

Background

Lunar regolith was first identified as a major issue during the Apollo missions. There are three characteristics of lunar regolith that cause issues: small size, rough surface topology, and particle charge. The lack of a magnetosphere allows solar wind to bombard the lunar surface which results in the regolith becoming charged. These charged particles will adhere to most surfaces and degrade thermal control systems. The lack of atmosphere and surface liquids on the lunar surface results in the regolith's small particle size, abrasive topology, and chemical reactivity. When the dust adheres to a surface, or the lunar lander exhaust kicks up dust regolith, it can impair instrument or thermal control system function, abrade optical surfaces, diminish range of motion, and mechanically degrade soft-goods such as gloves and astronaut suits. All of these examples were experienced during the Apollo missions.

The objective of this study was to select and evaluate abrasion-resistant ceramic materials for application on the lunar landing equipment.

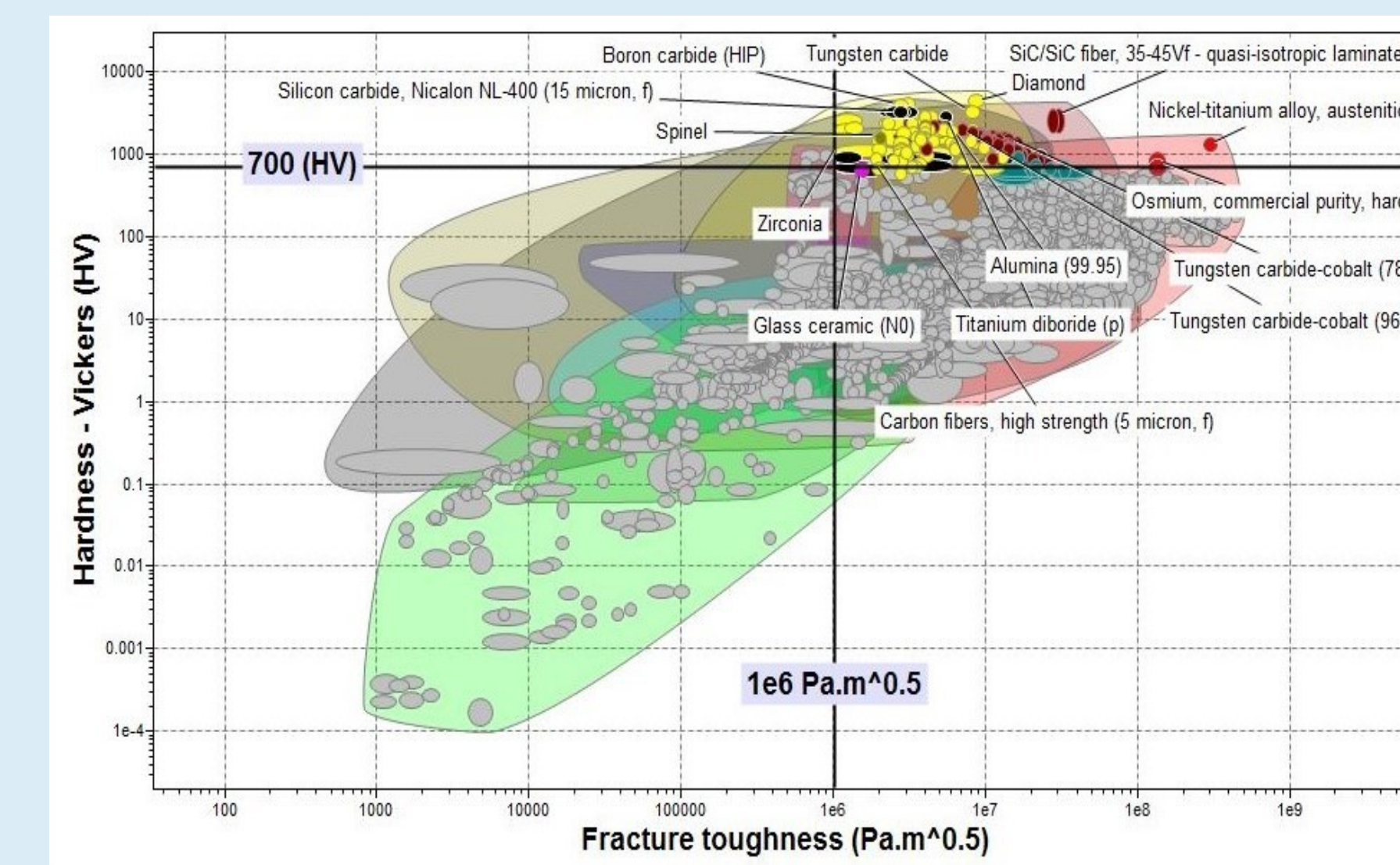
Material Selection

In order to help narrow down the list of candidate materials, GRANTA EduPack software was used to create Ashby plots. These helped balance wear resistance with mechanical functionality of the coating by ensuring sufficient surface hardness to aid in abrasion resistance while reducing the risk of fracture upon particle impact. Utilizing these plots, a down-selection of four materials and coatings were chosen for testing.

Down-selected Coating Materials

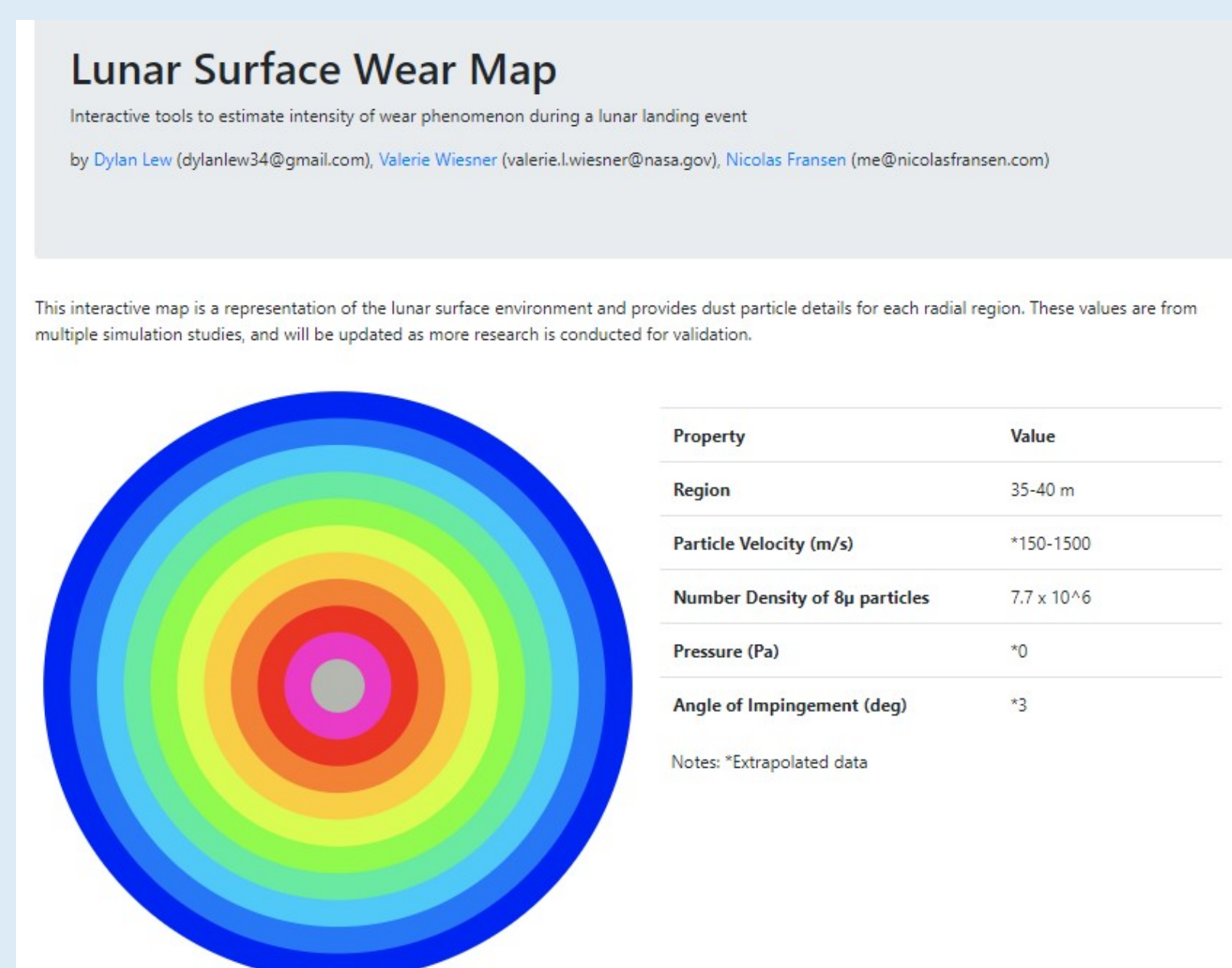
Material	Density (g/cm ³)	YM (Pa)	Vickers Hardness	Fracture Toughness (Pa.m ^{0.5})	Thermal Expansion Coef (Strain/C)
Substrate					
Ti-6Al-4V	4.43	1.15E+11	366	1.14E+8	9.10E-6
Aluminum 2219	2.87	7.57E+10	121	4.50E+7	2.38E-5
Coating					
Alumina (95)	3.76	3.20E+11	1850	4.50E+6	8.30E-6
Boron Carbide (HIP)	2.53	4.72E+11	4200	3.00E+6	9.40E-6
Chromium Oxide	5.22	8.00E+10	1200		3.70E-6
Tribaloy T-800	8.6	2.42E+11	1050	1.87E+7	1.24E-5

Vickers Hardness vs. Fracture Toughness CES Ashby Plot



Lunar Dust Wear Map

An integral component of the material selection process also included the development of a lunar dust wear map. This interactive website visually and quantitatively models the lunar surface environment during a landing scenario to further understand the lunar environment and the variability from a landing site. It further quantifies the complex plume/surface interactions using published CFD^[1] and DSMCS^[2] simulation data. Included with this map is detailed information on a list of materials that would survive the harsh lunar environment, and space to add validation information and additional materials as more data and research is conducted on the lunar surface.



Interactive and updatable lunar surface environment website hosted under NASA web services

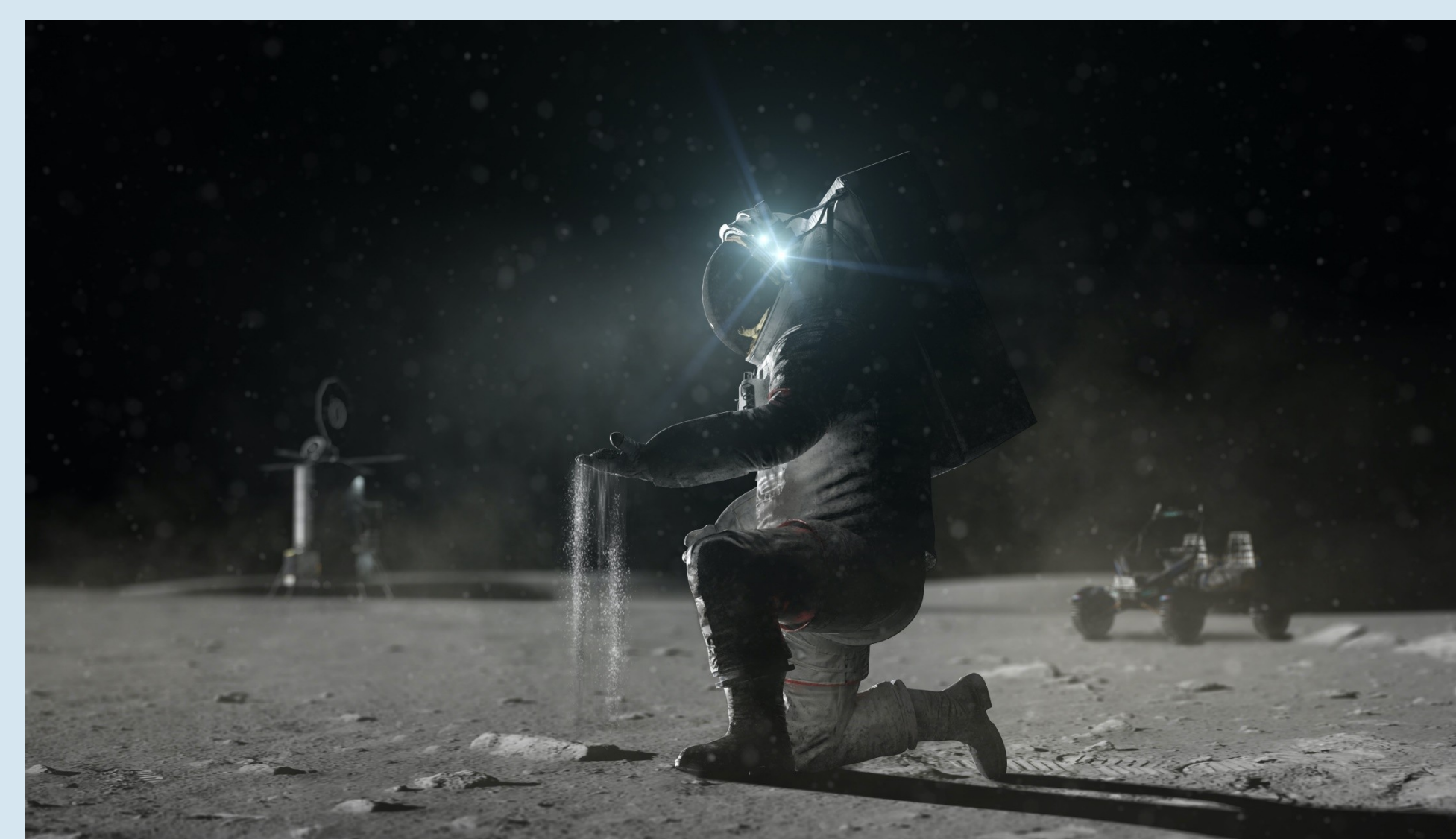
Test Matrix

Having selected materials to test, the next step in this work included creating a detailed testing plan and organizing quotes from substrate suppliers. Furthermore, the sample size restrictions and the number of samples needed for each test was determined to create a final order and machining layout to cut out the various samples needed.

Tests used to replicate and evaluate the lunar surface environment

- Taber Wear
- Sonic Wand^[3]
- Struer's Vicker's Hardness
- G200 Nanoindenter
- Erosion rig
- Optical microscopy
- Contact Profilometry
- SEM Imaging
- X-Ray Diffraction

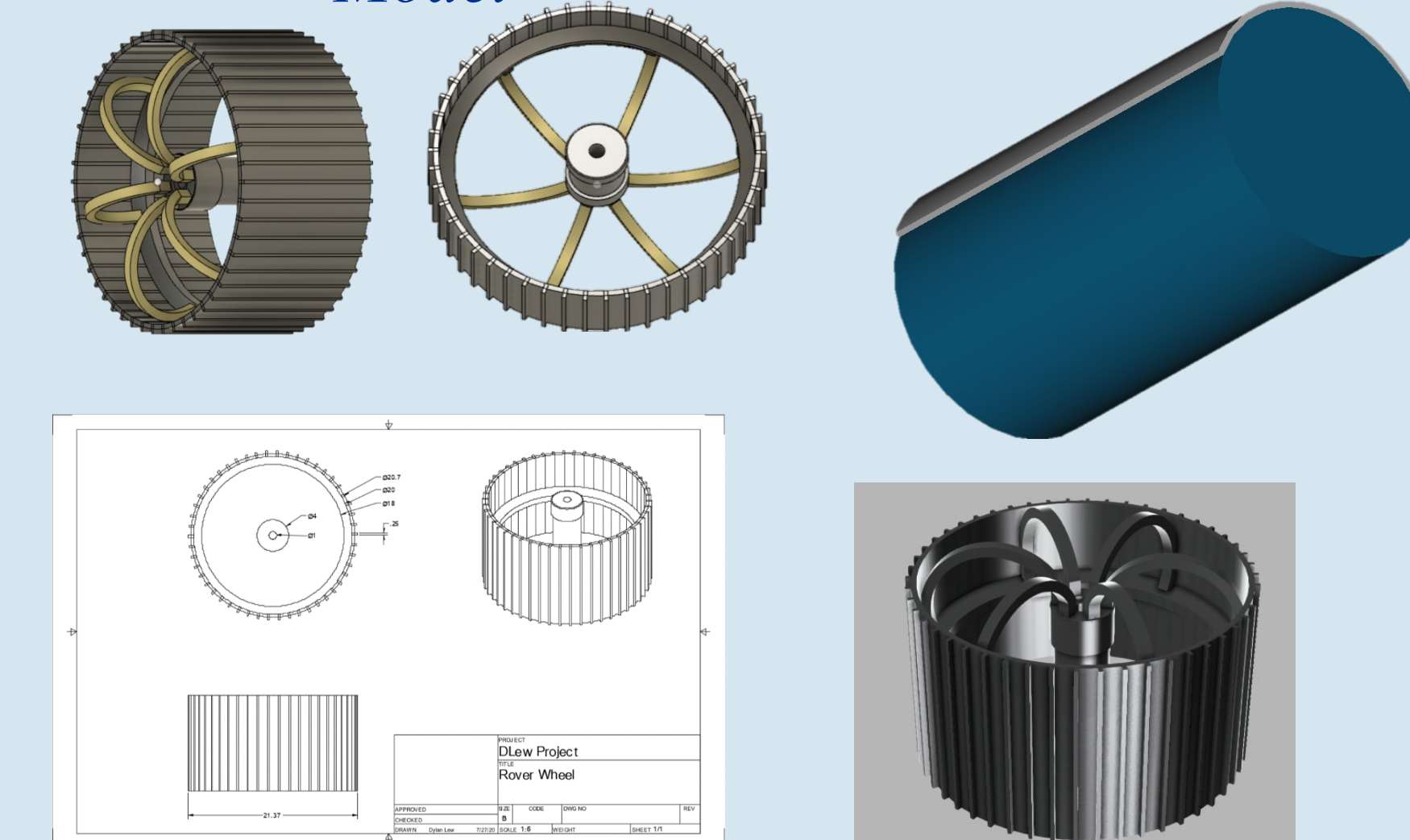
NASA artist depiction capturing the lunar surface environment [Image credit: NASA]



CAD Modeling Test Parts

In order to evaluate more realistic component geometries, laboratory testing of small disk samples as well as 3D modeled components were prepared. Fusion 360 software was used to model part of the lander leg as well as identify the rover wheel as another component that could benefit from these wear-resistant ceramic coatings. These rover wheels are made from aluminum with titanium traction, the same substrates as the lander leg.

Perseverance Rover Wheel Model Lunar Lander Leg Model



Conclusion

Four ceramic coating materials were identified through utilization of CES software and the development of a lunar surface wear map and adjunct material selection and property spreadsheet. Continued research and testing of these coatings will help us further develop durable materials to withstand the harsh environment.

Acknowledgements

I would like to thank my mentor, Dr. Valerie Wiesner for her guidance and help throughout this research project. I would also like to thank Dr. Christopher Wohl, Dr. Lopamudra Das, Nicolas Fransen, as well as everyone at NASA Langley Research Center and NASA Internships, Fellowship and Scholarships (NIFS) Program.

References

- [1] Lane, John E., and Philip T Metzger. "Lagrangian Trajectory Modeling of Lunar Dust Particles." CORE, core.ac.uk/reader/10574339.
- [2] Morris et al, "Lunar Dust Transport Resulting from Single- and Four-Engine Plume Impingement". AIAA Journal (54), 2016.
- [3] Wohl, C J, V L Wiesner, G C King, J W Connell, and S K Miller. 2020. "LOW SURFACE ENERGY MATERIALS FOR LUNAR DUST ADHESION MITIGATION."