IAF SPACE EXPLORATION SYMPOSIUM (A3)
Interactive Presentations - IAF SPACE EXPLORATION SYMPOSIUM (IP)

Author: Mr. Aagashram Neelakandan
TU Bergakademie Freiberg (TUBAF), Germany

Mr. Riyabrata Mondal
TU Bergakademie Freiberg (TUBAF), Germany

PHYSICS-INFORMED MACHINE LEARNING FOR LUNAR LANDING EROSION PREDICTION: ENABLING SAFE AND SUSTAINABLE LUNAR EXPLORATION

Abstract

Rocket plume-induced regolith erosion during lunar landings poses significant risks to mission safety, including crater formation, visual obscuration, and structural damage to landers. Traditional computational models, while accurate, are computationally intensive and impractical for real-time hazard mitigation. This study proposes a physics-informed machine learning framework to address this challenge by synergizing foundational principles of fluid dynamics, granular mechanics, and adaptive learning algorithms. The approach integrates compressible Navier-Stokes equations and shear-stress-driven erosion models into a neural network architecture, ensuring predictions adhere to physical laws while enabling rapid, resource-efficient simulations.

By leveraging existing Apollo mission data, synthetic plume-surface interaction datasets, and emerging Commercial Lunar Payload Services (CLPS) mission insights, the framework aims to predict dynamic regolith displacement and crater evolution under varying descent conditions. The model will prioritize generalizability across lunar terrains and scalability for integration into autonomous navigation systems. Key innovations include a physics-constrained loss function to enforce conservation principles and a modular design adaptable to diverse propulsion systems.

This work aligns with the broader objectives of sustainable lunar exploration by addressing critical gaps in real-time hazard prediction. The proposed methodology has the potential to reduce reliance on high-fidelity CFD simulations, enabling iterative mission planning and enhancing the safety of crewed and robotic landers, thus contributing to the long-term vision of interplanetary human presence.