DuSTI Outbrief

Dust Mitigation Characterization of Coatings and Pliable Cleaners

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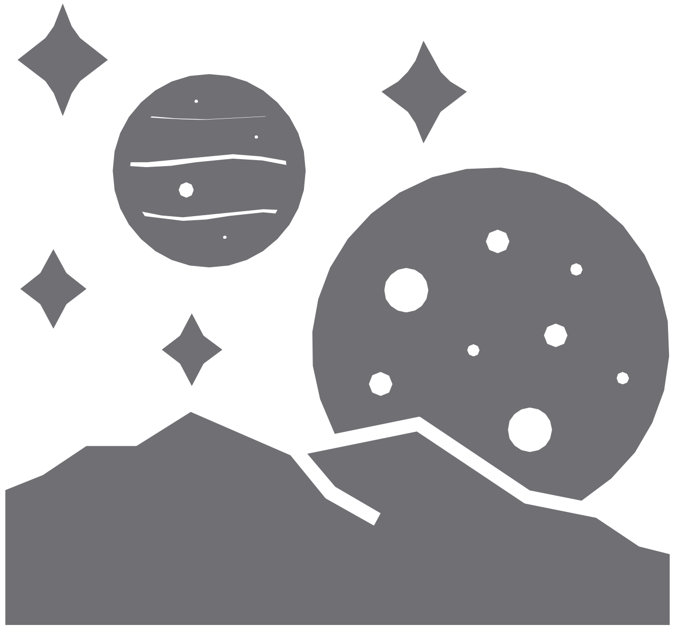
LSIC Dust Mitigation Focus Group – Thursday, January 20th, 2022

Agenda

- Executive Summary
- Technology Selection & Testing
- Results
- Future Work

Executive Summary

- DuSTI = Dust Solution Testing Initiative; a one-year study at NASA Johnson Space Center
- *Background:* Adhesion and abrasion of lunar dust are rated as one of the most **significant challenges** during the Apollo lunar exploration missions
- *Purpose:* Increase TRL of COTS technologies that have been used terrestrially to mitigate dust. Validate technologies in relevant environments with relevant materials (lunar regolith simulant)
- *Selected Technologies:* Coatings for soft goods, coatings for hard goods, pliable cleaners (aka cleaning gels or putties)
- *Process*: DuSTI performed several adhesion and abrasion tests on various substrates – in addition to mechanical strength tests for candidate materials that will be used for Artemis and future missions
- *Results:* The testing results provided data recommendations on coatings to use for adhesion and abrasion mitigation for lunar dust, increased Technology Readiness Levels (TRL) for commercial off the shelf technologies (COTS), and provided ideas for future work
- *Future:* A Technical Publication will be published in Feb 2022 with information on the testing process, detailed results, recommendations, and future work.



Technology Selection Rationale

The specific technologies identified for study were selected based on several factors:

- Market analysis of current terrestrial dust mitigation applications
- Practicality in lunar application
- Availability of the technology
- Accessibility of various testing facilities
- Cost of procurement

Technology Testing

Types of Tests Conducted	
Pliable Cleaners	
Rheometer Eval	Flammability
Temporal Usability	Off-gassing/Toxicity
Hardgoods Benchtop	Aluminum Nut & Bolt
FTIR Residue	
Hardgoods Coating	
Tape Press	Adhesion
Abrasion	
Softgoods Coating	
Folding Endurance	Stiffness
Tensile	Adhesion

COTS Technology Being Evaluated	
Pliable Cleaners	
Cyber Clean Home & Office (yellow)	
Cyber Clean Car (blue)	
Cyber Clean LeafCare (green)	
Cyber Clean Vinyl & Phono (gray)	
Hardgoods Coating	**Substrates**
Masterbond UV22DC80	Polycarbonate
Feynlab Waterline	Glass
Metashield NanoGlass	Glass
Masterbond EP114	Glass
Feynlab Industrial	Aluminum
Softgoods Coating	**Substrates**
UltraTech EverShield DOR 19	Orthofabric, PBI, Nomex, Nomex Felt

A snapshot of the substrates, tests, and technologies tested. Hardgoods, softgoods, and pliable cleaners were the main scope for the technologies.

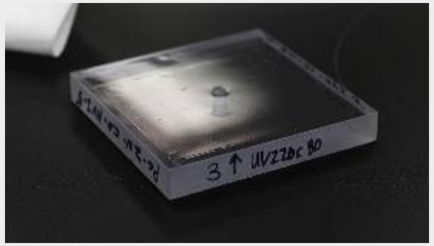
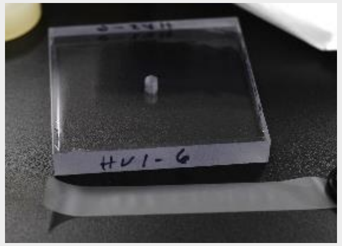
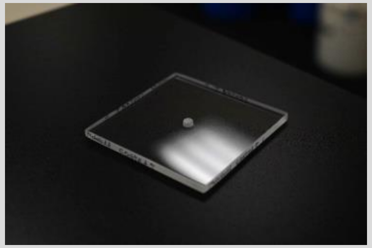
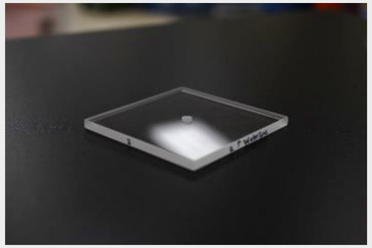
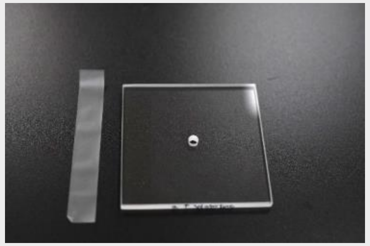
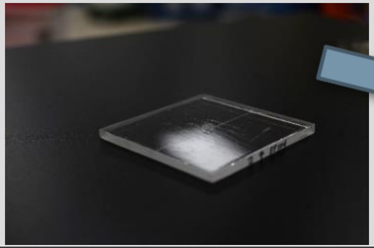
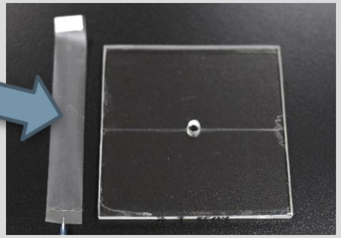
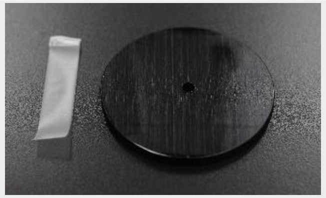
Hardgoods Testing Results*

*Information on the process and test setup can be found in the NASA Technical Publication.

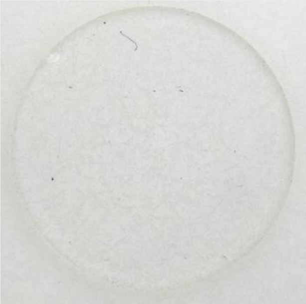
Hardgoods Tape Press Test for Coatings

Purpose: Verify that the coating had adhered to the substrate with the tape press test.

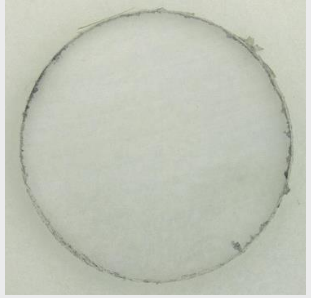
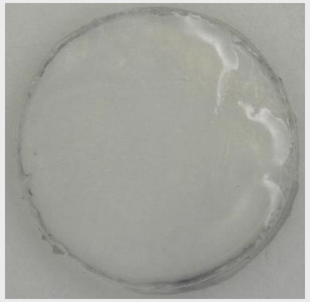
Results: All hardgoods samples passed, verifying the coating adhesion to the substrate.

Tape Press Results		
Sample Name	Before Test	After Test - Pass
Polycarbonate Masterbond (UV22DC80)		
Glass Metashield		
Glass Waterline (Feyn)		
Glass Masterbond (EP114)		
Aluminum Feynlab		

Hardgoods Pre-Adhesion

Glass			
Pristine	Waterline	Metashield	EP114
			

Aluminum	
Pristine	Feynlab
	

Polycarbonate	
Pristine	Masterbond
	

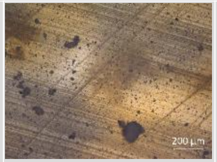
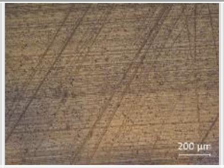
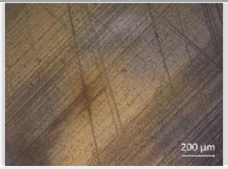
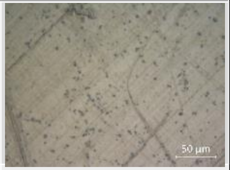
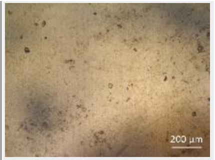
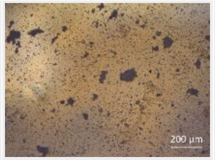
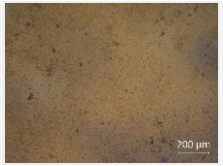
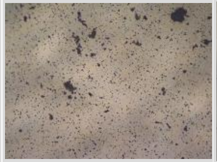
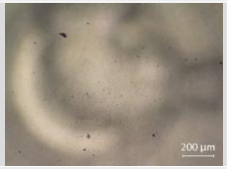
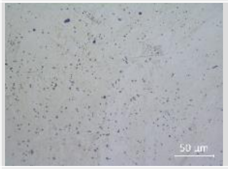
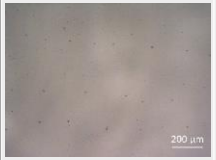
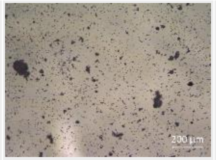
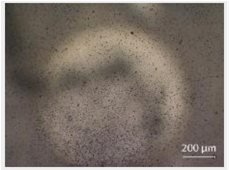
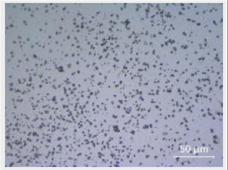
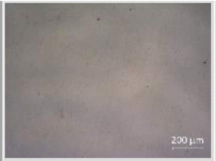
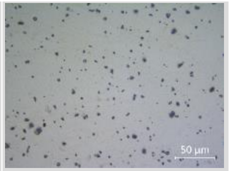
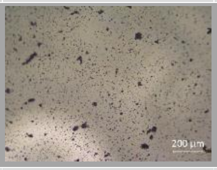
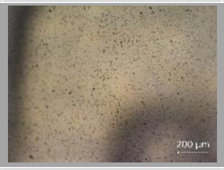
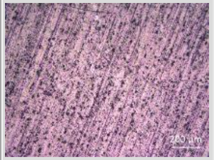
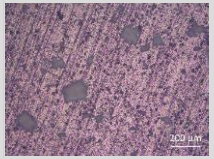
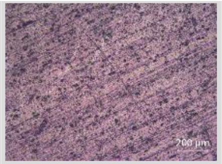
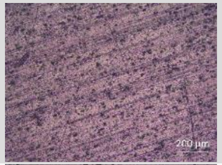
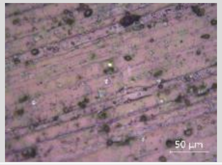
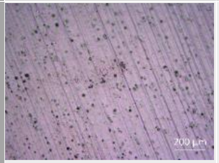
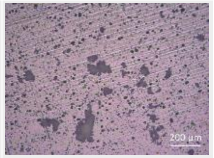
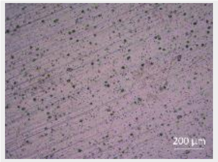
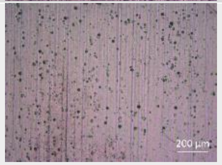
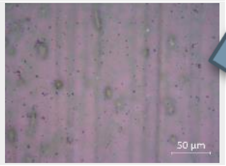
Hardgoods samples prior to shipping for LaRC.

Hardgoods Pre + Post Adhesion

<u>Purpose</u>: **Evaluate adhesion resistance of the coatings** when tested with LHS-1D lunar simulant (<30 µm).

This is a passive dust mitigation approach to reduce the amount of lunar dust adhered to the coated surfaces.

<u>Results</u>: Aluminum coating, Feynlab Industrial, was only coating to show adhesion resistance in comparison to the other coatings, which decreased adhesion performance.

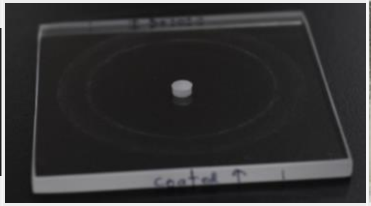
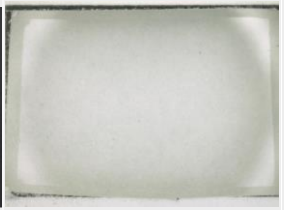
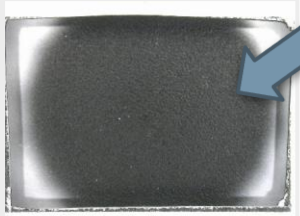
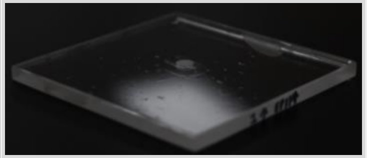
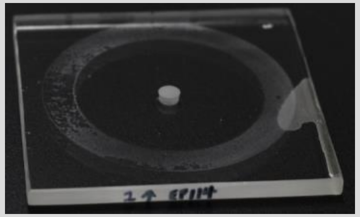
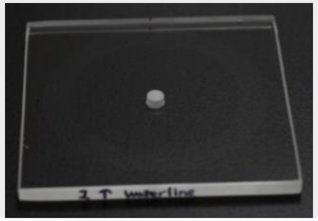
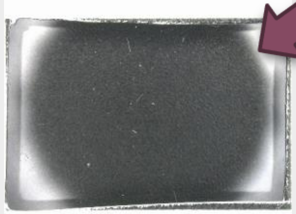
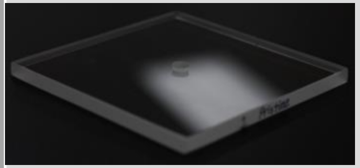
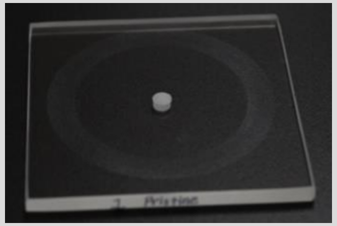
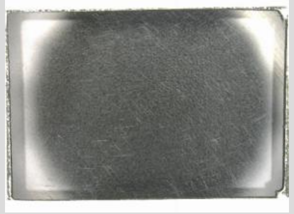
Sample Name	Control image (10x)	After dust deposition (10x)	After initial test (10x)	After full test 20-40% (10x)	After full test (50x)
Polycarbonate Pristine					
Polycarbonate Masterbond				None available	None available
Glass Pristine					
Glass Metashield					
Glass Waterline					
Glass EP114					
Aluminum Pristine					
Aluminum Feyn					

Hardgoods Pre + Post Abrasion – Glass

Purpose: **Evaluate the abrasion resistance of the coatings.**

Results: Ranking 1st and 2nd were Metashield and Feynlab Waterline; they were more abrasion resistant than uncoated glass. They both passed post-abrasion haze requirements set by JSC 66320.

EP114 showed poor abrasion resistance – not an effective abrasion resistant coating.

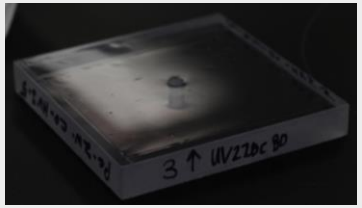
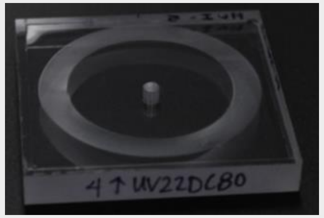
Before & After Abrasion Photo Table				
Coating	Before Macro	After Macro	Before Micro	After Micro
Metashield, Sample #2				
EP114, Sample #1				
Waterline, Sample #1				
Pristine Glass, Sample #1				

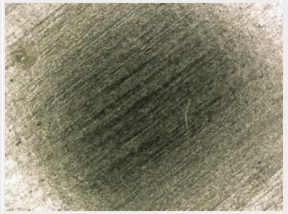
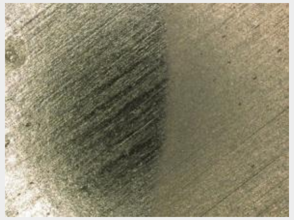
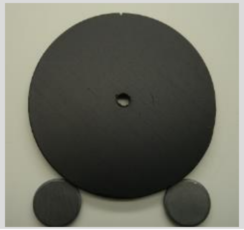
Hardgoods Pre + Post Abrasion – Polycarbonate & Aluminum

<u>Purpose</u>: **Evaluate the abrasion resistance of the coatings**.

<u>Results</u>:
Polycarbonate: Masterbond UV22DC80 coating performed better than the uncoated polycarbonate but didn't pass post-test haze requirements.

Aluminum: There were no discernible differences for the abrasion performance between the coated/uncoated aluminum samples.

Before & After Abrasion Photo Table				
Coating	Before Macro	After Macro	Before Micro	After Micro
UV22DC80, Sample #3 + 4				
Pristine Polycarbonate, Sample #2				

Before & After Abrasion Photo Table				
Coating	Before Macro	After Macro	Before Micro	After Micro
Feynlab Aluminum, Sample #3				
Pristine Aluminum, Sample #1				

Hardgoods Coating Haze + Transmittance Pass/Fail

<u>Purpose</u>: Determine the level of abrasion the optical samples displayed via Haze and Transmittance testing with Pass/Fail metrics.

Transmission testing determined the percentage of light that was allowed to pass through the samples. Failure during this test means the light was too scattered or unable to pass through the sample.

Haze determined the amount of light that was scattered as it went through the sample medium. The lower value for haze, the better clarity.

Test	Metashield	EP114	Waterline	Pristine glass	UV22DC80	Pristine PC
Transmittance (pre/post)	Pass/Pass	Pass/Fail	Pass/Pass	Pass/Pass	Pass/Fail	Pass/Fail
Haze (pre-test)	Fail	Fail	Pass	Pass	Pass	Pass
Haze (post-test)	Pass	Fail	Pass	Pass	Fail	Fail
Color balance (pre/post)	Pass/Pass	Pass/Fail	Pass/Pass	Pass/Pass	Pass/Fail	Pass/Fail

Softgoods Testing Results*

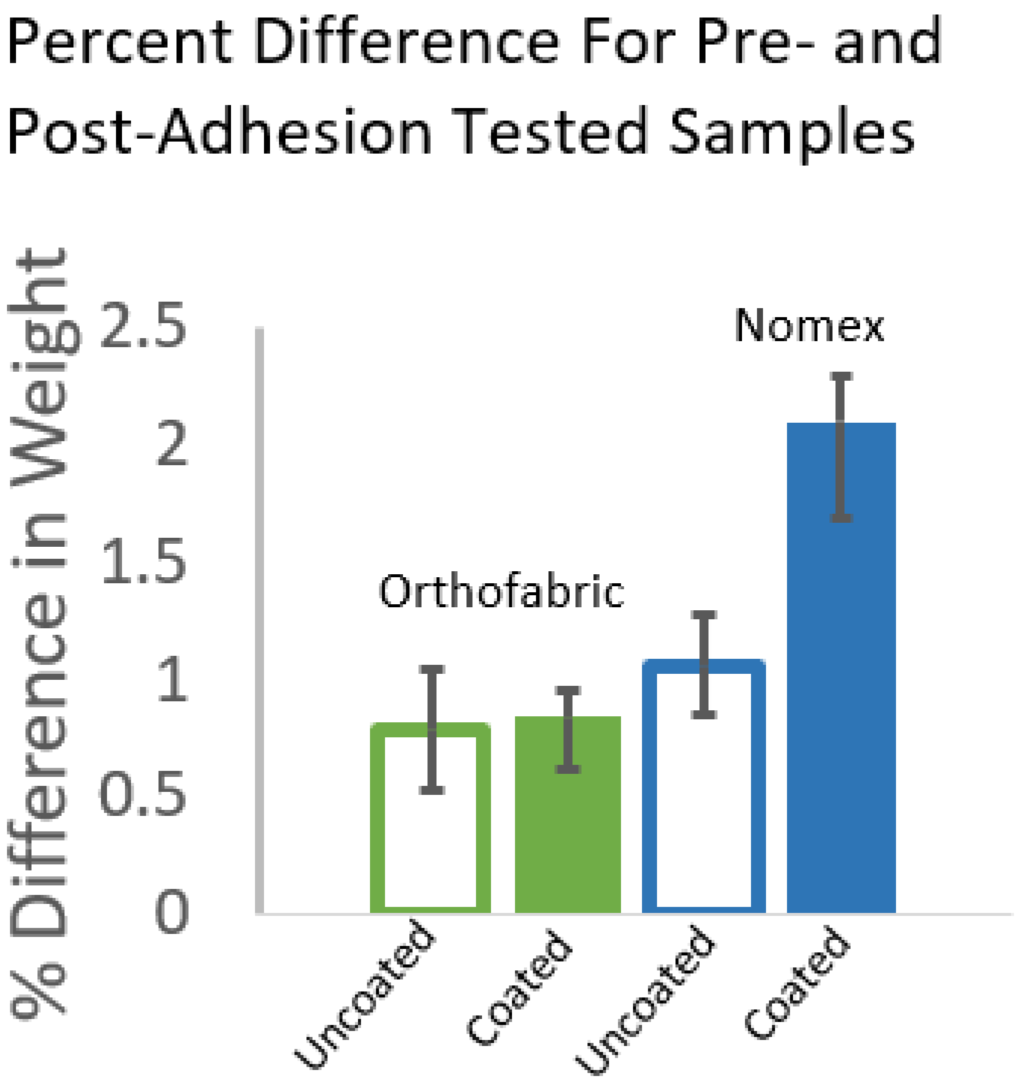
*Information on the process and test setup can be found in the NASA Technical Publication.

Softgoods Pre-Adhesion

Coated Orthofabric prior to adhesion testing.

Softgoods Pre- & Post-Adhesion

- **Purpose**: Evaluate adhesion resistance of the coating when tested with LHS-1D lunar simulant (<30 µm)
- This is a passive dust mitigation approach to reduce the amount of lunar dust adhered to the coated surfaces
- Adhesion testing was performed on Orthofabric and Nomex as coated and uncoated samples
- **Results**: Coating was counterproductive and measured by percent difference in weight
    - Coated Orthofabric samples performed similar to the uncoated sample counterpart
    - Coated Nomex samples retained twice as much lunar simulant than an uncoated Nomex sample



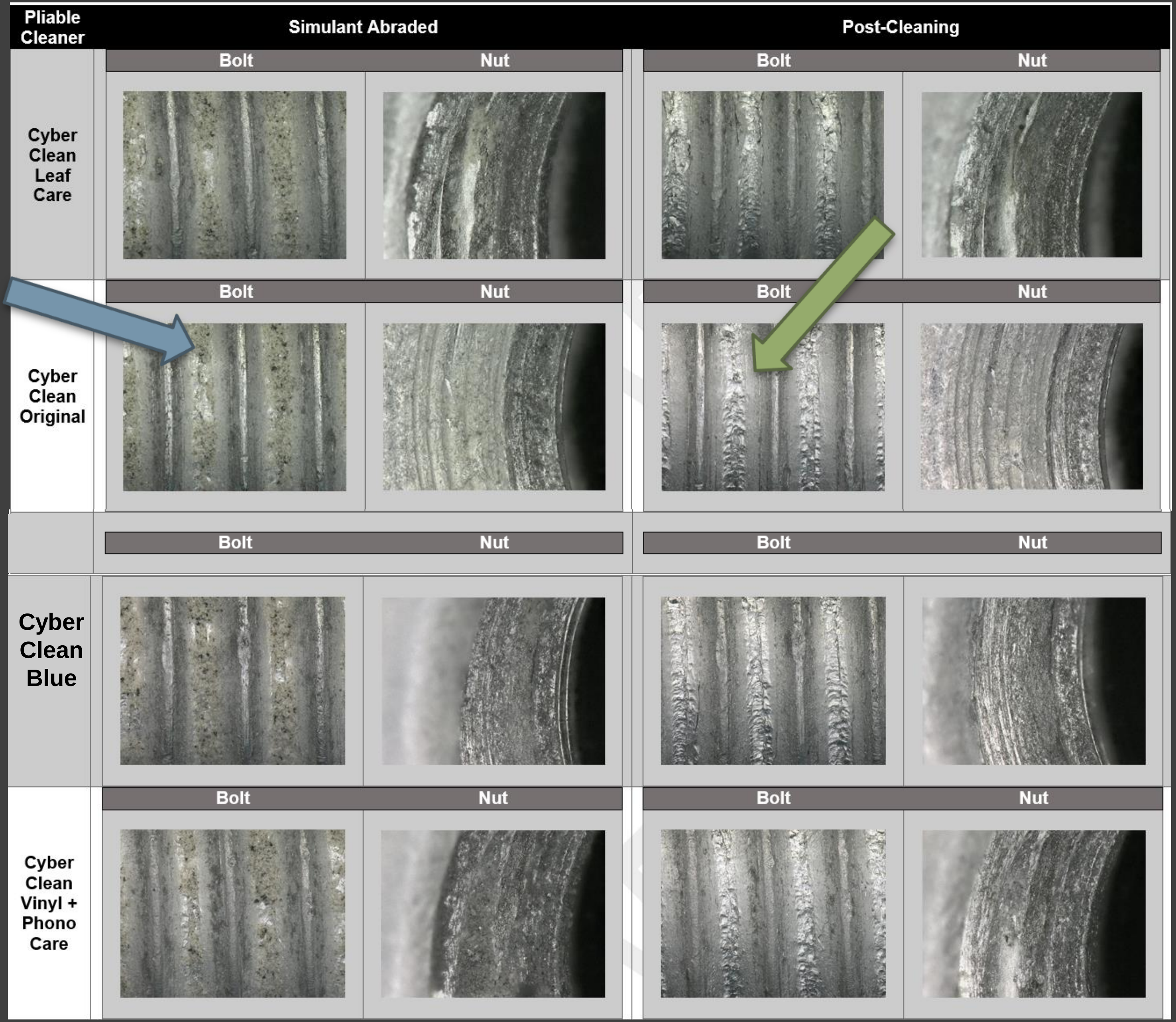
Additional Softgoods Testing Material Strength Tests

- Tensile:
  - **Purpose**: A controlled tension destructive test to evaluate the force loaded onto the material at the final moment before it breaks.
  - Tensile tests were performed on uncoated, coated, baseline (non-folded), and folded samples. Fill and warp thread directions were also considered in the testing.
  - **Results**: Coated substrate samples that were not folded prior to testing (baseline samples), had lower tensile results than uncoated samples (except for Nomex). For the 40,000-cycle folded and coated samples, however, they had higher results than their folded uncoated sample counterparts (except for Nomex).
- Stiffness:
  - **Purpose**: To evaluate the flexibility of the material after the coating was applied.
  - Stiffness tests were performed on uncoated, coated, baseline (non-folded), and folded samples. Fill and warp thread directions were also considered in the testing.
  - **Results**: Nomex felt was the only substrate to show a higher stiffness value for **both** coated baseline and coated folded samples. This behavior was expected for all substrates.

Pliable Cleaner Testing Results*

*Information on the process and test setup can be found in the NASA Technical Publication.

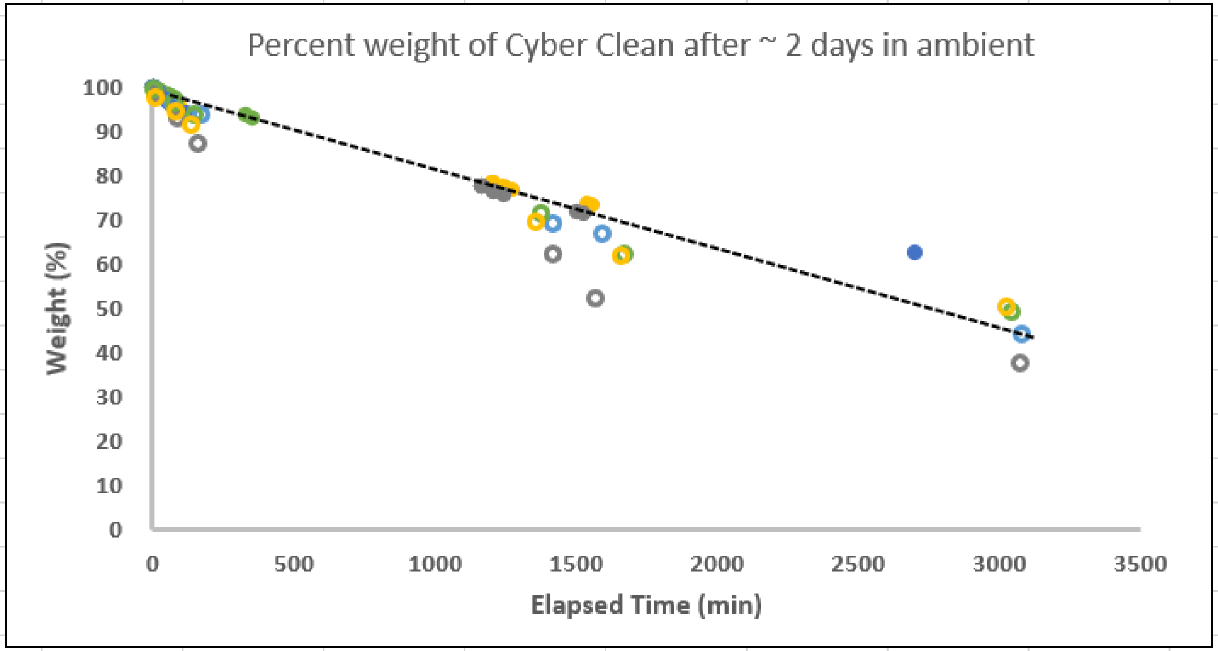
Pliable Cleaners Bolt + Nut



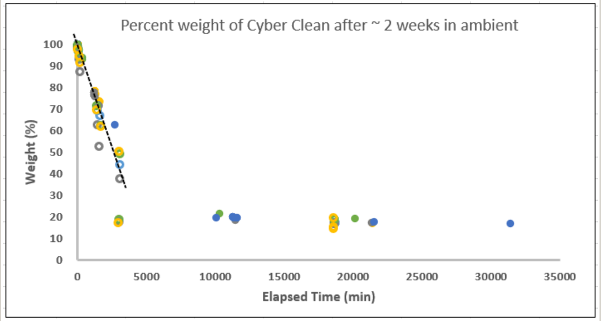
Purpose: To verify pliable cleaner **effectiveness** at removing LHS-1D lunar simulant between the small threads of bolts and nuts.

Results: All pliable cleaners were effective in removing simulant. Effectiveness between pliable cleaner types did not change.

Pliable Cleaners – Temporal Useability



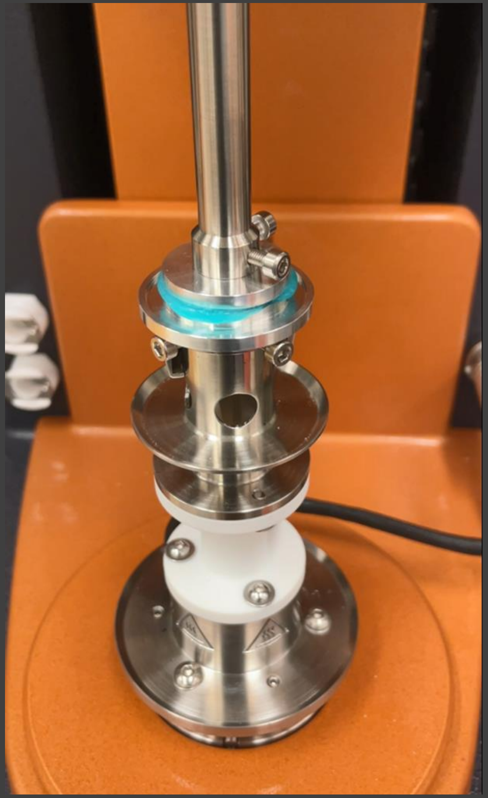
- CyberClean Yellow
- CyberClean Green
- CyberClean Black
- CyberClean Blue



Purpose: To determine the time window for 'usable amount of time' with the pliable cleaner and monitor weight loss in ambient conditions.

Temporal Useability: All pliable cleaners behaved similarly in that they lose significant mass and viscous properties to evaporation over time. Special attention must be made to properly seal when not in use or mitigation effectiveness deteriorates after 2 days.

Pliable Cleaners – Rheometer Test



Purpose: Rheometer testing was used to understand the pliable cleaner viscosity changes over time. However, the pliable cleaner does not follow Newton's law of viscosity, so a non-Newtonian test is required. The rheometer test measured the elasticity and viscosity properties of the pliable cleaner by observing the force and shear rate onto the material.

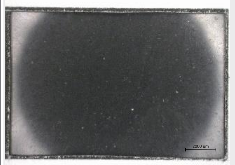
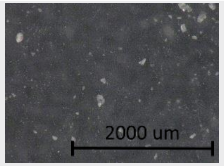
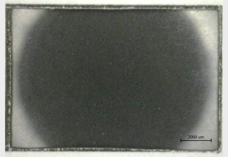
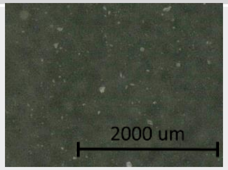
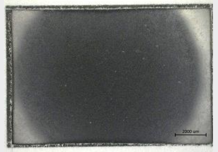
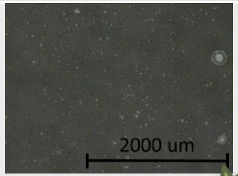
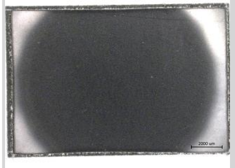
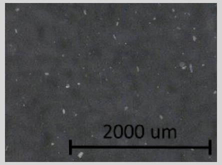
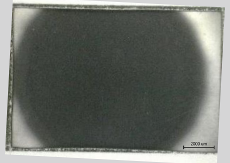
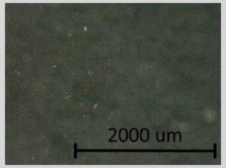
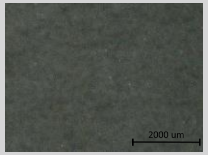
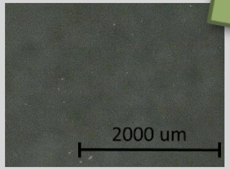
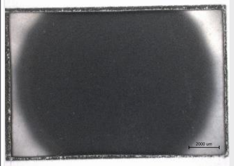
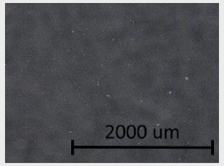
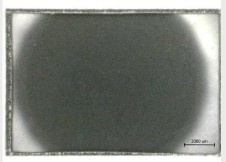
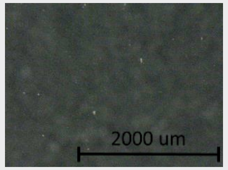
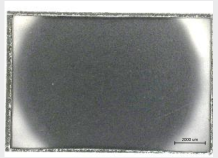
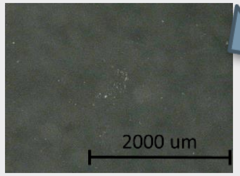
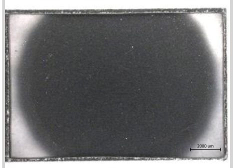
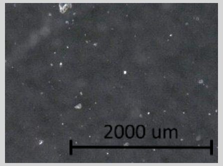
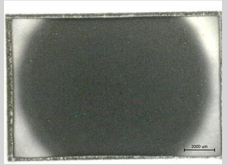
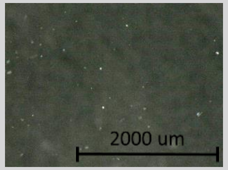
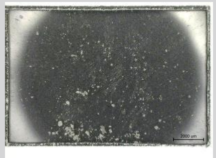
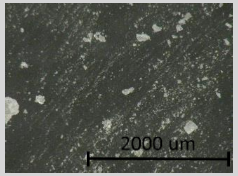
Results: The Cyber Clean Leaf Care was the most effective in viscosity performance. Even though this was opened and stored for a while, it still performed much better than the other two pliable cleaners.

Pliable Cleaners Hardgoods Benchtop – Glass

Purpose: To observe temporal feasibility of cleaning effectiveness with the pliable cleaner over an extended period.

Results: Cyber Clean Car and Cyber Clean Home and Office were the best pliable cleaners because they picked up the simulant relatively well in comparison to the other two pliable cleaners, Cyber Clean LeafCare and Cyber Clean Vinyl and Phono.

Cyber Clean Car and Cyber Clean Home and Office also did not leave behind any residue or extra particles when being used for cleaning.

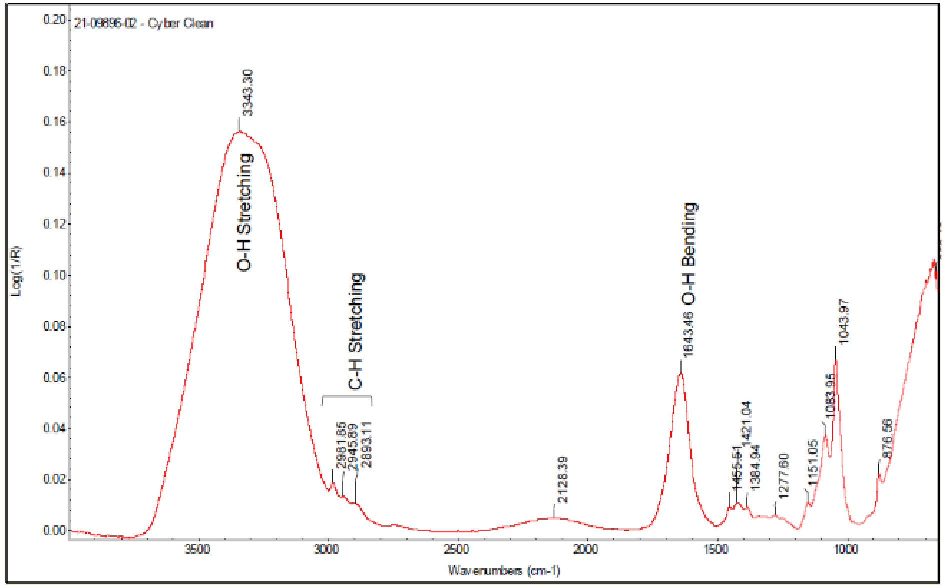
	Post Cleaning Operations (Days in elapsed time)					
Pliable Cleaner	0 Day, #1 (x20)	0 Day, #1 (x200)	1 Day, #4 (x20)	1 Day, #4 (x200)	2 Days, #6 (x20)	2 Days, #6 (x200)
Cyber Clean LeafCare						
Cyber Clean Home & Office					 (x100)	
Cyber Clean Car						
Cyber Clean Vinyl and Phono						

FTIR Residue

Purpose: To determine how much, and if, residue remains on the surface of various substrates (glass, Orthofabric, PBI) after applying Cyber Clean Home & Office. The Fourier Transform Infrared spectroscopy test was performed at Balazs Nano Analysis laboratory at the White Sands Test Facility in New Mexico. The instrument used was a Nicolet iS50 FTIR system coupled to a CONTINUUM FTIR microscope.

Results: FTIR results indicate that residue from Cyber Clean Home & Office did not remain on the surfaces of the Glass or Orthofabric substrates. Visual inspection and FTIR analysis did indicate that Cyber Clean remained present on the surface of the PBI Fabric after contact when average pressure was applied. When very light pressure was applied, no visible pliable cleaner residue was present on the PBI and FTIR analysis indicates there was no Cyber Clean present.

Recommendation: Implications are that Cyber Clean can leave residue on select softgoods and its use should be restricted to pre-approved materials.



FTIR Analysis of Cyber Clean Home & Office – Note OH and C-H peak absorbance bands

Pliable Cleaners Off-gas/Toxicity

Purpose: To determine if there are any hazardous chemicals exhibited from the evaporation of the Cyber Clean Home & Office pliable cleaner that could pose a threat to spaceflight missions.

This test was conducted at the NASA White Sands Test Facility by Susana Harper.

Results: Cyber Clean Home & Office preliminarily suggest concerning concentrations of Formaldehyde, which is not likely to be suitable for flight. Significant ethanol content (alcohols like ethanol) degrade the ISS ECLSS water processor.

Future Work

- Information on the testing process, the selected technologies, detailed results, recommendations, and future work will be presented at **LPSC** and published in a **NASA Technical Publication**.
- **This effort started investigations into coatings and pliable cleaners, but there is plenty of work to qualify these technologies for use in flight. This could be suitable for others to continue…**

Any questions?