The Grainger College of Engineering
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

HINDER

Holistic Integration of Navigational Dynamics for Erosion Reduction

NASA HuLC HUMAN LANDER CHALLENGE

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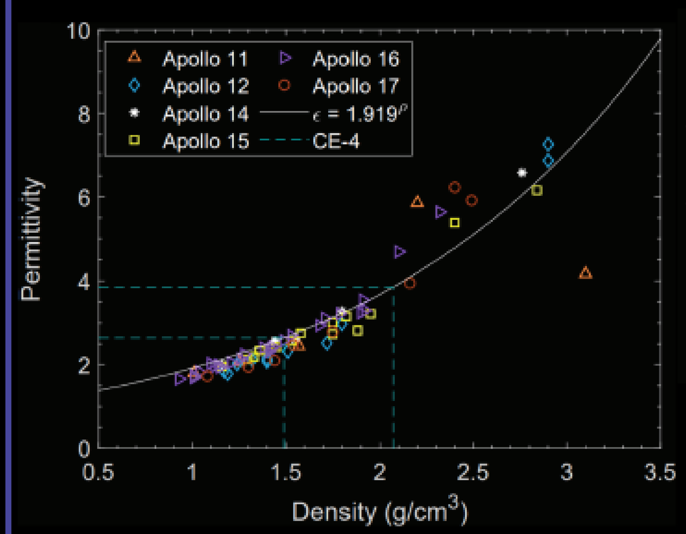
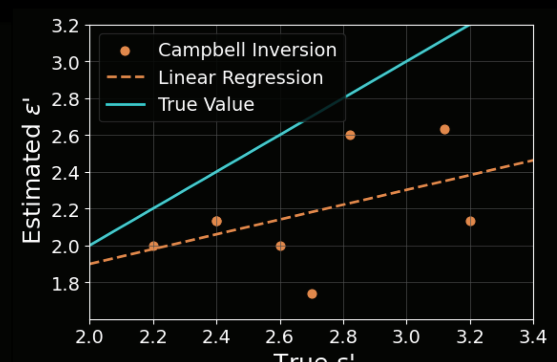
Target Site Selection

- Identify unprepared landing sites less vulnerable to PSI due to natural geology
- Inverse correlation between bulk density and erosion rate
- Use existing dielectric constant data from LRO & Chandryaan
- Locate sites with highest bulk density, estimated by dielectric constant
- Demonstrated with modified Campbell Model & LRO datasets (1)

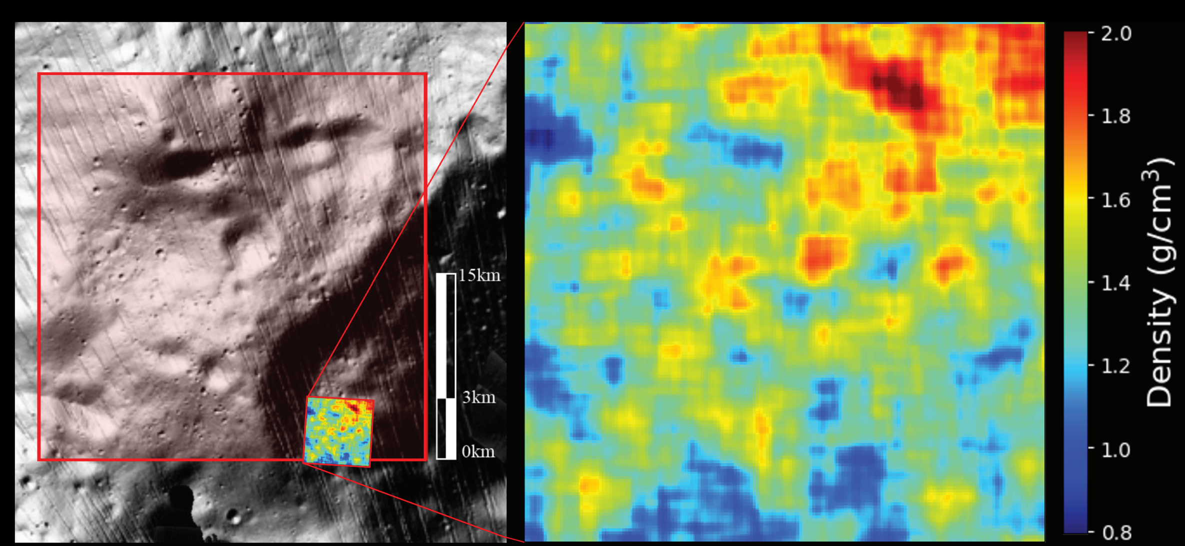


(Bulk) Density vs. Permittivity (Dielectric Constant) Graph (2)



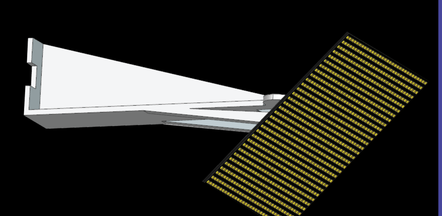
$$\varepsilon' = \left(\sin(\phi)/\sin\left[\arccos\left(\frac{\sigma^0_{LH}}{\sigma^0_{LV}}\right)^{0.25} - \phi\right]\right)^2$$

Campbell Model Validation (3)



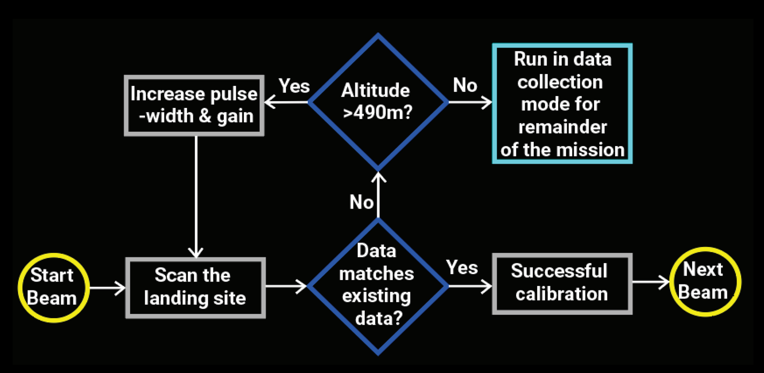
Hazard Relative Navigation

- Phased-array radar used as a scatterometer enacts process similar to Terrain Relative Navigation (TRN)
- Leveraging the extensive testing and validation of COTS automotive radars
- Operational in dark, shadowed, and illuminated regions on the lunar surface

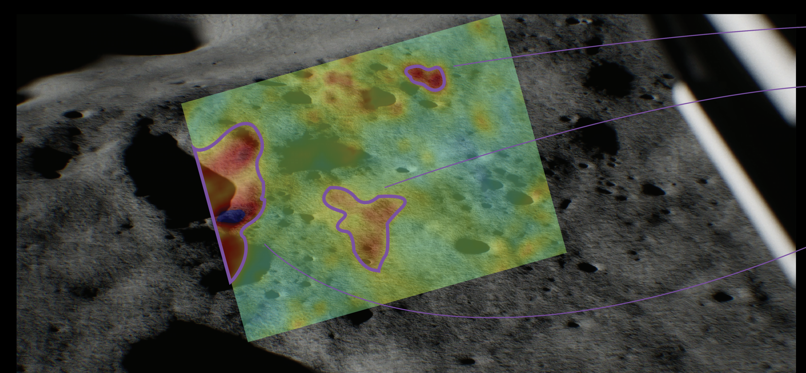


Requirement	Value
Frequency	24 GHz
Wavelength	12.5 mm
Antenna Size	0.36x0.36 m
Estimated Total Mass	15-25 kg
Beamsteering	Electronic
Beam-Angle Range	0-30 degrees
Beam Width	3.1-3.5 degrees
Number of Elements	1024
Total Power	20 W
Antenna Efficiency	30%
Transmit Power	114.8 dBm
Pulse Width	10 ns

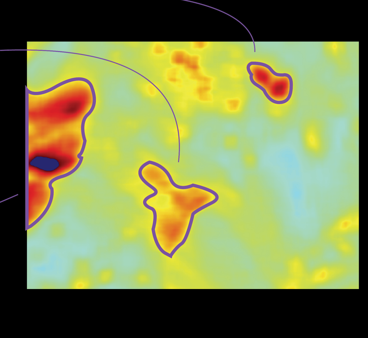
High-Level Radar Parameters



Hazard Relative Navigation Logic Flowpath



Radar POV with overlayed dielectric constant map



LRO Map from equivalent location

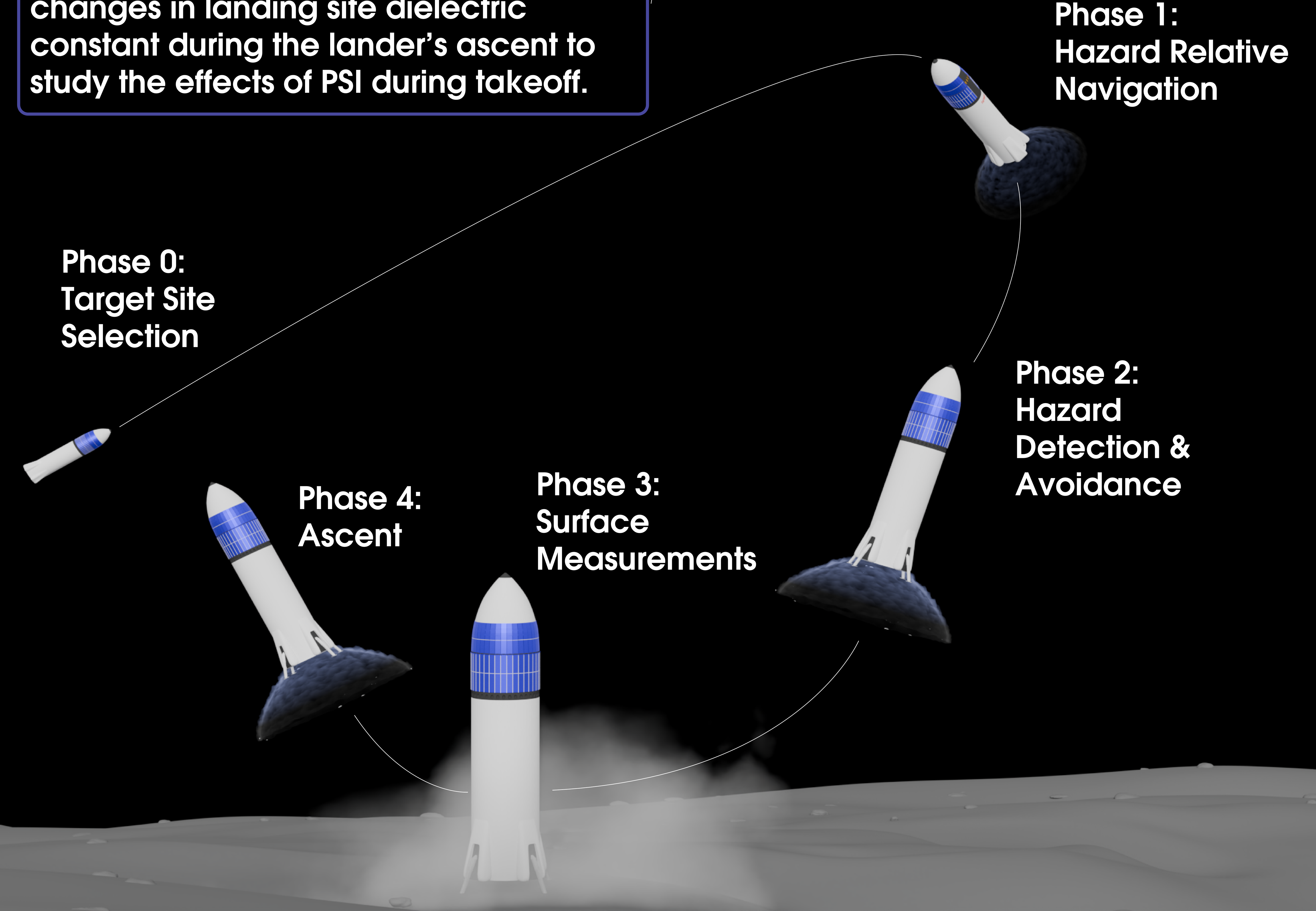
Phase 0:
Prior to launch, use existing radar data sets to map estimated regolith dielectric constant and bulk density to identify sites vulnerable to high erosion under PSI.

Phase 1:
A phased-array radar is used to image the surface underneath within the pre-selected landing zone during initial descent. Radar data transmitted and received in real-time during descent is compared against existing dielectric constant maps to ensure nominal radar performance and positioning.

Phase 2:
Use the onboard phased array radar instrument to supplement pre-flight maps with higher resolution estimates. Identify potential hazards to landing due to poor surface characteristics for PSI. Coordinate with the Precision Landing & Hazard Avoidance (PL&HA) hazard maps to avoid hazards and reduce PSI.

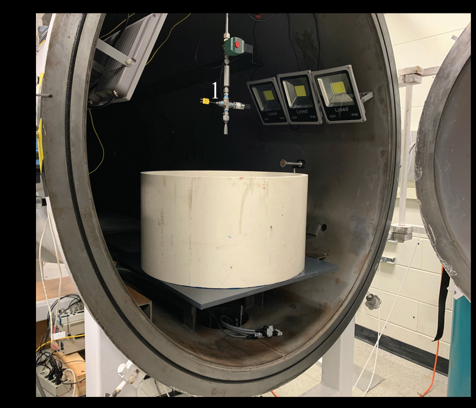
Phase 3:
The instrumentation system remains active during terminal descent, measuring changes in dielectric constant during active erosion to collect data and inform soil models.

Phase 4:
After surface operations are complete, the instrumentation system measures changes in landing site dielectric constant during the lander's ascent to study the effects of PSI during takeoff.

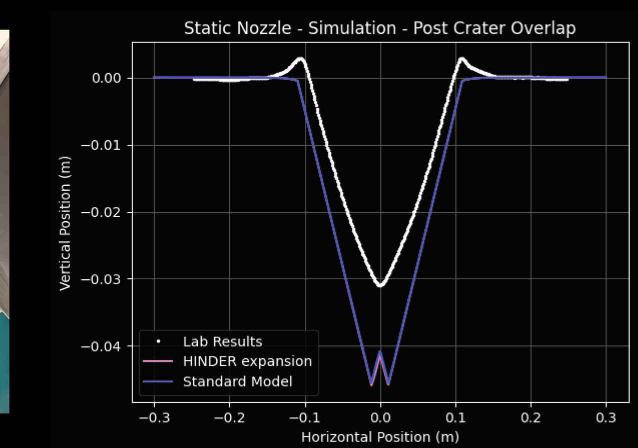


Hazard Detection & Avoidance

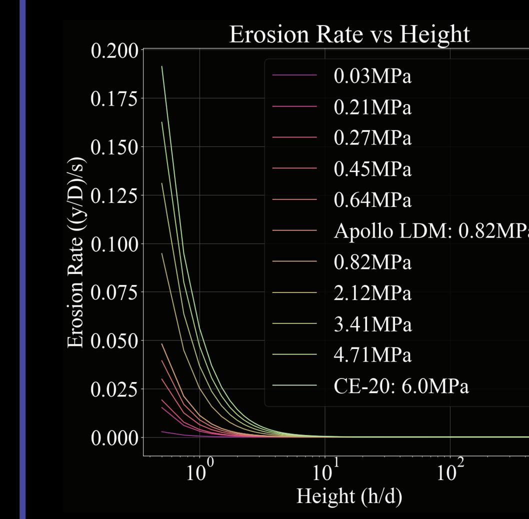
- Collaboration with University of Illinois PSI research group to verify Roberts' Model implementation



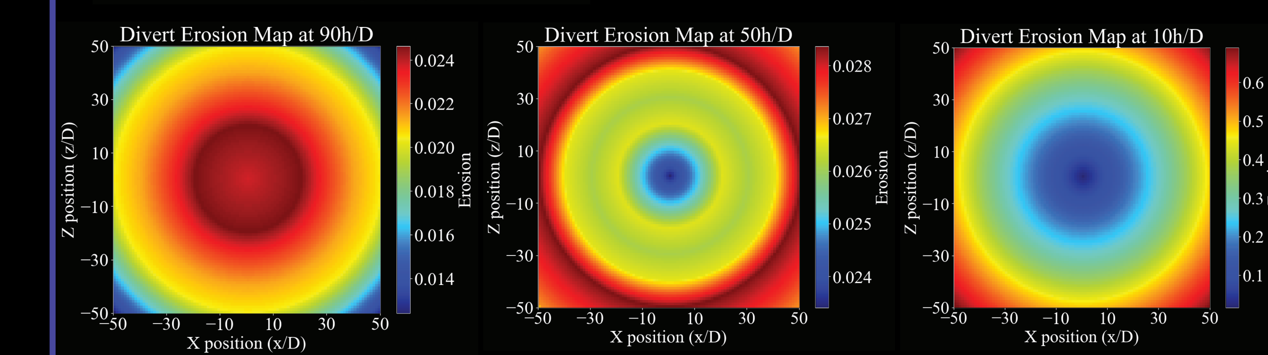
Vacuum Chamber Sub-Scale Testing PSI Facility at UIUC



Experimental vs. Actual Cratering Results



- Crater growth is modeled as a function of chamber pressures of past lunar landers
- Erosion becomes significant at heights below 100 h/D
- Rapid model used to bound height for further analysis in generating divert hazard maps

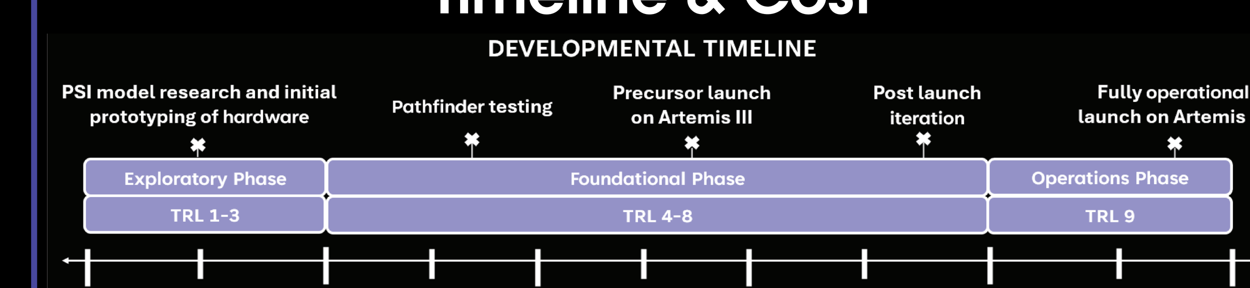


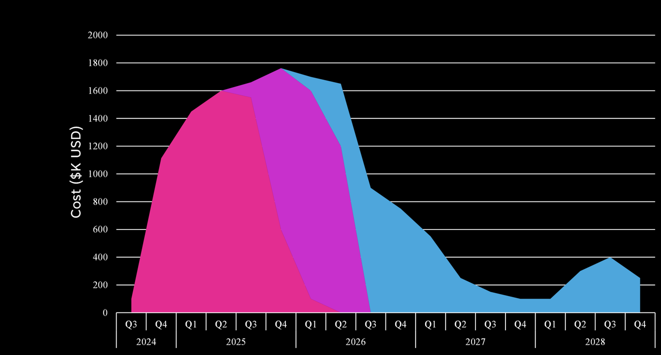
- Three-dimensional implementation of Roberts' Model is used to create hazard maps, showcasing cost of diverting to new landing site
- Radar outputs divert hazard maps in real-time during descent
- Hazard maps from multitude of HDA sensors onboard the lander, including HINDERs' maps, are fused together
- Final fused hazard map determines cost of landing at each location within the pre-selected landing site

Surface Measurements & Ascent

- High-resolution dielectric constant data before and after landing used to detect landing site surface changes due to PSI
- Erosion rates and crater shape correlated with imaged data

Timeline & Cost





(1) LRO: Mini-RF. PDS Geosciences Node Data and Services: LRO Mini-RF. (2021, December 31). https://pds-geosciences.wustl.edu/missions/lro/mrf.htm

(2) Feng, J., Siegler, M., & White, M. (2022). Dielectric properties and stratigraphy of regolith in the lunar South Pole-Aitken basin: Observations from the Lunar Penetrating Radar. Astronomy & Astrophysics, 661. doi:10.1051/0004-6361/202143015

(3) Gao, Y., Dang, Y., Lu, P., Hou, W., … Wang, R. (2023). Investigating the dielectric properties of lunar surface regolith fines using Mini-RF SAR data. ISPRS Journal of Photogrammetry and Remote Sensing, 197, 56–70. doi:10.1016/j.isprsjprs.2023.01.008