SIMULATING MARS EXPLORATION ROVER OPPORTUNITY DRIVES USING ARTEMIS

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Introduction: Opportunity has been traversing the Meridiani plains since January 2004 and after reaching Matijevic Hill at the inboard edge of Cape York on the rim of Endeavour Crater on October 18, 2012 has traveled over 35.1 km (based on wheel odometry). We have developed realistic simulations of rover-terrain interactions during traverses to help engineers define safe and efficient paths to way points, in addition to using the rover as a virtual instrument to retrieve terrain properties from images and engineering data collected during traverses. To that end we have developed a software package called Artemis (Adams-based Rover Terramechanics and Mobility Interaction Simulator) using validated mechanical models for the rovers and realistic topography, soil properties, and bedrock exposures. This abstract summarizes simulations of Opportunity's drives using Artemis, including the high sinkage and slippage encountered in Meridiani Planum while ripple crossing on Sol 2143, and high motor currents encountered while driving on a tilted bedrock surface on Sols 2808.

Artemis summary: Artemis contains multiple components: a rover mechanical model, a wheel-terrain interaction model, and terrain, bedrock, and soil models. Opportunity is a 6-wheel drive, 4-wheel steered vehicle with a rocker-bogie suspension system. A 200-element Adams mechanical model of the Opportunity rover is implemented in Artemis. Artemis employs a classical Coulomb friction contact model for wheel-bedrock interactions and a terramechanics-based model for wheel-soil interactions. The code calculates forces, stresses, and torques generated at the wheel-bedrock/soil interaction and transfer them to Adams/Solver. Terrain surfaces are modeled using digital elevation models derived from Opportunity's stereo Navcam and Pancam. Multiple soil regions and multi-pass effect are also implemented in Artemis. A wheel-terrain contact module is used to detect wheel-terrain contacts, including the entry/exit angles and sinkages for deformable soils, and contact points for bedrock. To replicate drive commands sent to Opportunity on Mars, a rover motion control module was developed in order to simulate Opportunity's blind and autonomous navigation drive modes.

Artemis has been validated through single-wheel laboratory-based tests and the Opportunity testbed rover field tests on dunes in the Mojave Desert. More details about Artemis and validation approaches can be found in [1].

Modeling High Slip Event on Sol 2143: Crossing large ripples has dominated high slippage and wheel sinkage events while traversing across the Meridiani plains. On Sol 2143 Opportunity was commanded to traverse a ~5 m wide, ~0.4 m high wind-blown sand ripple. A 59% 3D slip was recorded in the telemetry during the traverse. Artemis was applied to simulate this high slip event using terrain profile based on the derived topography from stereo image coverage and soil properties initially inferred from the morphology of the ripple and wheel track patterns [2]. As shown in Fig. 1, the terrains at the beginning and end of the ripple crossing consist of a mix of bedrock and a thin soil cover, whereas most of the ripple is dominated by deformable soil. Therefore, we modeled the soil properties in three categories using an iterative approach in which surface properties were adjusted to match flight data. Telemetry 3D slip and rover pitch angle, as well as wheel sinkage were compared with simulated results (Fig. 2-4). Telemetry slippage was estimated from the autonav data that showed true locations relative to wheel turn-based estimates for each of the 13 commanded visodom updates during the traverse. Wheel sinkage was estimated using digital elevation maps of wheel tracks generated from Navcam stereo images taken after the crossing. The comparisons in Fig. 2-4 provide a validation of the simulation's predictive capability for analysis of similar ripple crossings later in Opportunity's mission.

Modeling Stick-Slip Bedrock Drive on Sol 2808: Greeley Winter Haven, Opportunity's latest winter site, is an impact breccia outcrop with an irregular surface and a tilt ~15°. On Sol 2808, Opportunity was commanded to drive forward and then turn-in-place using visodom on this tilted outcrop. Limits were set on wheel drive actuator currents to ensure a safe set of motions on this irregular surface. In fact, the drive stopped during a turn-in-place. The increase in the right front wheel actuator current caused the drive to automatically stop because a current threshold was reached. To better understand the underlying cause of this anomaly, an Artemis bedrock model was used to simulate the drive segments (Fig. 5). The simulation showed that the high currents on the right front wheel can be explained as a consequence of having more weight on that wheel (it was the downhill wheel), and a stick-slip wheel-rock interaction on the irregular outcrop. The other wheels could not provide sufficient traction to move the vehicle. Because of its higher load, the right front wheel attempted to draw a higher current to achieve its commanded angular velocity, but reached the current limit (represented as an increased torque in Artemis Fig. 6). Based on the results of the simulation, the rover planners were able to confidently plan a rearward drive to place the vehicle in a better solar position for the winter.

Future Work: Artemis is used on a continuing basis in a predictive manner to evaluate mobility issues over candidate Opportunity drives. We also expect Artemis to be used to retrieve Martian terrain properties by comparison of model and actual drive results.

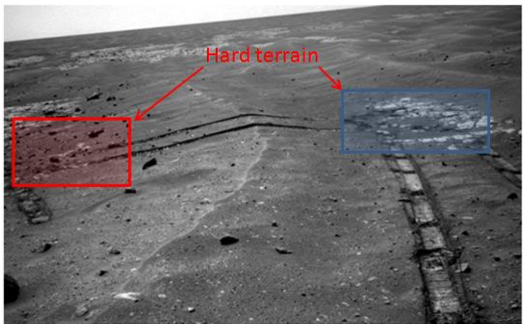

Fig. 1 – Navcam images acquired after the ripple crossing on Sol 2143. Red and blue rectangles represent the hard terrain at the beginning and ending part of the ripple crossing drive, respectively.

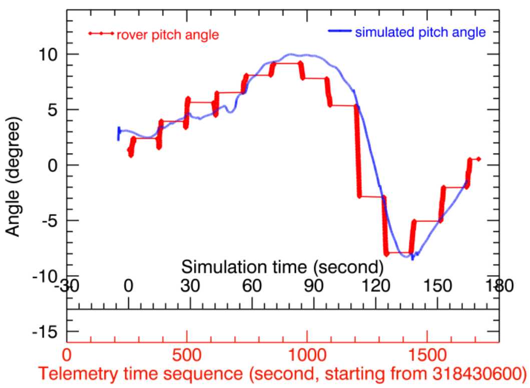

Fig. 2 – Simulated and observed Opportunity's pitch angles on Sol 2143.

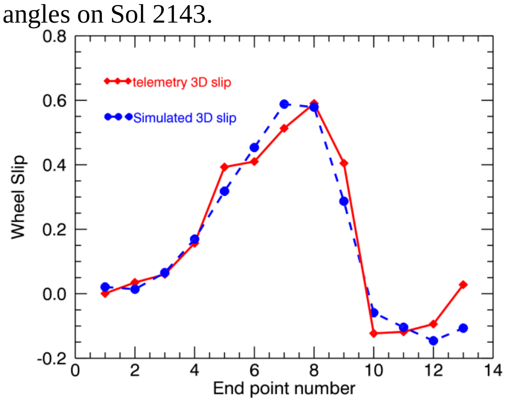

Fig. 3 – Telemetry-based 3D and simulated slips on Sol 2143.

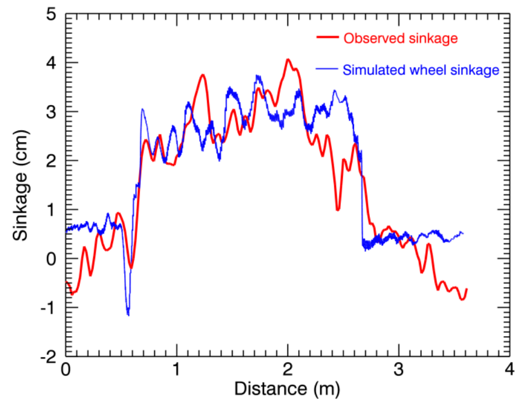

Fig. 4 – Simulated and observed Opportunity wheel sinkages on Sol 2143.

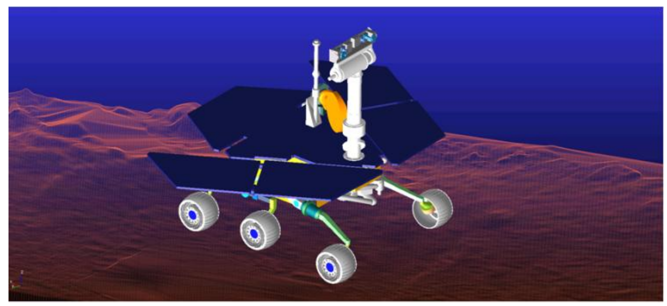

Fig. 5 –Opportunity is tilted approximately 15 degrees on simulated bedrock outcrop.

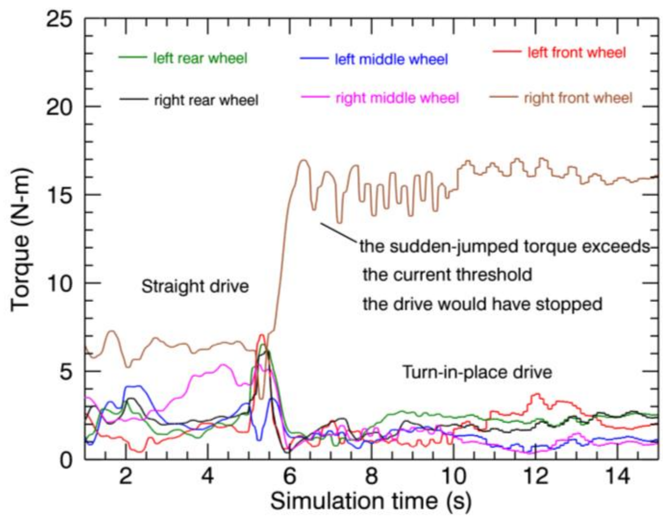

Fig. 6 – Simulated torques for each wheel on Sol 2808 (wheel-drive-actuator current anomaly).

References: [1] Zhou, F. et al. (2012), J. Field Robotics, submitted. [2] Arvidson, R. et al. (2011), J. Geophysical Research.