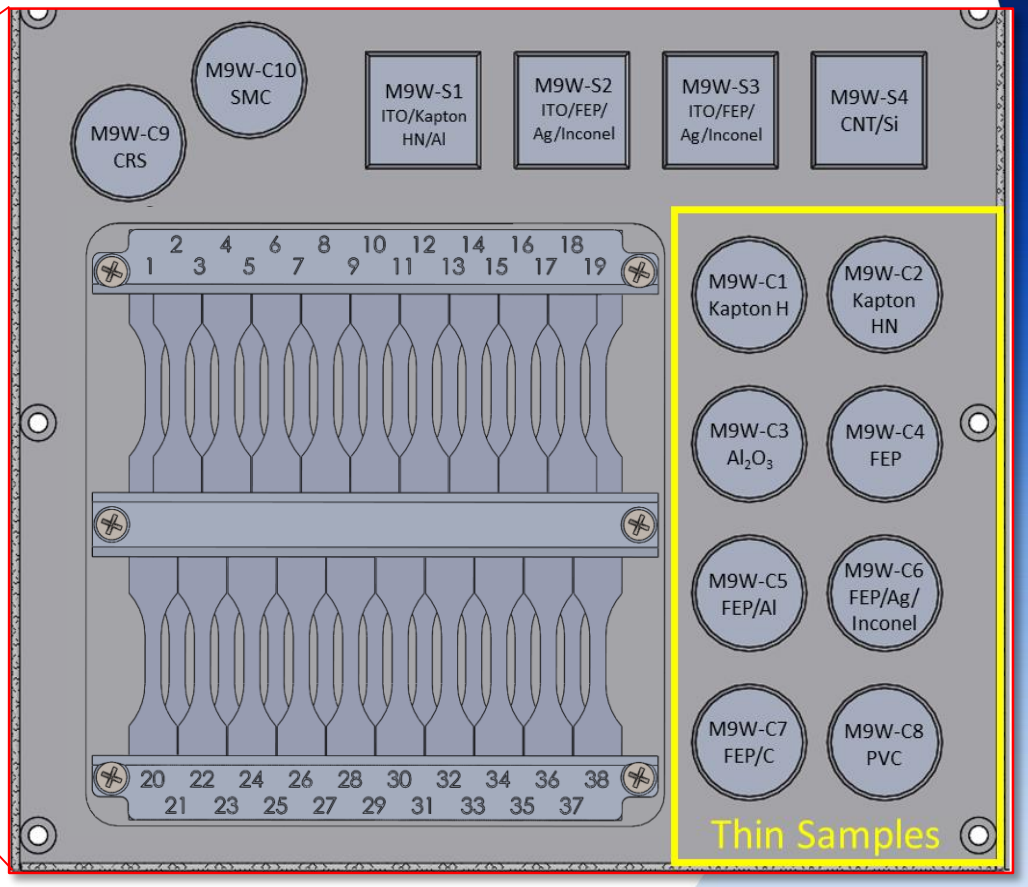
MISSE-9 PCE Wake Samples

52 samples: 38 tensile & 14 1-inch

MISSE-9
MSC W3



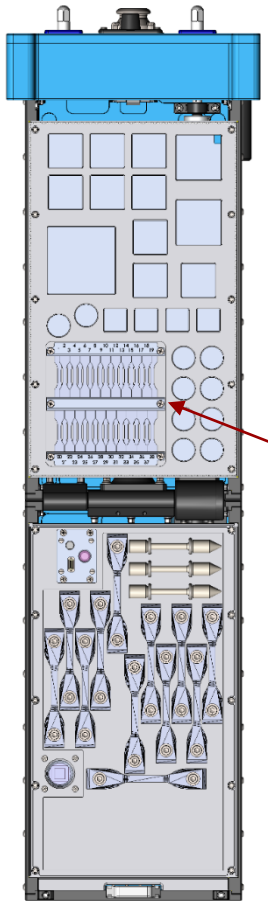


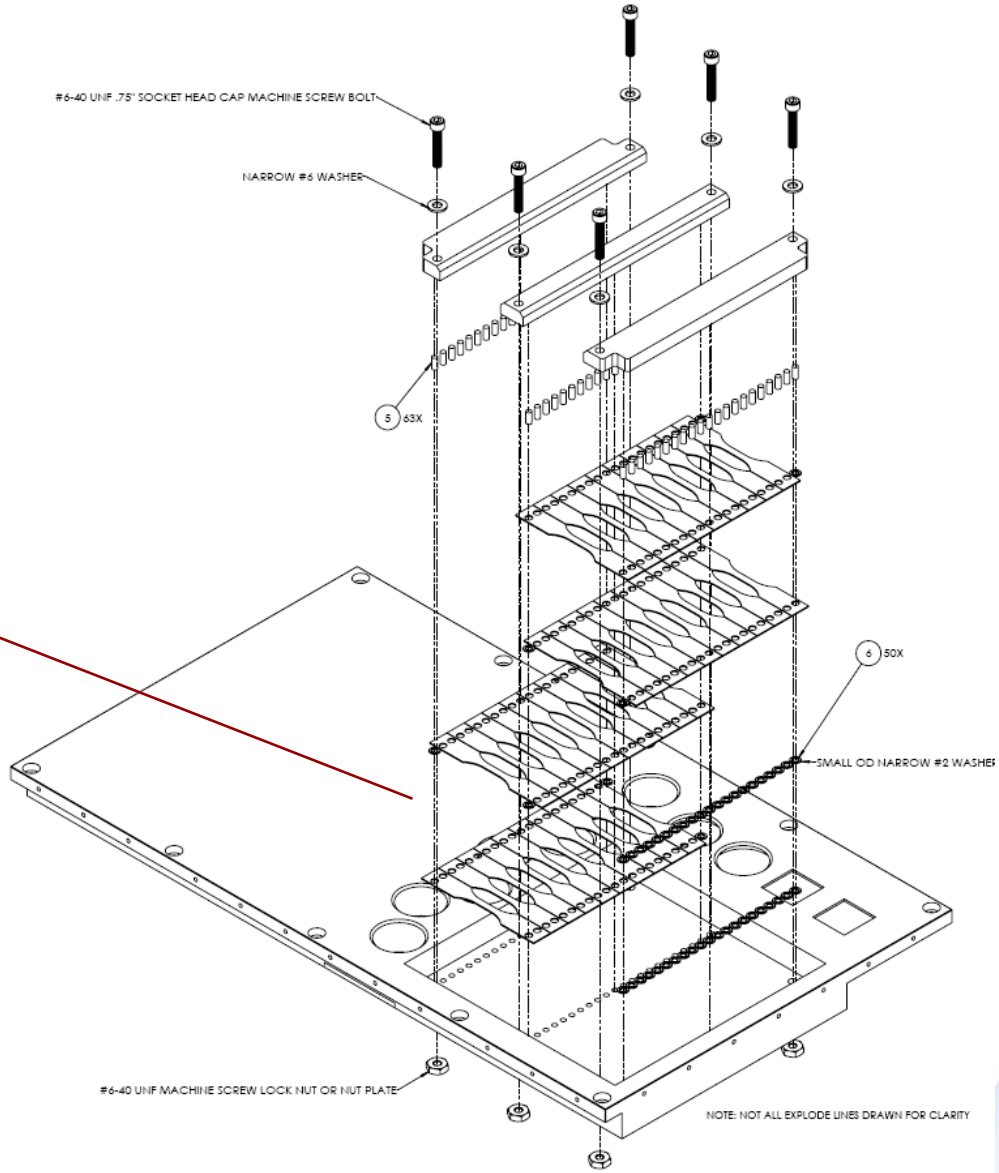


W2 mount side

Images courtesy of Alpha Space

MISSE-9 PCE Wake
Tensile Sample Assembly





Images courtesy of Alpha Space

Overview of PCE Wake Samples

(Very little AO & moderate solar exposure)

Blue: Environment data
Black: New sample data
Green: AO E_y vs. environment data
Purple: Verify previous data
Red: Heating effects data

- **Wake 1-inch Samples:**
  - Kapton H for MISSE-9 wake AO fluence determination
  - Al_2O_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

Cosmic Ray Shielding sample

- **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)

MISSE-9 ID	Material	Abbrev.	Thickness (inch)	C or S
M9Z-C1	Polyimide (PMDA) (Kapton H)	Kapton H	0.005	C
M9Z-C2	Polyimide (PMDA) (Kapton HN)	Kapton HN	0.005	C
M9Z-C3	Alumina slide	Al_2O_3	0.063	C
M9Z-C4	Fluorinated ethylene propylene (Teflon FEP)	FEP	0.005	C
M9Z-C5	Aluminized-Teflon (FEP/Al)*	Al-FEP	0.005	C
M9Z-C6	Silver-Teflon (FEP/Ag/Inconel)*	Ag-FEP	0.005	C
M9Z-C7	Back-surface carbon painted Teflon (FEP/C/FEP)*	C-FEP	0.015	C
M9Z-C8	Ethylene-chlorotrifluoroethylene (Halar)	ECTFE	0.003	C
M9Z-C9	Polytetrafluoroethylene (Teflon PTFE)	PTFE	0.005	C
M9Z-C10	Chlorotrifluoroethylene (Kel-F)	CTFE	0.005	C
M9Z-C11	Ethylene-tetrafluoroethylene (Tefzel ZM)	ETFE	0.003	C
M9Z-C12	Polyvinylidene fluoride (Kynar)	PVDF	0.003	C
M9Z-C13	Polyethylene	PE	0.002	C
M9Z-C14	Polyvinylfluoride (clear Tedlar)	PVF	0.001	C
M9Z-C15	Crystalline polyvinylfluoride w/white pigment (white Tedlar)	PVF-W	0.002	C
M9Z-C16	Polyimide (BPDA) (Upilex-S)	Upilex-S	0.001	C
M9Z-C17	Shape memory composite (SMC) sample	SMC	0.236	C
M9Z-C18	Magnesium Fluoride	MgF_2	0.108	C
M9Z-S1	Z307 (black paint)/aluminum	Z307/Al	0.035	S
M9Z-S2	Ball Infrared Black (BIRB) paint/aluminum	BIRB/Al	0.100	S
M9Z-S3	Carbon nanotube (CNT) coated SiC	CNT/SiC	0.130	S
M9Z-S4	EpoCNT (carbon nanotube in epoxy matrix)/aluminum	EpoCNT/Al	0.064	S
M9Z-S5	Indium tin oxide coated silver-Teflon	ITO/FEP/Ag/Inconel	0.005	S

*FEP layer is space facing; C: Circular; S: Square

MISSE-9 PCE Zenith Tensile Samples (24)

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

*FEP is space facing

Tensile Samples 24

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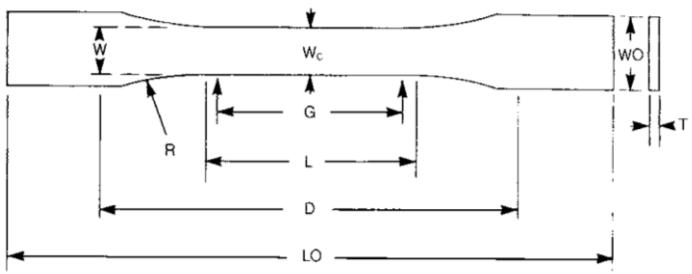
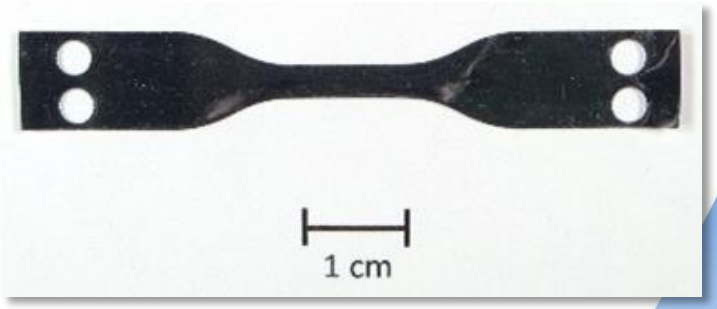


TYPES I, II, III & V



ASTM D638-08 Type V Specimen Dimensions	
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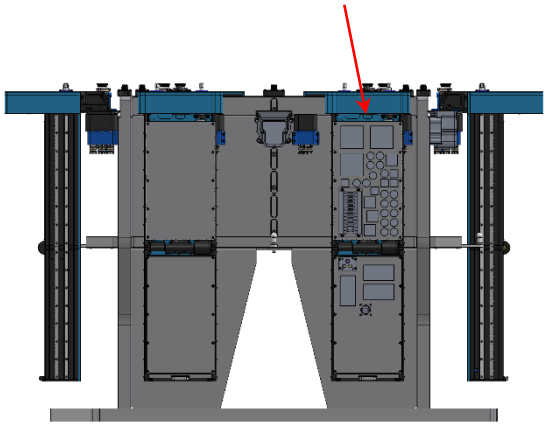
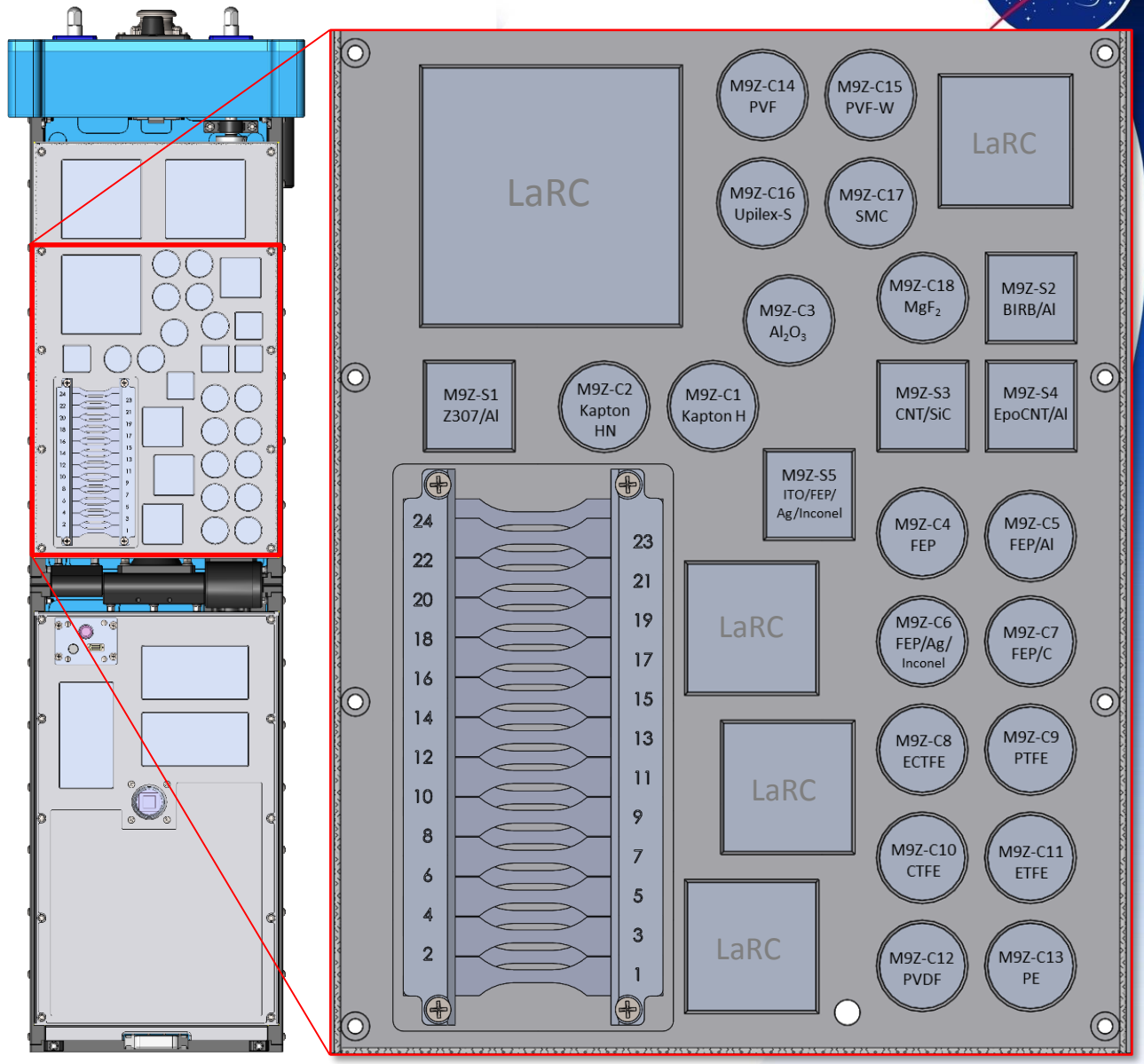
L—Length of narrow section	9.53 mm (0.375 in.)
WO—Width overall, min	9.53 mm (0.375 in.)
LO—Length overall, min	63.5 mm (2.5 in.)
G—Gage length	7.62 mm (0.300 in.)
D—Distance between grips	25.4 mm (1.00 in.)
R—Radius of fillet	12.7 mm (0.500 in.)

MISSE-9 PCE Zenith Samples

47 samples: 24 tensile & 23 1-inch

MISSE-9
MSC Z3





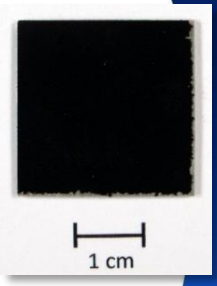
Z3 mount side

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_2O_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



Z307/Al

Blue: Environment data
Black: New sample data
Green: AO E_y vs. environment data
Purple: Verify previous data
Red: Heating effects data

- **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*

Summary

- 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

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