Lunar Habitat Resilience: Vibration Isolation and Fatigue Study

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Introduction

Lunar habitats might be vulnerable to low-frequency, long-duration vibrations from moonquakes, necessitating robust mitigation strategies. This study is part of a project that proposes a novel vibration isolation system using a bladder system to transfer vibrational forces to Vectran straps, absorbing tensile loads and mitigating vibrations. We analyze mechanical fatigue induced by Apollo Moonquake data and characterize fatigue damage to the straps, revealing potential vulnerabilities in current design practices. Fatigue degradation patterns over time might contribute to the interruption of operation in future habitations, if not accounted for in the design.

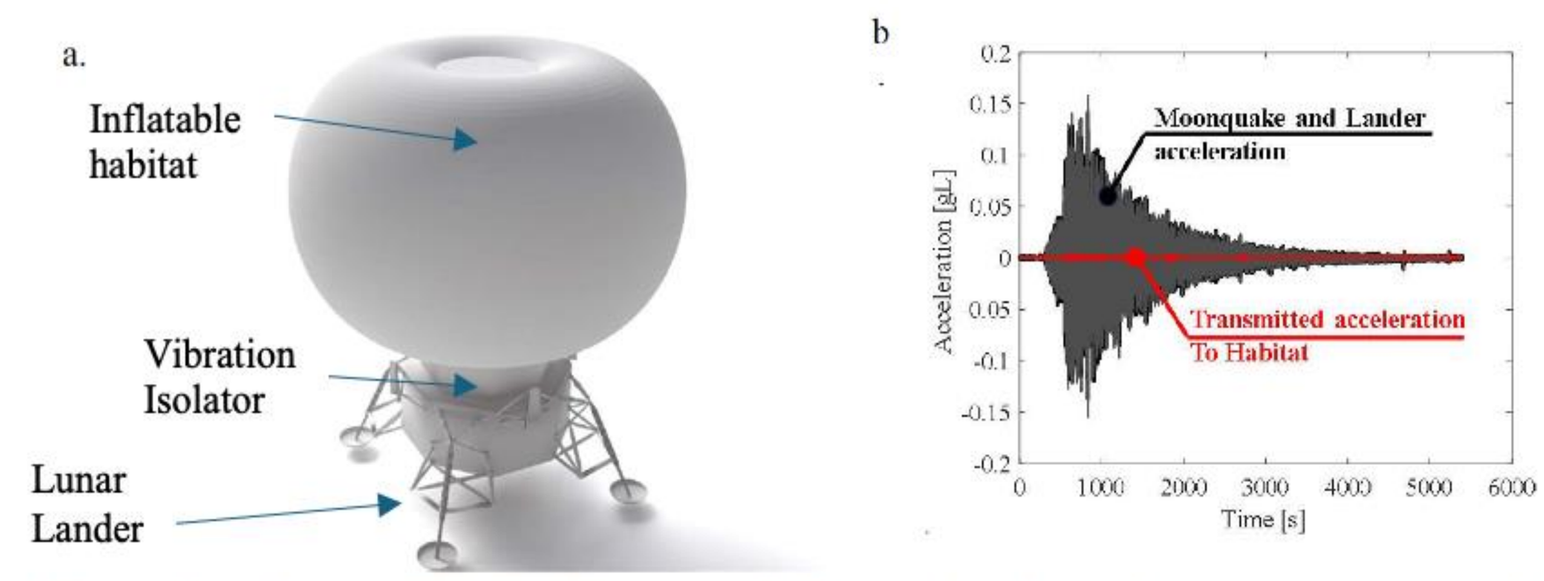

Figure 1: a) Lunar Habitat Concept. b) Transmitted acceleration using a scaled moonquake from Apollo 16 station, Mar-13-73

Project Description

Sustained human presence on the lunar surface faces many challenges, including moonquakes —lower than launch frequencies, long-duration seismic activities from the moon. These can threaten the structural integrity of lunar habitats.

The isolation system ensures stability in the lunar environment as highlighted in Fig 3a and 3b below.

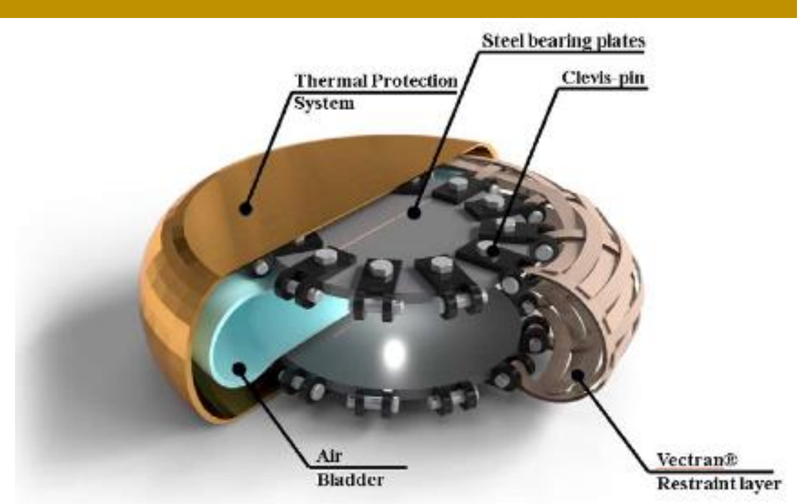

Figure 2: SIDE device graphical representation

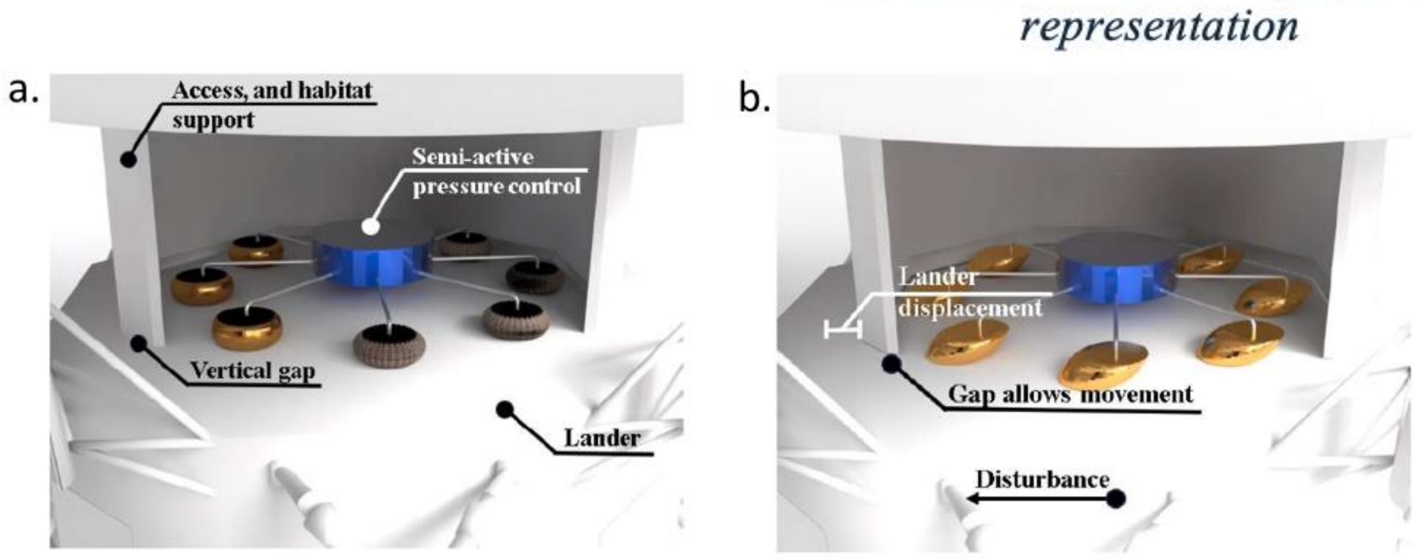

Figure 3: a. Undisturbed description of isolation system. b. Disturbed isolation system

The isolation system ensures stability in the lunar environment. Initially flat within the connection interface device (Fig 4a), it inflates on the lunar surface, lifting the habitat and initiating vibration isolation (Fig 4b).

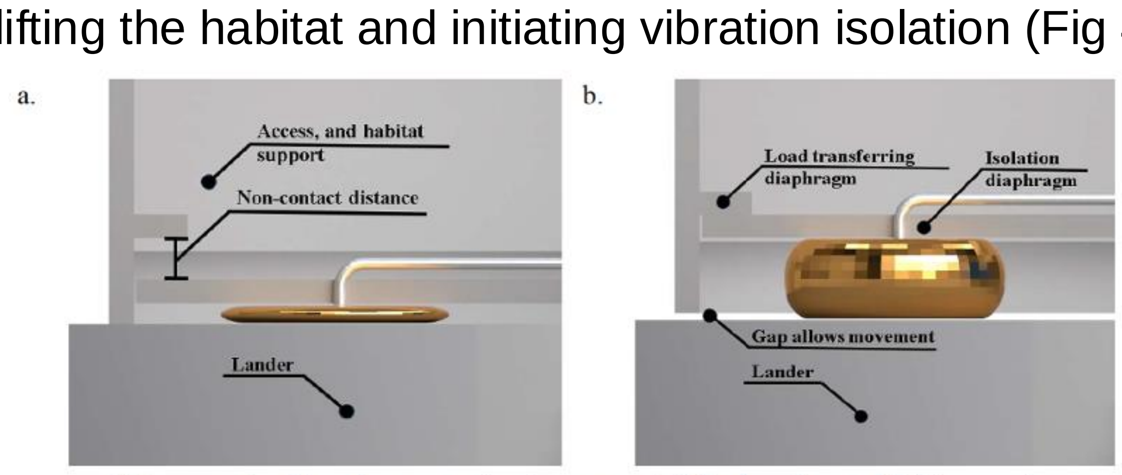

Figure 4: Deployment phase: a) Undeployed/ Stowed condition. b) Deployed

Understanding material fatigue from cyclic loading is crucial. This research characterizes fatigue damage to Vectran straps, a key component of the vibration isolation device, under simulated lunar vibrations.

Methodology

A comprehensive fatigue analysis using the S-N curve predicts material fatigue life under cyclic loading. Stress-strain relationships and deformations are examined, with loading histories simplified by the rainflow counting algorithm. FEM analysis assesses stress-strain responses, and results are compared with experimental data to validate the models.

Figure 5: Test Protocol

Expected Outcome

A tensile testing machine will evaluate the mechanical properties of the Vectran strap (Fig 5) under cyclic loading, simulating operational stresses. This will be analysed using the rainflow counting algorithm creating hysteresis loops, showing the force-displacement relationship and material deformation behavior.

Combining experimental data with analytical methods, the research aims to validate the Vectran straps for SIDE and optimize the system for long-term reliability in lunar seismic conditions.

Future Work

Fatigue analysis will extend to individual components of SIDE (Soft-Goods Isolation Device Experimentation) using S-N curve and stress-strain methodologies. Detailed fatigue simulations for the Apollo lunar lander will be conducted to understand vibration propagation. A FEM model will simulate the strain/stress hysteresis plot of the landing leg and compare it with its deformed shape.

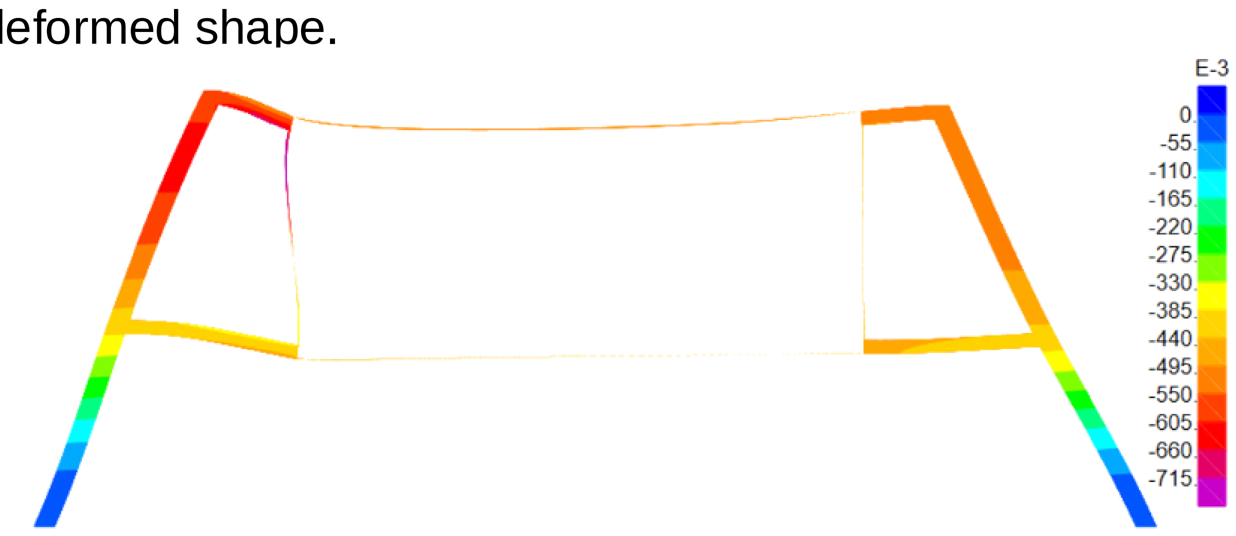

Figure 6: Lunar Lander model

The next phase will focus on dynamic analysis and testing of SIDE. Vibration tests via a shake table (Fig 7) will simulate moonquakes recorded from Apollo seismometers to assess the system's ability to mitigate acceleration transfer to the habitat. These tests will provide proof-of-concept data and refine the device for optimal performance.

1. Specimen
2. Rigid diaphragm
3. Lateral load transferring table
4. Lateral actuators with 3kips force capacity and 2in stroke each.
5. Hydraulic jack to induce the vertical force
6. Pressure control system
7. Control computer
8. Reaction frame
9. Foundation

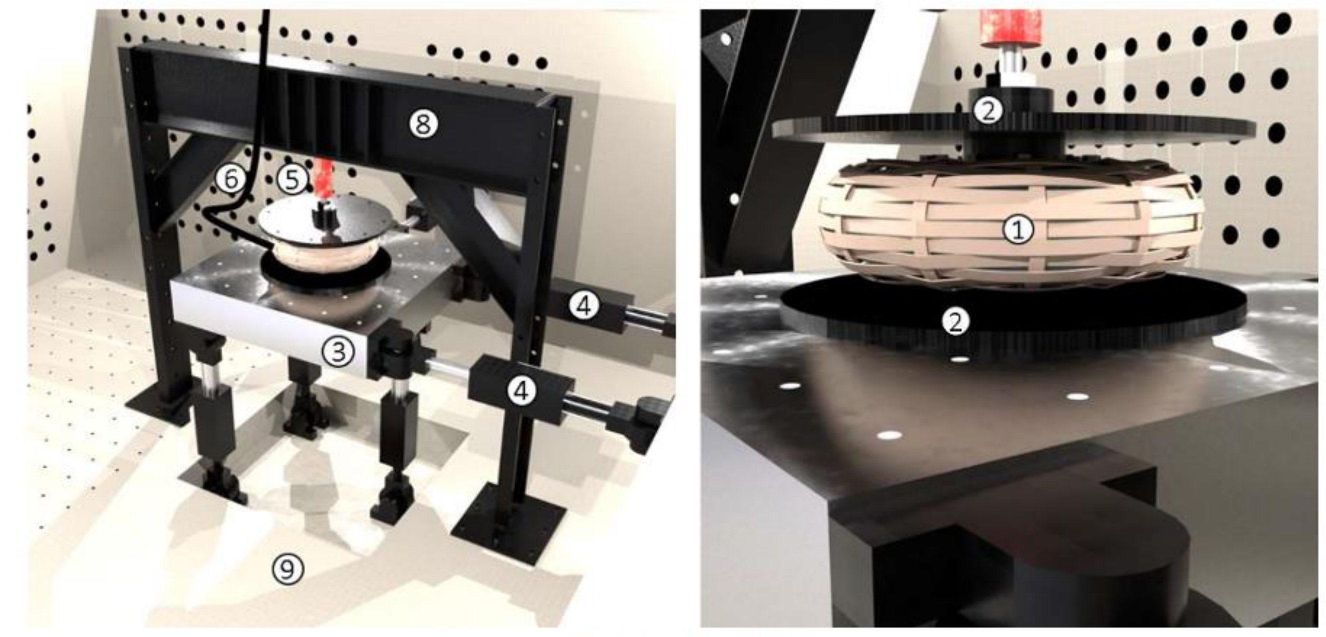

Figure 7: Shake table test

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