Assessing Impact of Joint Actuator Failure on Lunar Rover Mobility. C. A. Pavlov[1], A. Rogg[2] and A. M. Johnson[1], [1]Carnegie Mellon University, Department of Mechanical Engineering, 5000 Forbes Ave, Pittsburgh PA 15213. [2]KBRwyle, NASA Ames Research Center, Moffett Field, CA 94043. (Contact: catherine-pavlov@gmail.com)

Figure 1. VIPER test rover at NASA Glenn Simulated Lunar Operations Laboratory, reproduced from [1].

Introduction: Wheeled rovers are critical to exploration of the lunar surface, and loss of mobility actuators can have mission-ending consequences. NASA's upcoming Volatiles Investigating Polar Exploration Rover (VIPER) has a four-wheeled active suspension, which gives it flexible extreme terrain mobility at the cost of an increased number of mobility actuators and potentially a higher mobility cost due to actuator loss than might occur on a similar six-wheeled rover [2]. We present both quantitative and qualitative assessments of rover mobility with multiple failure modes in the form of drawbar pull tests and motion-tracked driving. Preliminary analysis shows that mobility impact varies greatly by both the affected joint and its failure state, and that in some cases modification of driving strategy may be able to partially mitigate mobility impact.

Methods:

Data collection. All tests were conducted on a mock lunar rover with similar kinematics to the VIPER rover in GRC-1 lunar simulant [3]. 3D motion tracking was used to record the rover's position and orientation, and actuator speeds and positions were recorded for each suspension, steer, and drive motor. For drawbar pull testing, a fixed load was applied to the rover chassis via a tether to induce slippage, with tether load and length measured. Nominal driving performance with all actuators operational was measured with the same experimental setup as a mobility benchmark.

Failure modes. There are many potential failure modes for actuation of an active suspension; we consider a rover with four wheels, each of which has three actuators associated with it – one drive motor, one steering motor, and one suspension motor, for a total of 12 actuators. Each motor can potentially fail in a "stuck" (fixed orientation) state, as in the case of a rock jam [4], or "free rolling" state, such as in a power loss or actuator damage event. In addition, in the case of a stuck suspension or steering actuator the position at which an actuator fails can massively alter the mobility impact. A subset of potential failure modes were explored due to limited testing time, with a mixture of more operationally likely failure states and an attempt at representative coverage. The following failure states were tested individually: free-rolling drive actuator, stuck drive actuator, suspension locked with single wheel raised, and a single steer actuator locked at a fixed nonzero angle.The rover was driven both forwards and backwards for each free driving test, so that each failure mode was effectively tested on both a front and rear actuator.

Results: Loss of a drive actuator was associated with a high increase in slip, while steer and suspension actuators had a more moderate impact on mobility loss. In the most extreme case, a stuck drive actuator can result in the rover pivoting about the impacted wheel while making little forward progress. Steer actuator loss primarily impacts steering performance, while a stuck suspension can result in oscillatory behavior from the rover as it tips between the two support triangles formed by its wheels. Preliminary attempts at mitigating mobility reduction for different types of actuator loss were tried with underwhelming results, but gave insight into the future development of driving strategies.

Discussion: We have shown that actuator loss could be mission-ending for a four-wheeled rover such as VIPER, and mitigation strategies should be developed. Work on generation of driving strategies for actuator failure compensation through terramechanics modeling is in progress.

References: [1] K. Sands. (2022) A VIPER in the Sand. https://www.nasa.gov/glenn/image-feature/2022/latest-VIPER-prototype-navigates-lunar-surface-of-SLOPE [2] VIPER: The Rover and Its Onboard Toolkit. https://www.nasa.gov/viper/rover [3] H.A. Oravec et al., (2010) *JTM, V 47, I 6,* 361-377. [4] P.C. Leger et al. (2005) *IEEE ICSM, 2,* 1815-1822.