The TCNJ Adaptable Regolith Retention Platform - T.A.R.R.P.

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Abstract

The TCNJ Human Lander Challenge team has developed a proof of concept for the implementation of a single use landing platform, constructed from a carbon matrix carbon composite material with a graphite foil. This platform is intended to mitigate the production of ejecta during the powered descent, landing, and ascent of the Human Landing System and Commercial Lunar Payload Services vehicles. By extension, this platform would also reduce the occurrence of ejecta damage to the vehicles themselves and allow for the delivery of mission-critical infrastructure to the lunar surface in service of the upcoming Artemis 3 mission.

The testing process has been modified and completed due to several complications that developed within the test environment over the course of the initial testing process. Preliminary testing showed promising results with zero deformation at the center of the platform and an average of 10.8 mm deformation at the immediate edges of the platform. Recommendations for future testing include increasing the size of the test chamber, further refining data collection process through the implementation of additional depth cameras, and material validation to ensure that chosen materials can withstand the extreme temperatures and shear forces of powered descent and ascent.

TARRP Design

The TARRP consists of a decagonal base plate and polygonal fin assembly with hollow aluminum rods extending radially outward from the fins. These rods support a flexible foil/felt atop the baseplate and fin assembly, intended to cover the interstitial area between the fins. The initial design includes a deployment mechanism consisting of torsional springs stored in compression and released upon controller signal, with the first fin to fall pulling the remaining fins. Spring selection will depend on the size of the descent vehicle, which will determine the size of the TARRP required. This model features both a transport and deployment mode as seen in Figures 1 and 2.

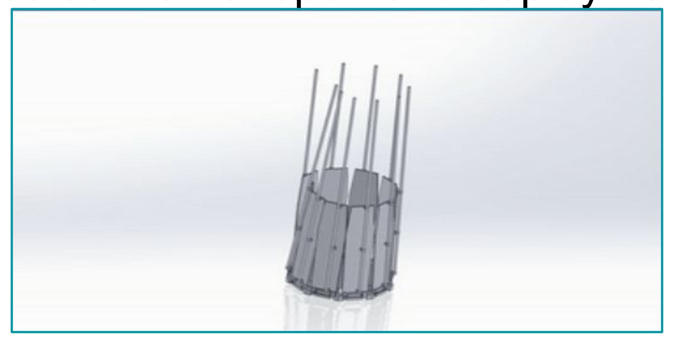

Figure 1. Folded TARRP 3D Model

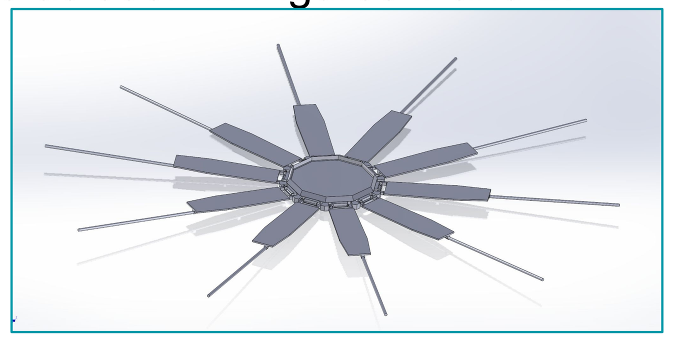

Figure 2. Expanded TARRP 3D Model

The baseplate and fin assembly are to be composed of a carbon-matrix carbon composite material. This material was chosen for its inherent properties, such as high in-plane and relatively low cross-plane thermal conductivity [1]. The flexible material chosen for the top surface is a combination of a flexible graphite foil with a carbon felt backing. The graphite foil was chosen for its thermal properties, as well as its low permeability, preventing the plume from directly contacting the lunar regolith beneath the TARRP. The carbon felt provides an additional layer of insulation for the baseplate and fin assembly. These materials are commonly used commercially in high temperature and vacuum environments, thus consideration could be given to evaluating the Technology Readiness Level (TRL) of the material components as TRL 3 with further testing required to elevate them to TRL 4.

The preliminary TARRP design has a dry mass of 309.82kg. This value was estimated using SolidWorks to calculate the volume of the design and summing the product of the overall volume with the volume fractions of the materials and their respective densities.

The design of the TARRP is based on several assumptions:

1) Apollo-style descent vehicle that will leave the descent stage on the lunar surface.
2) Single-use design. As the descent stage is to remain atop the landing platform, there is no expectation that the platform will be reused for multiple landings.
3) Vertical, or near-vertical landing trajectory [2]. It is assumed that suitable landing zones will be identified prior to the descent vehicle launch by the Gateway and / or the orbiting CubeSats. The descent vehicle will have a well-defined landing zone prior to launch.

Testing

In order to test the effectiveness of the TARRP, an acrylic vacuum chamber was designed and manufactured to function as a testing chamber for the TARRP. This design process began with the creation of a 3D model, Figure 3, as well as performance of Ansys simulation, Figure 4 to ensure failure would not occur while drawing vacuum. For the simulation, it was assumed that the chamber had reached a perfect vacuum of 14.7 psi of atmosphere acting on the outside of every surface.

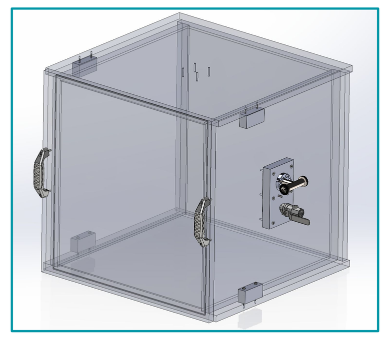

Figure 3. Vacuum Chamber 3D Model

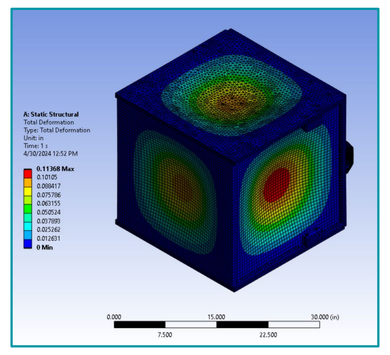

Figure 4. Ansys Deformation Test

It was found that the max stress and deflection was 409 psi and 0.113” respectively with a minimum safety factor of 3.4. These results indicated that it was time to start manufacturing and perform live testing on the chamber.

The fully assembled box is 2x2x2 ft held together by a stepped puzzle piece design and acrylic weld on with the incorporation of rubber O-rings and silicon gel. Extensive testing was performed to ensure the safety and effectiveness of the chamber. While drawing vacuum, 20 in of mercury or 10 psi (68% atm) was safely achieved which was then used for thruster testing. Figure 5 displays the assembled testing chamber and Figure 6 displays the first thruster test.

Figure 5. Vacuum Chamber Apparatus

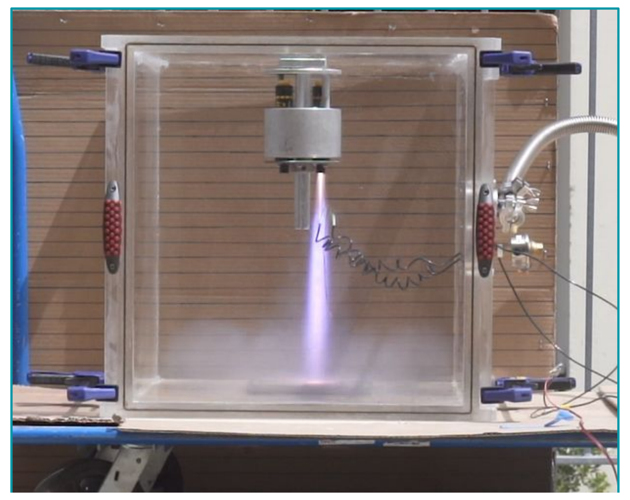

Figure 6. Thruster Test

A preliminary thruster test was performed to confirm that the rocket would fire under vacuum. While the rocket firing was a success, critical damages sustained to the chamber resulted in a failure on the top left wall during the second test. Due to time and budget constraints, a modification was made to the experiment which would allow for testing of the concept and showcase the overall idea of the TARRP.

The modified testing consisted of firing compressed air, maintained at 120 psi, into a bed of regolith 33 mm in depth. Multiple tests were performed under atmospheric conditions with and without the footprint of the TARRP in place. Figure 7 shows the testing apparatus with the TARRP in place.

Figure 7. Modified Testing

References:

[1] C. Ohlhorst, W. Vaughn, and P. Ransone, “NASA Technical Memorandum 4787 Thermal Conductivity Database of Various Structural Carbon-Carbon Composite Materials,” National Aeronautics and Space Administration, Langley Research Center, 1997. Accessed: Nov. 05, 2023. [Online]. Available: https://ntrs.nasa.gov/api/citations/19970041399/downloads/19970041399.pdf

[2] M. Loucks, J. Carrico, T. Carrico, and C. Deiterich, “A Comparison of lunar landing trajectory strategies using numerical solutions,” presented at the International Lunar Conference, Accessed: Oct. 22, 2023. [Online]. Available: https://astrogatorsguild.com/wp-content/Astrogator_Training/LunarLanding.pdf

Data Collection and Results

With the use of computer vision and python programming, a computer program was developed to aid in the data collection process. Using an Intel Realsense D435i depth camera, a top down depth scan was taken after the performance of each test to measure the regolith impingement level done by the simulant rocket plume. Testing was performed on the bare surface with no mitigation tactics in place and then performed on the TARRP covered surface where the results of each test could be compared to measure the level of effectiveness of the TARRP as a mitigator of plume surface interaction. Figure 8 is a snapshot of a test done with no mitigation tactics and Figure 9 is a test done with the TARRP in place. Table 1 shows the results of the performed tests.

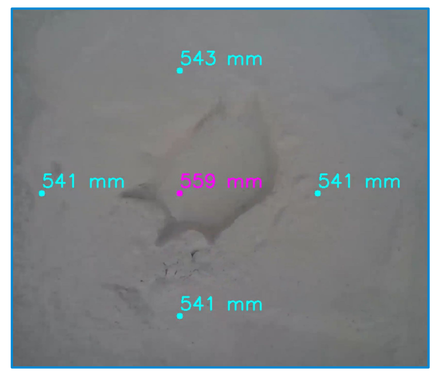

Figure 8. Test I

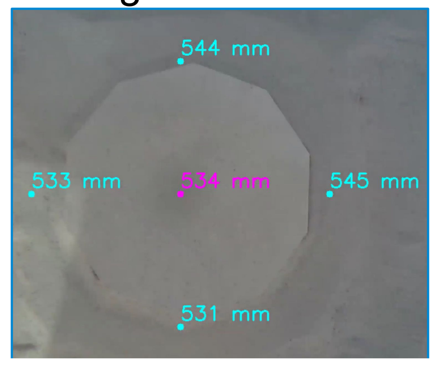

Figure 9. Test II

Table 1. Supplemental Testing Results

** Constant Fire Height of 120 mm was maintained w/ Fire Time of 5 seconds**			
Average Central Impingement	**Average Outer Deformation**	**Regolith Depth**	**Test #**
No Mitigation			
17.5 mm	N/A	27 mm	1
17.25 mm	N/A	27 mm	2
19.75 mm	N/A	26 mm	3
TARRP Covered Surface			
0 mm	6.25 mm	25 mm	4
0 mm	10.5 mm	27 mm	5
0 mm	15.75 mm	25 mm	6

Simulation

The simulation component is intended to supplement the physical test results and to capture PSI data that would be difficult to otherwise gather (such as vorticity of the flow, and velocity and acceleration of the regolith particles). A total of twenty simulations were run in Ansys Fluent and treated as 2-D Euler-Euler multiphase problems. This simulation modeled the interaction between two fluids: the bed of regolith and atmospheric air acting as the rocket thruster. The regolith was considered spherical grains with a mean particle diameter of 60 μm and a density of 1.27 g/cm^3. These properties were chosen to match those of the simulant regolith used in the physical testing. The depth ranged from 15-30mm across the twenty tests where four simulations were conducted without the TARRP compared to sixteen tests done with it. The atmospheric air dispersed from the top left side of the simulation was expended at 2110.7 m/s with the top, right and bottom walls being held at an absolute vacuum.

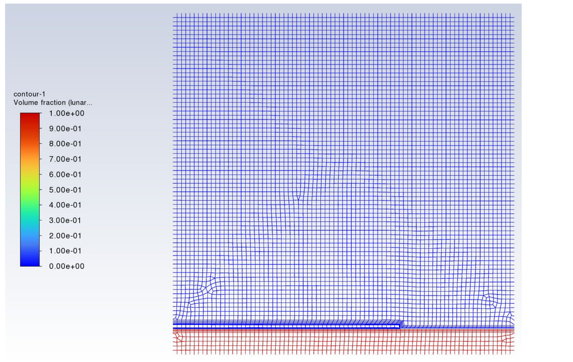

Figure 10. Simulation Start

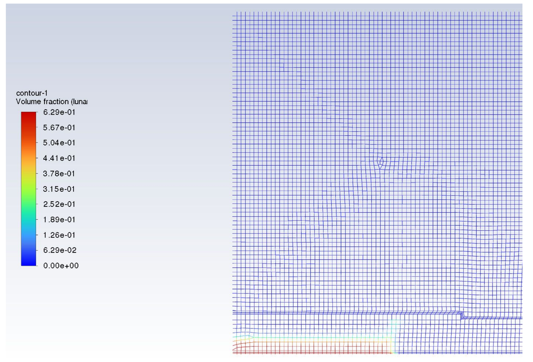

Figure 11. Simulation End

The TARRP was modeled as a stationary wall with dimensions of 133.35 mm x 3.18 mm, corresponding to those of the average radius and thickness of the scaled TARRP used in testing. A 2.5 mm mesh was used, and the simulation was initialized and run using the above conditions for 1000 time steps, with each time step representing 2.5 milliseconds. Figure 10 shows the 200 x 200 mm geometry patched with the regolith at a depth of 15 mm. The simulation results universally showed an excavation of regolith from underneath the TARRP due to the no-slip boundary condition that exists at the TARRP surface. The flowlines traced the outer edge of the TARRP, and the resulting shear forces on the surface of the regolith removed the material over time. As the simulations continued to run, a gap eventually formed between the regolith surface and the bottom surface of the TARRP. Figure 11 shows the final frame of the 200 x 200mm, 20mm depth simulation with the gap visible.