Assessing Impact of Joint Actuator Failure on Lunar Rover Mobility

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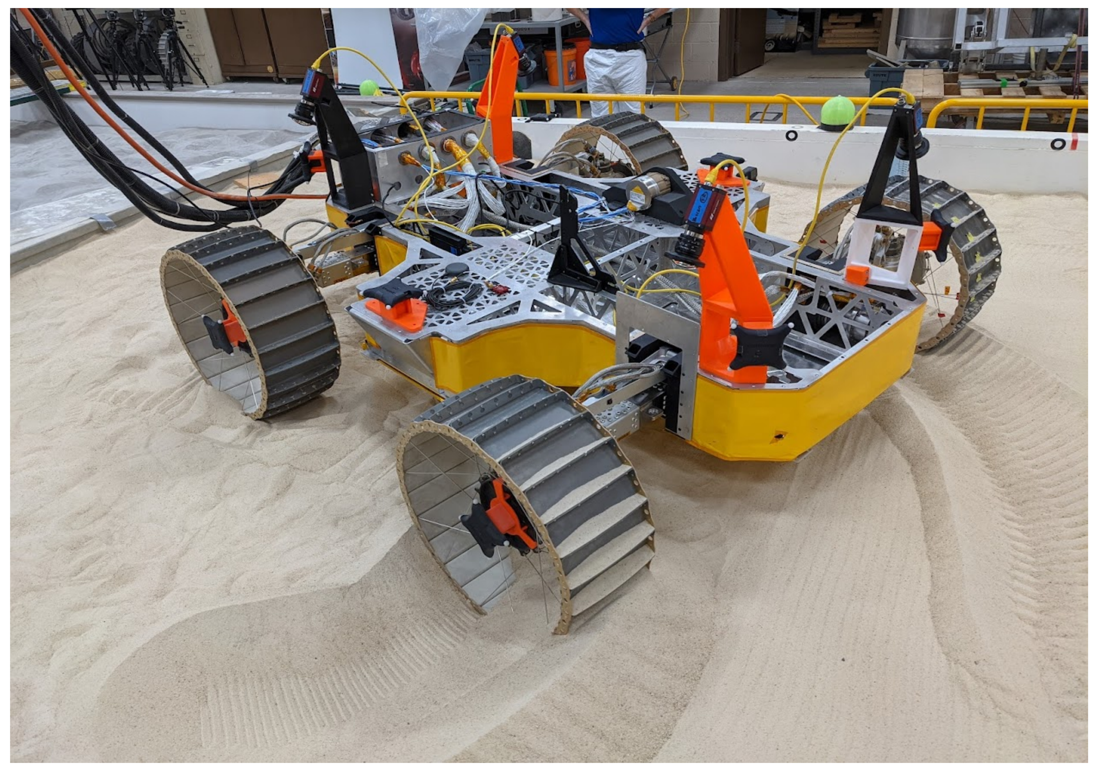
Background



VIPER rover mobility prototype MGRU3

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 Explora-tion 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 [1]. Impact varies greatly by both the affected joint and its failure state, and that in some cases modfication of driving strategy may be able to par-tially mitigate mobility impact.

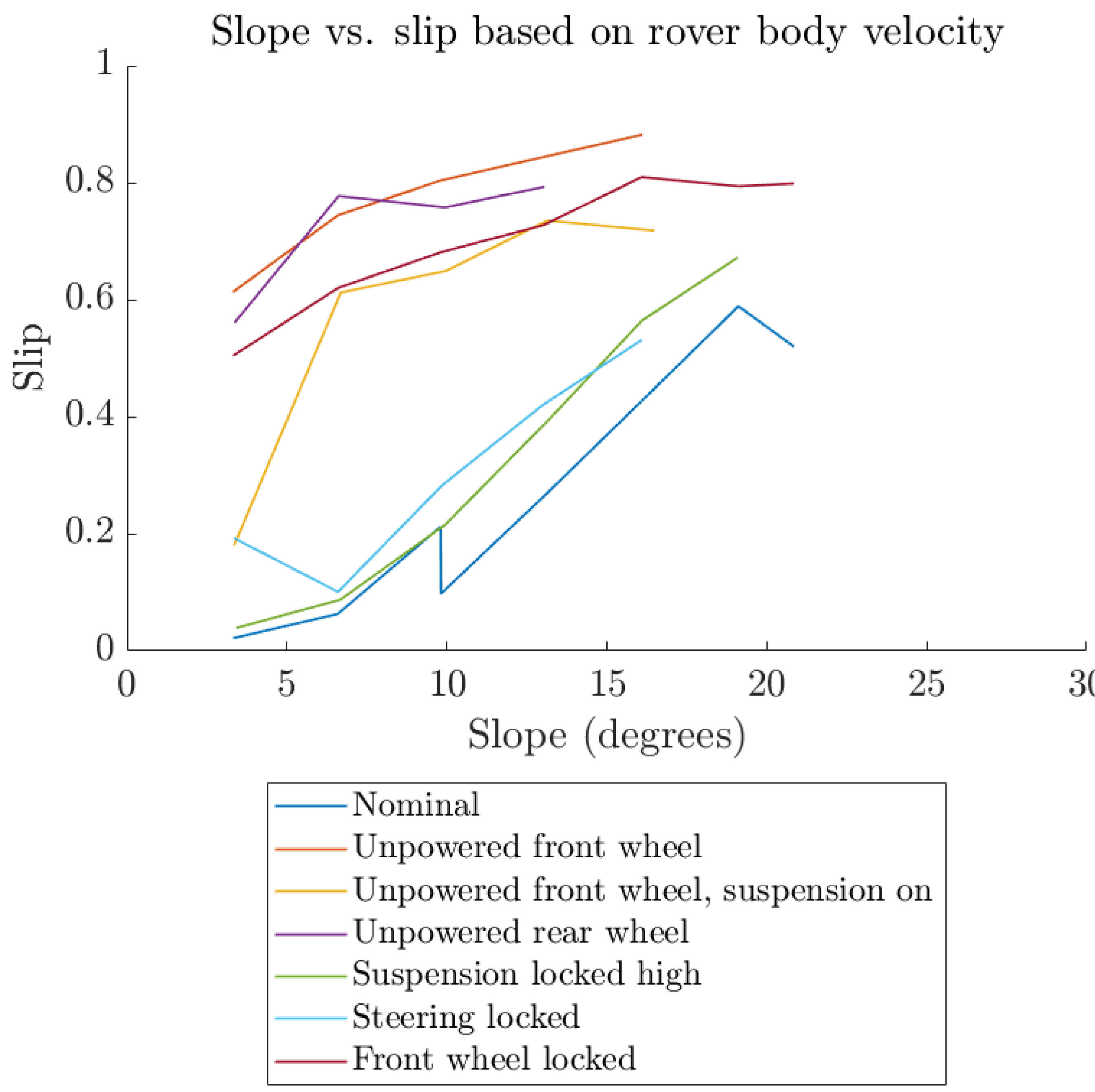
Methods

All tests were conducted in GRC-1 lunar simulant [2] on the Moon Gravitation Representative Unit 3 (MGRU3), a VIPER engineering model. MGRU3 has flight software, motors, gearboxes, and joints, with a lighter mass of 844 N to better simulate lunar mobility. MGRU3 has a wheelbase of approximately 1m x 1m, with wheel width and radii of .1m and .2m, respectively. Each wheel has an in-hub drive motor, a steering motor, and a suspension motor which can raise and lower the wheel via a linkage. The suspension can be set to fixed positions or balance loads on the wheels.

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.

Results

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 [3], 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.



Discussion

Loss of power to a drive motor was associated with a 200% increase in slip on slopes of 15 degrees, and a 25 x increase on shallow inclines of 3 degrees. Use of the suspension to balance forces on the wheels reduced slip on the 3 degree slope to 0.2 from 0.6 but had a more moderate impact on steeper slopes.

Locking a single suspension joint into a raised position only increased slip by 0-50%, with minimal impact on low angles. However, the tethered rig may be less representative of the actual impact here, as in free driving tests the rover rocked between opposite wheels. Locking a steering joint had similar impact on tractive ability, but with the rover unable to maintain a straight heading.

If a limit of 50% maximum slip is set as a limit for safe operation, VIPER can safely ascend slopes of 18 degrees with nominal performance and 16 degrees with a disabled suspension or steering actuator. With this limit, VIPER cannot safely drive with uncompensated loss of a drive actuator, but may be able to maintain some mobility on flat ground with proper control of the suspension.

Future Work

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] VIPER: The Rover and Its Onboard Toolkit. https://www.nasa.gov/viper/rover [2] H.A. Oravec et al., (2010) JTM, V 47,I 6, 361-377. [3] P.C. Leger et al. (2005) IEEE ICSM, 2, 1815-1822.

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