# Including the effect of gravity in wheel/terrain interaction models

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## Extended Abstract

Predicting the motion of wheeled robots in unstructured environments is one of the most challenging applications of multibody system dynamics. In order to correctly predict the outcome of manoeuvres with wheeled robots on soft terrain, a realistic model of this interaction is required.
As part of continuum-based models, finite element method is computationally expensive and not suitable for fast and real-time simulations. This has led to the search for computationally efficient approaches, such as semi-empirical terramechanics relations and elastoplasticity-based formulations [1]. These methods appropriately capture slip-sinkage behaviour and multi-pass effect, provided that an accurate characterization of the terrain is available.

The study of extraterrestrial exploration rovers on soft terrain requires to consider the effect of changes in gravitational acceleration on the forces and torques developed at the wheel/terrain interface. As shown experimentally in [2], gravity affects the terrain reaction forces, which cannot be correctly captured in simulation just by reducing the load that each wheel is bearing. In reduced gravity environments, where soil particles experience smaller confining stress, shear resistance reduces. This leads to increased soil flow and smaller traction force. Experimental results with a single wheel on sandy terrain showed that reducing the wheel load under earth gravity overestimates the travel distance and predicts less sinkage than is actually observed in reduced-gravity measurements [2]. Accordingly, wheel/terrain interaction models that do not account for this factor will overestimate rover performance.

In their original form, terramechanics relations and most elastoplasticity-based algorithms do not provide any way to model the terrain response under different gravity levels, other than tuning the terrain parameters. In particle-based models, however, gravity directly affects the dynamics of each particle and, therefore, pressure-sinkage curves under partial gravity can be obtained using the discrete element method. Given the computational intensity of particle-based models, this research instead incorporates the effect of gravity in an elastoplastic, velocity-field-based model of the wheel/terrain interaction that can be used in the efficient simulation of planetary exploration rovers. Gravity changes can be reflected in both the velocity field and the parameters of the elastoplastic model, such as the hardening curve. Figure 1 shows the stress distributions obtained for two soils with different hardening profiles.

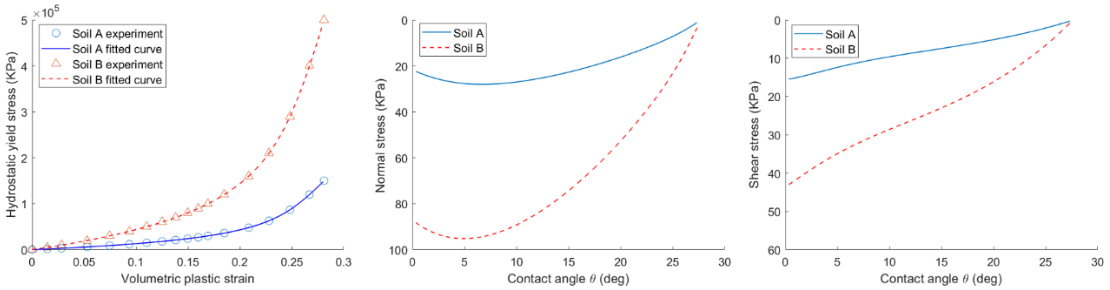

Figure 1: *Wheel/terrain simulation results using elastoplastic, velocity-field-based model*

These observations have laid the groundwork for understanding the soil behaviour in environments subjected to lower gravity from test data. To this end, an instrumented single-wheel testbed has been developed. In addition, a high-speed camera records the motion of soil particles under the wheel and Soil Optical Flow Technique (SOFT) [3] is used for visualizing and analyzing wheel interaction with granular terrain. This technique enhances the dataset and makes it ideal for developing velocity-field-based models. Several gravity levels will be generated by placing the test bed in an aircraft and performing 30 parabolic motions. The results will be used to capture and formulate the effect of gravitational force on terrain reactions and overall wheel performance.

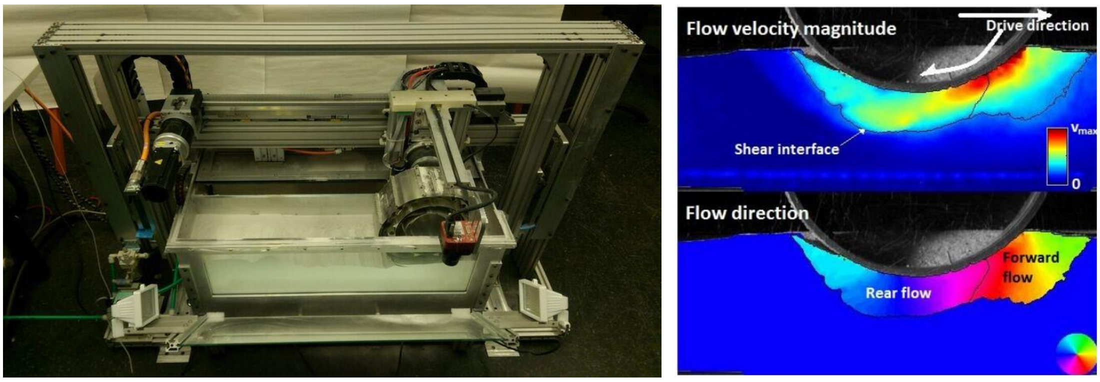

*Figure 2: Instrumented single-wheel testbed (left) and example SOFT analysis (right)*

## References


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