EFFECT OF RAM AND ZENITH EXPOSURE ON THE OPTICAL PROPERTIES OF POLYMERS IN SPACE

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Abstract

The temperature of spacecraft is influenced by the solar absorptance and thermal emittance of the external spacecraft materials. Optical and thermal properties can degrade over time in the harsh low Earth orbital (LEO) space environment where spacecraft external materials are exposed to various forms of radiation, thermal cycling, and atomic oxygen. Therefore, it is important to test the durability of spacecraft materials in the space environment. One objective of the Polymers and Zenith Polymers Experiments was to determine the effect of LEO space exposure on the optical properties of various spacecraft polymers. These experiments were flown as part of the Materials International Space Station Experiment 7 (MISSE 7) mission on the exterior of the International Space Station (ISS) for 1.5 years. Samples were flown in ram, wake or zenith directions, receiving varying amounts of atomic oxygen and solar radiation exposure. Total and diffuse reflectance and transmittance of flight and corresponding control samples were obtained post-flight using a Cary 5000 UV-Vis-NIR Spectrophotometer. Integrated air mass zero solar absorptance (α_s) of the flight and control samples were computed from the total transmittance and reflectance, and compared. The optical data are compared with similar polymers exposed to space for four years as part of MISSE 2, and with atomic oxygen erosion data, to help understand the degradation of these polymers in the space environment. Results show that prolonged space exposure increases the solar absorptance of some materials. Knowing which polymers remain stable will benefit future spacecraft design.

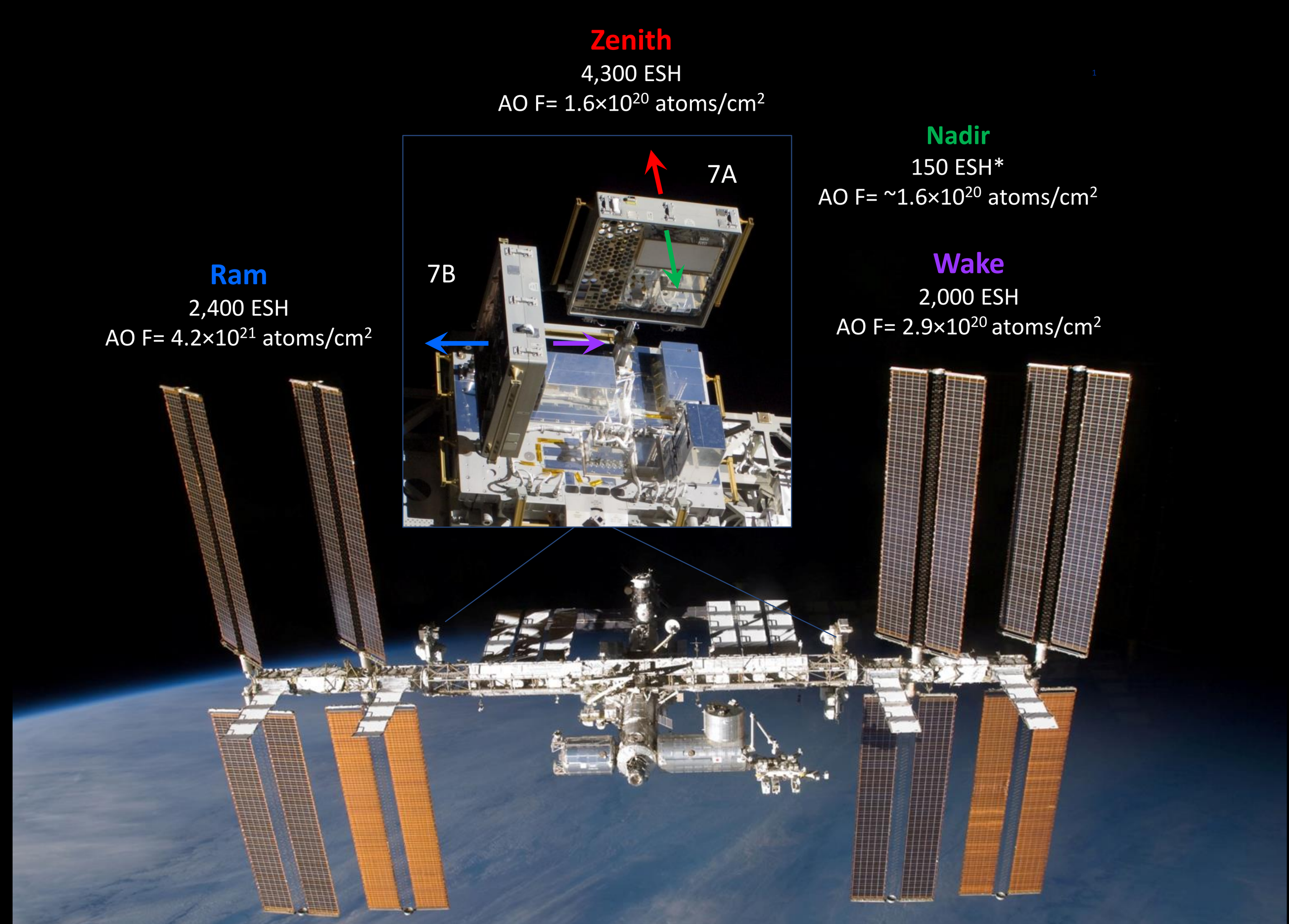
Atomic Oxygen (AO)

- AO is the predominant species in LEO (≈180-650 km)
- At ram impact velocities (17,000 mph) the impact energy is 4.5 eV
- AO is formed when O_2 is broken apart by energetic UV radiation
- AO oxidizes certain materials, producing gas - so *the material erodes away...*

Atomic Oxygen Erosion Yield (Ey)
volume loss per incident oxygen atom (cm³/atom)

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

where:
ΔM_s = mass loss of polymer sample (g)
A_s = area of polymer sample (cm²)
ρ_s = density of sample (g/cm³)
F_k = AO fluence measured by Kapton H witness samples (atom/cm²)



Equivalent sun hours (ESH): hours of sunlight
* de Groh 2016 ISS R&D Conference

Optical Procedures

- Cary 5000 UV-Vis-NIR Spectrophotometer
- Total and diffuse reflectance (TR , DR) and total and diffuse transmittance (TT, DT) were obtained from 250 nm to 2500 nm
  - Data was obtained post-flight on both the flight and control samples
- Specular reflectance (SR) and specular transmittance (ST) were computed using the following equations:
  - SR = TR - DR
  - ST = TT - DT
- Solar absorptance (α_S) was determined through the equation: α_S = 1 – (TR + TT)
- Data from the flight and control samples were compared to determine effect of LEO space exposure on the optical properties of the polymers

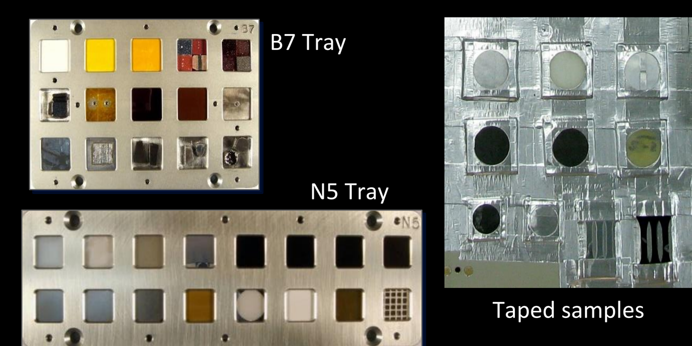
Materials International Space Station Experiment 7

MISSE 7 Polymers Experiment

The MISSE 7 Polymers Experiment is a passive experiment with 45 samples flown in ram or wake orientations on MISSE 7B

Objectives include:
1. *Determine the LEO AO erosion yield (Ey, volume loss per incident oxygen atom, cm³/atom) of the polymers*
2. *Determine the effect of ram or wake space exposure on optical properties*

Ram samples:
- *38 samples were flown in the ram orientation exposing them to high AO fluence and solar radiation*
- *30 samples were flown for AO Ey & 6 for tensile testing*
- *Kapton H polyimide was flown for AO fluence determination*
- *Only 7 ram samples were an appropriate size for optical measurements (the wake samples were all too small)*



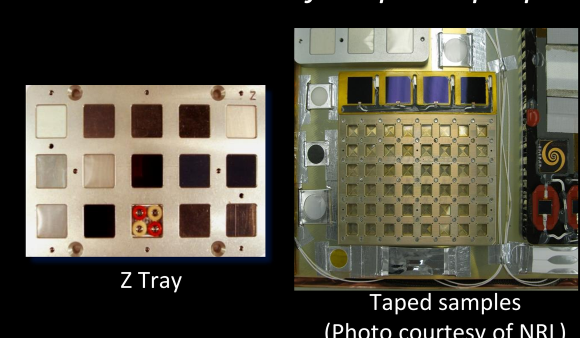
Pre-flight photos

MISSE 7 Zenith Polymers Experiment

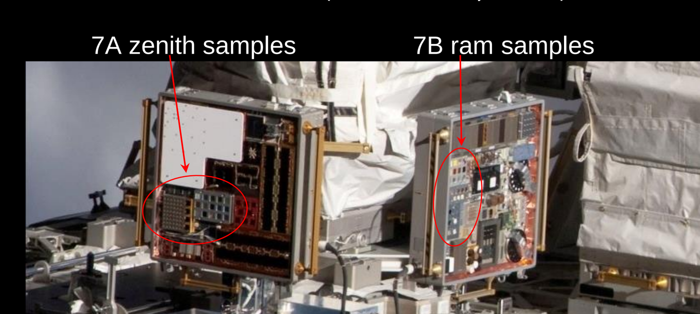
The MISSE 7 Zenith Polymers Experiment is a passive experiment with 25 samples flown in a zenith orientation on MISSE 7A

Objectives include:
1. *Determine the effect of solar exposure on the LEO AO Ey of fluoropolymers under high solar/low AO exposure*
2. *Determine the effect of zenith exposure on optical properties*

Zenith samples:
- *14 – 1" square samples were flown in the Z Tray and 10 "taped" samples were flown in handmade Al holders*
- *18 samples were flown for AO Ey & 5 for tensile testing*
- *Kapton H polimide was flown for AO fluence determination*
- *15 zenith samples were measured for optical properties*



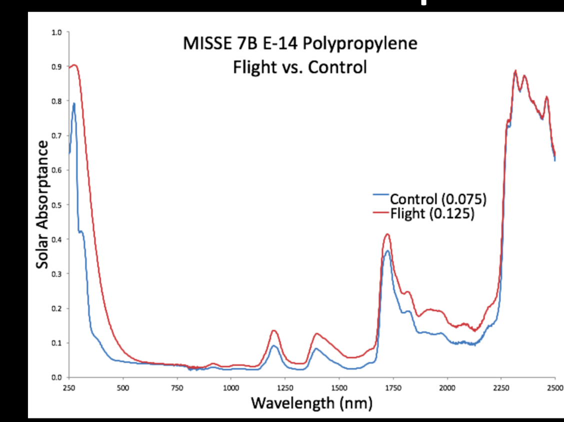
Pre-flight photos

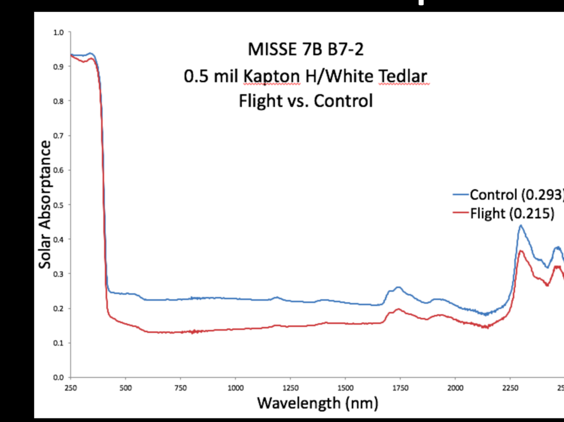


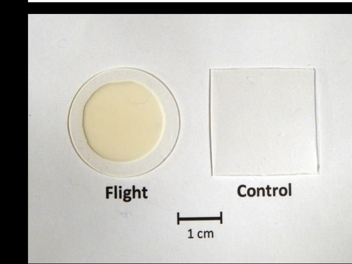
MISSE 7 Ram Polymers Optical Property Data

MISSE Sample ID	Material	Thickness (mils)	# Layers	Flight vs Control	TR	DR	SR	TT	DT	ST	α_s	$\Delta\alpha_s$
B7-8	Kapton H	5	1	Flight	0.070	0.050	0.021	0.561	0.314	0.247	0.368	0.039
			1	Control	0.112	0.007	0.105	0.559	0.012	0.547	0.329	
B7-9	Vespel	19.7	1	Flight	0.166	0.163	0.003	0.179	0.179	0.000	0.655	-0.001
			1	Control	0.183	0.166	0.018	0.161	0.144	0.017	0.656	
B7-1	White Tedlar	2	1	Flight	0.701	0.699	0.001	0.077	0.077	0.000	0.222	-0.070
			1	Control	0.622	0.619	0.004	0.086	0.085	0.000	0.292	
B7-2	0.5 mil Kapton H /White Tedlar	2	1	Flight	0.710	0.710	0.000	0.075	0.075	0.000	0.215	-0.078
			1	Control	0.621	0.617	0.005	0.086	0.085	0.001	0.293	
B7-3	1.0 mil Kapton H /White Tedlar	2	1	Flight	0.710	0.710	0.000	0.072	0.072	0.000	0.218	-0.075
			1	Control	0.622	0.618	0.004	0.085	0.084	0.001	0.293	
E-14	Polypropylene (PP)	20	1	Flight	0.191	0.185	0.051	0.684	0.664	0.020	0.125	0.050
			1	Control	0.086	0.035	0.006	0.840	0.339	0.500	0.075	
E-13	Al_2O_3 Contamination Slide	625	1	Flight	0.141	0.003	0.137	0.856	0.003	0.853	0.003	0.005
			1	Control	0.142	0.004	0.139	0.859	0.003	0.856	-0.002	

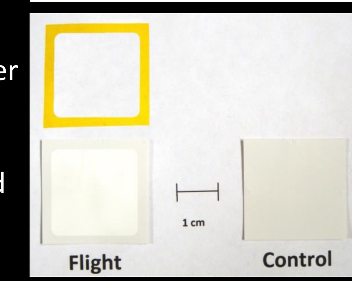
Solar Absorptance of Select MISSE 7B Ram Samples







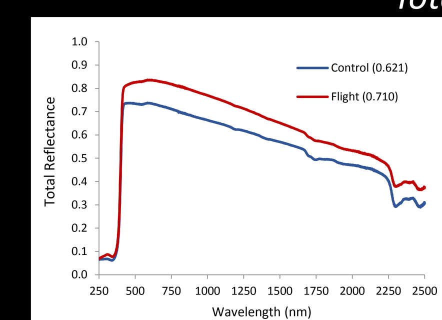
Textured and darker leads to increases in DR, DT, a decrease in TT, and increase in α_s

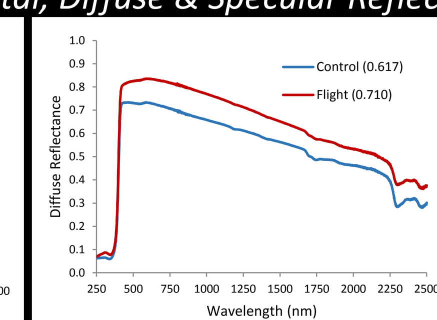


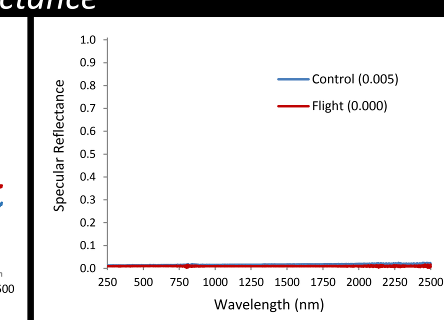
Textured and brighter which resulted in decrease in α_s

Spectral Data for B7-2 White Tedlar (0.5 mil Kapton H cover)

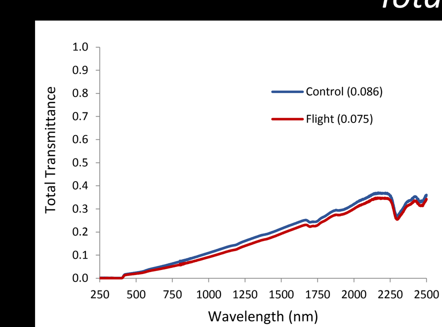
Total, Diffuse & Specular Reflectance

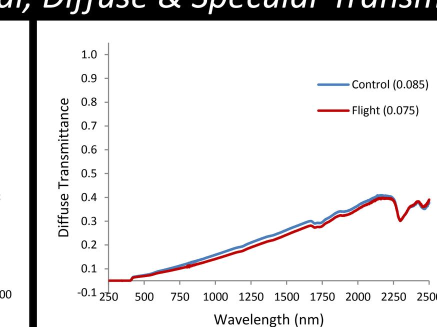


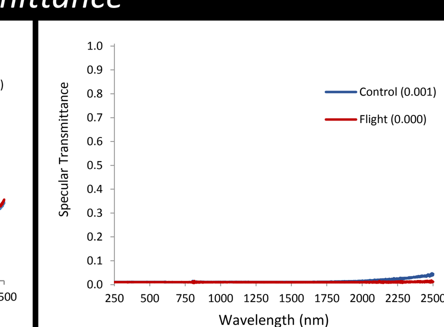




Total, Diffuse & Specular Transmittance





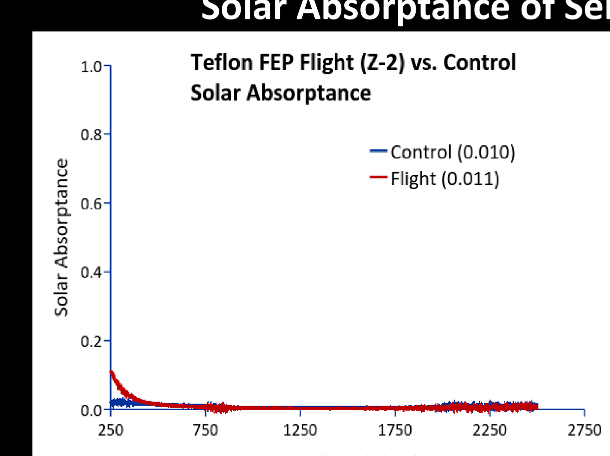


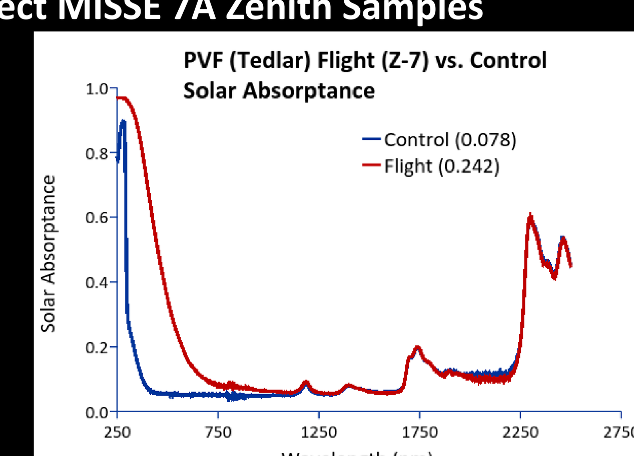
MISSE 7 Zenith Polymers Optical Property Data

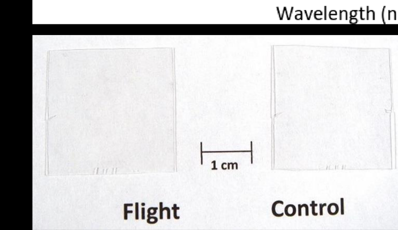
MISSE ID	Material	Thickness (mils)	# Layers	Flight vs Control	TR	DR	SR	TT	DT	ST	α_s	$\Delta\alpha_s$
Z-1	Polytetrfluoroethylene (PTFE), Teflon	5	1	Flight	0.135	0.124	0.011	0.808	0.339	0.469	0.057	0.001
				Control	0.144	0.134	0.010	0.800	0.340	0.460	0.056	
Z-2	Fluorinated ethylene propylene (FEP), Teflon	5	1	Flight	0.049	0.029	0.020	0.939	0.028	0.911	0.011	0.001
				Control	0.051	0.019	0.032	0.939	0.030	0.909	0.010	
Z-3	Chlorotrifluoroethylene (CTFE), Kel-F	5	2	Flight	0.113	0.047	0.066	0.844	0.020	0.824	0.042	0.021
				Control	0.118	0.012	0.106	0.861	0.018	0.843	0.021	
Z-4	Ethylene-tetrafluoroethylene (ETFE), Tefzel	5	2	Flight	0.104	0.069	0.035	0.809	0.333	0.475	0.087	0.072
				Control	0.107	0.013	0.093	0.878	0.022	0.856	0.015	
Z-5	Polyvinylidene fluoride (PVDF), Kynar	3	2	Flight	0.113	0.106	0.008	0.713	0.563	0.151	0.173	0.133
				Control	0.132	0.094	0.038	0.828	0.644	0.184	0.004	
Z-6	Ethylene-chlorotrifluoroethylene (ECTFE), Halar	3	3	Flight	0.191	0.150	0.041	0.549	0.415	0.133	0.261	0.225
				Control	0.177	0.066	0.111	0.788	0.148	0.640	0.036	
Z-7	Polyvinyl fluoride (PVF), Clear Tedlar	3	12	Flight	0.366	0.343	0.240	0.392	0.342	0.051	0.242	0.164
				Control	0.453	0.327	0.127	0.468	0.342	0.127	0.078	
Z-8	Polyimide, Kapton H	1	3	Flight	0.182	0.126	0.056	0.351	0.174	0.177	0.467	0.029
				Control	0.201	0.030	0.170	0.361	0.028	0.333	0.438	
Z-9	Aluminized-FEP (FEP/Al)	2	1	Flight	0.783	0.159	0.623	0.000	0.000	0.000	0.217	0.061
				Control	0.844	0.435	0.409	0.000	0.000	0.000	0.156	
Z-10	Silverized-FEP (FEP/Ag)	5	1	Flight	0.867	0.320	0.547	0.000	0.000	0.000	0.133	0.052
				Control	0.919	0.053	0.865	0.000	0.000	0.000	0.081	
Z-11	Polyethylene (PE)	5	8	Flight	0.356	0.324	0.032	0.556	0.337	0.219	0.088	0.017
				Control	0.399	0.284	0.115	0.530	0.324	0.207	0.071	
Z-12	Si/2 mil Kapton E/Al	2	1	Flight	0.579	0.037	0.542	0.000	0.000	0.000	0.421	-0.002
				Control	0.576	0.042	0.535	0.000	0.000	0.000	0.423	
Z-14	Al_2O_3/FEP	2	1	Flight	0.117	0.092	0.026	0.817	0.022	0.795	0.066	0.025
				Control	0.132	0.045	0.087	0.826	0.027	0.799	0.041	

Note: Optical properties of zenith samples (all except Z-5 & Z-6) were reported by H. Leneghan (OAS 2015)

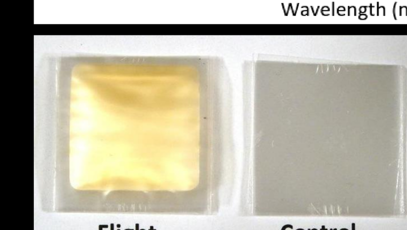
Solar Absorptance of Select MISSE 7A Zenith Samples







Flight is clear like control, α_s change essentially zero



Flight became yellow, α_s increase of 0.164

MISSE 7 Ram vs. MISSE 2 Ram

	MISSE 7				MISSE 2			
Materials	AO Fluence (atoms/cm²)	Solar Exposure (ESH)	$\Delta\alpha_s$	Ey (Ref. 1)	AO Fluence (atoms/cm²)	Solar Exposure (ESH)	$\Delta\alpha_s$ (Ref. 2)	Ey (Ref. 3)
PP	4.22E+21	2400	0.050	3.12E-24	8.43E+21	6300	0.145	2.68E-24
Vespel	4.22E+21	2400	-0.001	2.94E-24	N/A	N/A	N/A	N/A
Kapton H	4.22E+21	2400	0.039	3.00E-24*	8.43E+21	6300	0.077	3.00E-24*
White Tedlar	4.22E+21	2400	-0.070	1.48E-25	8.43E+21	6300	-0.104	1.01E-25
White Tedlar (0.5 mil Kapton H)	3.79E+21	2400	-0.078	1.54E-25	N/A	N/A	N/A	N/A
White Tedlar (1 mil Kapton H)	3.37E+21	2400	-0.075	1.67E-25	N/A	N/A	N/A	N/A
Al_2O_3	4.22E+21	2400	0.005	N/A	N/A	N/A	N/A	N/A

* Visentine, J. T., et al., AIAA-85-0415, 1985.
1: de Groh, K. K., et al., TM-2016-219167, March 2017.
2: Waters, D. L., et al., Proc. of ISMSE-11, Aix-en-Provence, France, 2009.
3: de Groh, K. K., et al., High Performance Polymers 20 (2008) 388-409.

- The MISSE 7 ram Al_2O_3 slide had very little change in optical properties indicating very low contamination to samples
- As the ram AO fluence for White Tedlar increases the Ey decreases as AO durable TiO_2 particles build up on the surface with erosion forming a AO barrier with higher fluence
  - *Change in α_s (brightness) was found to have stabilized with the lowest AO fluence of 3.37 E21 atoms/cm²*
- Ram samples with high Eys are observed to have large α_s changes. This is due to the change in texture, color, and/or thickness during erosion
- MISSE 2 ram samples, which have 2.6X ESH and 2X AO fluence as MISSE 7 ram samples, are found to have greater Δ α_s

MISSE 7 Zenith vs. MISSE 2 Ram

	MISSE 7		MISSE 2	
Materials	$\Delta\alpha_s$	Ey (Ref. 1)	$\Delta\alpha_s$ (Ref.2)	Ey (Ref. 3)
PTFE	0.001	9.19E-25	0.025	1.42E-25
FEP	0.001	9.74E-25	0.004	2.00E-25
CTFE	0.021	2.15E-24	0.105	8.31E-25
ETFE	0.072	1.49E-24	0.095	9.61E-25
ECTFE	0.239	3.56E-24	0.116	1.79E-24
PVDF	0.133	1.74E-24	0.153	1.29E-24
PVF	0.164	1.44E-24	0.096	3.19E-24
Kapton H	0.029	3.00E-24*	0.077	3.00E-24*
FEP/Al	0.061	2.22E-24	N/A	N/A
FEP/Ag	0.052	1.17E-24	N/A	N/A
PE	0.017	8.13E-24	N/A	>3.74E-24
Si/2 mil Kapton E/Al	-0.002	1.17E-25	N/A	N/A
Al_2O_3/FEP	0.025	6.22E-26	N/A	N/A
PVOH	0.124	1.22E-23	N/A	N/A
PP	0.050	2.77E-24	0.145	2.68E-24

* Visentine, J. T., et al., AIAA-85-0415, 1985.
1: de Groh, K. K., et al., TM-2016-219167, March 2017.
2: Waters, D. L., et al., Proc. of ISMSE-11, Aix-en-Provence, France, 2009.
3: de Groh, K. K., et al., High Performance Polymers 20 (2008) 388-409.

MISSE Environmental Exposure	MISSE 7	MISSE 2
Solar Exposure (ESH)	4300	6300
AO Fluence (atoms/cm²)	1.58×10^{20}	8.43×10^{21}

*flight orientation for MISSE 2 ECTFE and PVDF are ram

- MISSE 2 ESH and AO fluence were greater than MISSE 7, but MISSE 7 solar/AO fluence ratio was significantly greater than MISSE 2
- The Ey of the MISSE 7 samples is greater than the corresponding MISSE 2 samples (except PVF)
  - *Due to solar radiation and corresponding temperature effects playing a significant role in the erosion of fluoropolymers*
- The $\Delta\alpha_s$ for the MISSE 2 samples is greater than for the MISSE 7 samples (except ECTFE & PVF)

Summary and Conclusions

- MISSE 7 ram and zenith samples were characterized and compared to corresponding MISSE 2 samples
  - *Optical properties were obtained on 7 ram & 14 zenith MISSE 7 samples (12 zenith samples were reported previously)*
  - *AO E_y data were compared*
- MISSE 7 ram Al_2O_3 slide had very little change in optical properties indicating very low on-orbit contamination
- The $\Delta\alpha_s$ for the MISSE 2 samples is greater than for the MISSE 7 samples (except ECTFE & PVF)
- The Ey of the MISSE 7 samples is greater than for the MISSE 2 samples (except PVF) due to solar effects
- Understanding data on changes in polymers' optical properties and E_y allows the determination of the most durable and best-fit samples for spacecraft design
- Samples with high increases in α_s or with high Ey should be avoided, or protected, when considering materials for thermal control or other exterior spacecraft applications