Designing for Success: Resolving Resonance Challenges for Payloads on the Moon

Sreelekshmi Sreekumar; Torin Bowman

Mechanical Systems and Analysis Branch (Code ARC-RE) , NASA Ames Research Center

Abstract

NASA collaborates with commercial partners through its Commercial Lunar Payload Services (CLPS) Program to deliver scientific experimentation and cutting-edge technology for investigation on the lunar surface, while increasing affordability and accessibility of lunar missions under the Artemis program. Two key payloads on the CP-12 Draper SERIES-2 Lander, a CLPS lander headed for the Schrödinger basin, are integral to this initiative (NASA Science, 2023). These include the Farside Seismic Suite (FSS) from NASA's Jet Propulsion Laboratory and the Lunar Surface Electromagnetics Experiment (LuSEE) from UC Berkeley's Space Sciences Lab (NASA Science, 2023). The FSS is equipped with seismometers to study lunar micrometeorite impacts and tectonic activity on the far side of the Moon, while LuSEE employs sensors and electronics on a 23-foot antenna (named V3) to investigate the Moon's electric and magnetic field environment (NASA Science, 2023).

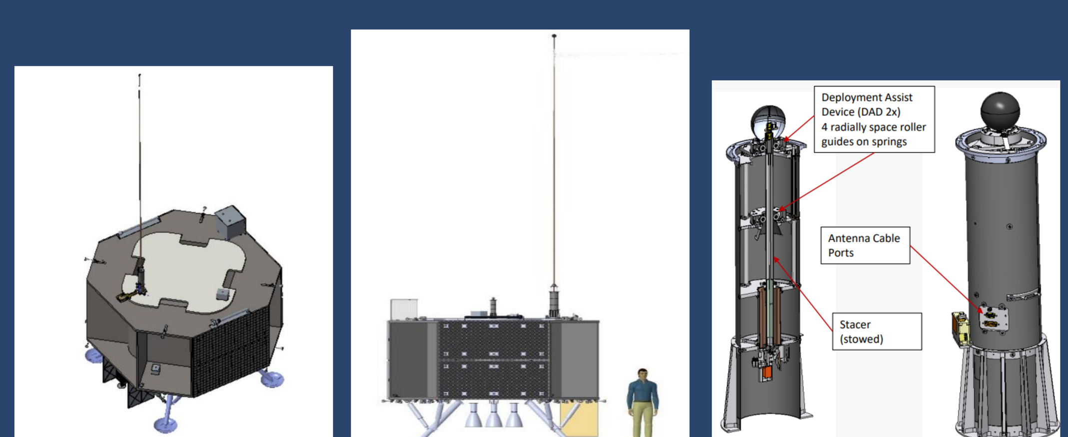
During compatibility analysis, an issue emerged: the deployed LuSEE-V3's first mode resonance is in the middle of the science measurement range of the FSS. Both experiments will function for the initial two weeks on the lunar surface, after which all payloads, except the FSS, will cease operations. The FSS, however, is designed to endure the lunar night and operate for up to a year. Thus, it's crucial to devise a mechanism that shifts LuSEE-V3's primary resonance outside the FSS's interest range, ensuring successful FSS data. This poster aims to outline the challenges of designing this mechanism to function on the lunar surface along with our approach to testing and verification.

Introduction

Ensuring that payload missions perform successfully under the CLPS supervision is pivotal. Thus, due to the inherent incompatibility between two of the three CLPS payloads on the CLPS CP-12 Draper SERIES-2 Lander set to launch in 2025 to the Schrödinger Basin, it is necessary for NASA to engineer an in-house solution to resolve the incompatibility in to maximize the scientific output of these critical lunar experiments.

Payload	Farside Seismic Suite (FSS)	Lunar Surface Electromagnetics Experiment (LuSEE)
Owner	NASA Jet Propulsion Laboratory	UC Berkeley's Space Sciences Lab
Description	The FSS holds two seismometers intended to "return the agency's first seismic data from the far side of the Moon" (NASA Science, 2023).	LuSEE uses an assortment of sensors and electronics mounted on a 23-foot STACER (Spiral Tube & Actuator for Controlled Extension/Retraction) antenna (labeled in the pictures below as V3) "to measure and characterize the electric and magnetic field environment of the lunar surface" (NASA Science, 2023).

LuSEE will cease operations after two weeks, and the FSS will operate for up to a year on the lunar surface. Thus, it is possible to modify or remove the antenna after it has taken its necessary data from the lunar environment and make way for the FSS to take its data.

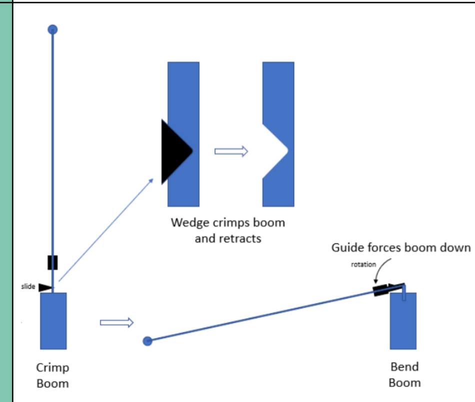
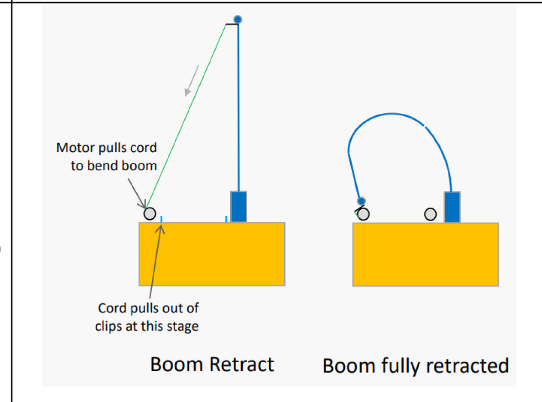
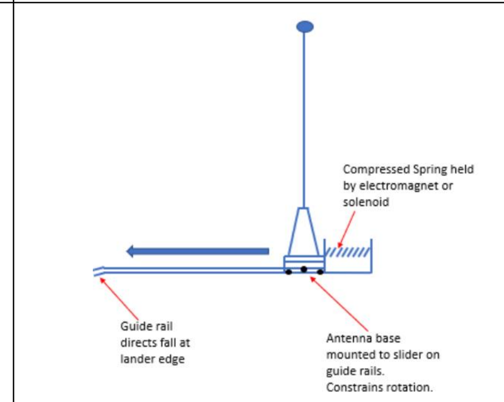
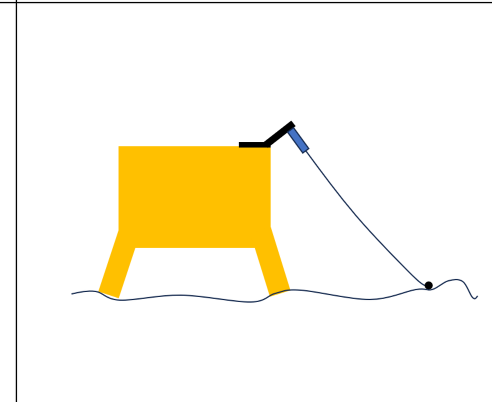


Pictures of LuSEE-V3 and the lander.

Objective

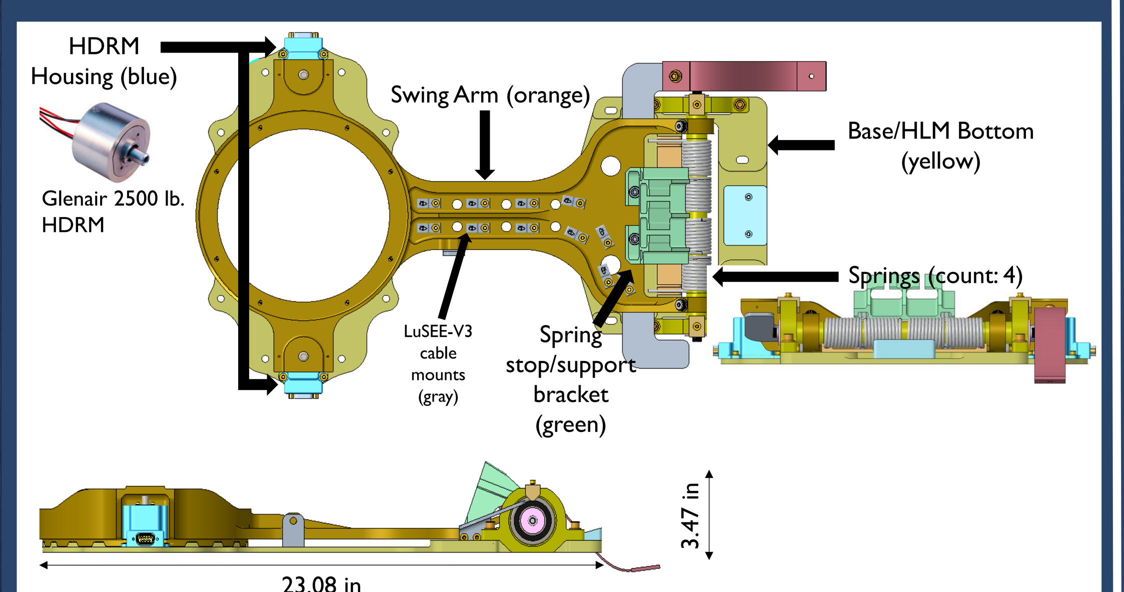
Design and implement a mechanism that increases the primary resonance of the Lunar Surface Electromagnetic Explorer V3 antenna outside the band of interest for the Farside Seismic Suite instruments on the CLPS CP-12 Draper SERIES-2 Lander. LuSEE-V3 has a primary resonance of 0.37 Hz for the lunar environment in the deployed configuration, but the primary band of interest for science data for the FSS payload is 0.1-1.0 Hz. The objective is to push the resonance of the LuSEE-V3 as far from the measurement range of the FSS instruments as practical.

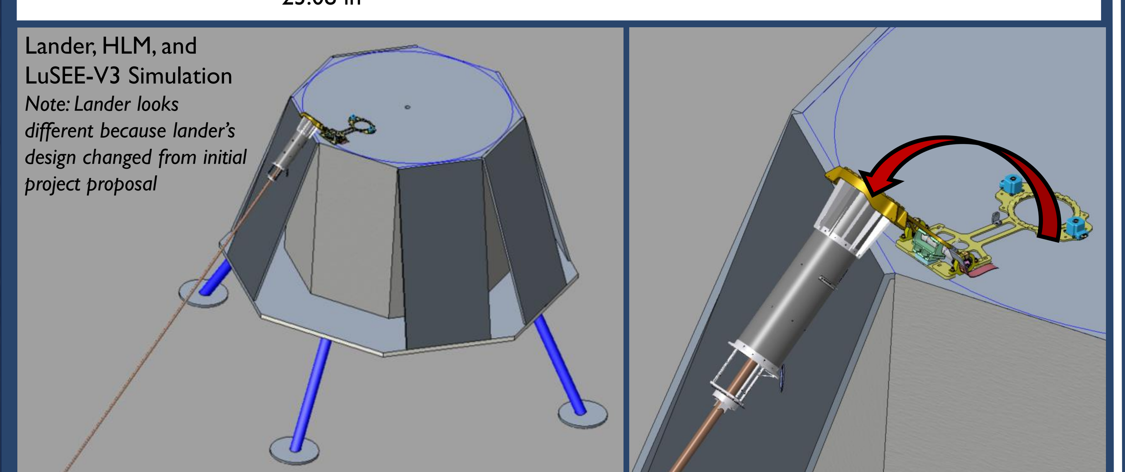
Methods and Project Design: Trade Studies

Previous Ideas	Crimp LuSEE-V3	Bend LuSEE-V3	Eject LuSEE-V3	Flip LuSEE-V3
Description	A mechanism with a wedge would crimp and force the antenna over in a particular direction	A motor and cable would be used to connect to the antenna tip with the purpose of spooling in and deforming the antenna upon activation	A guide rail and spring system would be used to roll the antenna off the lander into a freefall beyond the edge of the lander	A hinge mechanism would be used to rotate the antenna across the lander and lay it on the Moon's surface after it's use
Picture				
Reasons for Rejection	(1) Unsupported antenna tip (2) Unknown associated frequency response (3) Possible damage to surrounding area (4) High overall complexity	(1) Does not fit within the allowable mass for the mechanism on the lander (2) Necessitates attachment to the antenna tip and potentially intefering with the antenna (3) High overall complexity	(1) Unknown final state of antenna (2) Necessitates breakaway connections which adds complexity (3) Requires utilizing a large area on the lander	N/A (This concept was selected)

Results: Design & Analysis

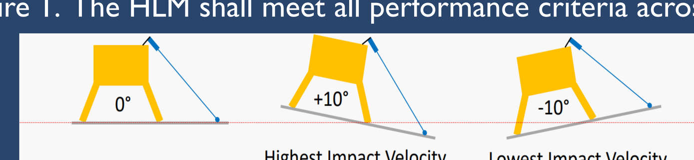
- The design that was selected is called the **Hinge Layover Mechanism (HLM)** (Rick G. Brewster[1] sketched the initial concept). Unlike the previous three ideas, this solution secured the position of the antenna after the operation, ensured that neither the payloads nor the lander would be damaged, and fits within the given size and mass limitations.
- It is a spring-loaded hinge mechanism that will be attached close to an edge of the lander, and it will have LuSEE-V3 attached on top.
- Upon activation and release of the two Hold Down Release Mechanisms (HDRMs) (its housing is shown below in blue), the springs will release and allow the HLM to rotate LuSEE-V3, enabling LuSEE-V3 to impact the lunar surface. It will remain like this the rest of the lander's mission.
- Data such as mass, center of gravity, center of mass, moments, rotational inertia etc. of all the components involved in the LuSEE-V3 and preliminary HLM system were taken through testing, computer simulating, and kinematic modeling using NASTRAN FE, MSC Software, and Excel spreadsheets.



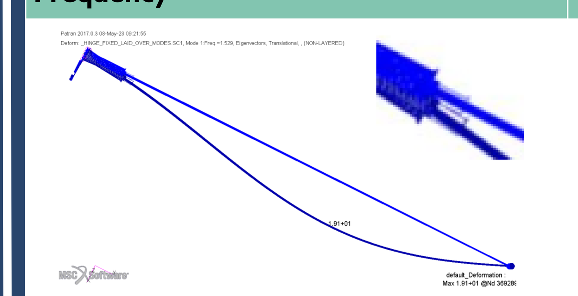
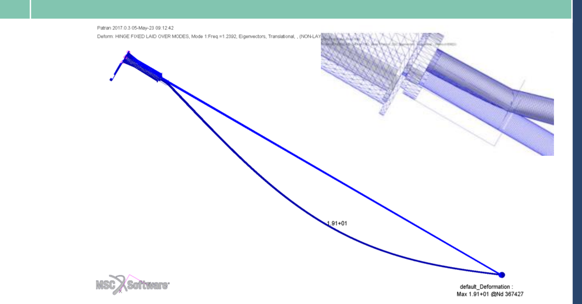


Credit: Rafael O. Talavera[2]

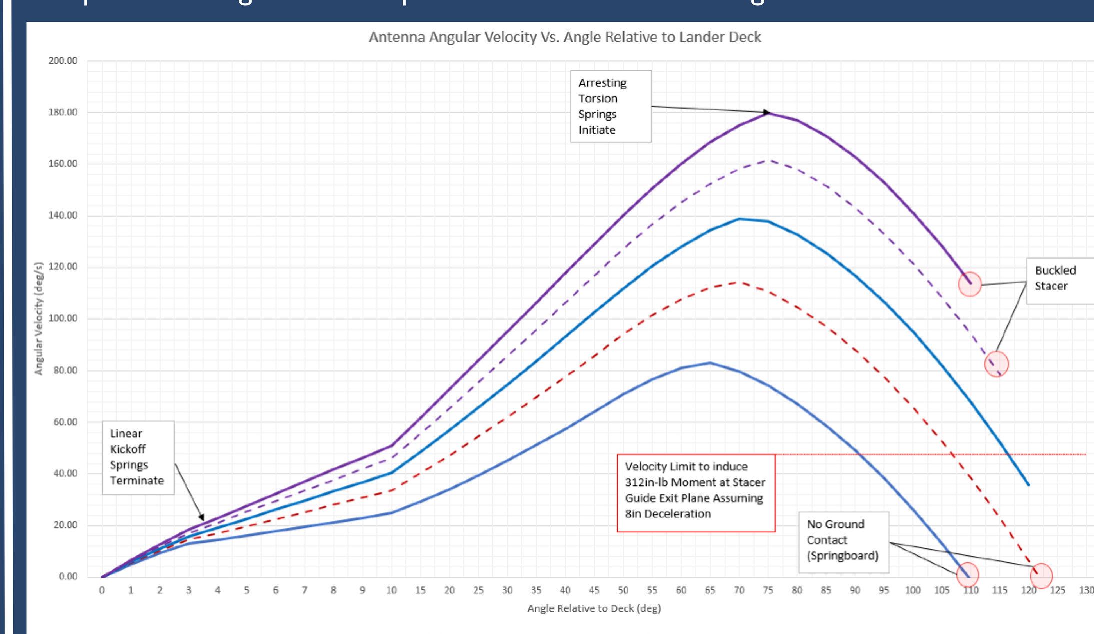
Additional Key Requirement:
6.1.12. Lander Orientation
The top surface of the mounting plane shall be within ±10° of the YZ plane as defined in Figure 1. The HLM shall meet all performance criteria across this range.



Computer simulations of the buckling characteristics of the STACER tube of LuSEE-V3 were acquired to assist in the initial designing process of the HLM. A LuSEE-V3 model was mounted to a preliminary version of the HLM arm with representation of the arm's mass and stiffness.

Non-Buckled, Laid Over STACER Frequency	Buckled Laid Over STACER Frequency
	
LuSEE-V3's lowest vibration frequency **with** HLM arm: 1.53 Hz	LuSEE-V3's lowest vibration frequency: 1.24 Hz *(Note: Too close to being within 0.1-1.2 Hz frequency requirement.)*

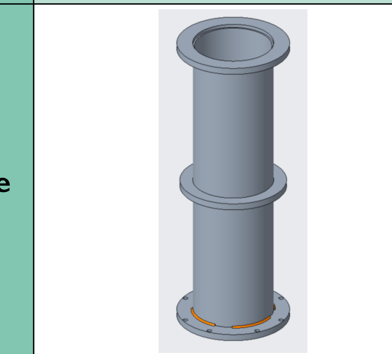
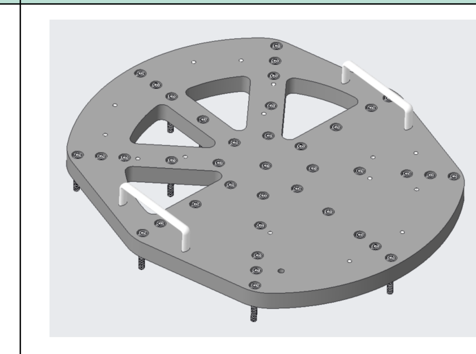
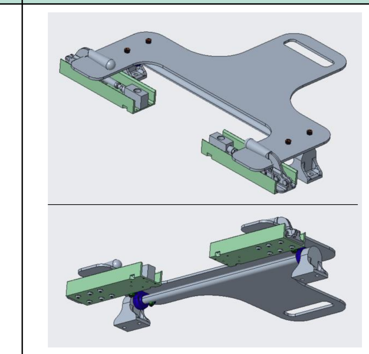
- A separate kinematic model was created to evaluate angular accelerations, end of stroke velocity, and moments of the system.
- It was discovered that it was difficult for the initial spring driven design to make surface contact at the high impact velocity lander position of +10° without buckling and be able to make acceptable surface contact at the low impact velocity lander position of -10° orientation at the same time.
- It is necessary to allow the STACER tube to buckle post layover for the HLM to operate throughout the required lander orientation range of ±10°.



Based on these findings, the initial requirements of the HLM mechanism needed to be adjusted.

Down-Selected Options	
Option 1: Relax frequency isolation requirement to 0.1 – 1.0 Hz from initial frequency isolation requirement of 0.1 – 1.2 Hz (expect >1.2 Hz)	Option 2: Switch to motor integrated design or complex mechanism; no change to frequency requirement
• Design will stay spring driven • Allows for buckled STACER tube • Simple, cheap, and robust design • Allows for a larger range of lander orientation angles than ±10° if desired	• Motor and controller integrated near hinge • Adds complexity to project, but it is not a technically challenging solution • May affect cost and lead-time

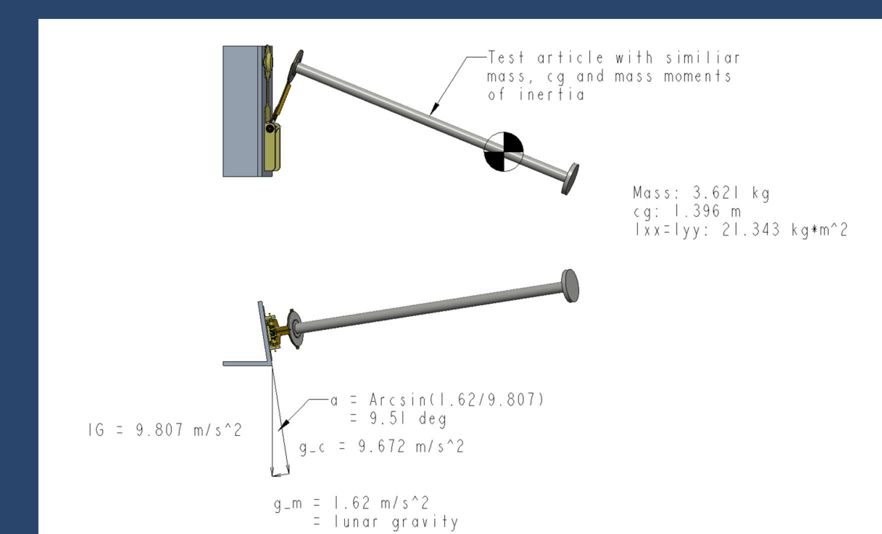
Results: Project Accomplishments

Name	Stowed Antenna Simulator	Vibration Test Fixture	3D-Printed HLM Model	3D-Printed LuSEE-V3 Tip Simulator	Mechanical Hold Down Release Mechanism
Picture					
Purpose	This welded aluminum structure is meant to replicate the mass and center of gravity (CG) values of LuSEE-V3 for testing.	• This aluminum plate is meant to act as an adaptor when connecting the HLM to test set-ups (i.e, vibration tables). • The cut outs and shape help reduce extra vibration and keep the CG in the center of the plate when the HLM and LuSEE-V3 models are mounted.	This model of the HLM helps us with design evaluation and prototyping. (Note: This will not be used for testing.)	• This is a mass simulator for testing of the LuSEE-V3 sphere tip that holds sensors and electronics. • The gap allows support material to melt out so its mass matches the mass of the actual LuSEE-V3 tip.	• This football goal shaped aluminum plate allows us to flip up two push-pull toggle clamps that will hold down the spring-loaded HLM when testing. • It acts as a replacement to actual HDRMs to reduce testing costs.

Conclusions

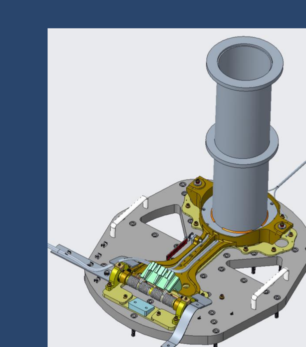
In conclusion, the design objective to mitigate the compatibility issue between the Lunar Surface Electromagnetic Explorer V3 antenna and the Farside Seismic Suite on the CLPS CP-12 Draper SERIES-2 Lander has been achieved. This engineering solution aligns with the necessity of ensuring the success of CLPS missions. As we transition into the testing phase, we anticipate that the mechanism will efficiently relocate LuSEE-V3's primary resonance outside the specified band of interest for FSS instruments, thus facilitating the coexistence of both payloads at the Schrödinger Basin on the Moon.

Future Work

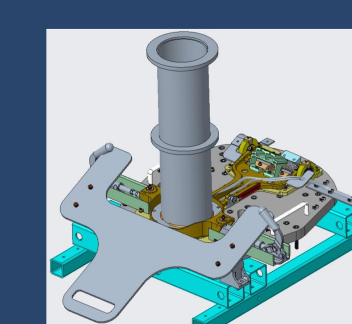


To simulate the Moon's gravity on Earth, Earl T. Daley[3] proposed the idea of tilting some of the test set ups so that the vertical component of Earth's gravity is equivalent to the Moon's overall gravity. Down below is a general summary of our testing plans to prove our design meets the requirements of all stakeholders.

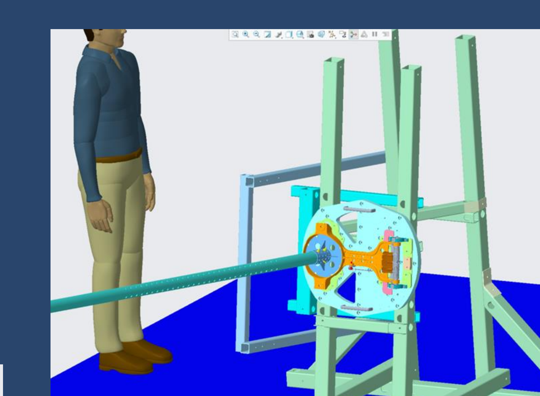
Category	Description
Checkout Testing	A series of tests in which we do HLM release and impact tests to verify structural integrity under different conditions, verify release works as intended with HDRMs, and prove test setups and procedures.
STACER Testing	Two tests in which we verify structural similarity of the test model versus flight LuSEE-V3 as well as verify buckling characteristics and moment. This will be done through a form of vibration testing and release of the HLM with LuSEE-V3 against an impact plate to induce buckling.
Environmental Testing	A series of tests to assess electrical bonding, vibration, and thermal cycling of the entire system to verify performance and structural integrity of mechanical and electrical components in the Lunar environment.
Performance Testing	Three tests that will test the HLM at worst-case operational conditions including at highest impact velocity and stiffest springs as well as with only one HDRM secured.



Horizontal and vertical vibration tests assembly



Portion of test set-up with ME HDRM assembly



Working design for HLM release tests with tilt induced to simulate Moon's gravity.

Acknowledgements

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References and Citations:

[1]NASA. (2023, October 24). Commercial Lunar Payload Services. NASA. https://www.nasa.gov/reference/commercial-lunar-payload-services/

[2]NASA Science. (2023, May 22). NASA Payloads for (CLPS PRISM) CP-12 – Draper SERIES-2 Lander. NASA Science. https://science.nasa.gov/lunar- science/deliveries/cp-12/