DEVELOPMENT OF A FULL-SCALE ROVER WHEEL TESTING PLATFORM AT THE COLORADO SCHOOL OF MINES. A. S. Glover[1,2], E. Urbani[1], A. Armbruster[1], W. He[1], A. L. Soleta[1], E. M. Williams[1], I. E. Jehn[2], C. B. Dreyer[2], and F. Zhu[1], [1]Colorado School of Mines (CSM) Robotic Space Exploration (RoSE) Lab (1610 Illinois St, Golden, CO 80401; abigail_glover@mines.edu, urbani@mines.edu, ava_armbruster@mines.edu, wenshao_he@mines.edu, ainsley_soleta@mines.edu, emily_williams@mines.edu, frankie.zhu@mines.edu), [2]CSM Space Resources Program (1310 Maple St, Golden, CO 80401; ijehn@mines.edu, cdreyer@mines.edu).

Introduction: For years, rovers have pioneered humanity's expansion into the solar system, serving as teleoperated agents that perform critical tasks in challenging environments, collect scientific data, and provide range and flexibility for astronauts engaged in extravehicular activities [1, 2]. As mission objectives transition from solely scientific exploration to establishing a long-term presence on the Moon, the need for rovers capable of constructing lunar infrastructure through In-Situ Resource Utilization (ISRU) grows [3]. Due to the nature of infrastructure development, such as diverse terrain interaction and multi-agent coordination, there is a heavy push in the robotics community for rover autonomy to redistribute workload and increase productivity [4]. This shift necessitates a fundamental leap in how engineers approach reliable mobility, demanding increasingly complex rovers to operate in dynamic environments without the safety net of constant human oversight. However, a critical gap in terramechanics currently exists: robotic systems cannot reliably predict how unknown terrain will respond to wheel forces in real time [5]. In an effort to address this, the Colorado School of Mines (CSM) is developing a full-scale Wheel Testing Platform (WTP) to correlate the geotechnical properties of lunar highland surface material (regolith) with rover wheel proprioceptive sensors. This data will inform data-driven algorithms of potential hazards that may go unseen by visual sensors, enabling corrective measures to be taken in advance.

Background:

Single-Wheel Testing. Single-wheel testbeds provide the measurement capabilities necessary to develop wheel-terrain interaction mappings and to enable terramechanics modeling for validating ML predictors through direct translational shearing of the surface. These workflows rely on accurate characterization of near-surface regolith shear strength and the resulting vehicle response metrics (slip, sinkage, torque) [6]. During terrestrial testing, these measurements are typically obtained in single-wheel or small-module experiments [7]. For instance, the CSM Space Resources Program previously utilized a 1 m long wheel-testing platform (now decommissioned) to characterize drawbar pull and slippage of the ASPECT rover wheel (Fig. 1). While other institutions have developed similar systems [9, 10, 11], they are often tailored to specific parameters, resulting in numerous facilities that provide varying capabilities. In addition, many lack the structural capacity needed to simulate robust terrain interactions under full Earth-gravity loads across various wheel diameter sizes, resulting in overly optimistic performance estimates [12]. The combination of these factors ultimately limit the datasets used in ML training workflows. For this reason, a broad-use, adaptable facility with the flexibility of gravity or non-gravity offloading is needed to enable the development of diverse, reliable wheel–terrain models to support sustained lunar surface operations, including mobility systems for ISRU excavation and material transport.

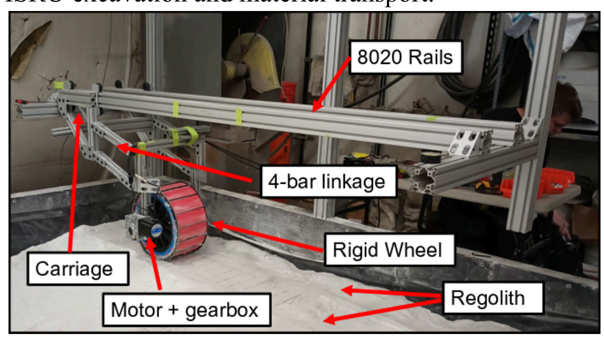

Figure 1: Original WTP designed for the ASPECT rover [8].

Mines Lunar Surface Simulator (MLSS). The MLSS is a 108 m^2, 110 metric ton, regolith simulant testbed designed to simulate the lunar highland regions. It utilizes Colorado School of Mines - Lunar Highlands Type - Testbed (CSM-LHT-T) simulant, which mimics the geotechnical behavior observed during the Apollo missions, with key parameters (density, compression index, and friction angle) differing by less than 30% [13]. As a state-of-the-art facility, the MLSS also incorporates overhead LiDAR and motion capture (MoCap) systems to evaluate terrain deformation and movement of surface operators. Leveraging this existing sensor suite, integrating the WTP into the testbed establishes a comprehensive pipeline for rigorously evaluating complex wheel-terrain dynamics and supporting broader rover testing.

Design Methodology: The WTP will span roughly 10 m, with the primary operating zone targeted to the 5 m directly in the center. The working zone is centralized to maximize the effective range of the LiDAR and MoCap systems mounted on the MLSS gantry (Fig. 2). The system is designed to accommodate wheel diameters from 30 to 100 cm, supporting nominal loads up to 200 kg and critical impact loads of 300 kg. The platform's maximum load capacity is scaled to baseline historical Earth-based testing data from the Apollo Lunar Roving Vehicle (LRV), with the hopes to support future testing of Lunar Terrain Vehicle (LTV)-sized vehicles [14]. To accommodate the multi-use nature of the MLSS, the WTP is also designed to be fully retracted from the surface of the regolith bed via a pulley system and secured in a designated stowage position, allowing for rapid terrain reconfiguration and uninterrupted testing of other mobile systems.

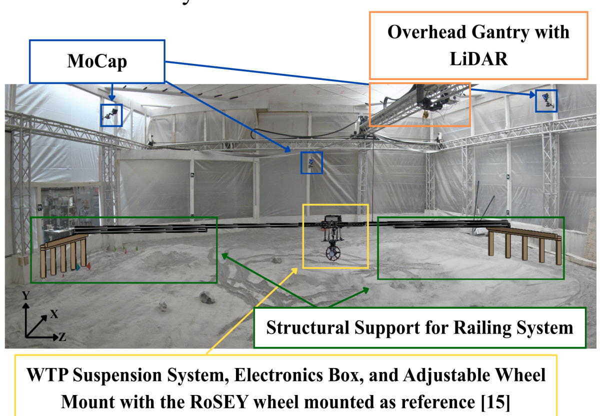

Figure 2: Working location of the WTP with key components labeled.

Surface Preparations. The WTP adapts to various regolith simulant configurations, including craters and mounds up to 5 cm deep or high, with slopes up to 30°. The system incorporates suspension to accommodate sudden terrain changes and accurately reflect the impact loads experienced by the wheel. To maximize the prepared surface, the platform's railing system features lateral (X-direction) indexing notches (Fig. 3). This mechanism allows the rail to shift between trials so the wheel traverses pristine simulant. By eliminating the need to reset the terrain between trials, multiple tests can be executed across diverse configurations within a single preparation cycle, significantly increasing testing throughput.

Testing Parameters: The WTP integrates a comprehensive sensor suite to capture multi-modal data during trials. Key observables are grouped into three categories: kinematic metrics (linear translation, angular rotation relative to the testbed coordinate frame, speed), dynamic forces (drawbar pull, experienced versus applied load), and environmental interactions (wheel entry via computer vision, terrain deformation via overhead LiDAR). A graphical user interface (GUI) displays selected metrics in real time, while comprehensive telemetry results are logged for subsequent analysis.

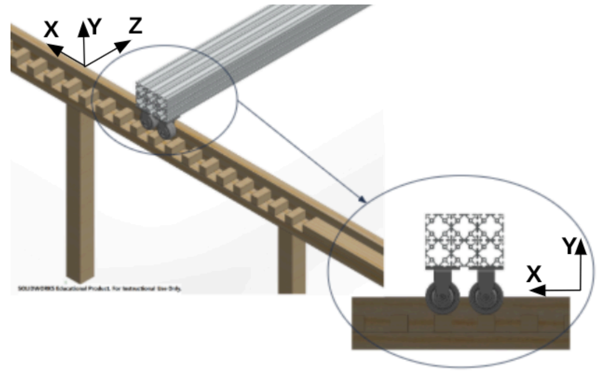

Figure 3: CAD model of the WTP system's indexing notches.

Discussion: Unlike previously developed wheel-testing facilities, the WTP at CSM is uniquely positioned within a broader, multi-use ecosystem. This integration provides unparalleled flexibility to adapt to diverse terrain and rover configurations, and to analyze numerous parameters simultaneously, building on and expanding the capabilities of similar systems. Furthermore, while many existing systems rely on lunar gravity offloading or lack the physical scale to accommodate full-size hardware [10], the WTP bridges this gap by supporting full-scale, full Earth-gravity testing.

Conclusion: The design and ongoing development of the WTP at CSM provide a critical tool for bridging the current gap in real-time terramechanics prediction and extending the capabilities of the MLSS. Correlating regolith geotechnical properties with wheel proprioceptive sensors will enable future rovers to autonomously navigate unseen hazards, ensuring the safety and efficiency of ISRU on the Moon and beyond.

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