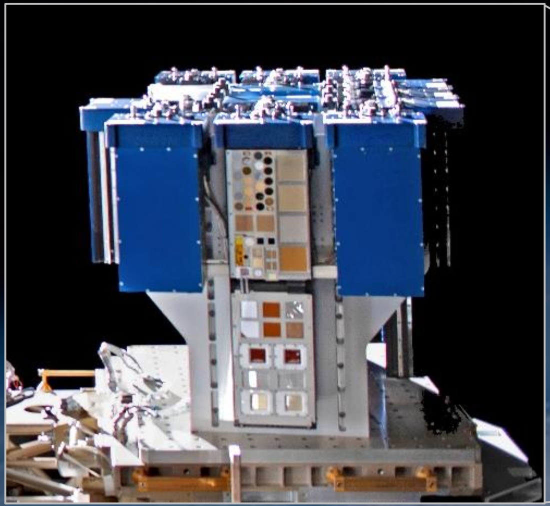
Initial Results of the MISSE-Flight Facility Polymers and Composites Experiment 1-4 (PCE 1-4)

Kim K. de Groh[1], Bruce A. Banks[2], Alexa S. Mills[3] and Loredana Santo[4]

[1] NASA Glenn Research Center
[2] SAIC at NASA Glenn
[3] Hathaway Brown School
[4] University of Rome Tor Vergata



MISSE-Flight Facility (MISSE-FF)

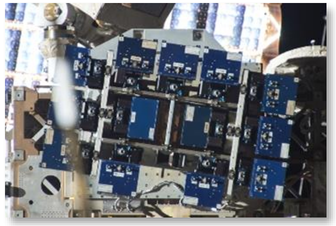
Presented at the joint 15th International Symposium on Materials in the Space Environment (ISMSE-15) and 13th International Conference on Protection of Materials from the Space Environment (ICPMSE-13) September 18-23, 2022 in Leiden, The Netherlands

Polymers and Composites Experiment 1-4 (PCE 1-4)

Principal Investigator (PI): Kim de Groh (NASA GRC)
Co-Investigator: Bruce Banks (SAIC/GRC)

- NASA Glenn has 4 experiments with 365 flight samples flown on the MISSE-FF
  - ➢ *MISSE-9 (138), MISSE-10 (43), MISSE-12 (86*), MISSE-13 (98) & MISSE-15 (42 re-flight*)*
- **Objective**: Study the performance of polymers, composites and spacecraft component materials in the harsh LEO space environment
- 41 Sample Collaborators from 21 Organizations:
  - ➢ *Government: NASA GRC, LaRC, GSFC, MSFC & DoD (AFRL, NRL)*
  - ➢ *Academia: Univ. of Rome T.V., Univ. of Akron, Johns Hopkins Univ., Michigan State Univ.*
  - ➢ *Industry: Ball Aerospace, Acktar Ltd, redhouse studios llc., NeXolve, RST Inc., etc.*
- Wide variety of flight samples:
  - ➢ *Spacecraft polymers & composites, shape memory alloys & shape memory polymer composites, cosmic ray shielding & melanin composites for radiation durability, docking seals, thermal & conductive coatings, tensile samples, contamination samples, etc.*
- Provides critical space environmental durability data for LEO, lunar and low Mars orbit (LMO) spacecraft and space structures
  - ➢ *Improved predictions of spacecraft component lifetimes in space*
  - ➢ *Improvements to Glenn's atomic oxygen erosion models*

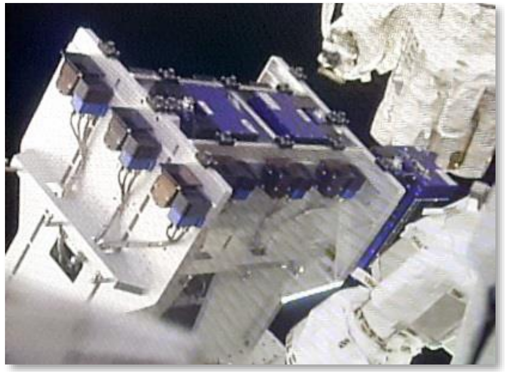
MISSE-FF Expt.	Flight Direction	# of Samples	Total
MISSE-9 PCE-1	Ram	39	138
	Wake	52	
	Zenith	47	
MISSE-10 PCE-2	Ram	21	43
	Zenith	10	
	Nadir	12	
MISSE-12 PCE-3	Ram	30	86
	Wake	42*	
	Zenith	14	
MISSE-13 PCE-4	Wake	39	98
		26	
	Zenith	33	
MISSE-15 PCE-3 Wake Re-flight	Wake	*42 Reflight**	*N/A*



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

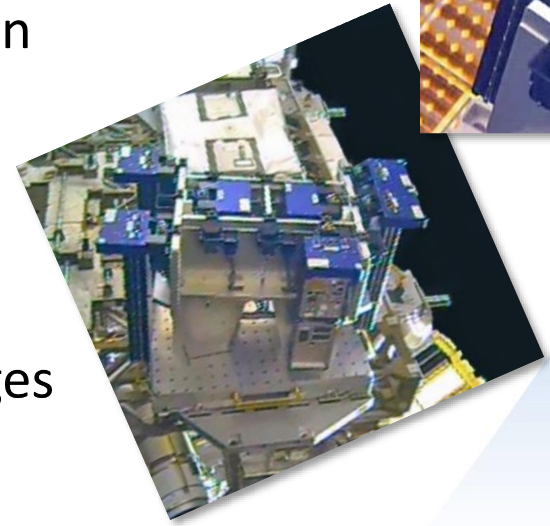
Aegis Aerospace (formerly Alpha Space)

- The MISSE-FF is an ISS permanent external material science platform that is modular and robotically serviceable
  - *Provides ram, wake, zenith and nadir exposures*
  - *Installed on **ELC-2 Site 3** on April 8, 2018 (+8 degree pitch)*
  - *Inaugural MISSE-9 experiments were deployed April 19, 2018*
- Modular design allows MISSE Sample Carriers (MSCs) with experiments to be added/replaced at different times
- Supports active experiments
- 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
- Remote control provides sample protection & on-demand images



MISSE-FF being moved to ELC-2

Robotic insertion of a MSC



MISSE-FF with 5 MSCs

__ELC-2 Site 3__: Express Logistics Carrier-2, Payload Site 3

Flight Orientations & Environmental Exposures

Ram:

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

Wake:

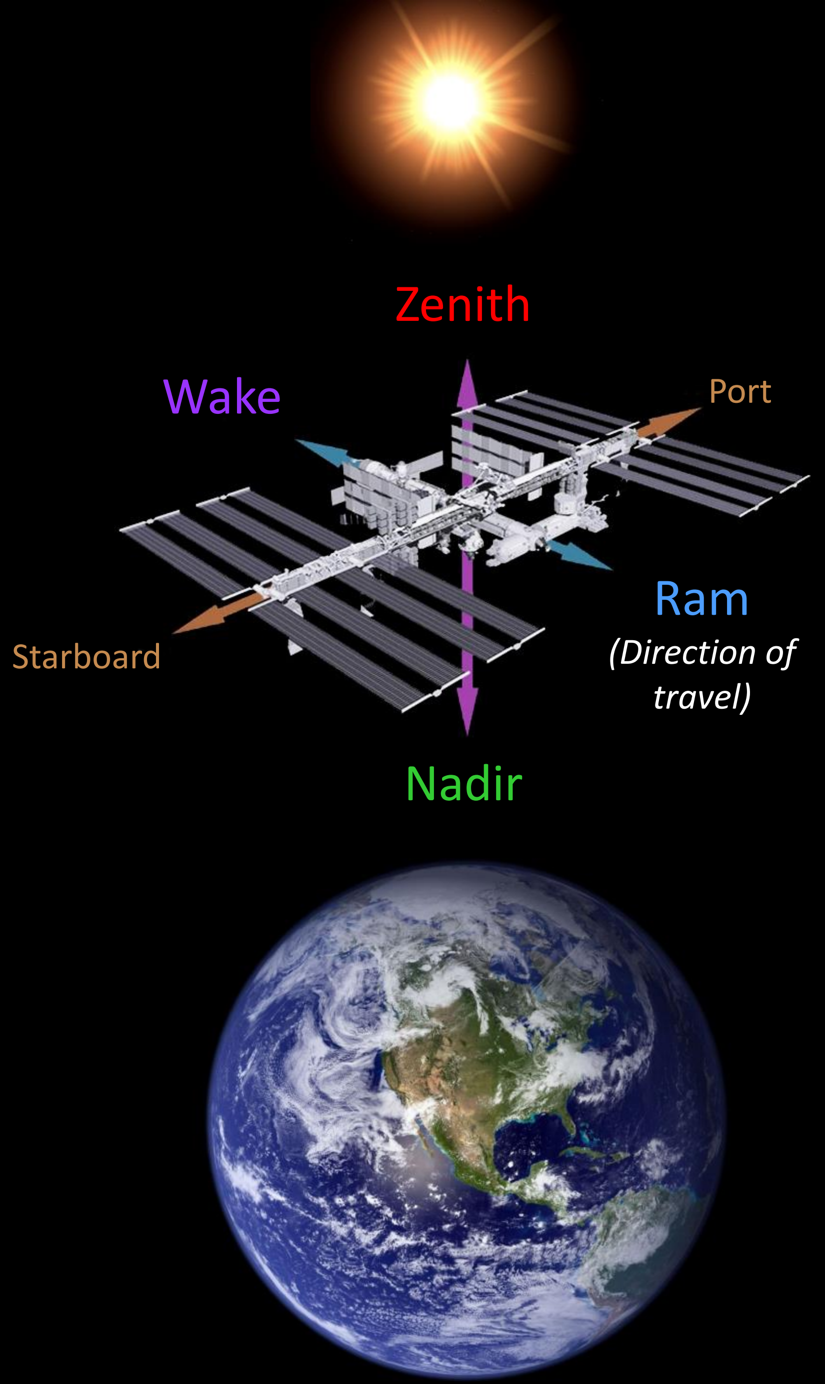
- *Facing away from the direction of travel (i.e. aft pointing or trailing edge)*
- *Essentially no AO & moderate solar exposure*

Zenith:

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

Nadir:

- *Facing towards Earth (i.e. straight down)*
- *Grazing AO & lowest solar exposure*



MISSE-9
Polymers and Composites Experiment-1 (PCE-1)

Principal Investigator (PI): Kim de Groh (GRC)

Co-Investigator: Bruce Banks (SAIC/GRC)

Sample Collaborators: Henry de Groh (NASA GRC), Jessica Cashman (NASA GRC), Maryann Meador (GRC Retired), Loredana Santo & Fabrizio Quadrini (University of Rome "Tor Vergata"), Genevieve Devaud & John Fleming (Ball Aerospace), Nathan Baier (Multek-Sheldahl) & Lawrence Drzal (Michigan State University)

Experiment Description:

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

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. *Determine functionality and durability of cosmic ray shielding & shape memory polymer composites*
5. *Use the flight data to improve AO predictive models (erosion and scattering)*

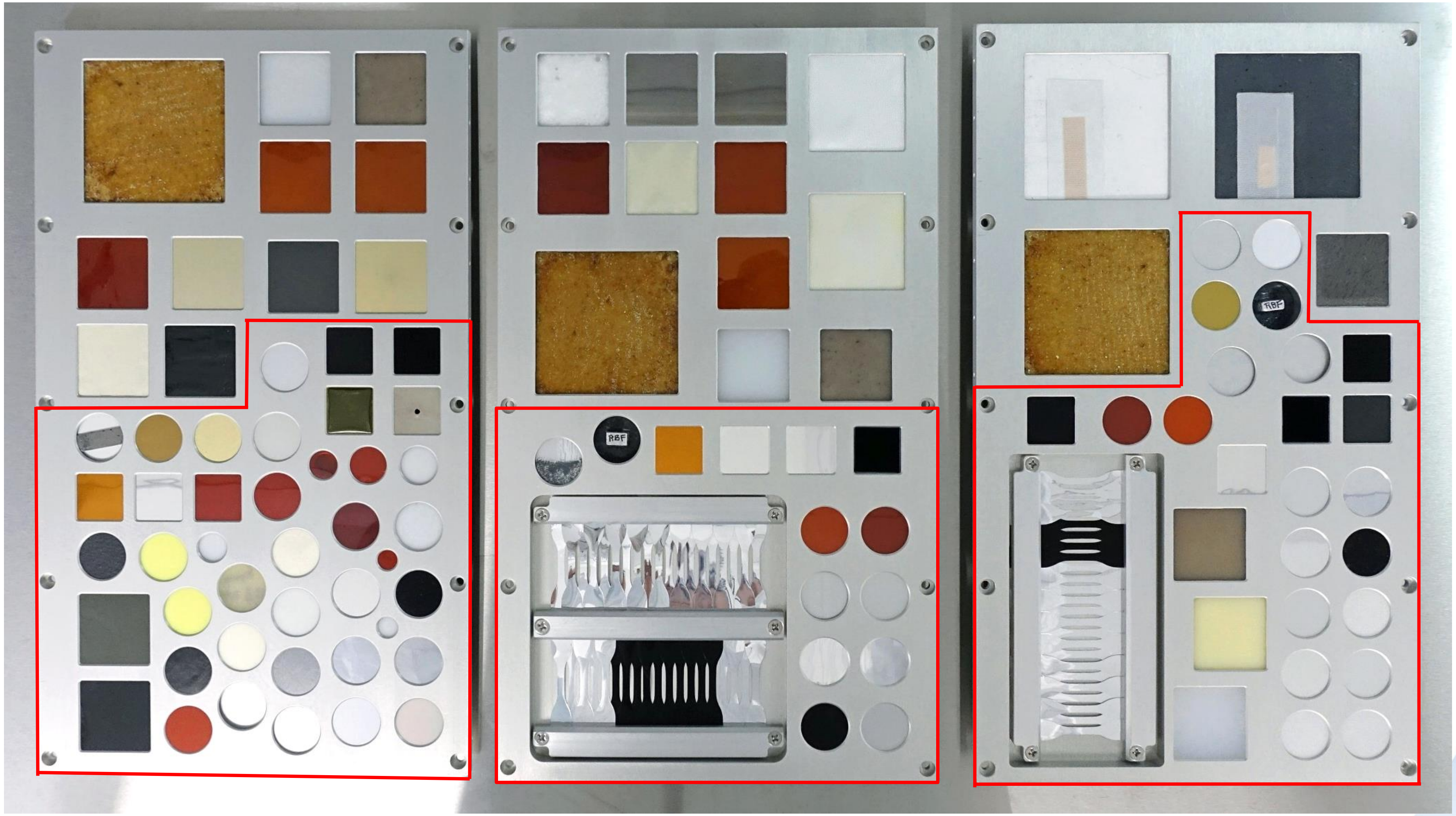
Pre-flight photograph of the PCE-1 samples in the M9 R2 (left), M9 W3 (center) and M9 Z3 decks (right)

Expected Results:

- LEO E_y values as a function of AO fluence, solar exposure and inorganic content
- Changes in optical, thermal and tensile properties
- AO fluence and contamination data in ram, wake and zenith directions

MISSE-9 PCE-1 Pre-Flight Decks

Ram	Wake	Zenith
(R2 MSC 3-MS)	(W3 MSC 8-MS)	(Z3 MSC 5-MS)



Note: The 3 larger square zenith samples are LaRC's samples

MISSE-10
Polymers and Composites Experiment-2 (PCE-2)

Principal Investigator (PI): Kim de Groh (GRC)

Co-Investigator: Bruce Banks (SAIC/GRC)

Sample Collaborators: Loredana Santo & Fabrizio Quadrini (University of Rome "Tor Vergata"), Genevieve Devaud (Ball Aerospace), Robert Bryant (NASA LaRC) & Jin Ho Kang (NIA/LaRC)

Experiment Description:

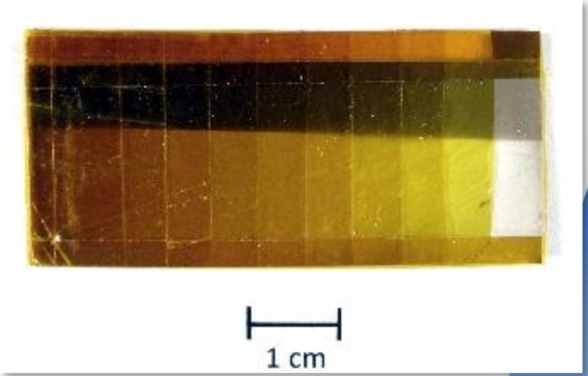
- Passive experiment with **43 samples** flown in ram, zenith & nadir orientations
  - 21 Ram, 10 Zenith & 12 Nadir
- Pre-flight & post-flight data are measured in ground-facilities

Primary Objectives:

1. *Determine the low Earth orbit (LEO) atomic oxygen (AO) erosion yield (E_y) of spacecraft polymers, composites and coated samples as a function of solar irradiation and AO fluence*
2. *Determine optical and thermal property degradation of spacecraft polymers in LEO*
3. *Determine AO fluence and contamination for MISSE-10 ram, zenith and nadir 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*

Expected Results:

- AO fluence and contamination data in ram, zenith & nadir directions (AO fluence vs. time - ram direction)
- LEO E_y values as a function of AO fluence, solar irradiation & sample holder design
- AO scattering characteristics (relevant to AO undercutting and "reflected" erosion degradation)
- Changes in optical & thermal properties, and functionality



M10R-R1AO Photo Monitor

M10N-C4 90° Kapton (Au & NaCl)

MISSE-12
Polymers and Composites Experiment-3 (PCE-3)

Principal Investigator (PI): Kim de Groh (GRC)

Co-Investigator: Bruce Banks (SAIC/GRC)

Collaborators: Santo Padula II, Othmane Benafan, Sharon Miller, Theresa Benyo*, Andrew Trunek*, Henry de Groh & Jessica Cashman (NASA GRC), Loredana Santo & Fabrizio Quadrini (Univ. of Rome), Genevieve Devaud, Samir Singh & John Fleming (Ball), Dina Katsir (Acktar Ltd.), Ben Jensen (Surrey), Dave Wilt (AFRL), Kathleen Spaner & Ronald DeMeo (RST, Inc.)

Experiment Description:

- Passive experiment with 86 samples flown in ram, wake & zenith orientations
  - 30 Ram, 42 Wake & 14 Zenith
- Pre-flight & post-flight data are measured in ground-facilities

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 property degradation of spacecraft materials in LEO*
3. *Determine the functionality of shape memory alloys (SMAs), shape memory polymer composites (SMPCs), melanin based composites and new solar cell cover slides after space radiation exposure*
4. *Determine AO fluence and contamination for MISSE-12 flight orientations*
5. *Use data to improve AO predictive models & archive data in MISSE MAPTIS database*

Expected Results:

- AO fluence and contamination data in each flight direction
- LEO E_y values as a function of AO fluence & solar irradiation
- Changes in optical, thermal & tensile properties
- Functionality of SMAs, SMPCs, melanin materials & solar cell cover slides after radiation exposure
- Quantification of AO erosion of bonded metals

Shape memory alloy (SMA) tires for rovers

ISS replacement solar array materials

** In collaboration with University of Akron, Johns Hopkins University, redhouse studio*

MISSE-13
Polymers and Composites Experiment-4 (PCE-4)

Principal Investigator (PI): Kim de Groh (GRC)

Co-Investigator: Bruce Banks (SAIC/GRC)

Collaborators: Othmane Benafan, Santo Padula II, Sharon Miller, Theresa Benyo*, Andrew Trunek*, Henry de Groh, Pat Dunlap, Stephen Gerdts & Tiffany Williams (GRC), Janice Mather (UA), Loredana Santo & Fabrizio Quadrini (Univ. of Rome), John Fleming & Ryan Cheng (Ball Aerospace), Joe Matus & Les Johnson (MSFC), Brandon Framer & D. Lynn Rodman (NeXolve)

Experiment Description:

- Passive experiment with 98 samples flown in wake & zenith orientations
  - 65 Wake & 33 Zenith
- Pre-flight & post-flight data are measured in ground-facilities

Pre-flight photograph of the PCE-4 flight samples in the M13 Z2 (left) and M13 W1 decks (center & right)

Primary Objectives:

1. *Determine optical and mechanical property degradation of spacecraft materials in LEO*
2. *Determine the functionality of shape memory alloys (SMAs), shape memory polymer composites (SMPCs), melanin based composites and elastomer seal samples after space radiation exposure*
3. *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*
4. *Determine AO fluence and contamination for wake and zenith MISSE-13 flight orientations*
5. *Use data to improve AO predictive models & archive data in MISSE MAPTIS database*

Expected Results:

- Changes in optical, thermal & tensile properties
- Functionality of SMAs, SMPCs, melanin based materials and elastomer seal samples after space radiator exposure
- AO fluence and contamination data in wake and zenith flight direction
- LEO E_y values as a function of AO fluence & solar irradiation

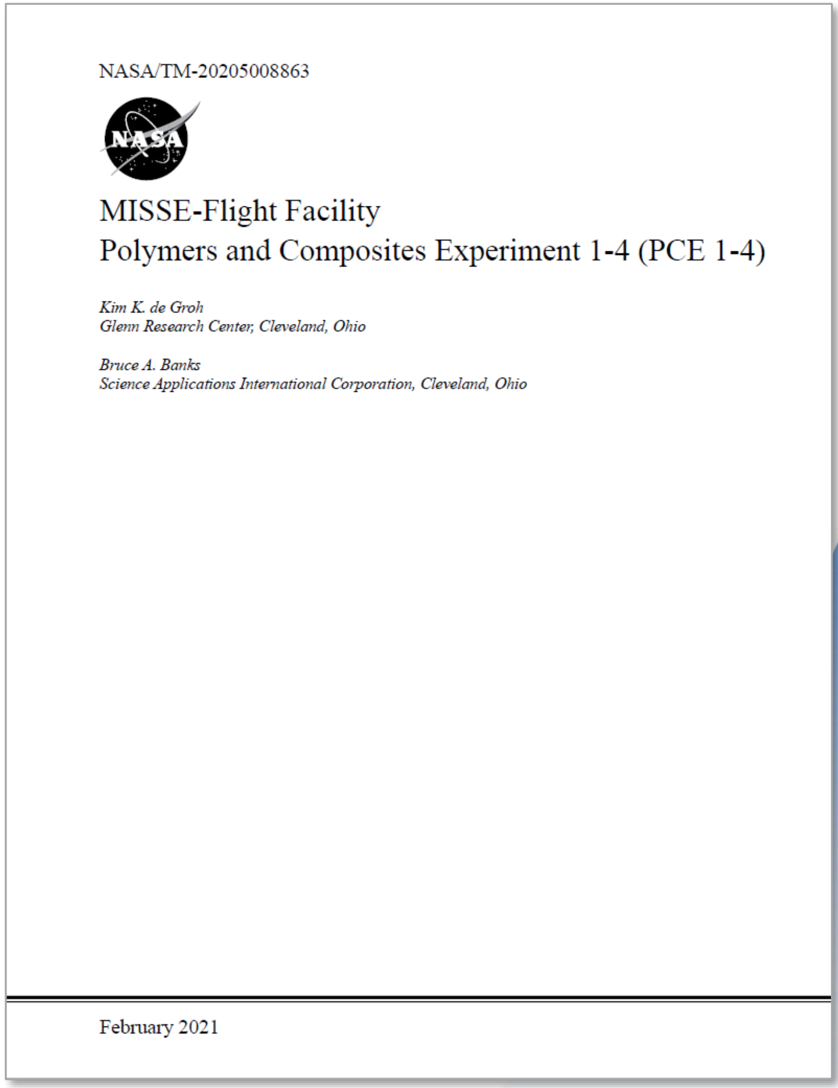
** In collaboration with University of Akron, Johns Hopkins University, redhouse studio*

NASA/TM-20205008863
Provides a List of the 365 PCE 1-4 Samples & Sample Collaborators

"MISSE-Flight Facility Polymers and Composites Experiment 1-4 (PCE 1-4)" by Kim K. de Groh & Bruce A. Banks, NASA/TM-20205008863, February 2021

NTRS website:

https://ntrs.nasa.gov/api/citations/20205008863/downloads/TM-20205008863%2003.29.21.pdf



NASA/TM-20205008863

MISSE-Flight Facility
Polymers and Composites Experiment 1-4 (PCE 1-4)

Kim K. de Groh
Glenn Research Center, Cleveland, Ohio

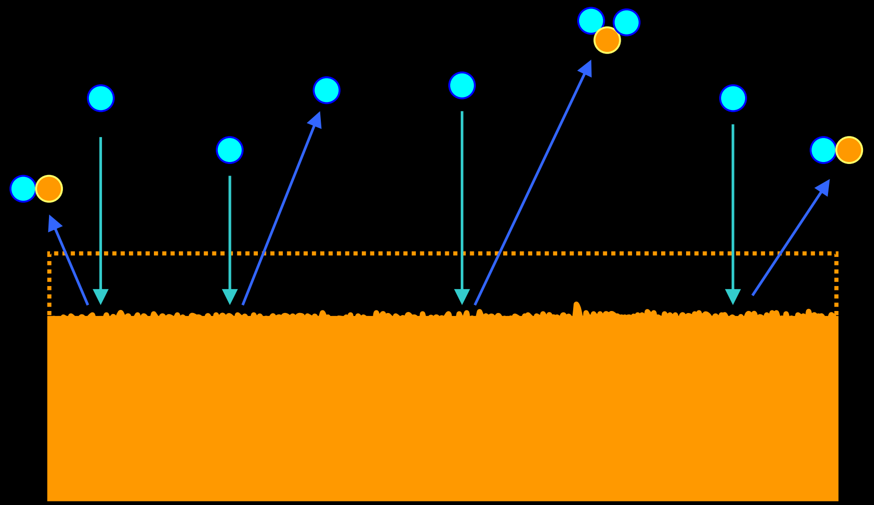
Bruce A. Banks
Science Applications International Corporation, Cleveland, Ohio

February 2021

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)



Erosion Yield (E_y) based on Mass Loss Measurements

Erosion Yield (E_y) of Sample

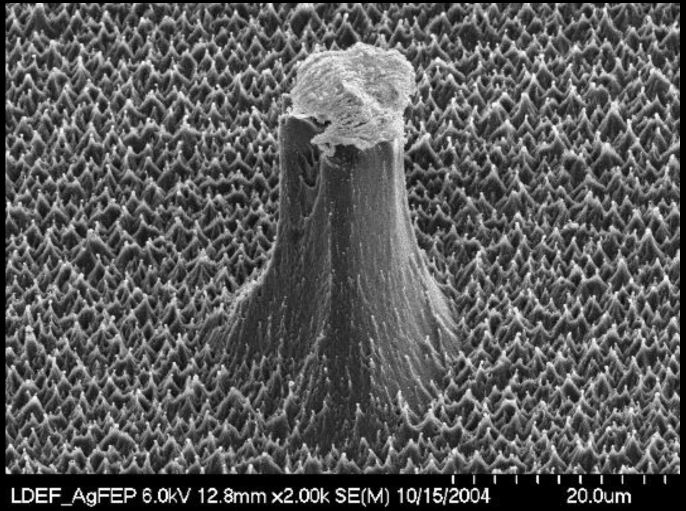
$$E_y = \frac{\Delta M_s}{A_s \rho_s F_k}$$

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)

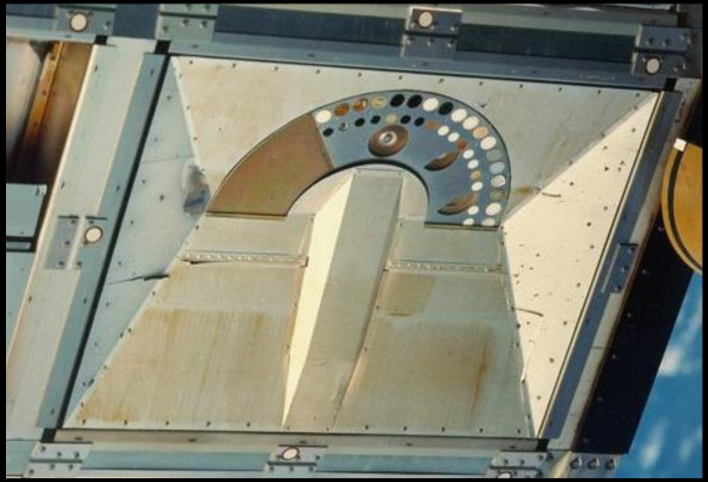


Space Environment Induced Degradation

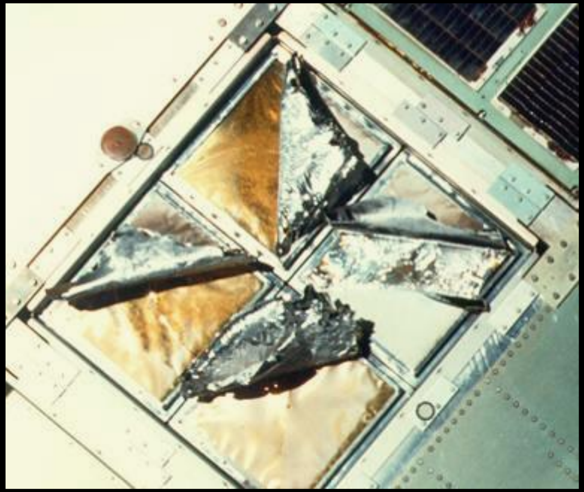
Optical Property Degradation

LDEF

5.8 years in space



Radiation induced darkening



Structural degradation & discoloration

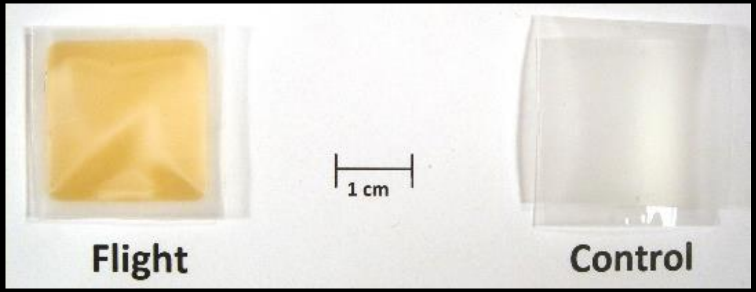
MISSE-2

4 years Ram Exposure

MISSE 2 PVDF (2-E5-46)

MISSE-7

1.5 years Zenith Exposure

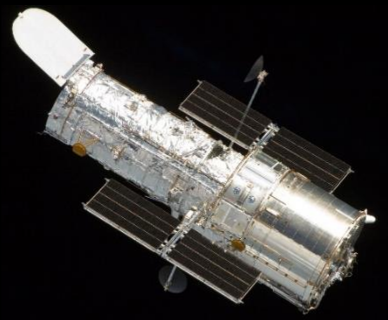


MISSE 7 PVDF (Z-5)

Space Environment Induced Degradation

Radiation Embrittlement

Radiation induced embrittlement & cracking of Hubble Space Telescope (HST) Teflon multilayer insulation (MLI)



Servicing Mission 2 (SM2)
6.8 years of space exposure

SM4 replacement of severely degraded Bay 8 MLI
19 years of space exposure

MISSE-9 PCE-1 Tensile Samples

38 Wake Samples

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

Wake Samples Pre-flight

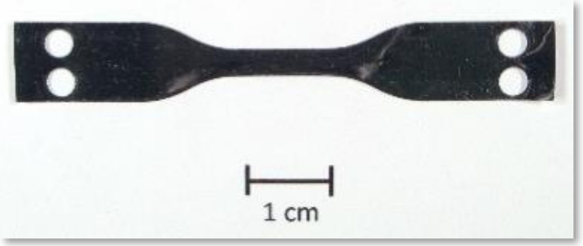
24 Zenith Samples

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

ASTM D638-08 Type V

Length: 2.5 inch (63.5 mm)
Width: 0.375 inch (9.53 mm)



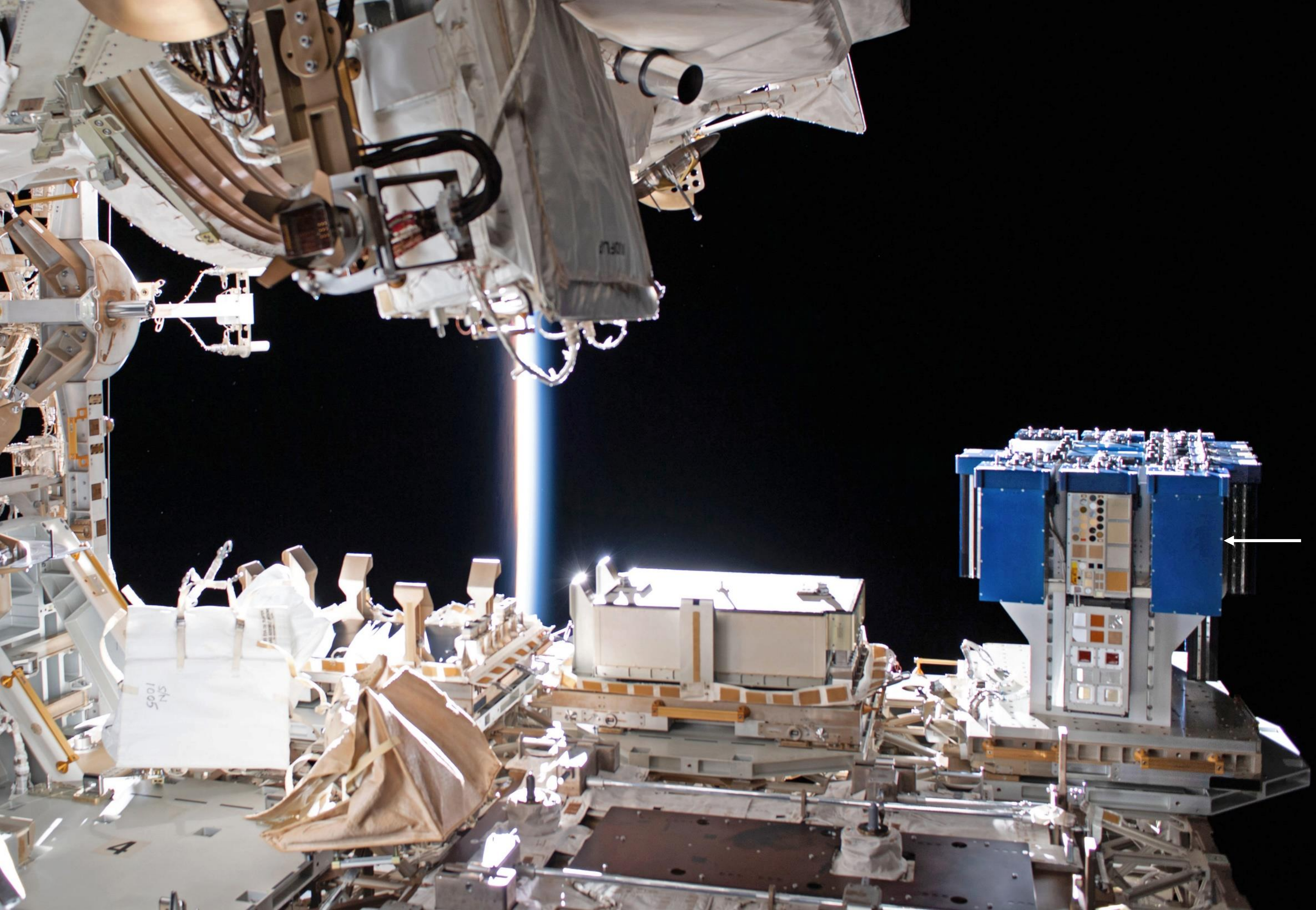
Zenith Samples Pre-flight

MISSE-13 PCE-4 Wake Tensile Samples (24)

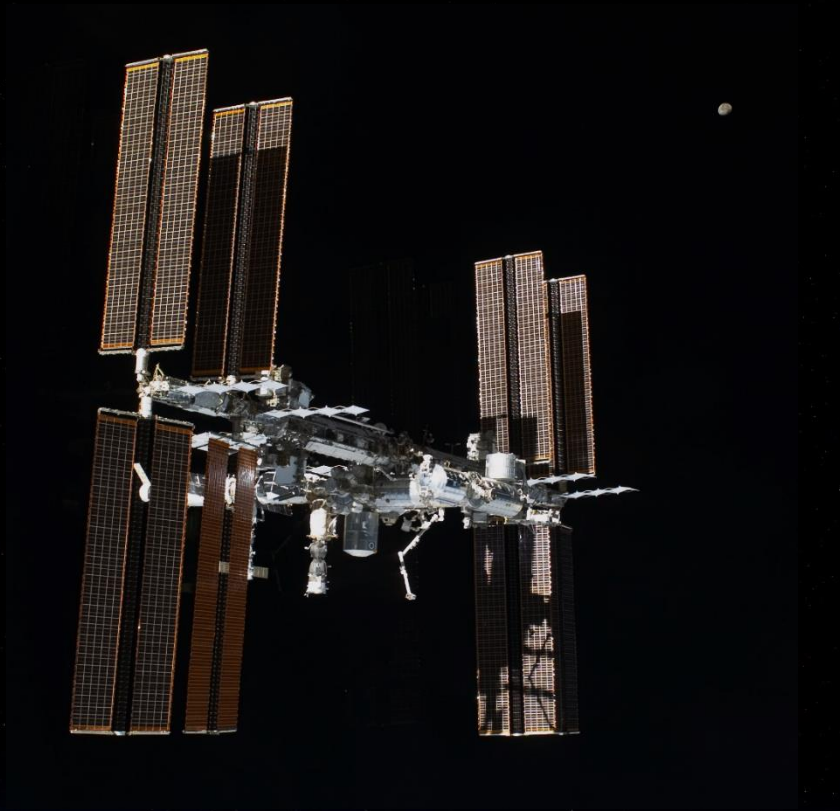
MISSE-13 ID	Material	Abbreviation	Thickness (mils)
M13W-T1 to T3	Teflon (FEP)	FEP	2
M13W-T4 to T6	Teflon (FEP) - AO textured on back surface	FEP-AO	2
M13W-T7 to T10	Teflon (FEP) - AO textured and C coated on the back surface	FEP/C	2
M13W-T10 to T12	Teflon (FEP)	FEP	5
M13W-T13 to T15	Teflon (FEP) - AO textured on back surface	FEP-AO	5
M13W-T16 to T18	Teflon (FEP) - AO textured and C coated on the back surface	FEP/C	5
M13W-T19 to T21	VDA/CP1 solar sail material (Kapton grip support on front)	VDA/CP1	0.2
M13W-T22 to T24	VDA/CP1-PTFE composite solar sail material (Kapton grip support on back)	VDA/CP1-PTFE	0.3

Note: All tensile samples are cut parallel to roll lines


MISSE-FF
on ELC-2 Site 3
ELC2


MISSE
Sample
Carrier
(MSC)

PCE 1-4
Initial Results



PCE 1-4 Mission Summary

MISSE-FF Expt.	Flight Direction	Number of Samples	MISSE Sample Carrier (MSC)	Launch Mission	Installed on MISSE-FF	Deployed	Final Time Closed	Retrieved from MISSE-FF	Return Mission	Time on MISSE-FF (Years)	Direct Space Exposure Duration (Years)
MISSE-9 PCE-1	Ram	39	R2 (MSC 3) MS	SpaceX-14 April 2, 2018	April 18, 2018	April 19, 2018	Oct. 2, 2019	Nov. 11, 2019	SpaceX-19 Jan. 7, 2020	1.57	**0.77**
	Wake	52	W3 (MSC 8) MS		April 18, 2018		Dec. 26, 2018	April 26, 2019	SpaceX-17 June 3, 2019	1.02	**0.54**
	Zenith	47	Z3 (MSC 5) MS		April 19, 2018					1.02	**0.54**
MISSE-10 PCE-2	Ram	21	R1 (MSC 11) MS	NG-10 Nov. 17, 2018	Jan. 4, 2019	April 26, 2019	Nov. 25, 2020	Nov. 25, 2020	SpaceX-21 Jan. 13, 2021*	1.90	**1.17**
	Zenith	10	Z2 (MSC 10) MS				March 12, 2020	March 18, 2020	SpaceX-20 April 7, 2020	1.20	**0.69**
	Nadir	12	N3 (MSC 13) MS							1.20	**0.48**
MISSE-12 PCE-3	Ram	30	R2 (MSC 4) SS	NG-12 Nov. 2, 2019	Nov. 11, 2019	Dec. 3, 2019	Nov. 25, 2020	Nov. 25, 2020	SpaceX-21 Jan. 13, 2021*	1.04	**0.89**
	Wake	42	W3 (MSC 6) MS			N/A	N/A	Nov. 27, 2020		1.05	**0****
	Zenith	14	Z1 (MSC 18) MS			March 20, 2020	Sept. 2, 2020	Nov. 26, 2020		1.05	**0.45**
MISSE-13 PCE-4	Wake	39	W1 (MSC 5) SS	SpaceX-20 March 6, 2020	March 18, 2020	March 20, 2020	Sept. 2, 2020	Nov. 27, 2020	SpaceX-21 Jan. 13, 2021*	0.70	**0.44**
		26	W1 (MSC 5) MS								
	Zenith	33	Z2 (MSC 19) MS				Sept. 3, 2020	Nov. 26, 2020		0.70	**0.46**
MISSE-15 PCE-3 Wake Re-flight**	Wake	42	W1 (MSC 10) MS	SpaceX-23 Aug. 29, 2021	Dec. 28, 2021	Jan. 6, 2022	July 18, 2022	Aug. 2, 2022	SpaceX-25 Aug. 20, 2022	0.60	**0.44**

MS: Mount side deck; SS: Swing side deck

*January 13, 2021 EST (January 14, 2021 UTC)

**The PCE-3 wake samples were re-flown as part of the MISSE-15 mission

Note: MSCs are closed for contamination avoidance during visiting vehicles, etc.

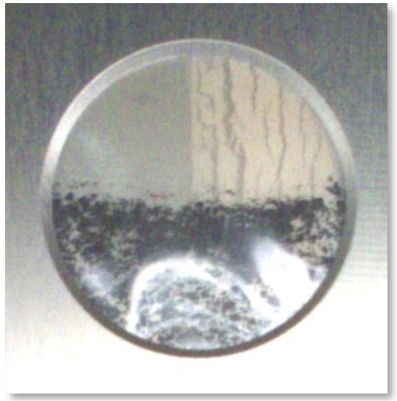
Polymers and Composites Experiment (PCE)

Wake (W3) On-Orbit Images

On-Orbit Sample Darkening

M9W-C9
Cosmic Ray Shielding (CRS)
On-orbit

4-23-18



12-26-18
0.54 years exposure

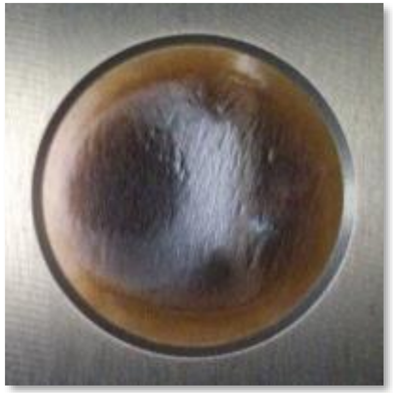
Pre-flight W3 Deck Image

M9W-C9

M9W-C8

M9W-C8
Polyvinyl chloride (PVC)
On-Orbit

4-23-18



12-26-18
0.54 years exposure

On-orbit sample photos courtesy of NASA and Aegis Aerospace

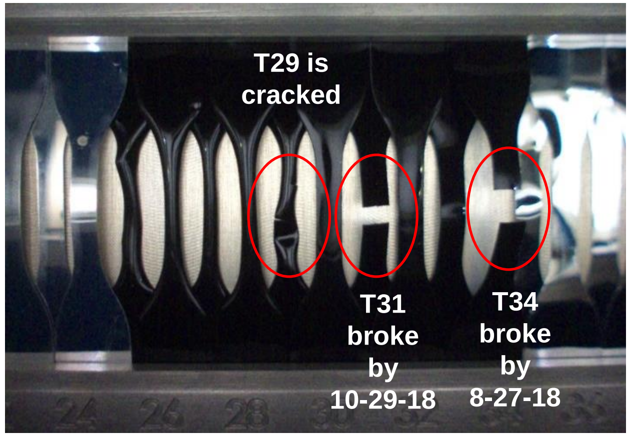
MISSE-9 Polymers and Composites Experiment-1 (PCE-1)
Wake (W3) On-Orbit Images

Pre-flight
W3 Deck Image

On-orbit image area

7-25-18 On-orbit Image
Wake samples are
NOT broken

12-26-18 On-orbit Image
M9W-T31 and M9W-T34
are BROKEN!



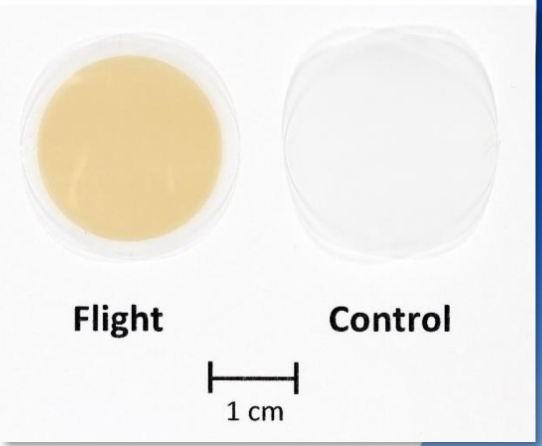
- Wake tensile sample M9W-T34 (carbon back-surface painted 5 mil Teflon FEP (FEP/C)) broke on-orbit after **≤5 months** of space exposure
- M9W-T31 (5 mil FEP/C) broke after **≤7 months** of space exposure & M9W-T29 (2 mil FEP/C) is cracked
- The black coating causes the sample to passively heat to a higher temperature than corresponding aluminized-Teflon (FEP/Al) samples
  - ➢ *The higher on-orbit temperature causes a synergistic effect that increases the radiation-induced embrittlement of Teflon FEP in LEO*

On-orbit sample photos courtesy of NASA and Aegis Aerospace

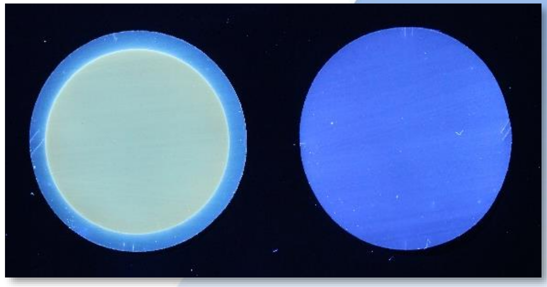
PCE 1-4 Post-flight Analyses

- Post-flight images – *completed**
  - *Flight hardware de-integration images*
  - *Flight vs. back-up (control) sample images (Visible light & 365 nm UV light)*
- Dehydrated mass of all E_y and optical samples – *completed**
- AO fluence for each mission's flight orientation - *in progress*
- LEO atomic oxygen (AO) erosion yield (E_y) of flight samples - *in progress*
- Optical properties of flight and control samples (250 – 2500 nm) - *in progress*
  - *Total Reflectance (TR) , Total Transmittance (TT) & Solar Absorptance (SA)*
- X-ray photoelectron spectroscopy (XPS) analysis of flight and control contamination samples - *in progress*
  - *25 contamination samples: 13 flight & 12 control samples*
- Tensile testing of flight and control tensile samples - *planned*
  - *250 tensile samples: 86 flight & 164 control samples*
- Testing of "unique" flight samples - *in progress*

M9Z-C12
Polyvinylidene fluoride (PVDF)



UV Light
(365 nm)



Flight Control

**The PCE-3 wake samples re-flown on MISSE-15 (& returned on SpaceX-25) are at Aegis Aerospace*

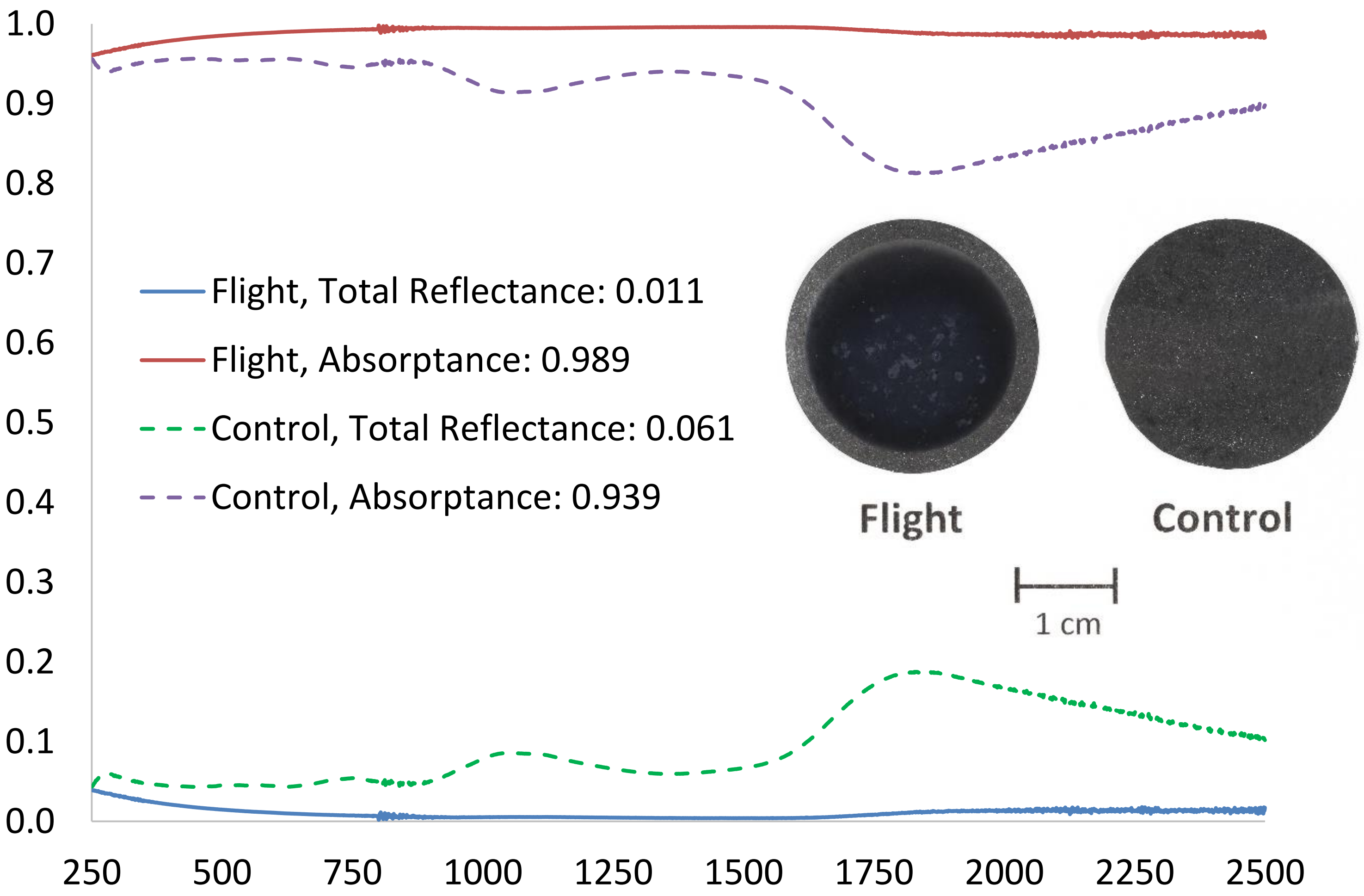
PCE 1-4 Unique Samples Being Analyzed

- **Photographic Atomic Oxygen (AO) Monitors** to determine AO fluence over time based on on-orbit images
- Various AO scattering effects samples including **Atomic Oxygen (AO) Scattering Chambers**
- **Specialty coatings** such as Z307 black paint, Ball Infrared Black (BIRB) paint, Magic Black, Fractal Black, Vantablack CX2, Vantablack (S-IR), StaMet coated Kapton XC and Ge coated Kapton XC for AO erosion and/or optical properties
- Low and high density **polyimide aerogels** for AO and radiation durability assessment
- Uncoated and coated **docking seal** (S383-70 silicone) samples for AO and UV durability assessment
- **Demron** radiation resistant fabric for AO durability and optical properties assessment
- **Indium tin oxide** (ITO) conductive coatings for optical and electrical performance and durability
- Potential **solar sail materials** for LEO environmental durability assessment
- **Shape Memory Polymer Composites** (SMPCs) for functionality assessment for space structures
- **Cosmic ray shielding** (CRS) samples for radiation durability assessment
- **Melanin** and **mycelium** composites for radiation protection
- **Shape Memory Alloys** (SMAs) to assess the radiation durability for space-based solid-state actuation and structural components (i.e., rovers, bearing alloys).
- **Pseudomorphic glass** and **flexible Optical Solar Reflector** (OSR) samples for PV optical and thermal property performance
- Spacecraft polymers flown in both unstressed and under **folding stress** configurations
- **Polyphenylsulfone** (PPSU) with and without BN additives to assess radiation durability for 3D-printable composites

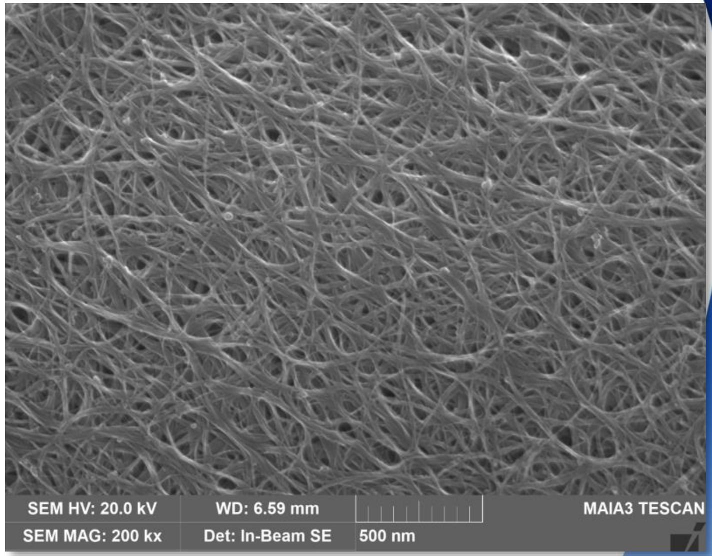
MISSE-9 Carbon Nanotube (CNT) Buckypaper (M9R-C31)

PI: Henry de Groh (NASA Glenn Research Center)
Collaborators: Skyler Gregor & Kim de Groh (NASA GRC), Wayne Jennings (HX5/NASA GRC)

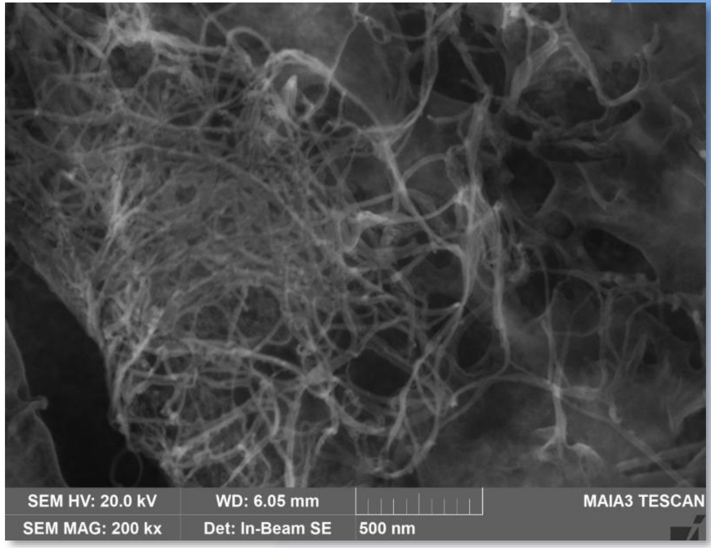
0.77 Years of Ram Exposure



Unexposed (200KX)



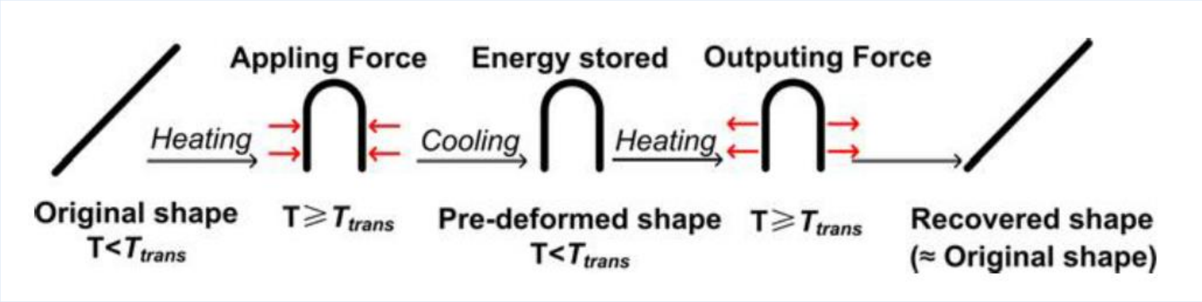
Exposed (200KX)



Shape Memory Polymer Composites (SMPC)

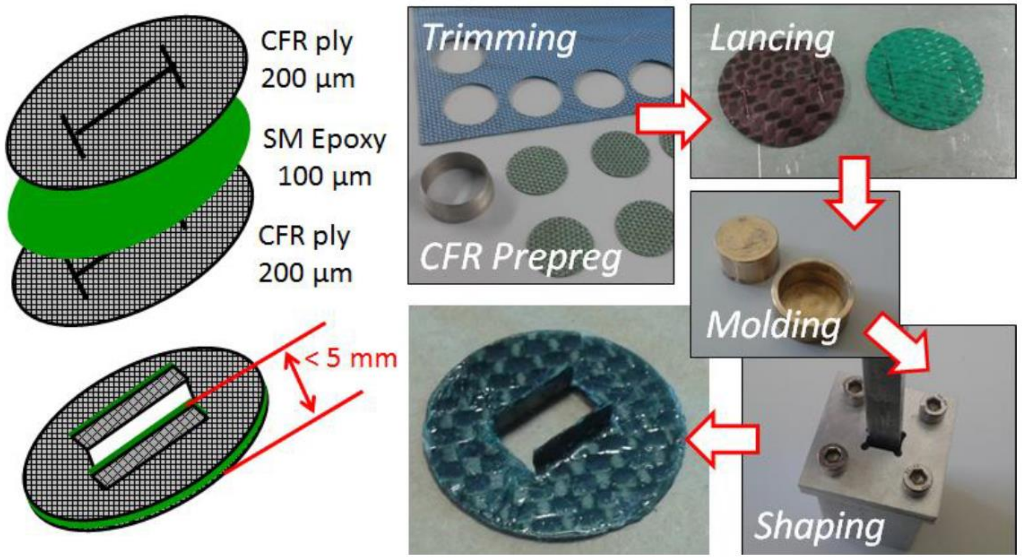
Principal Investigator: Loredana Santo, University of Rome Tor Vergata (URTV)

- Ability to fix and recover a given deformation by cooling below and heating above the Tg (thermo-mechanical cycle)



- Self-deployable structures, actuators, biomedical devices
- Advantages over shape memory alloys include: lightness, low cost, high shape recovery, easy to process

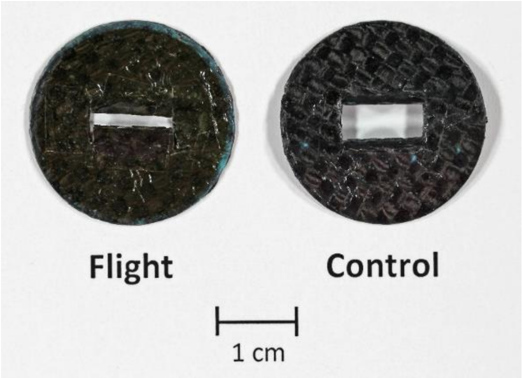
SMPC sample fabrication



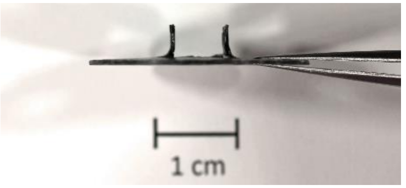
Reference: "Shape Memory Polymer Composites After Long-term Exposure in Space Environment by the MISSE Facility," L. Santo, F. Quadrini, D. Bellisario, L. Iorio and K. K. de Groh, presented at the ISSRDC 2022 Conference, July 25-28, 2022, Washington D.C.

MISSE-9 Zenith & Wake

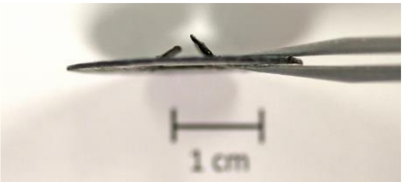
0.54 years of zenith and wake exposure



M9Z-C17



M9W-C10 Wake Sample



M9Z-C17 Zenith Sample

MISSE-10 Ram

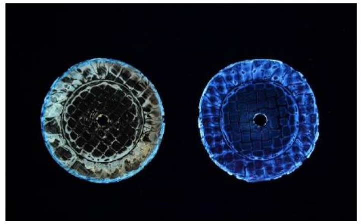
1.17 years of ram exposure

MISSE-10 Post-flight

Flight (left) and Control (right)

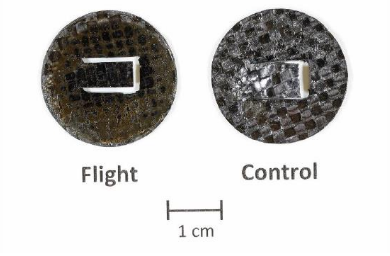
MISSE-10 Pre-flight

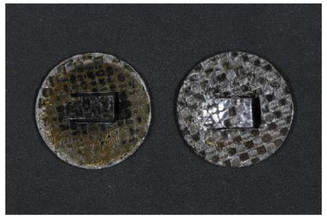
UV light photograph
Flight (left) and Control (right)



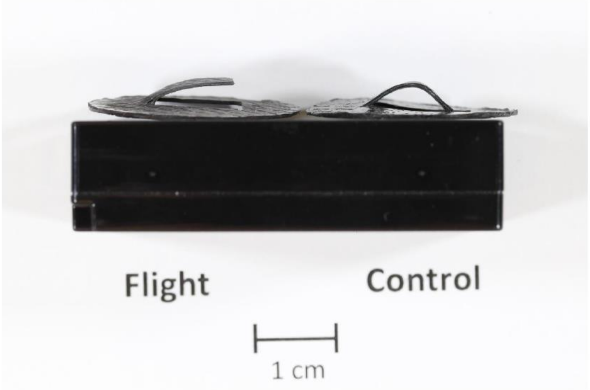
MISSE-12 Ram

0.89 years of ram exposure





Flight (left) and Control (right)



- Spaceflight experiments enable the evaluation of smart materials behavior in the space environment
  - *Mass loss & material degradation*
  - *Performance loss, including shape memory behavior*
- The MISSE-FF experiments have shown that SMPC sample recovery can happen on-orbit (direct heating from the Sun or heat transfer from surround payload)

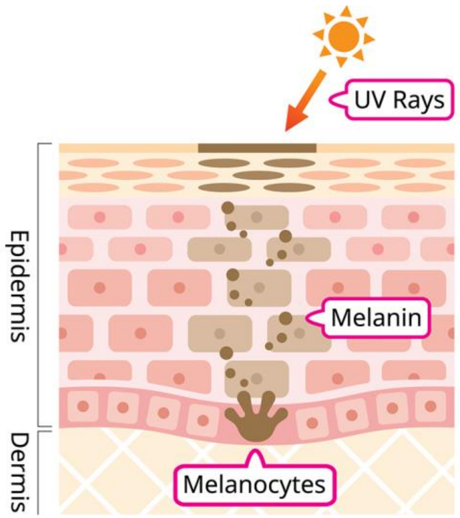
Reference: "Shape Memory Polymer Composites After Long-term Exposure in Space Environment by the MISSE Facility," L. Santo, F. Quadrini, D. Bellisario, L. Iorio and K. K. de Groh, presented at the ISSRDC 2022 Conference, July 25-28, 2022, Washington D.C.

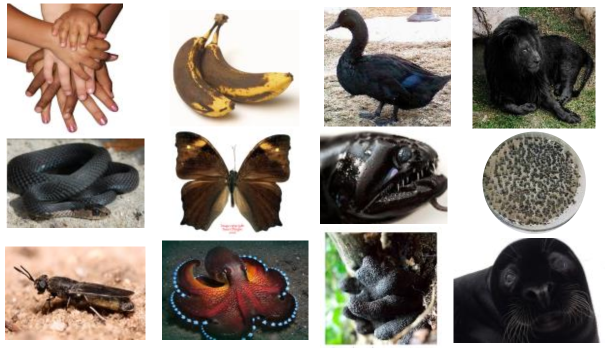
Melanin Samples for Radiation Protection

Arturo Casadevall [1], Radames JB Cordero [1], Quigly Dragotakes [1], Ali Dhinojwala [2], Saranshu Singla[2], Theresa Benyo [3], Kim K. de Groh [3], Andrew Trunek [3], Christopher Maurer [4]

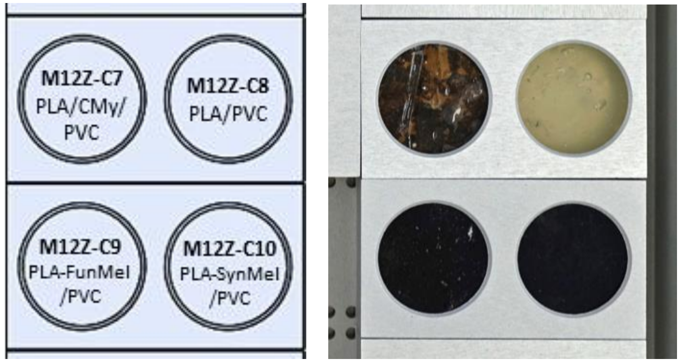
(1) John Hopkins University, (2) University of Akron, (3) NASA Glenn Research Center and (4) redhouse studio, llc.

Melanin: A Natural Sunscreen in Humans

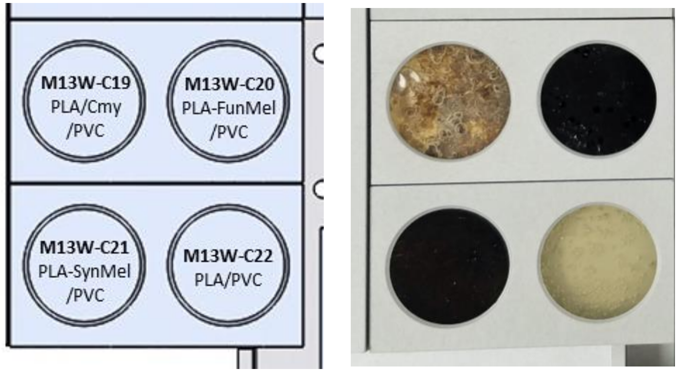




MISSE-12 Zenith



MISSE-13 Wake



Pre-flight photos

MISSE-12 PCE-3 Zenith Samples

MISSE-12 ID	Material	Abbreviation
M12Z-C7	Compressed mycelium with thin polylactic acid (PLA) coating	PLA/CMy/PVC
M12Z-C8	Polylactic acid (PLA)	PLA/PVC
M12Z-C9	Fungal melanin powders infused into PLA	PLA-FunMel/PVC
M12Z-C10	Synthetic melanin powders infused into PLA	PLA-SynMel/PVC

MISSE-13 PCE-3 Wake Samples

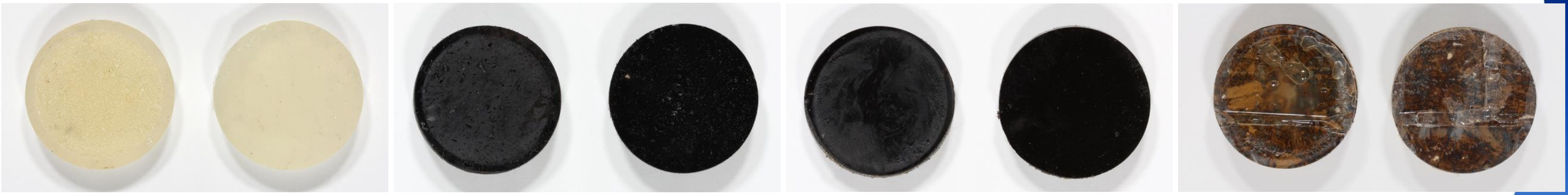
MISSE-13 ID	Material	Abbreviation
M13W-C19	Compressed mycelium with thin polylactic acid (PLA) coating	PLA/CMy/PVC
M13W-C20	Fungal melanin powders infused into PLA	PLA-FunMel/PVC
M13W-C21	Synthetic melanin powders infused into PLA	PLA-SynMel/PVC
M13W-C22	Polylactic acid (PLA)	PLA/PVC

Note: All samples have a polyvinyl chloride (PVC) backing layer

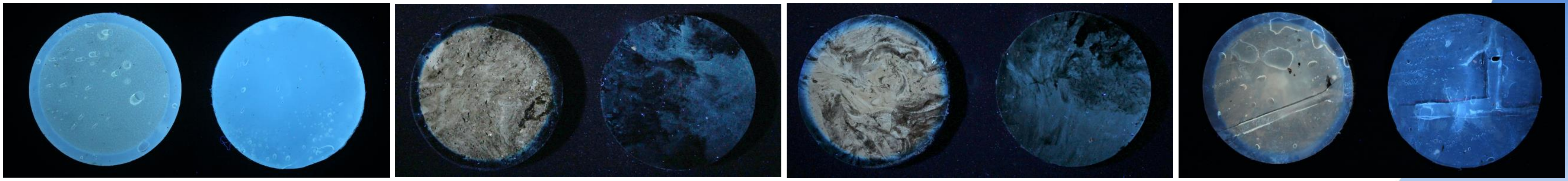
Ref.: "Melanin-based biomaterials for radiation shielding and harvesting applications in space," T. Benyo, A. Casadevall, R. JB Cordero, K. K. de Groh, A. Dhinojwala, Q. Dragotakes, C. Maurer, S. Singla and A. Trunek, presented at the ISSRDC 2022 Conference, July 25-28, 2022, Washington D.C.

Visual Changes Following 0.5 yrs LEO Zenith Exposure

PLA		PLA+Fungal Melanin		PLA+Synthetic Melanin		PLA+ Compressed Mycelium	
Flight	Control	Flight	Control	Flight	Control	Flight	Control



UV Imaging



Unpublished data

Preliminary results indicate that melanin-PLA composites were effective in shielding a PVC backing layer from LEO radiation damage

Ref.: "Melanin-based biomaterials for radiation shielding and harvesting applications in space," T. Benyo, A. Casadevall, R. JB Cordero, K. K. de Groh, A. Dhinojwala, Q. Dragotakes, C. Maurer, S. Singla and A. Trunek, presented at the ISSRDC 2022 Conference, July 25-28, 2022, Washington D.C.

Summary & Conclusions

- NASA Glenn's Polymers and Composites Experiment 1-4 (PCE 1-4) with 365 flight samples were successfully exposed to the space environment on the MISSE-Flight Facility (MISSE-FF)
  - *MISSE-9 PCE-1 (138 samples: 39 ram, 52 wake & 47 zenith)*
  - *MISSE-10 PCE-2 (43 samples: 21 ram, 10 zenith & 12 nadir)*
  - *MISSE-12 PCE-3 (86 samples: 30 ram, 42 wake* & 14 zenith)*

    **The 42 wake samples were re-flown as part of the MISSE-15 mission*
  - *MISSE-13 PCE-4 (98 samples: 65 wake & 33 zenith)*
- We have 41 sample collaborators from 21 organizations
- The primary objective of these experiments is to determine the AO and radiation durability of spacecraft polymers and composites
  - *In addition, each experiment has a wide variety of materials and numerous additional sample objectives*
- Samples are currently being analyzed for:
  - *AO fluence & AO erosion yield (E_y)*
  - *On-orbit contamination*
  - *Optical & tensile properties*
  - *Radiation & functional durability, etc.*
- The results from the PCE 1-4 experiments will provide spacecraft designers with AO and radiation performance and durability data needed for developing durable spacecraft components

Acknowledgements

This work is supported by the
Biological and Physical Sciences (BPS) Division