Artemis Suit Material Optical Property Testing of Dust Exposed Fabrics

ICES-2026-164

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DATE

7/14/26

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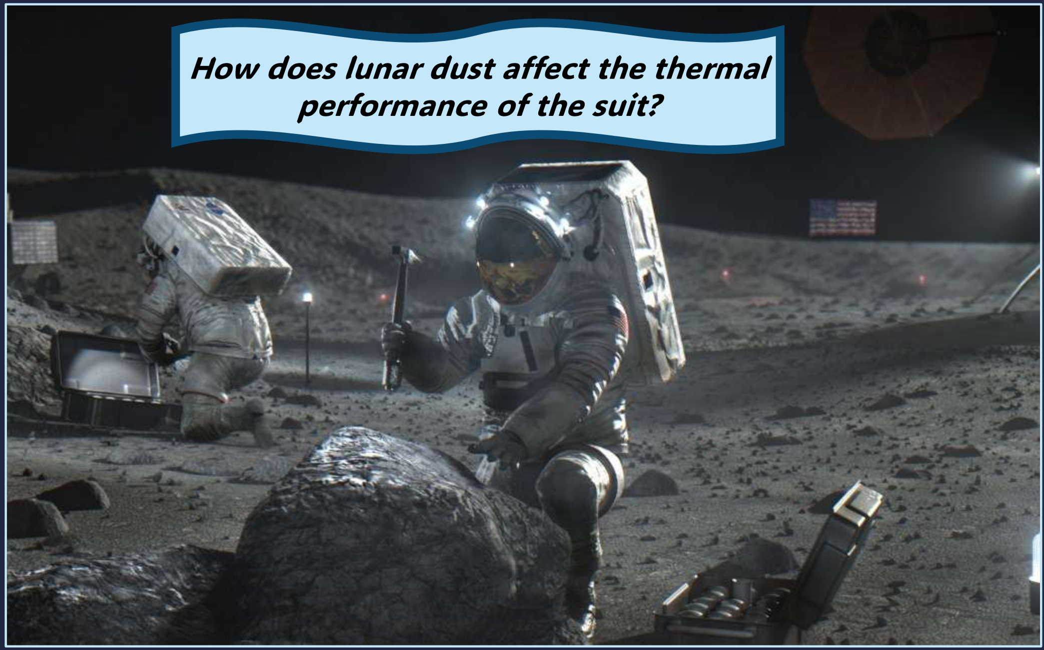
Overview

- Artemis Suit Material Overview presented in ICES-2025-56
  - Technology infusion project to design, fabricate and test new outer shell fabrics for lunar EVA suits

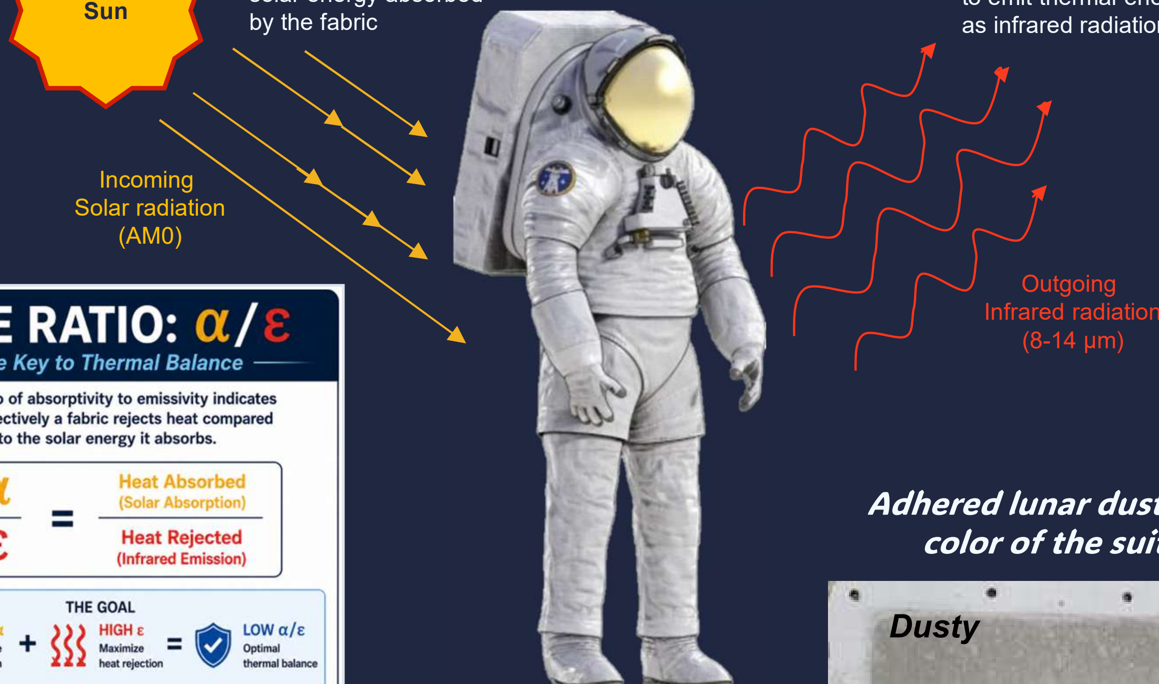


- BLUF: Lunar dust exposure significantly increases the solar absorptance of EVA outer-shell fabrics while producing only minor changes in emissivity

Optical Properties

① **Absorptivity (α)**
The fraction of incoming solar energy absorbed by the fabric

② **Emissivity (ε)**
The ability of the fabric to emit thermal energy as infrared radiation



THE RATIO: α/ε

The Key to Thermal Balance

The ratio of absorptivity to emissivity indicates how effectively a fabric rejects heat compared to the solar energy it absorbs.

$$\frac{\alpha}{\varepsilon} = \frac{\text{Heat Absorbed (Solar Absorption)}}{\text{Heat Rejected (Infrared Emission)}}$$

THE GOAL

LOW α (Minimize heat gain) + HIGH ε (Maximize heat rejection) = LOW α/ε (Optimal thermal balance)

EFFECTIVE THERMAL MANAGEMENT REDUCES LOADS ON THE PORTABLE LIFE SUPPORT SYSTEM (PLSS).

- LOWER CONSUMABLE USE (Water & Battery Power)
- LONGER EVA DURATION
- INCREASED MISSION PRODUCTIVITY

Adhered lunar dust alters the color of the suit fabric

ASM OPTICAL PROPERTY REQUIREMENTS

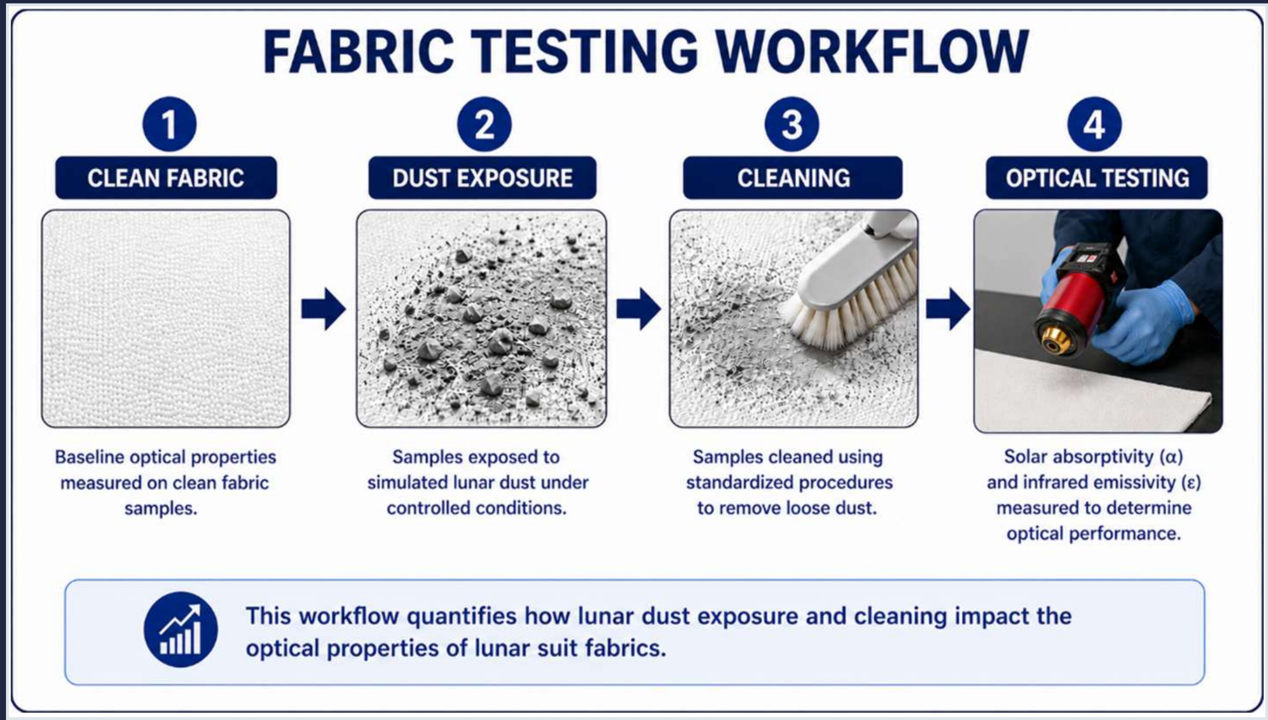
	Absorptance (α) (AM0 Solar)	Emissivity (ε) (8–14 μm)
BOL (Clean)	< 0.3	> 0.8
EOL (Dust Exposed)	< 0.6	> 0.8

Maintaining these properties throughout mission life is critical for astronaut safety and suit thermal performance.

Test Objective

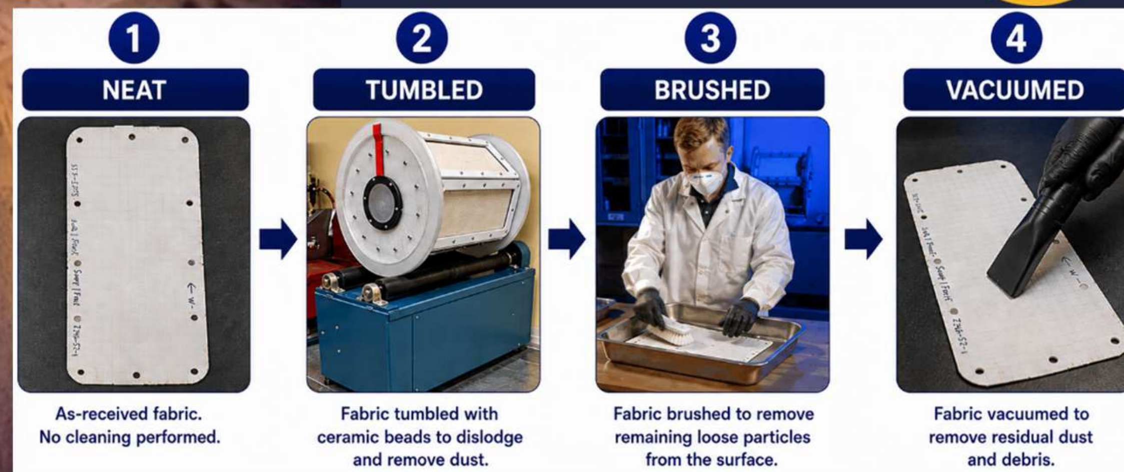
Test various EPG shell fabrics to determine:

- What happens to optical properties after lunar dust exposure
- If cleaning restores performance
- If backing material influences the measurements
- If a PTFE/TiO_2 film laminate improve performance



Rotary Tumbler Dust Exposure

Produces repeatable lunar-dust contamination and wear on fabric panels



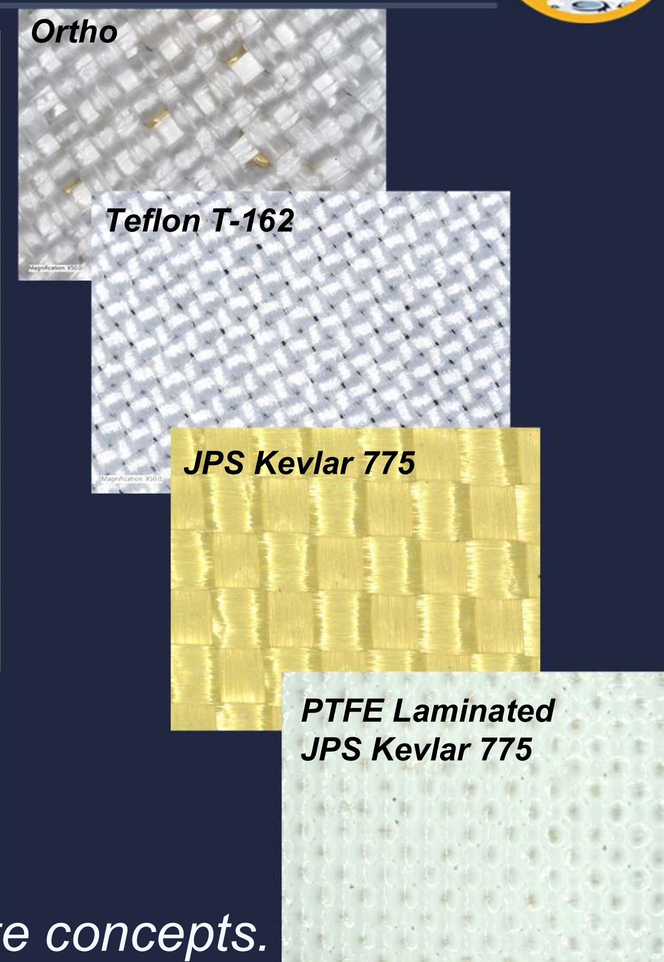
Tumbler Details

- 6 fabric panels per run
- 8-hour duration
- 1 lb. of lunar simulant
    - NU-LHT-4M
    - CSM-LHT-1
- 1 lb. of commercial ceramic tumbler media

Fabrics Evaluated

Fabric Name	Type	Manufacturer	Fiber Type	Simulant Type	Penetrated (g)
Ortho Fabric	Heritage/ Baseline	FDI	Gore-Tex, Nomex, Kevlar	NU-LHT-4M CSM-LHT-1	5.04 4.58
Teflon™	Heritage/ Baseline	Stern & Stern	PTFE	NU-LHT-4M	5.86
JPS Kevlar®	Candidate Base Layer	Dunmore/Dupont	Kevlar	NU-LHT-4M	0.58
PTFE Laminated Kevlar®	TiO_2 laminate concept	Force Engineering	Kevlar	NU-LHT-4M	0.00

Penetrated (g) = mass of simulant that penetrated through the fabric (grams).



Materials span heritage, candidate, and advanced laminate concepts.

Optical Test Method

Absorptance (ASTM C1549)

- Uses a Devices & Services 410 Solar Reflectometer device

- C1549: Field test/E903:Lab test
- Written for optically opaque materials
- Assumes transmittance is negligible
- Team selectively changed backer which is more in-line with ASTM C1549
- Solar irradiance: AM0 (air mass=0)
- Opaque materials:

$$\propto = 1 - reflectance\ (\rho)$$

- Non-opaque materials:

$$\tau = \frac{1}{2}\left[-\rho_{\text{sample}} + \sqrt{\frac{4x - 4\rho_{\text{sample}} + \rho_{\text{mirror}}\rho^{2}_{\text{sample}}}{\rho_{\text{mirror}}}}\right]$$

Calculate the solar absorptance, α_s:

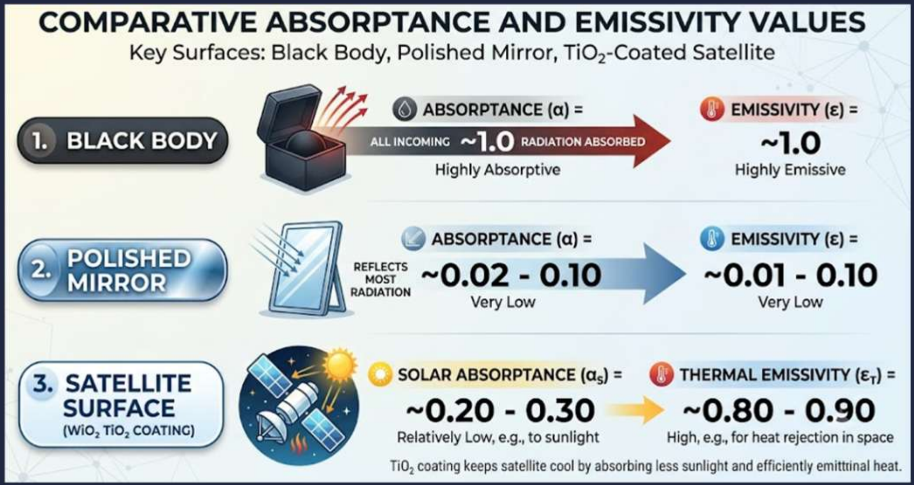
$$\alpha_s = 1 - \rho_{\text{sample}} - \tau_s$$

where

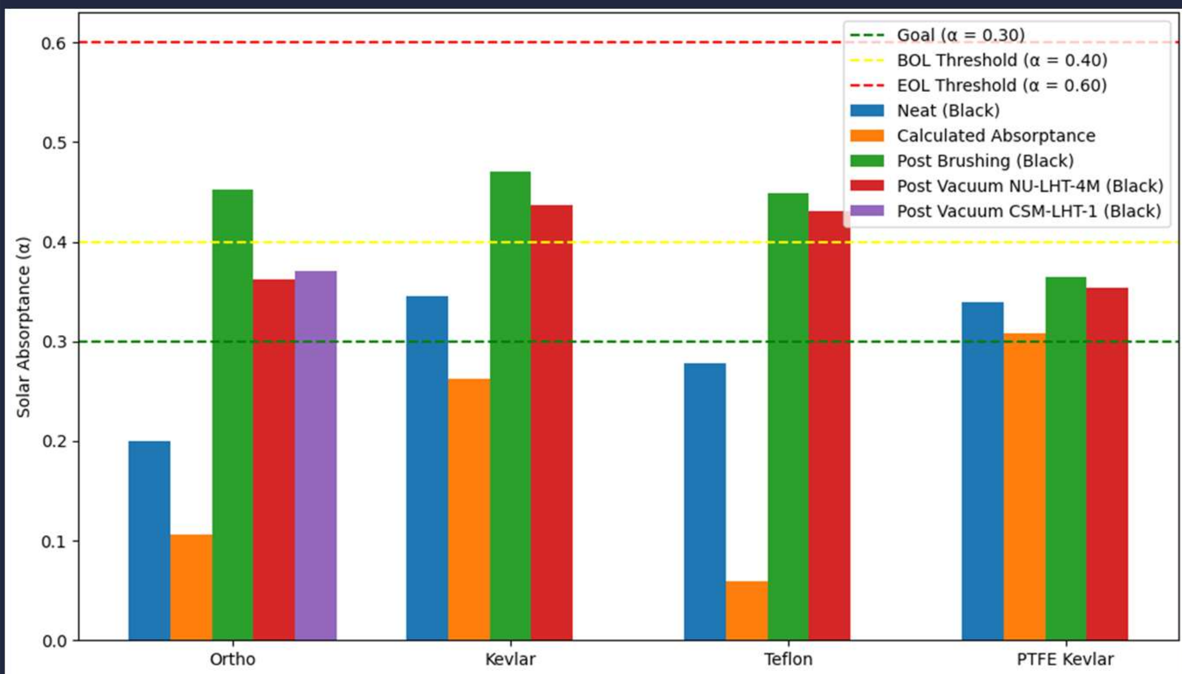
τ = transmission
ρ_{sample} = reflectance of sample measured with blackbody backing
x = reflectance of sample measured with reflective backing
ρ_{mirror} = reflectance of reflective backing.

Emissivity (ASTM E408)

- Uses Devices & Services ET-100 Emissometer
- Compares to blackbody radiation (ε=1)
- Also sensitive to backer material
- Slightly heats samples above ambient
- Infrared detectors measure thermal radiation



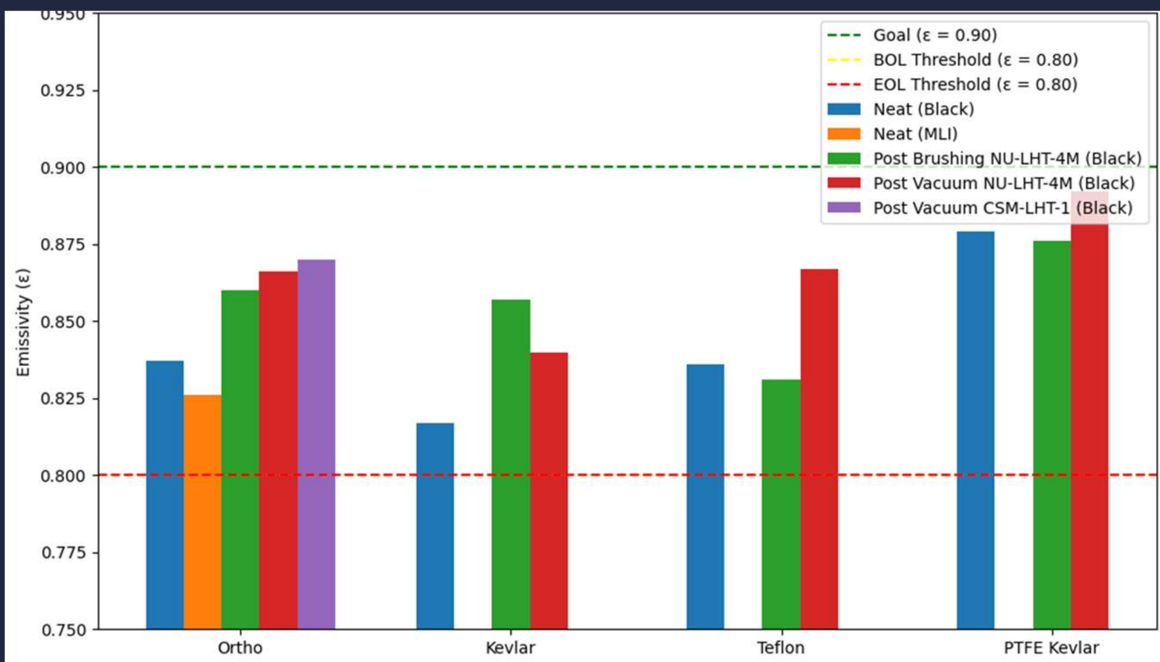
Absorptance Results



Fabric	Pre	⟶	Brush	⟶	Vacuum
Ortho *(Baseline)*	0.20	➡	0.45 +0.25 (+125%)	➡	0.36 -0.09 (-20%)
Kevlar	0.36	➡	0.47 +0.11 (+31%)	➡	0.44 -0.03 (-6%)
Teflon	0.29	➡	0.45 +0.16 (+55%)	➡	0.43 -0.02 (-4%)
P Kevlar	0.34	➡	0.37 +0.03 (+9%)	➡	0.35 -0.02 (-5%)

*Dust increases solar **absorptance** of some fabrics a significant amount*

Emissivity Results



Fabric	Pre	→	Brush	→	Vacuum
Ortho *(Baseline)*	0.860	→	0.866 +0.006 (+0.7%)	→	0.870 +0.004 (+0.5%)
Kevlar	0.857	→	0.840 −0.017 (-2.0%)	→	-
Teflon	0.831	→	0.867 +0.036 (+4.3%)	→	-
PTFE Kevlar	0.876	→	0.892 +0.016 (+1.8%)	→	-

*Dust marginally impacts **emissivity** therefore, it is not a limiting parameter!*

Backing Material Matters

Black backer compared to multilayered insulation (MLI)

α Absorptance (α)

Fabric	Black	MLI	% Change
Ortho	0.200	0.119	-40.5%
Kevlar	0.345	0.296	-14.2%
Teflon	0.278	0.090	-67.6%
PTFE Kevlar	0.340	0.320	-5.9%

% Change = (MLI − Black) / Black

ε Emissivity (ε)

Fabric	Black	MLI	% Change
Ortho	0.837	0.826	-1.3%
Kevlar	0.817	—	—
Teflon	0.836	—	—
PTFE Kevlar	0.879	—	—

MLI emissivity backer data collected for Ortho only

Some EVA fabrics are partially transparent and black-backed measurements can overestimate absorptance

PTFE/TiO_2 Laminate Performance

DUST CLEANABILITY PERFORMANCE (Neat Kevlar vs. PTFE Laminated Kevlar)						
FABRIC	ABSORPTANCE (α) *Lower is Better*			EMISSIVITY (ε) *Higher is Better*		
	Pre	Post Brushing (NU-LHT-4M Black)	Post Vacuuming (NU-LHT-4M Black)	Pre	Post Brushing (NU-LHT-4M Black)	Post Vacuuming (NU-LHT-4M Black)
Neat Kevlar	0.345	0.470	0.440	0.817	0.857	0.840
PTFE Laminated Kevlar	0.340	0.370	0.350	0.879	0.876	0.892
CHANGE (PTFE vs. Neat)	-1.4%	-21.3%	-20.5%	+7.6%	+2.2%	+6.2%

Pre Tumbler *Post Brushing* *Post Vacuuming*

Kevlar

PTFE Laminated Kevlar

Comparison to MISSE Flight Data

- Ortho and Kevlar flown on MISSE were previously tested in:

    NASA/TM-2017-219634

    "Comparison of High-Performance Fiber Materials Properties in Simulated and Actual Space Environments."

Material	Current Study (Absorptivity Index)	MISSE (Absorptivity Index)
Ortho α	~0.20	~0.31
Kevlar α	~0.35	~0.41

<u>Why do the results differ?</u>

- Instrument differences
    - Spectral response differences
- Geometry effects
- Transmission effects

Key takeaway: Absolute values differ but trends remain consistent

Conclusions

- Key Findings
  - ✓ Lunar dust significantly increases solar absorptance
  - ✓ Vacuum cleaning improves but does not fully restore performance
  - ✓ Fabric transparency can strongly influence optical measurements
  - ✓ PTFE/TiO_2 laminate showed the best optical stability
  - ✓ All tested fabrics met threshold ASM optical requirements
  - ✓ Emissivity remained high across all conditions

Future Work

- Measure fully dust-covered fabrics
- Measure fabrics with MLI backer
- Correlate tumbler duration to EVA duration
- Evaluate additional simulants
- Assess PSR dust effects
- Develop dust-resistant coatings
- Integrate optical results into thermal models

Maintaining low absorptance under lunar dust exposure remains a critical challenge for future Artemis EVA textiles.


ADVANCED SUIT TEAM
NASA
JSC

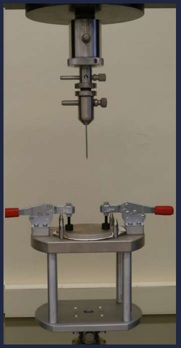
Lunar Fabric Test Procedure

- Testing locations
  - NASA JSC:
    - ASTM: Tensile/Elongation, Cut, Puncture, Tear, Abrasion, Air perm, Flex Cracking, Stiffness, Emissivity, Absorptivity, Mass, Thickness, 3-point fold, Drape
    - NASA Custom: Rotary Tumbler, Hot/Cryo Cut, Cryo stiffness, Dusty Glovebox, Dusty TVAC
  - Other NASA Centers:
    - UV exposure, Ionizing radiation, Flammability, Off/Out gassing, ESD, Tribocharging, Particle Penetration, Yarn cryo tensile
  - Out of House:
    - Hot/Cryo tensile/tear/puncture/stiffness, LHe tensile, Cryo flex fatigue
- Ortho Fabric serves as baseline for comparisons
- Fabrics are compared to each other and baseline to inform down select decisions

Tumbler Test

Tumbler Panel

Fabric Test Strips



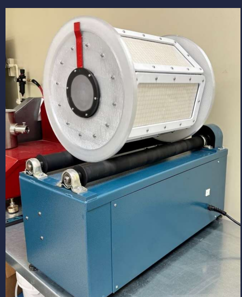
Puncture Test

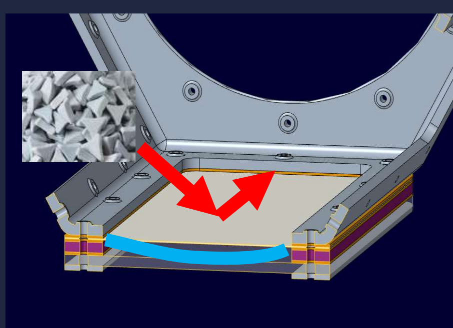
Cryo Cut Test

Cryo Flex Fatigue Test

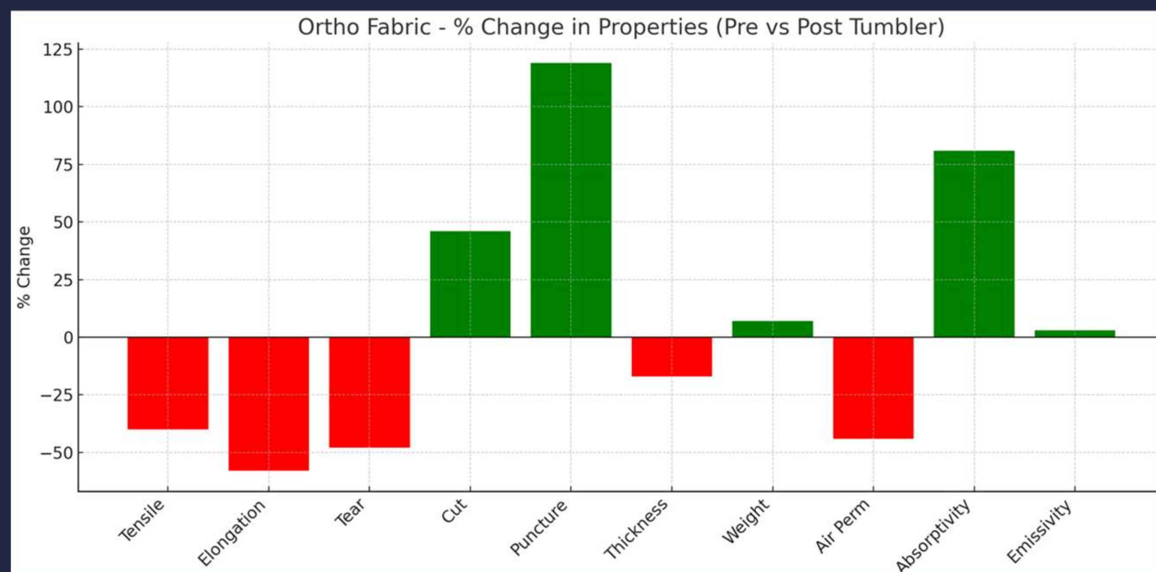
Tear Test

Baselining Ortho: Abrasion Exposure





Ortho Fabric	**Tensile (lbf)**	**Elongation (%)**	**Tear (lbf)**	**Cut (gf)**	**Puncture (ozf)**	**Thickness (in)**	**Weight (oz/yd^2)**	**Air Perm (CFM@125 PA)**	**Absorptivity**	**Emissivity**
Pre Tumbler (BOL)	507	59	229	437	38.8	0.024	14.5	22.5	0.200	0.837
Post Tumbler (EOL)	302	25	120	637	84.8	0.02	15.49	12.7	0.362	0.866
% difference	40%	58%	48%	-46%	-119%	17%	-7%	44%	-81%	-3%

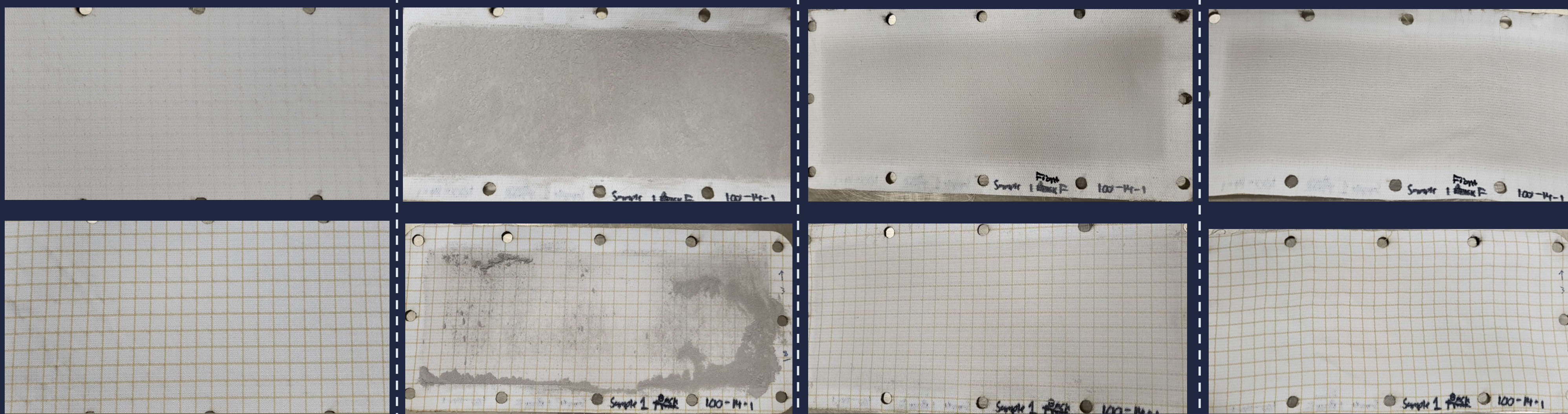


Baselining Ortho: Dust Exposure

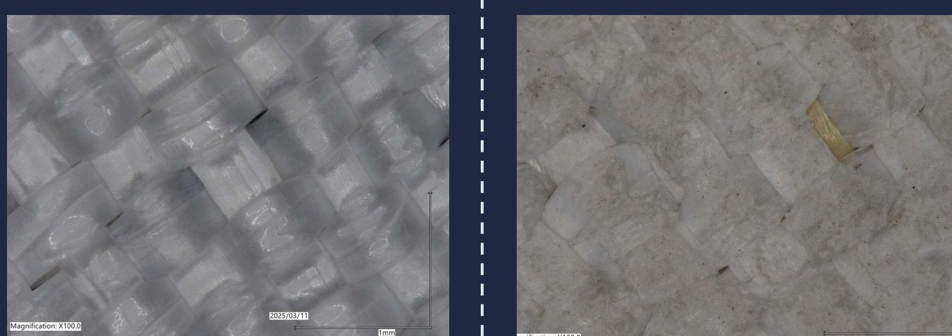
Pristine | **Post Tumble** | **Post Brushing** | **Post Vacuum**

Front

Back



Front Microscopy



Ortho Fabric 116				
Property	Avg. Post Tumbler	Max	Min	Std Dev.
Penetrated Simulant (g/m^2)	157	213	104	36.5
Simulant Adhesion (g/m^2)	284	282	81	78.3
Simulant Uptake (g/m^2)	19	33	14	5.4