Assessing Impact of Joint Actuator Failure on Lunar Rover Mobility

Catherine A. Pavlov, Arno Rogg, and Aaron M. Johnson

Motivation

NASA's Volatiles Investigating Polar Exploration Rover (VIPER) is a four-wheeled rover with fully actuated propulsion, steering and suspension joints [1]. The mobility performance cost of a joint failure is high. Actuator loss can be simulated to determine mobility impacts in advance and develop mitigation strategies.

VIPER prototype MGRU3 in GRC-1 at NASA Glenn Simulated Lunar Operations (SLOPE) Lab

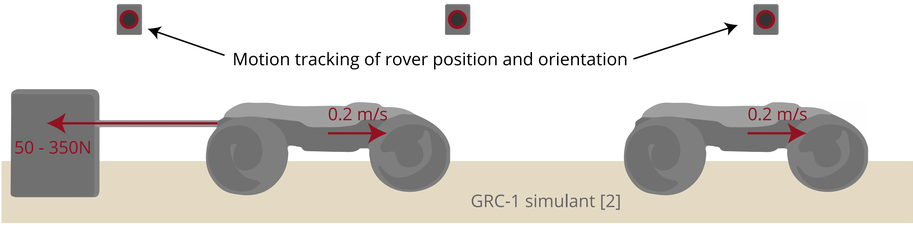
Methods

Simulated joint failure tests were conducted on the Moon Gravitation Representative Unit 3 (MGRU3), a VIPER model with the following features:

- Flight software, motors, gearboxes, and joints
- Lower mass to simulate lunar equivalent weight
- Each wheel has an in-hub drive motor, a steering motor, and a suspension motor for a total of 12 motors
- Suspension can do position control or force control

Each motor can potentially fail in a "locked" (fixed orientation) state, as in the case of a rock jam, or "unpowered" state, such as in a power loss or actuator damage event [3].

Drawbar Pull and Free Driving tests were conducted at the NASA Glenn Simulated Lunar Operations (SLOPE) Lab for multiple failure modes.



Tethered Drawbar Pull Tests | Free Driving Tests

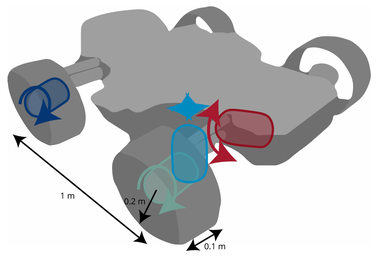
Results

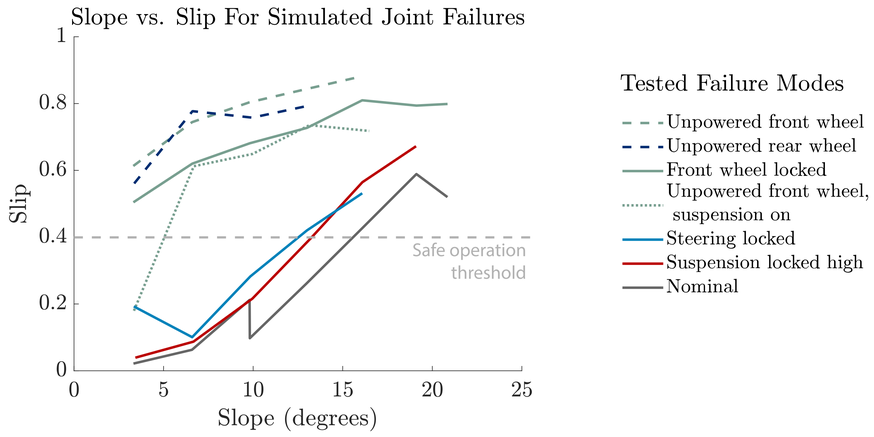
Loss of a rear or front drive motor was associated with a 200% increase in slip on slopes of 15 degrees, and a 25x increase on shallow inclines of 3 degrees. Use of the suspension to balance forces on the wheels reduced slip on the 3 degree slope to 0.2 from 0.6 but had a more moderate impact on steeper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

Locking a suspension joint into a raised position only increased slip by 0-50%, with minimal impact on low angles. In free driving tests the rover rocked between opposite wheels.

Locking a steering joint increased slip 25x on shallow inclines but only 0-50% increase on other slopes, but with the rover unable to maintain a straight heading.

VIPER's safe operation limit is 40% slip, based on optimal drawbar pull performance while minimizing sinkage [4]. With this limit, **VIPER can safely ascend slopes of 16 degrees with nominal performance and 14 degrees with a disabled suspension or steering actuator. 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.





Discussion

Actuator loss could be mission-ending for a four-wheeled rover such as VIPER, and mitigation strategies should be developed.

Control of wheel speeds and steering angles and suspension positioning and loads can sometimes offset joint failure, as shown below on KREX-2, which is able to drive straight despite a wheel stuck at a 60° steering angle. Work on automatic generation of driving strategies for actuator failure compensation through terramechanics modeling is in progress.

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KREX-2 rover in the Atacama Desert

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] Townsend, J. et al., (2014). Mars exploration rovers 2004-2013: Evolving operational tactics driven by aging robotic systems. *SpaceOps*, 1–22. [4] E. Rezich et al. (2020). VIPER 2020 Single Wheel TREC Testing. *Internal NASA report.*

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