Facility Description of Dr. van Susante's MTU Planetary Surface Technology Development Laboratory (www.huskyworks.space)

The Planetary Surface Technology Development Laboratory (PSTDL) is a new research facility designed and led by Dr. van Susante at Michigan Technological University (MTU) and consists of several spaces with various equipment and supporting labs. The goal of the PSTDL is to prototype, build, test and quickly increase the TRL of technology being developed for lunar and mars missions. The central piece of the PSTDL is a custom built rectangular 60inchx60inchx80inch Dusty Thermal Vacuum chamber (DTVAC) with a usable volume inside the thermal shroud of 50x50x70 inches, that can be cooled as low as -196˚C and heated as high as 150˚C, reach a vacuum of 10^{-6} Torr (10^{-4} Torr with simulant) and contain a box with up to 3000 lbs of Regolith simulant. Outside the lab, the dedicated 3,125 Gallon Bulk LN_2 tank supplies the liquid nitrogen to the DTVAC thermal shroud and plate and allows for long duration testing at cryo temperatures. The chamber has two 10 inch viewports, 16 smaller ports for power and data feed throughs and for future use, including a 20 inch diameter expansion port if vertical expansion of the vacuum space would be required (this would require major modifications though). The DTVAC facility is now operational as of January 15, 2021.The chamber will have a regolith bin that can hold up to 3000 lbs of simulant and can be rolled into and out of the chamber. There will be two regolith bins so one can be prepared while the other is being tested. Water, compressed air and any power need can be met in the lab and fed into the chamber as needed.

The other part of the PSTDL is a new 1100+ ft^2 lab that contains a 6 axis Fanuc m-710*i*C/50 industrial robotic arm with a reach of 2m and a 50 kg load capacity. In the robot's reach is a 14 ft^3 chest freezer in which lunar simulant can be mixed with water and frozen for excavation and measurement testing of end-effectors / payloads for operation on the lunar surface (or on Mars or other planetary surfaces). An augmented reality sandbox system is installed to function together with the excavation sandbox filled with regular playsand and the robotic arm. Another major piece of the lab is a 14ftx6ftx1ft regolith

simulant filled sandbox that is enclosed, kept under slight negative pressure for dust control as well as an 'airlock' to mitigate dust, has an overhead rail system that has as a gravity off-loading system (up to 200 lbs total load) installed. Slopes up to 45˚ are possible to be built into the box.

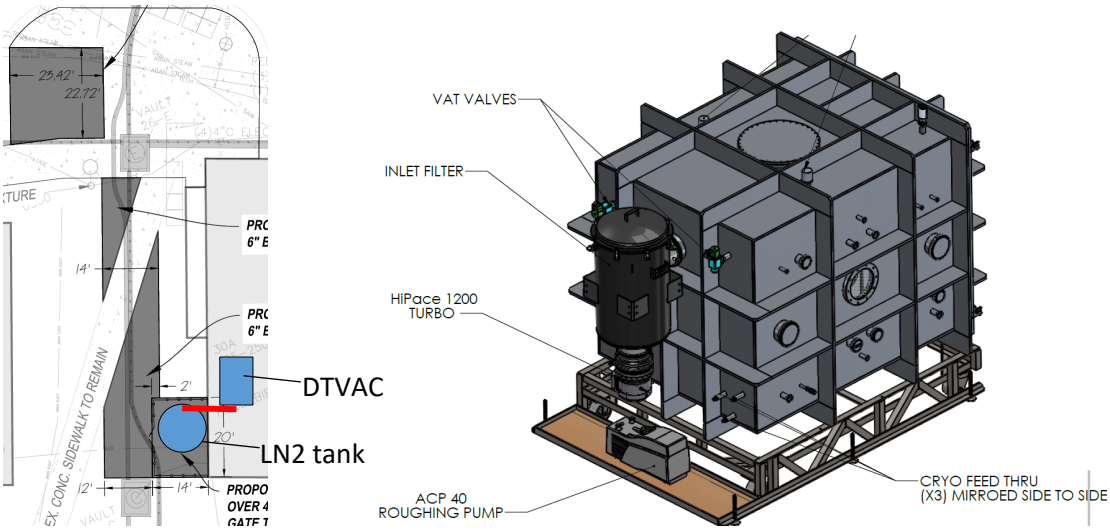

Figure 1: Illustration of completed concrete work and placement of LN2 tank and DTVAC inside the highbay space (Left) and the design of the DTVAC to be fully operational in the first week of January 2021.

PPE and respirator certification are maintained for use with the facility. In addition to the test facilities, the PSTDL space contains mechanical and electrical build areas as well as several computational systems dedicated to designing, analyzing and modeling (CAD, FEA, DEM, CFD, etc.) the technology systems under development. Several groups of students under Dr. van Susante's supervision have access to the PSTDL. They have all received extensive safety training to be allowed to work in the lab and those working with specific hazards and PPE as needed (robot, regolith simulant extended exposure, DTVAC, LN2) and will receive additional safety training as needed in coordination with our environmental and safety staff. Currently 35 undergraduate students of Dr. van Susante's Mining INnovation Enterprise that are participating in the NASA Lunabotics Mining Competition have access to the PSTDL to design, build and test their robot for the competition and build a trencher for operation in the DTVAC. Five graduate students will be working on more advanced design, modeling, building and testing of space qualified hardware for the DTVAC and hopefully future CLPS payloads. A total of 15 full time undergraduate (12) and graduate students (3) worked on 4 funded projects in the PSTDL during summer 2020. We expect to grow in 2021. Figure 2 shows the layout of the lab. We have also procured a small 18 inch sided cube acrylic vacuum chamber for use in the PSTDL.

Current Ongoing Research Grants:

Co-PI on NASA Early Stage Innovation Co-PI for the project "Low mass, low power, non-mechanical excavation of gypsum and other evaporites for water production on Mars", Awarded**, $500k**, January 2018 - January 2021

Co-I on NASA BAA ISRU, sub-award from Honeybee Robotics for the project "RedWater: Extraction of Water from Mars' Ice Deposits", awarded ($2M+), **$122.5k** (PI at MTU) for 3.5 years, August 2019 – February 2023

Co-I on "Center for Lunar and Asteroid Surface Science", a NASA Solar System Exploration Virtual Institute, $7.5M total over 5 years, **$150k** ($30k/year) PI at MTU, Period of Performance: October 1, 2019 – September 2024

PI on NASA BIG IDEA challenge proposal "T-REX, Tethered – permanently shaded Region EXplorer), **$162,637.-** Feb 14, 2020 – April 30, 2021

Co-I on NASA NIAC Phase II, "Lunar Polar Mining Outpost", Transastronautica Corporation, $500k, MTU portion **$100k**, Sept 1, 2020 – Aug 31, 2021

PI on "NASA GCD: In-Situ Construction", submitted 3/31/2020, $6.59M, MTU portion **$170k** (Oct 1, 2020 – sept 30 2023) – awaiting contract

PI on "NASA GCD: Molten Regolith Electrolysis", submitted 3/31/2020, $7M, MTU portion **$754,887** (Oct 1, 2020 – sept 30 2023) – awaiting contract

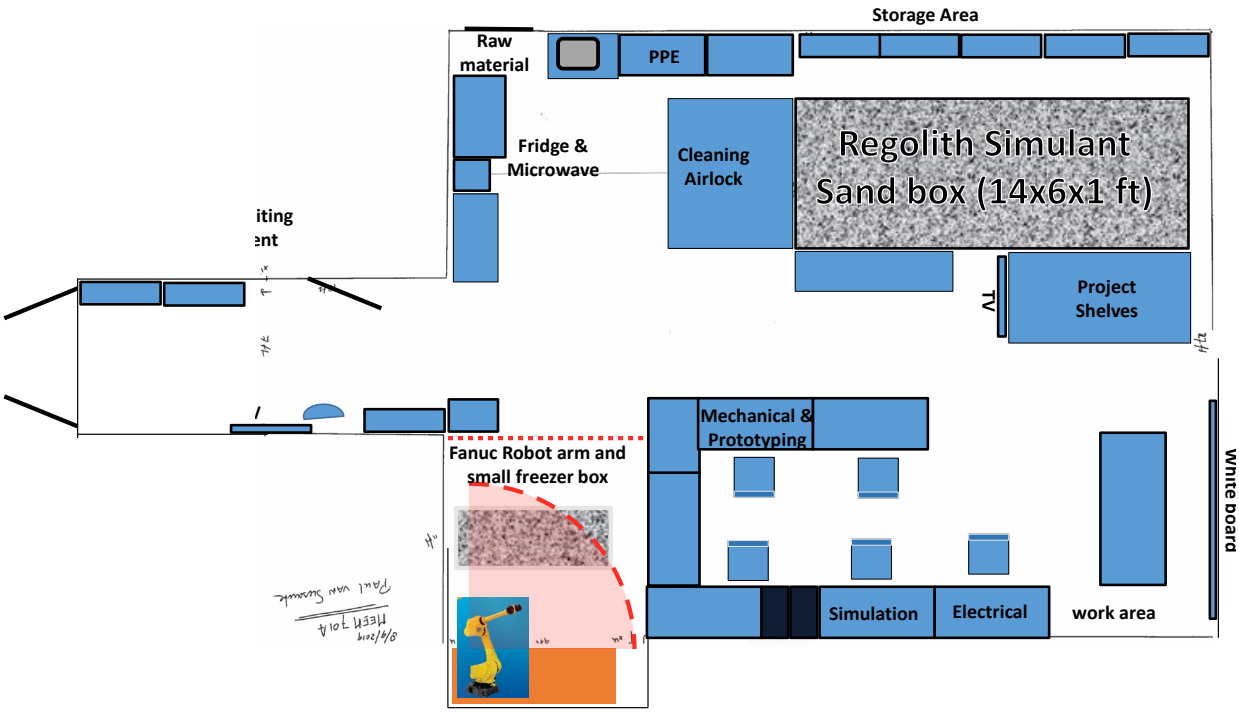

Figure 2: layout of the PSTDL 1100+ sq. ft. design, model, prototype and test lab space.

Submitted/Pending

PI on MTU portion of "eXtreme Construction thru Additive-manufacturing of Lunar Infrastructure with a Binder-Regolith composite (XCALIBiR)", white paper submitted May 6, 2020 to CAN No. 80MSFC19N0001, $201,708.-, MTU portion **$75k**

PI on NASA LuSTR: "Percussive Hot Cone Penetrometer and GPR for Geotechnical and Volatiles Mapping", **$1.99M**, submitted 9/9/2020, (May 16, 2021 – May 15, 2023)

PI on NASA LuSTR: "SPICE (Shadowed Polar ICE) Harvester: Research and Development to Advance the Technology Readiness of Extraction and Collection of Water from Lunar Polar Regolith", **$1.99M**, submitted 9/9/2020, (May 1, 2021 – April 30, 2023)

PI on NASA 2021 BIG Idea Lunar Dust Challenge: "The Lunar Armor Stone Protection In-Situ Surfacing (ASPIS) Rover", **$179,999.-,** submitted 12/13/2020, (Jan 31, 2021 – Nov 31, 2021)

Various commercial companies testing in our facilities for CLPS and other payloads.

Figure 3: Dr. van Susante's Planetary Surface Technology Development Lab mechanical and electrical construction station

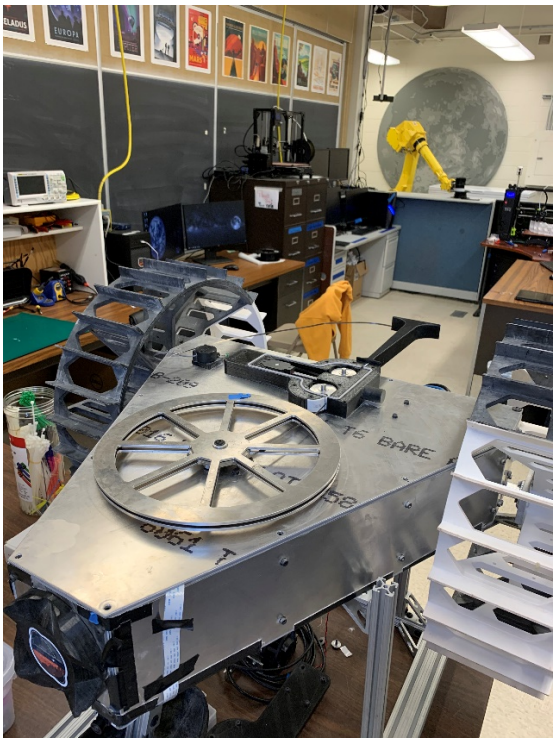

Figure 4: Computer modeling and prototyping stations with 3D printers. Robotic arm in background and T-REX rover Mk 2.0 in foreground.

Figure 5: Dr. van Susante's Planetary Surface Technology Development Lab under construction (the dust containment enclosure and hepa filtration systems are complete and 5000 lbs of lunar regolith simulant has been produced in-house; MTU-LHT-1A)

Figure 6: Completed Augmented Reality sandbox. Projector and Kinect. Trencher for excavation tests. Freezer box for testing with the trencher and robotic arm and creation of ice blocks for melt probe testing.

Figure 7: Dr. van Susante's Planetary Surface Technology Development Lab under construction

Figure 8: First test of the regolith sandbox, enclosure (left) and integrated with the gravity off-loading system (right)

Figure 9: Sandbox with black background deployed and the MK 2.5 rover being tested in the sandbox. Slope testing as indicated below will happen soon.

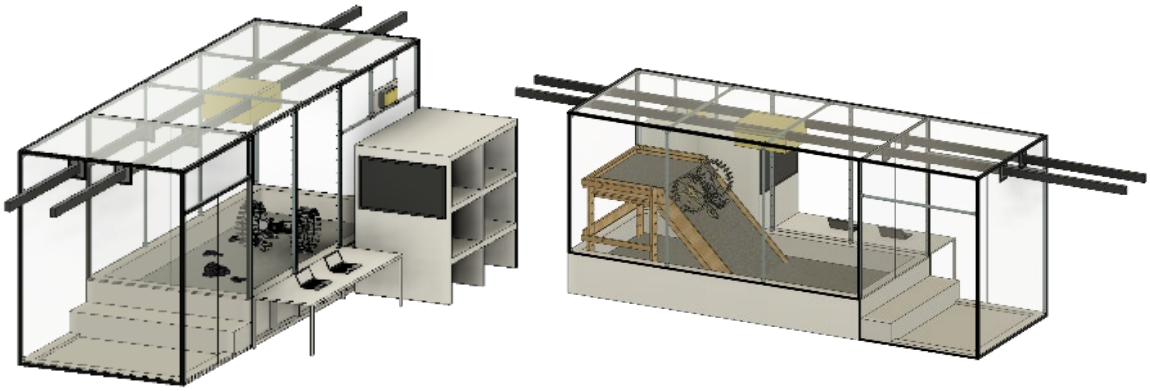

Figure 10: Illustrations of test setups in the regolith sandbox for the NASA BIG Idea Challenge using the gravity offloading system to test control, steering, traction, obstacle handling and slope traverse capabilities.

Figure 11: T-REX rover super-conducting cable deployment testing on 45 degree slope in lunar regolith simulant testbed.

Figure 12: Dr. van Susante as a judge at the 2018 NASA Robotics Mining Competition at Kennedy Space Center illustrating the PPE requirements for working in the regolith sandbox (includes respirator training). We have the hardhat version of the positive air pressure respirator due to the overhead rails and gravity off-loading system in the sandbox.

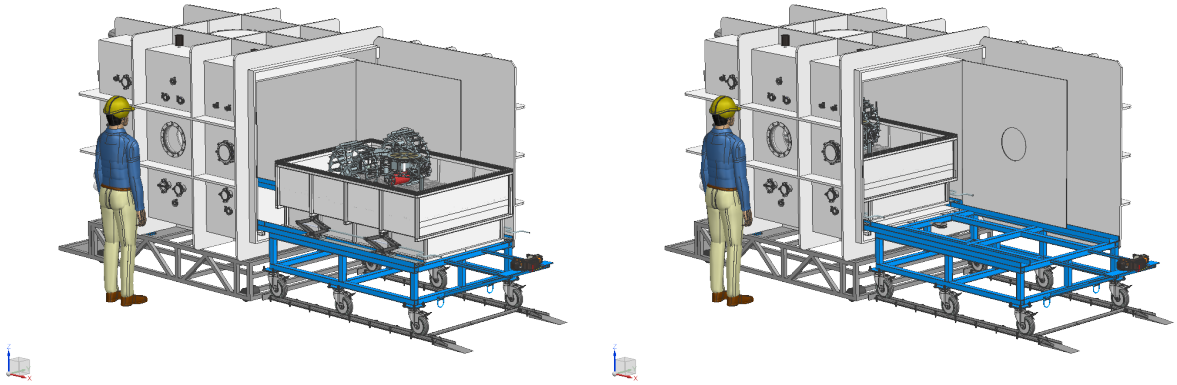

Figure 13: Illustration of the regolith sandbox loading into the DTVAC (we will have two of these so while one is being tested, the other can be prepared for the next test and quick turn-around time).

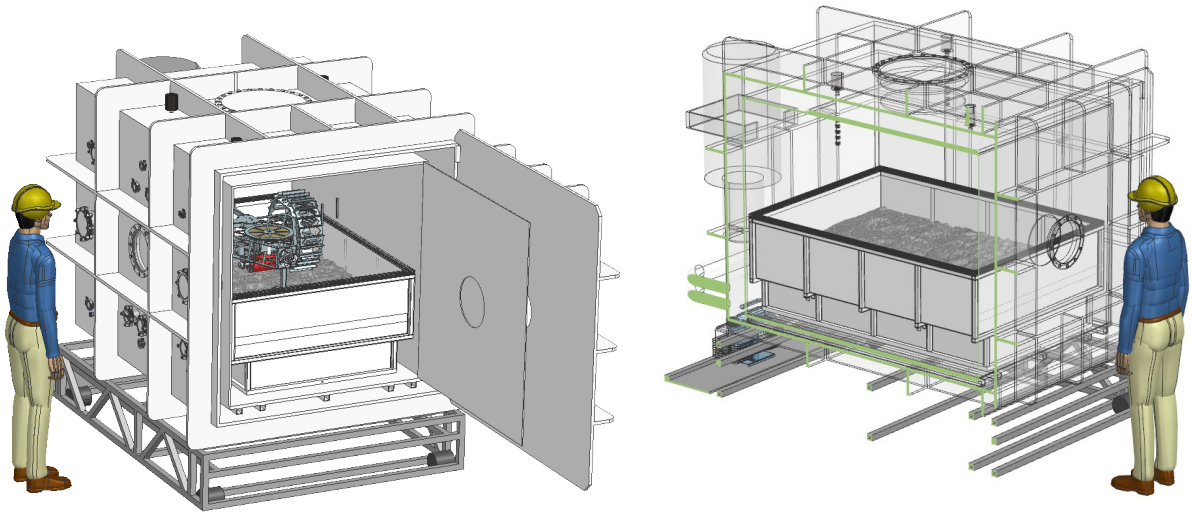

Figure 14: Illustration of the loaded regolith box into the DTVAC. We will have two of these systems to be able prepare one regolith box while the other is in the DTVAC for testing.

Figure 15: DTVAC Regolith box and loading system components completed (2nd one almost completed)

Figure 16: Dusty Thermal Vacuum Chamber has arrived and is being installed (only power left to connect in first week of January 2021)

Figure 17: Dusty Thermal Vacuum Chamber has arrived and is being installed (only power left to connect in first week of January 2021). Also shown the regolith bin and loading system line-up and fit testing.

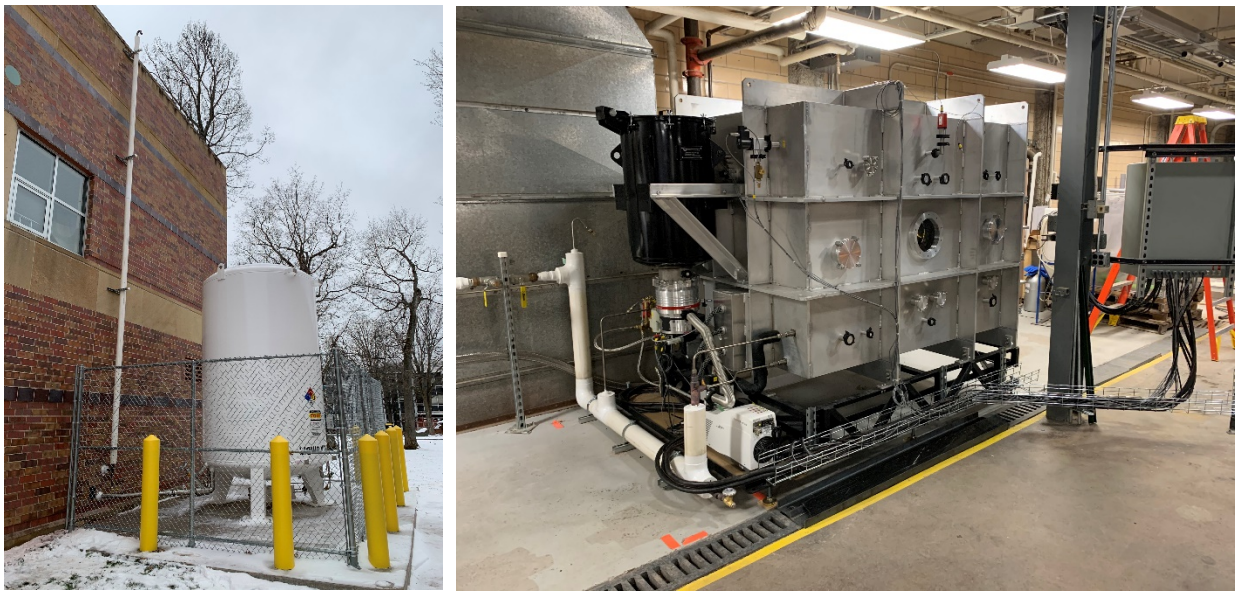

Figure 18: Dusty Thermal Vacuum Chamber LN2 supply lines to thermal plate and shroud as well as N2 exhaust system is installed and connected.

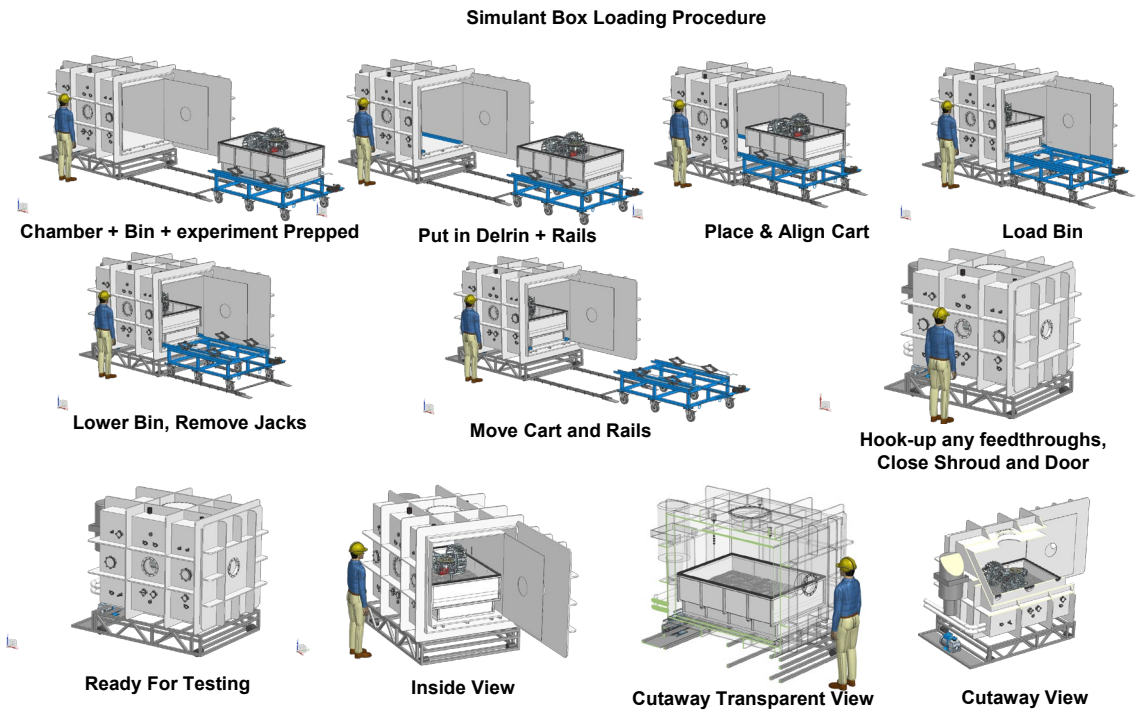

Figure 19: Illustrated loading and testing procedure for the DTVAC

Figure 20: Current Gypsum excavation and water extraction test setup in the Benedict lab

Figure 21: The 20,000 lbs of simulant ingredients (basaltic scoria and anorthosite) in the storage unit and 110 buckets for processing in the rock crushing lab. The simulant components will be sieved and run through an air classifier to achieve the desired particle size distribution and mineral mixture accurately. The first 5000 lbs of MTU-LHT-1A have been produced and are in the sandbox.

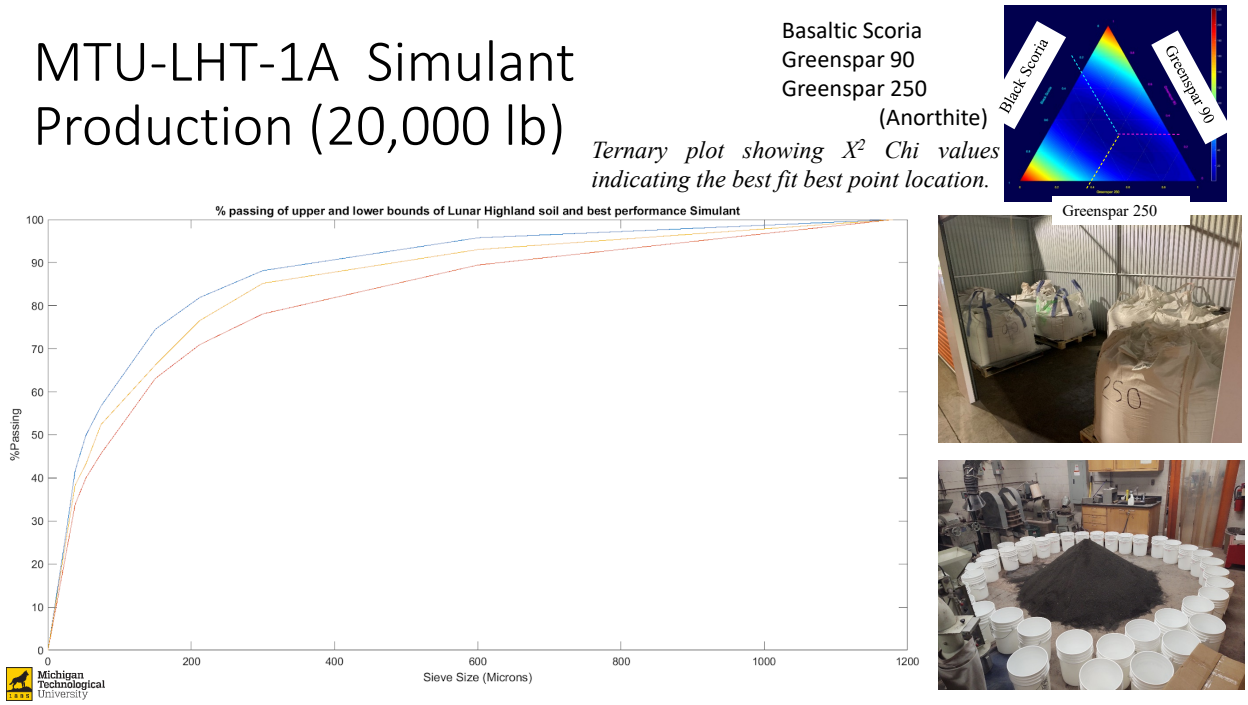

Figure 22: MTU-LHT-1A simulant production and mixture from Basaltic Scoria, Greenspar 90 and Greenspar 250

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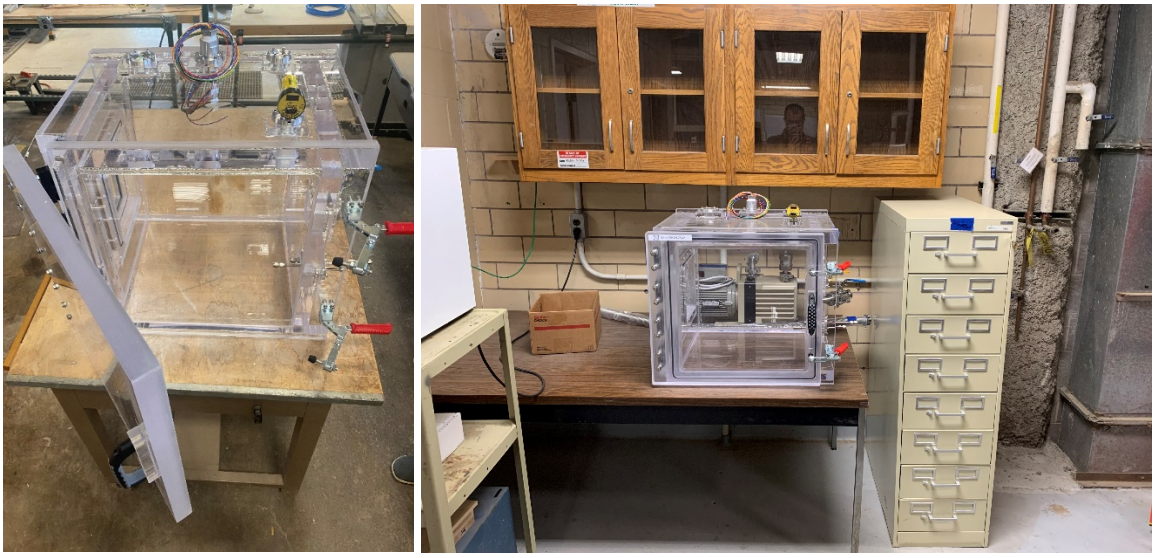
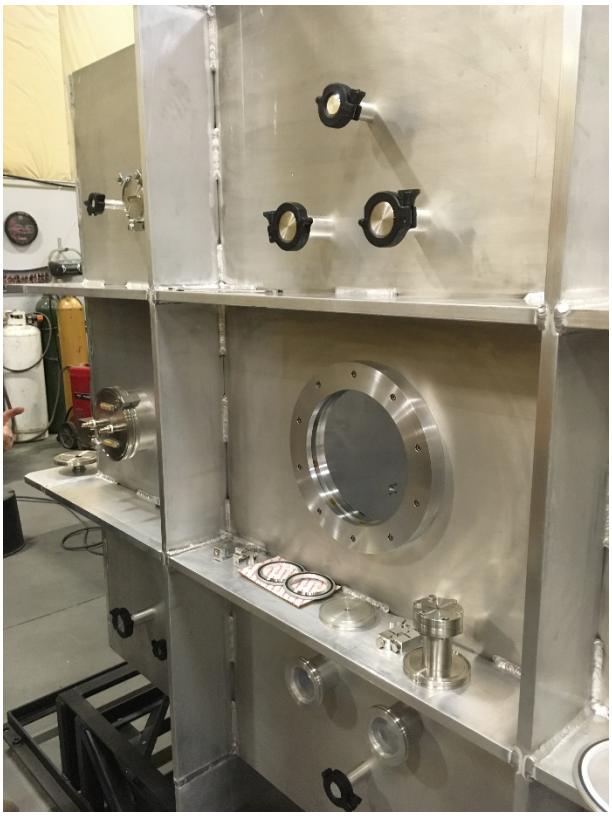
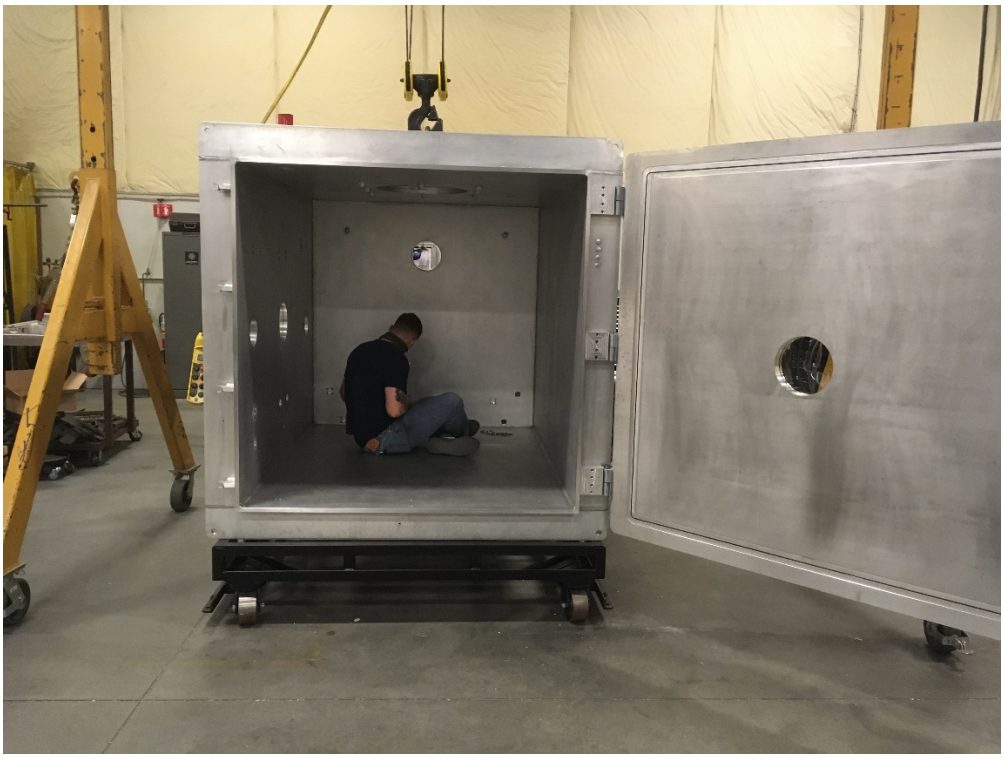


Figure 23: Our brand new 18 inch cube vacuum chamber (10-2 torr) with LN2 feedthrough for cooling of iceblocks and regolith/ice/volatile mixtures plus various other ports for thermocouples, etc. currently used for determining cryo-ice melting energies and probe designs. The LN2 feed and N2 exhaust will be tied into the same system as the large DTVAC.

BONUS: Additional DTVAC construction pictures





DTVAC construction pics

DTVAC thermal shroud incorporated in chamber (10/12/2020) but without MLI that needed to be added.

DTVAC status as of 10/07/2020 (thermal shroud put together, ports installed on outer walls

DTVAC construction pics (10/9/2020)

Thermal shroud is all connected and being wrapped in 10 layers of MLI before placement into DTVAC chamber for full integration and final testing before shipment.

Integration of the completed thermal shroud into the chamber (10/29/2020)

Integration of the completed thermal shroud into the chamber (10/29/2020)

Vacuum pump and dust filter installation, fully integrated testing is complete and the chamber is being readied for shipping to MTU after Thanksgiving.