Development of Coated Additively Manufactured (AM) Materials for Tribological and Radiation Resistance Improvement at Lunar and Martian Surfaces (MERCRI)

(Mercury- Roman God of Travelers): Metallic Environmentally Resistant Coating Initiative

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Challenge/gap that the project addresses

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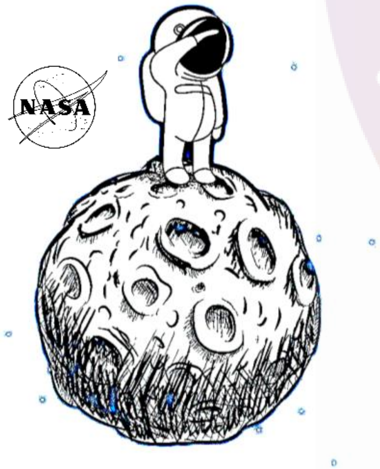
Light Weight Alloys

Poor Wear Resistance



Substrates:
Light weight alloys
High Friction & Poor wear

Aluminum & Titanium

Type of coatings

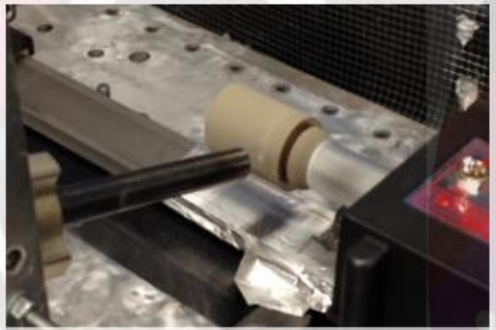
Low friction, high wear resistance, high radiation resistance (for BN-based)

NiTi

BN-based

Possible Solutions

Cold Spray Vs Plasma Spray

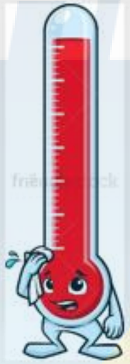


High Pressure Cold Spray Unit. Plasma Processes, LLC

Plasma Spray Unit. Florida International University

High Velocity

High Temperature

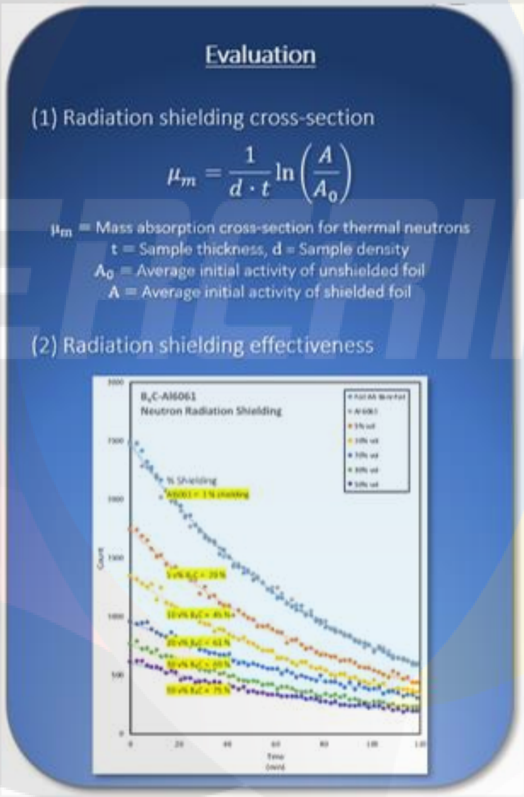


Florida International University (FIU)

Plasma Processes, LLC

Environmental Exposure

- Particle radiation
- Neutron radiation
- Thermal cycle (moon temperature cycles)



NASA Langley Research Center

NASA Marshall Space Flight Center

Wear Test

- Three body abrasion

- Surface erosion by high velocity regolith impact

AM
(additively manufactured)
&
CM
(Conventionally manufactured)

JSC-1A

Florida International University (FIU)

Plasma Processes, LLC

NASA Marshall Space Flight Center

NASA Glenn Research Center

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Radiation and Thermal Test Environment Development

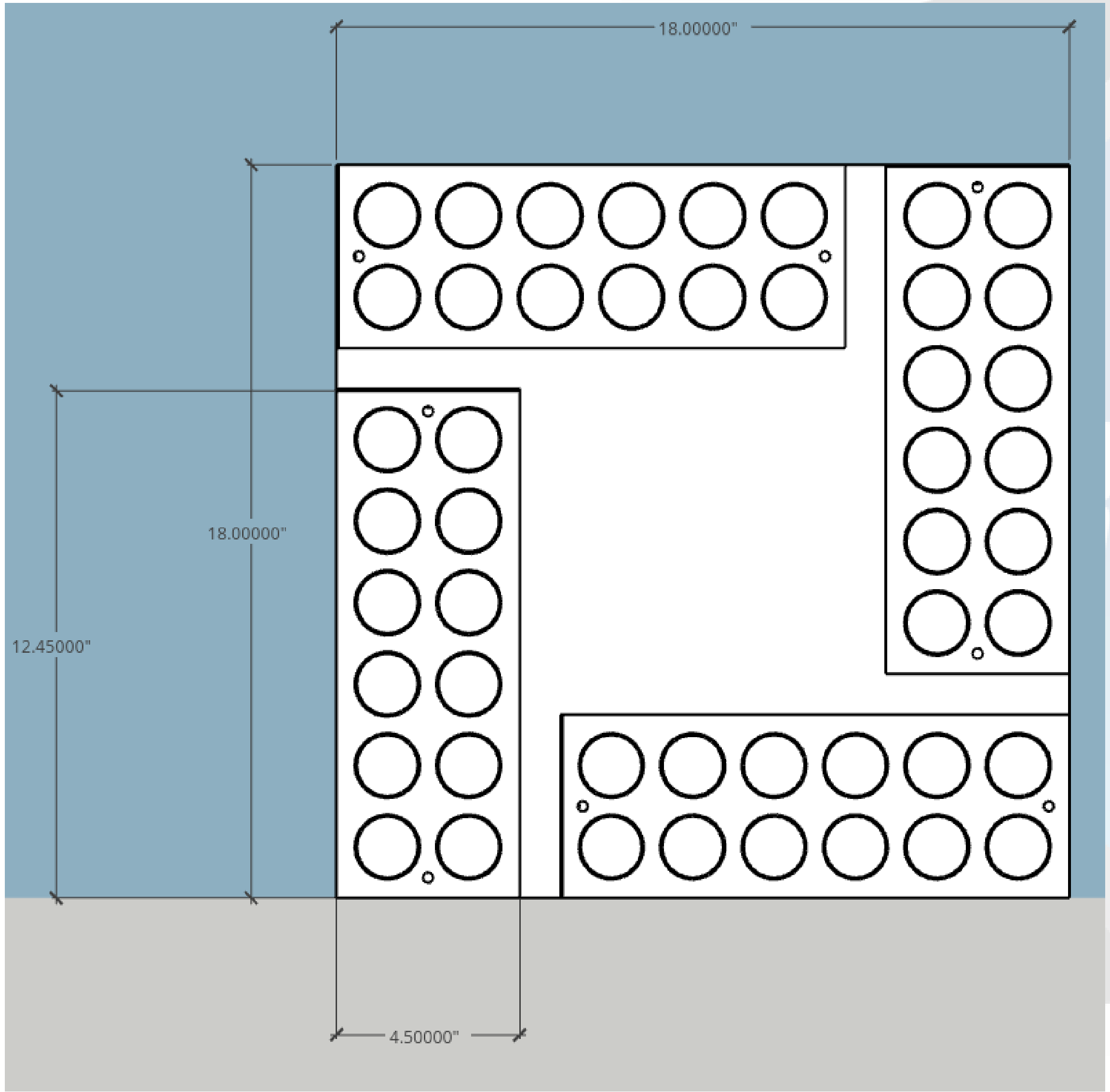
NASA MSFC EM41 Radiation Environment Test

Environment Definition Source: SLS-SPEC-159, Revision H, August 12, 2020, Cross-Program Design Specification for Natural Environments (DSNE), Table 3.3.1.10.2-6. Integral Electron and Proton Fluence for 15 Year Exposure to Solar Wind and Earth's Magnetotail in a Near Rectilinear Halo Orbit, 95th percentile.

For Phase I Down Select, we worked with NASA MSFC EM41 SEE Team to develop a flat dose of radiation for 1 Mrad, that would scale accordingly for the four coating variations (where the calculated difference in dose to hBN 2% and 10% were negligible). As such, we plan to expose the Radiation Only and Combined sample subsets in the same Pelletron Electron run. Per discussions with Dr. Cheol Park (LARC) it was recommended to increase the dose to 6 Mrad, with the understanding that the flux be adjusted to operator preference.

For Phase II Materials Testing & Phase II Simple/Complex Mechanisms Testing, we will further develop and compare our test profile to better match the dose described in the DSNE documentation. We will likely be using a similar test spec for the Phase III Flight Mechanism Testing.

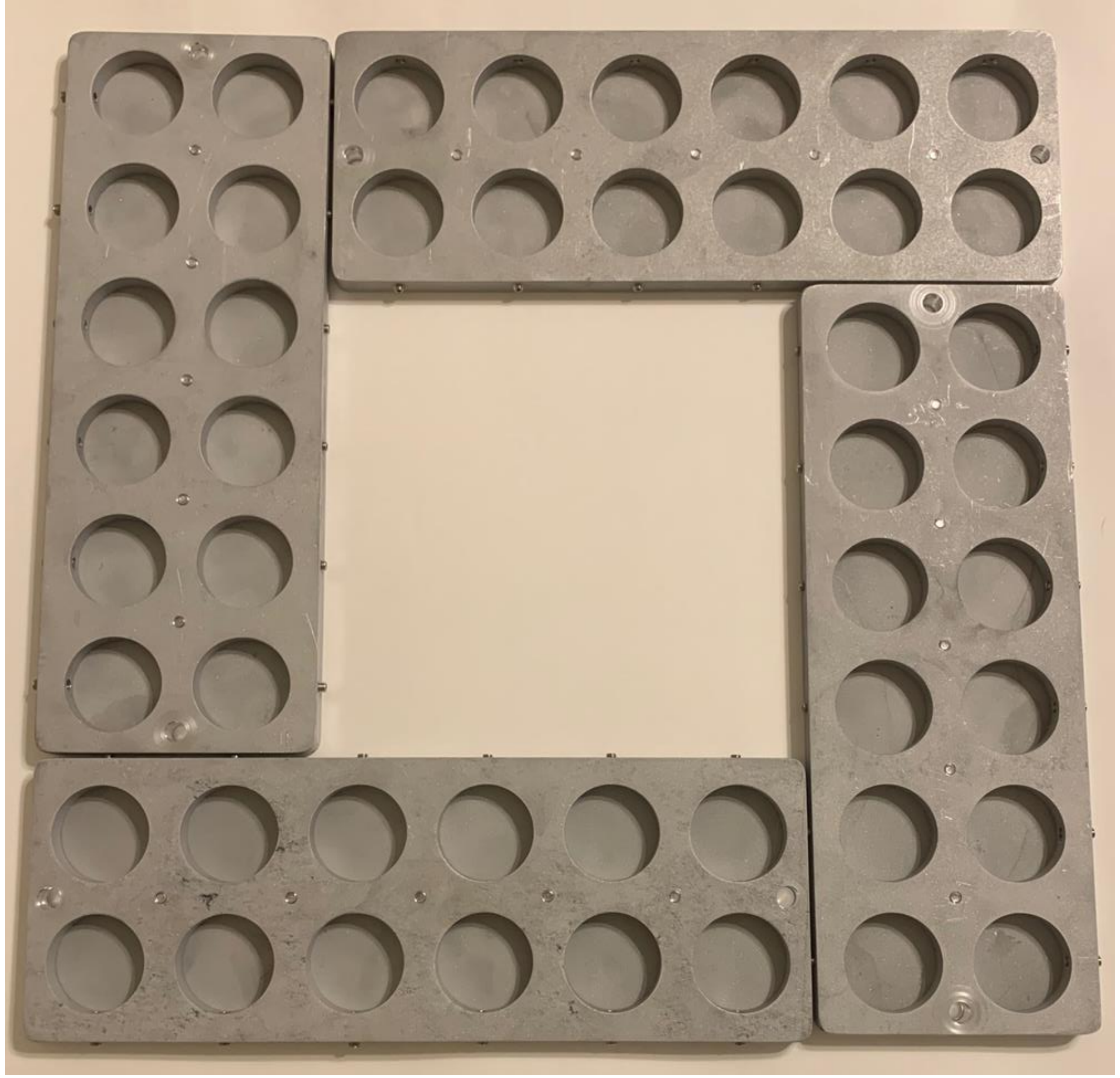
Title: Radiation and Thermal Test Environment Development



Pelletron Electron Test Assumptions

- Electron Energy is 400 keV
- Electron Flux is 1 nA/cm^2
- 6 Mrad dose in each coating
- Coatings are 200 µm thick
- Durations Estimates
  - Coating #1: NiTi+W2
    - Density: 7.148 g/cm^3
    - Duration: 7.5 hrs
  - Coating #2: Ti-2%vol hBN
    - Density: 2.433 g/cm^3
    - Duration: 4.8 hrs
  - Coating #3: Ti-10%vol hBN
    - Density: 2.406 g/cm^3
    - Duration: 4.8 hrs
  - Coating #4: Al2O3
    - Density: 3.987 g/cm^3
    - Duration: 4.2 hrs

Title: Radiation and Thermal Test Environment Development



NASA MSFC ET20 Vacuum Thermal Cycle Test

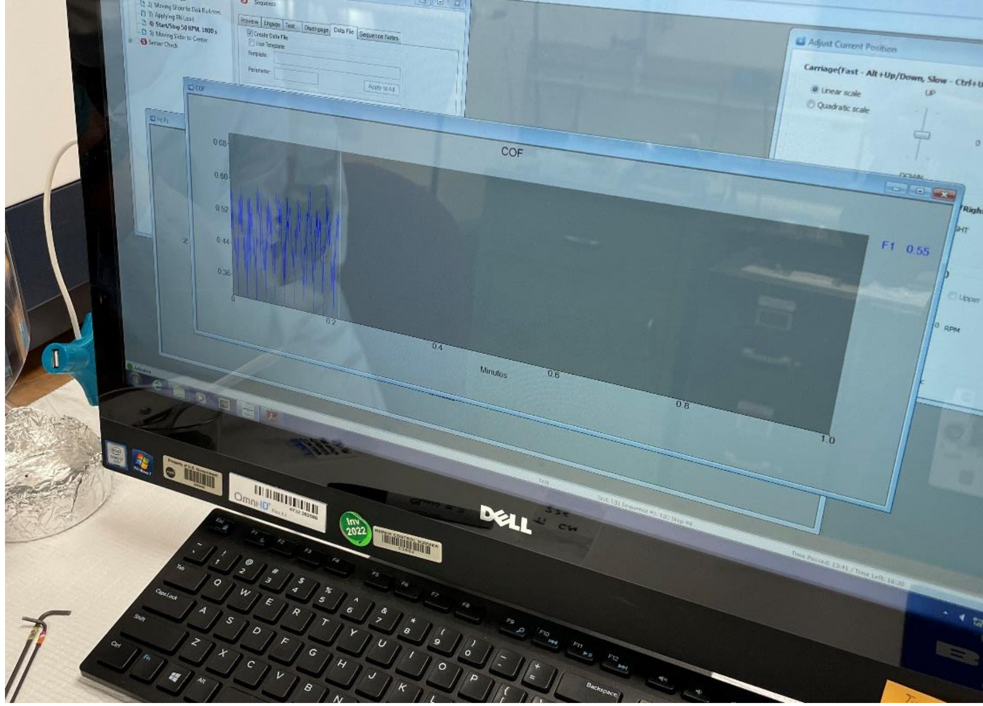
For Phase I down-select testing, we decided to target a thermal profile ranging from 120 ± 10 °C with a DNE threshold of 130 °C down to -175 ± 10 °C on the cold side. To reduce cycles to the shortest possible cycle duration, we would only hold soaks until the trailing TC is within the tolerance window (no artificial soak durations). We were initially targeting 288 cycles, if able to be completed with the project allowable schedule.

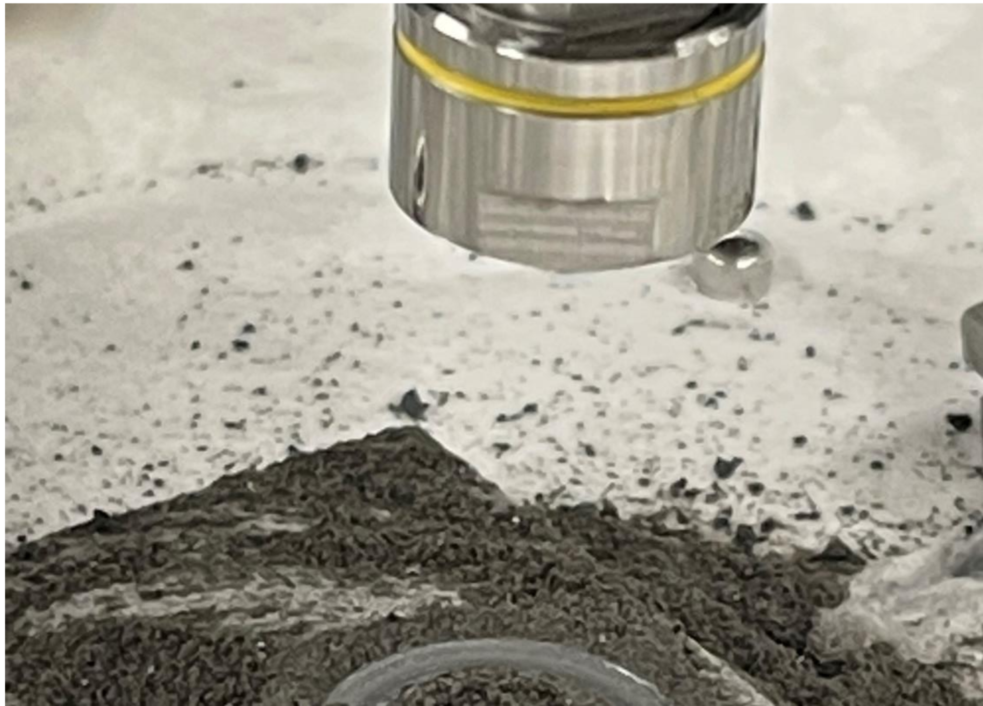
The Phase I TVAC was important particularly for providing a pathfinder experience that would feedback to the team members working the mechanism designs in parallel, optimizing the Phase II & Phase III TVAC testing to come later in the project life.

Title: Radiation and Thermal Test Environment Development

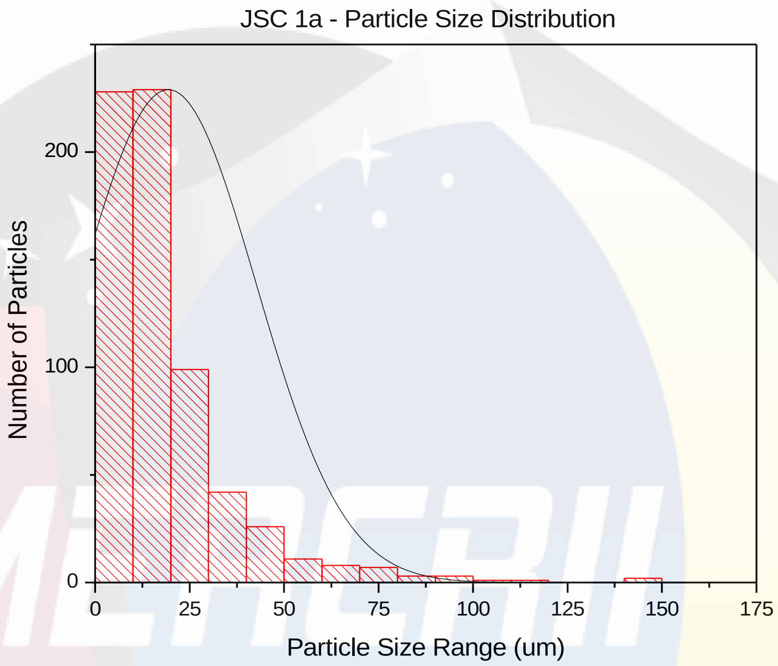
Tribological Tests


BRUKER
UMT

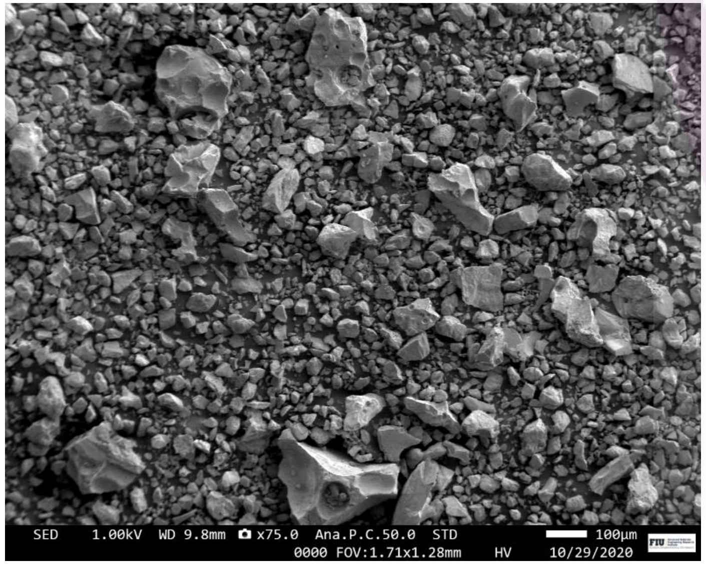

COF
Minutes
DELL

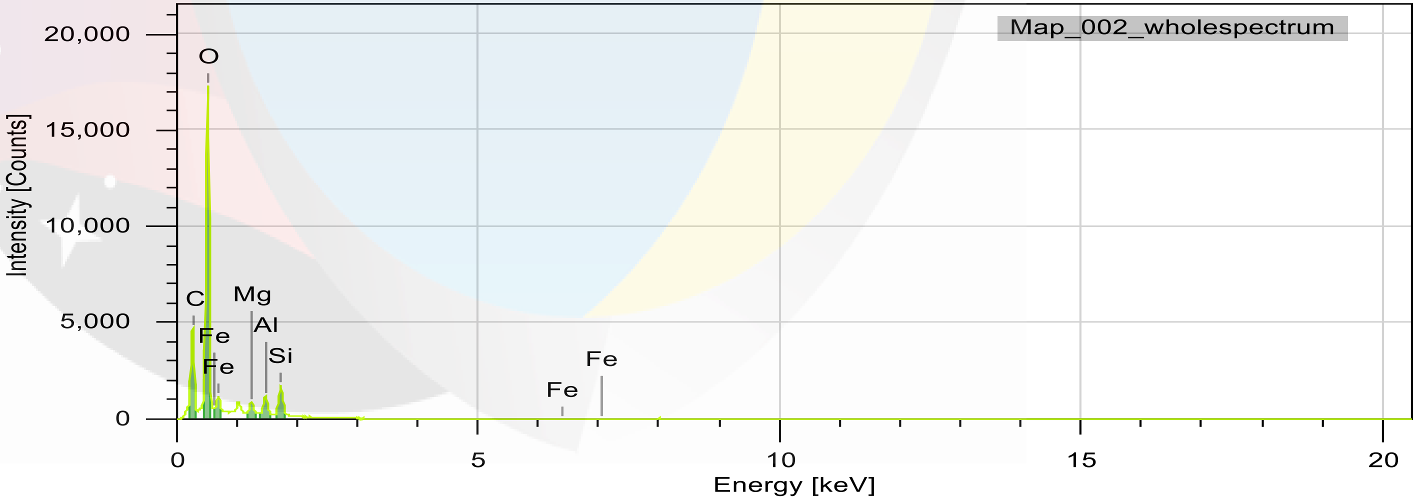


Lunar Regolith Simulant: JSC-1a

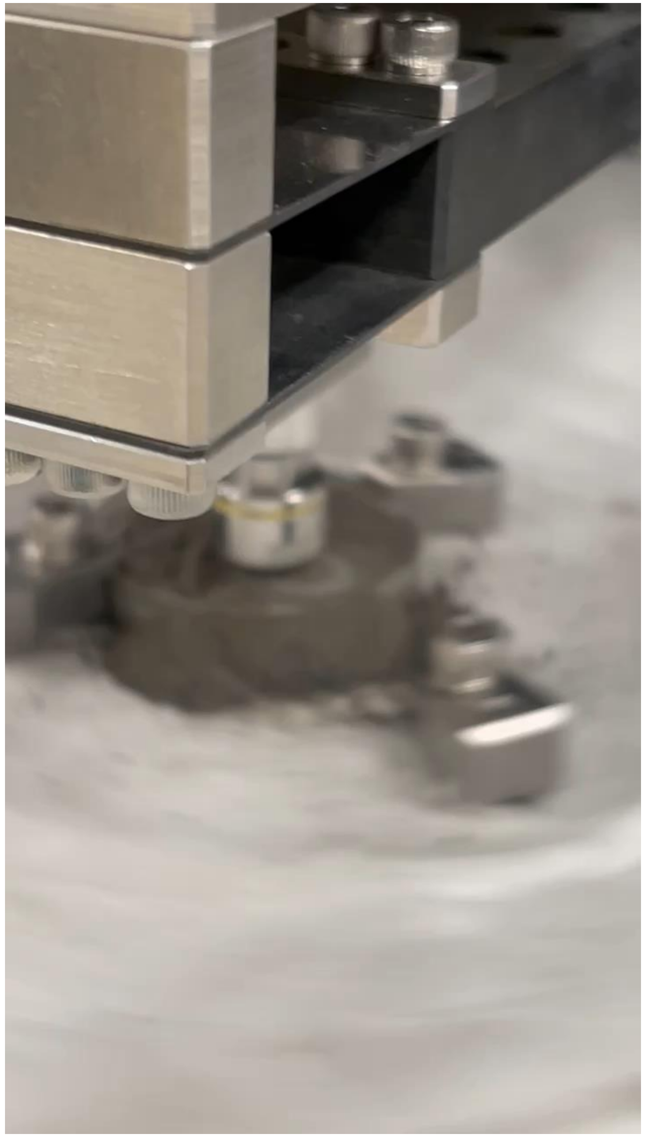


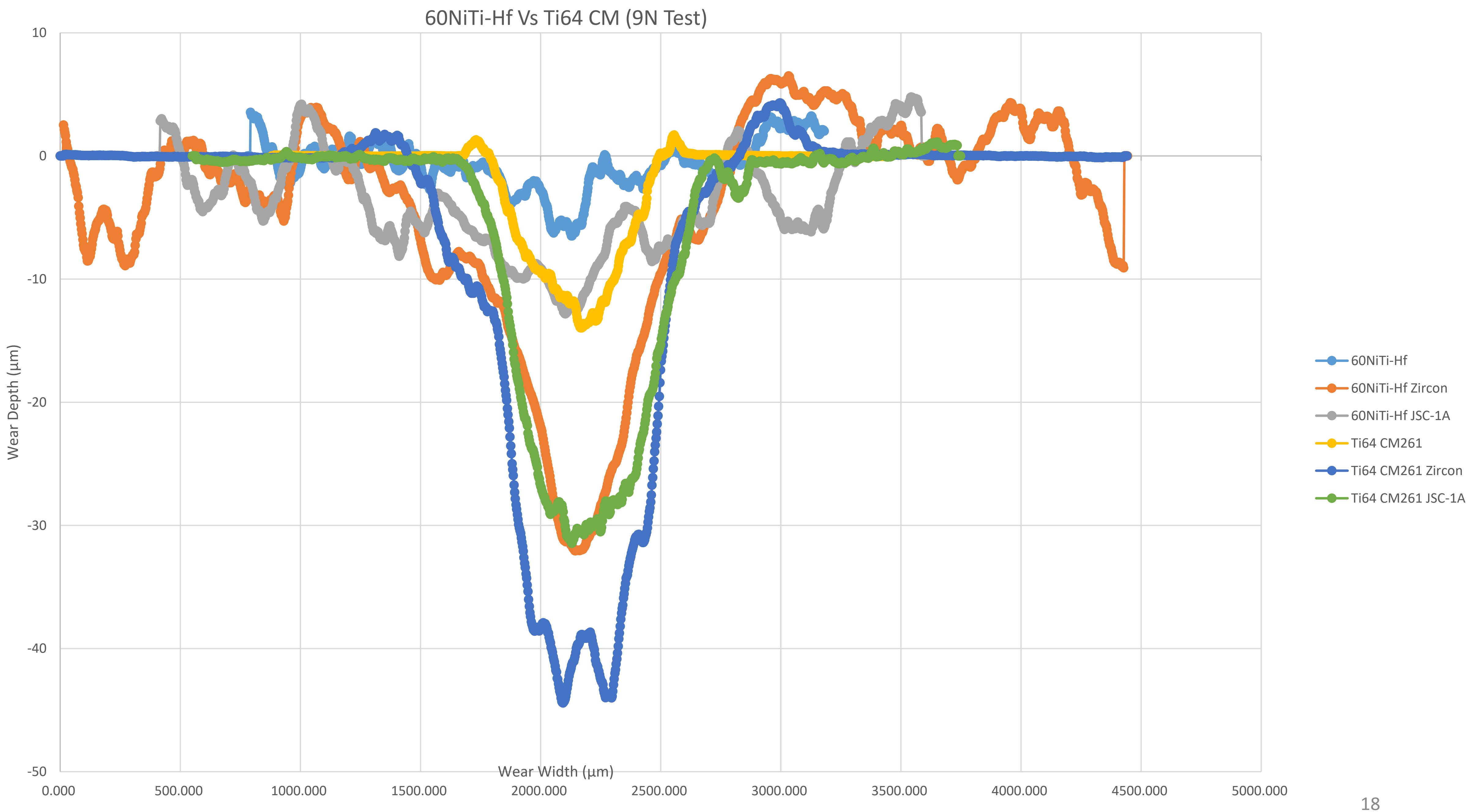
- Simulates regolith found in Lunar Mare regions (lowlands).
- Comparable to soil brought back from Apollo 15.



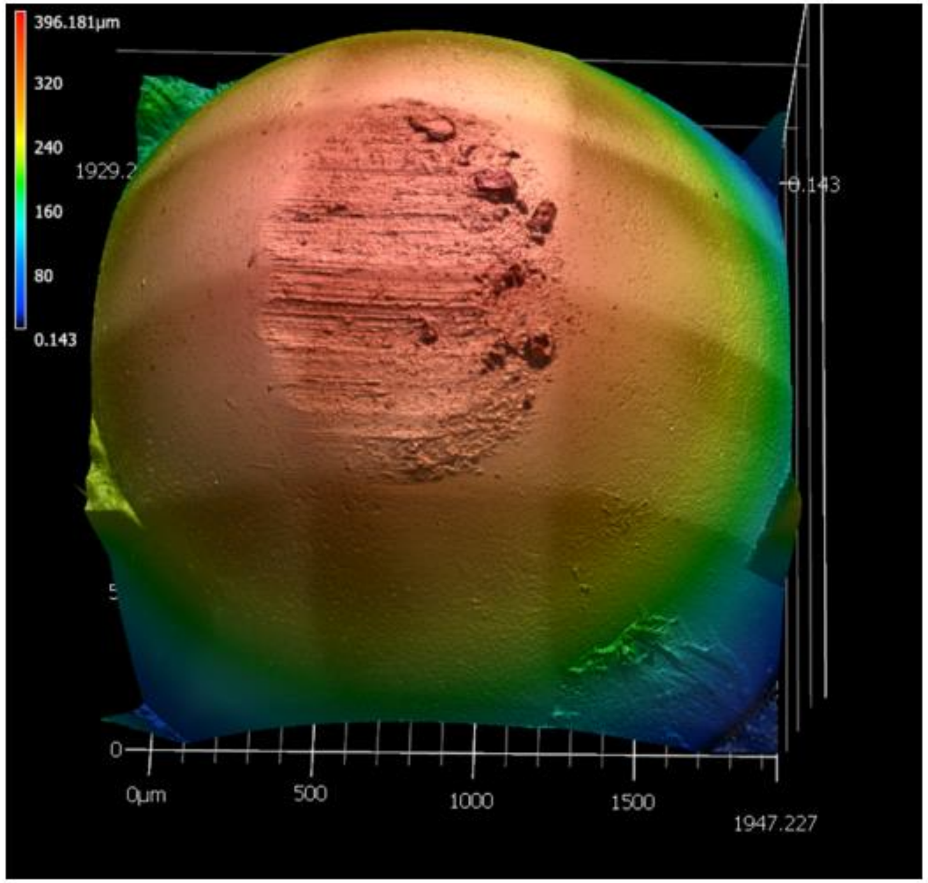


Pin on disk test with JSC-1A simulant

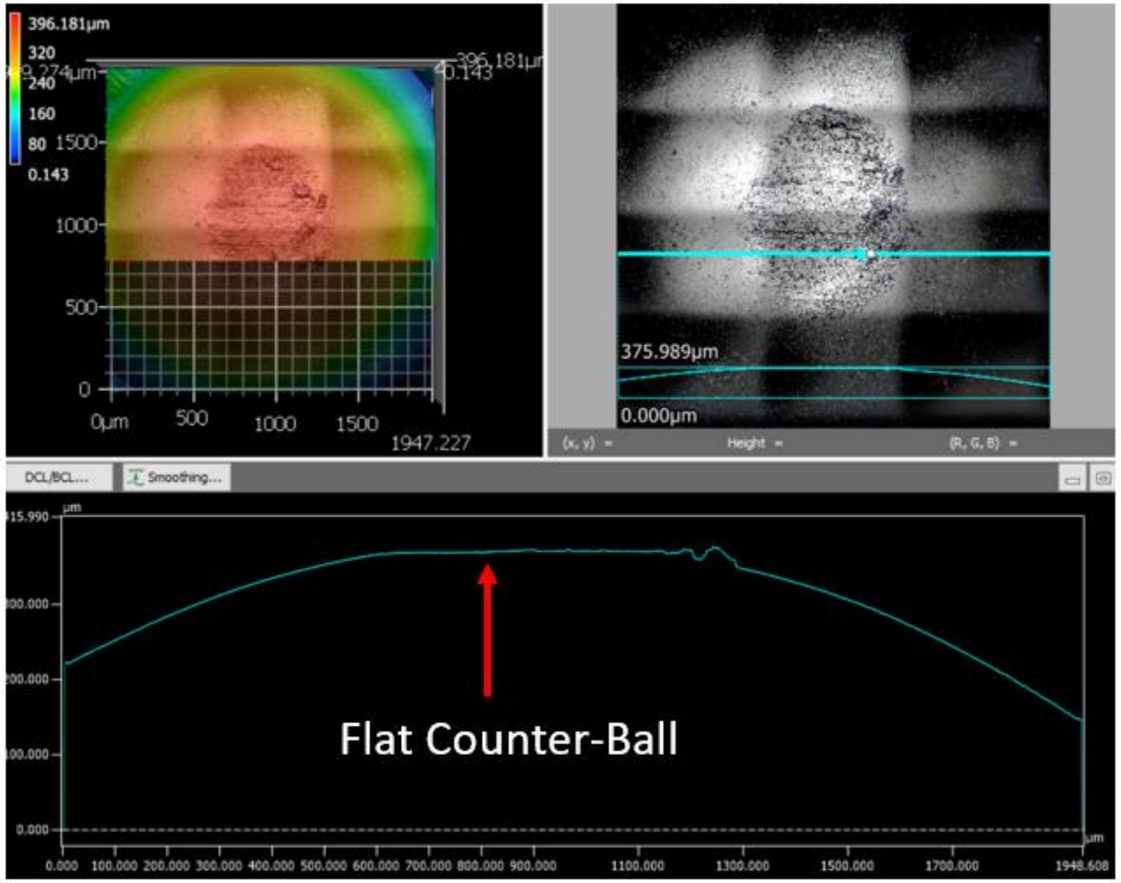



60NiTi-Hf Vs Ti64 CM (9N Test)
10
0
-10
-20
-30
-40
-50
Wear Depth (µm)
Wear Width (µm)
0.000
500.000
1000.000
1500.000
2000.000
2500.000
3000.000
3500.000
4000.000
4500.000
5000.000
60NiTi-Hf
60NiTi-Hf Zircon
60NiTi-Hf JSC-1A
Ti64 CM261
Ti64 CM261 Zircon
Ti64 CM261 JSC-1A

60NiTi-Hf 9N



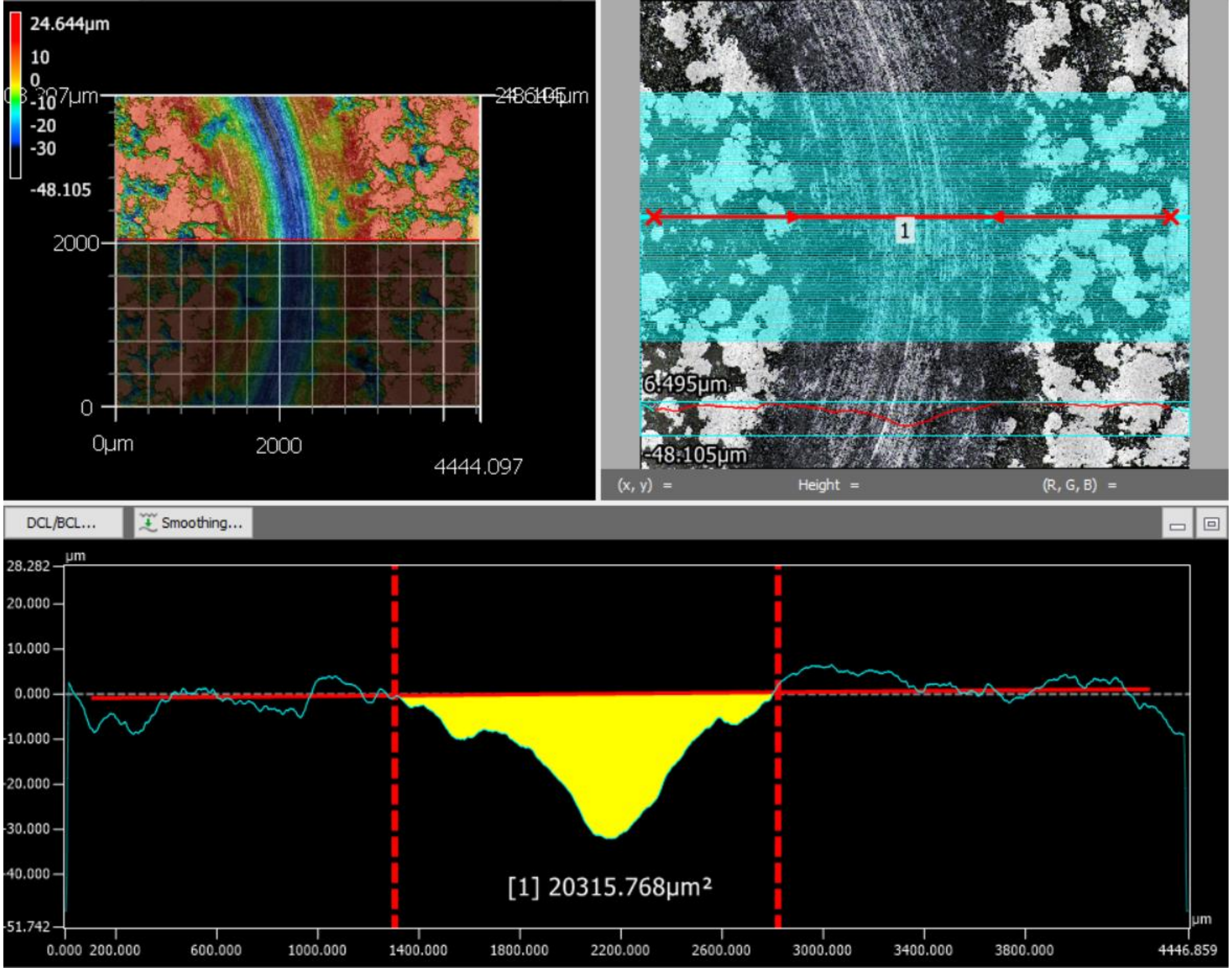
396.181μm
320
240
160
80
0.143
1929.2
0.143
0μm
500
1000
1500
1947.227



396.181μm
320
240
160
80
0.143
1500
1000
500
0
0μm
500
1000
1500
1947.227
375.989μm
0.000μm
Flat Counter-Ball

60NiTi-Hf Zircon

9N



Tribology

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Coating Provider	Powder Formula	Application Process	Substrate	Vendor Provided	Radiation Env	Combined Env	Thermal Env	Virgin Quantity
Plasma Processes / Applied Tungstenite	Ni (60%), Ti (40%), WS2*	Vacuum Plasma Spray Coated, post spray WS2 film added	Conventionally Manufactured Aluminum Puck	1B, 2B, 3B, 1S, 2S	1B	2B	3B	1S
Plasma Processes / Applied Tungstenite	Ni (60%), Ti (40%), WS2*	Vacuum Plasma Spray Coated, post spray WS2 film added	Conventionally Manufactured Titanium Puck	262, 263, 264, 265, 266	262	263	264	265
Plasma Processes	Aluminum Oxide	Vacuum Plasma Spray Coated	Conventionally Manufactured Aluminum Puck	41, 42, 43, 44, 45	41	42	43	44
Plasma Processes	Aluminum Oxide	Vacuum Plasma Spray Coated	Conventionally Manufactured Titanium Puck	236, 237, 238, 239, 240	236	237	238	240
Plasma Processes	Ti64 (98%), hBN (2%)	Vacuum Plasma Spray Coated	Conventionally Manufactured	36, 37, 38, 39, 40	36	37	38	39
Plasma Processes	Ti64 (98%), hBN (2%)	Vacuum Plasma Spray Coated	Conventionally Manufactured Titanium Puck	226, 227, 228, 229, 230	226	227	228	230
Plasma Processes	Ti64 (98%), hBN (2%)	High Pressure Cold Spray Coated	Conventionally Manufactured Aluminum Puck	26, 27, 28, 29, 30	26	27	28	29
Plasma Processes	Ti64 (98%), hBN (2%)	High Pressure Cold Spray Coated	Conventionally Manufactured Titanium Puck	221, 222, 223, 224, 225	221	222	223	224
Plasma Processes	Ti64 (90%), hBN (10%)	Vacuum Plasma Spray Coated	Conventionally Manufactured Aluminum Puck 1.50 in Ø x 0.25 in thick	31, 32, 33, 34, 35	31	32	33	34
Plasma Processes	Ti64 (90%), hBN (10%)	Vacuum Plasma Spray Coated	Conventionally Manufactured Titanium Puck 1.50 in Ø x 0.25 in thick	231, 232, 233, 234, 235	231	232	233	234
FIU	Ti64 (98%), hBN (2%)	Plasma Spray Coated	Conventionally Manufactured Aluminum Puck 1.50 in Ø x 0.25 in thick	003-007	3	4	5	6
FIU	Ti64 (98%), hBN (2%)	Plasma Spray Coated	Conventionally Manufactured Titanium Puck 1.50 in Ø x 0.25 in thick	201-205	201	202	203	204
FIU	Ti64 (90%), hBN (10%)	Plasma Spray Coated	Conventionally Manufactured Aluminum Puck 1.50 in Ø x 0.25 in thick	008-012	8	9	10	11
FIU	Ti64 (90%), hBN (10%)	Plasma Spray Coated	Conventionally Manufactured Titanium Puck 1.50 in Ø x 0.25 in thick	207-211	207	208	209	210
Aluminum Substrate Contol	NA	Uncoated Substrate	Conventionally Manufactured Aluminum Puck 1.50 in Ø x 0.25 in thick		Spare	Spare	Spare	
Titanium Substrate Control	NA	Uncoated Substrate	Conventionally Manufactured Titanium Puck 1.50 in Ø x 0.25 in thick		Spare	Spare	Spare	

NASA MSFC EM41 Mechanism Design

Intent

- To fully confirm the coating performance, flight-like testing is critical
- A series of mechanisms will be designed to demonstrate modes of wear and analogs to in-mission applications
  - Subscale simple and complex mechanisms
  - Beginning ambient conditions and moving toward relevant environments
- Provides opportunity for process mastery of coating application in more complex geometries

Small simple machines → **Small complex mechanism** → **Large flight-like mechanism**

Mechanism Attributes

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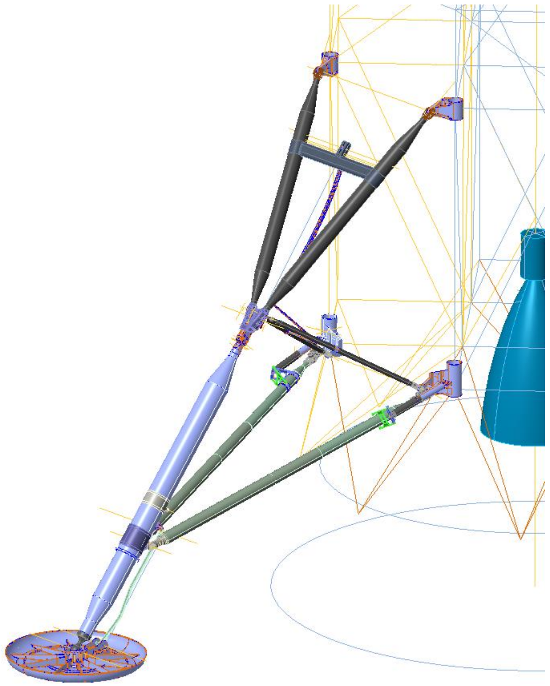
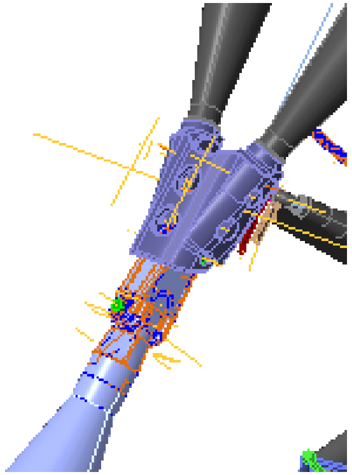
Small Simple Mechanisms	Small Complex Mechanisms	Large Scale Mechanisms

• Intended to demonstrate onset wear mechanisms through simple designs coated by spray process
• Proving ground for spray process and coating wear-resistance in ambient environment
• Joint Examples:
    • Simple hinge
    • Pin joint
    • Ball and socket joint
• Replicated motion
    • Rolling
    • torsion
• Findings used to develop evaluation criteria
	• Taking onset wear motion, and increasing complexity of mechanisms to further augment coating application process mastery
	• Performed in lunar environment
	• Added geometric complexity
	• 2 options carried for from previous array of testing
		• Full scale mechanism based on lunar architecture
		• Taking lessons learned from previous array of testing
		• Parts destructively evaluated for wear properties

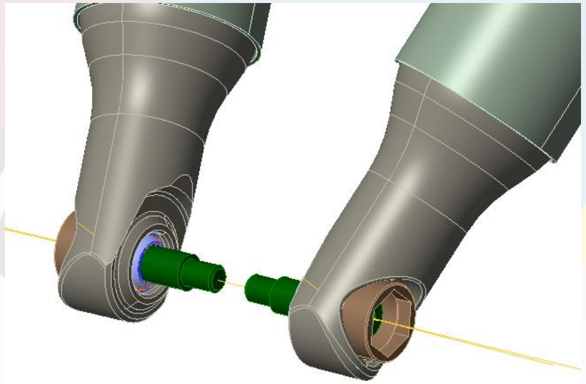
Lander Joints

- Using lander concepts provided by LaRC combined with Apollo Lunar Module to derive types of mechanisms and ranges of motion
- Primarily looking at joints with more actuation in use and complex geometries.

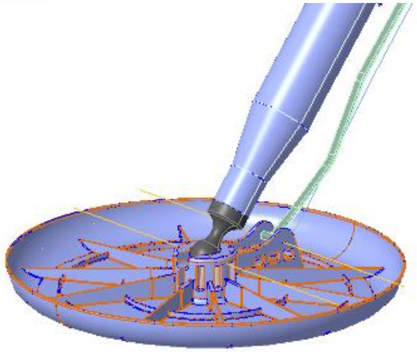




Pin joint



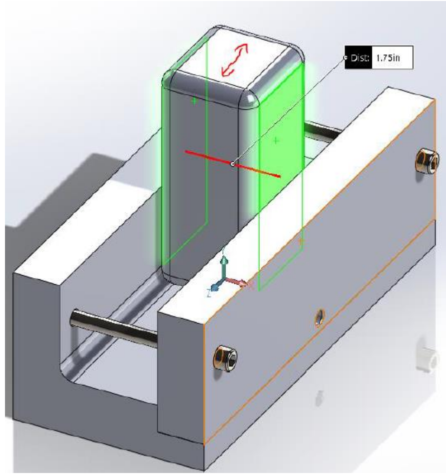
Locking joint



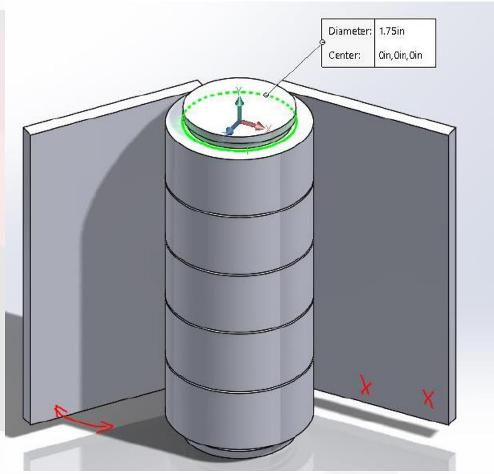
Ball joint

Proposed Simple Mechanism Joints

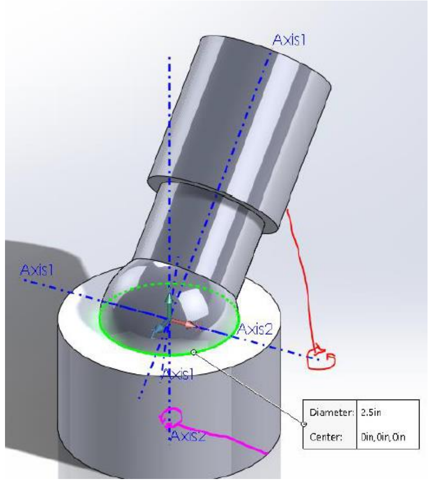
- Simple joints replicating types of motions found in lunar structures (pasted and proposed for future)
  - Easily assembled, optimized for thermal cycling and coating application
- Provides multiple surfaces to collect data from
- Each demonstrates a different type of wear-inducing motion



Slot



Hinge



Ball and socket

Forward Work

- Mechanism fabrication and thermal cycling
- Designing Test Environments and test parameters
  - Vacuum, regolith simulant delivery, temperature requirements based on known lunar environments
  - Determination of contact loads

Questions?