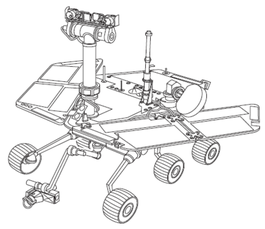
Mars Exploration Rover Opportunity Terramechanics Across Ripple-covered Bedrock in Meridiani Planum



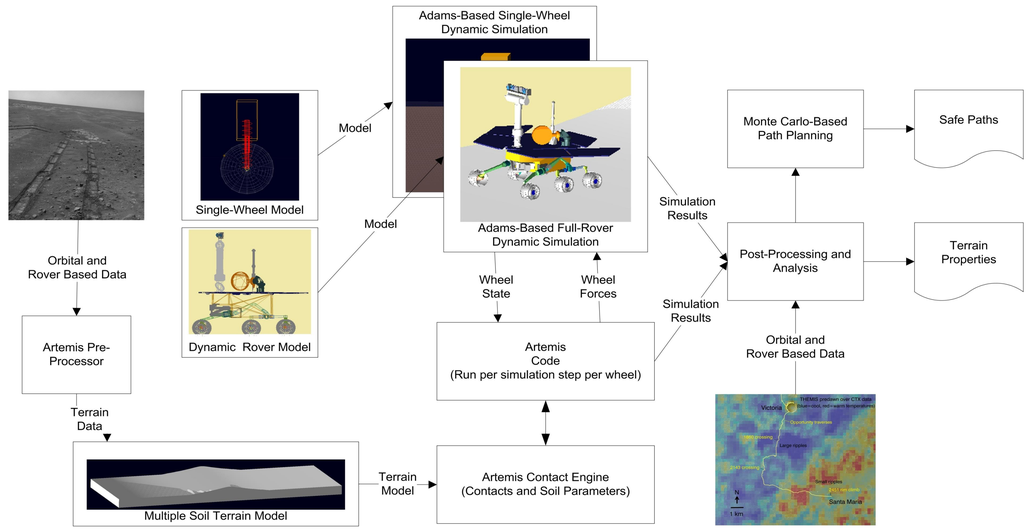
R. E. Arvidson[1], L. van Dyke[1], K. Bennett[1], F. Zhou[1], K. Iagnemma[2], C. Senatore[2], R. Lindemann[3], B. Trease[3], S. Maxwell[3], P. Bellutta[3], A. Stroupe[3], F. Hartman[3], V. Verma[3], A. Shaw[1]

[1]Earth and Planetary Sciences, Washington University in Saint Louis, Saint Louis, MO (arvidson@wunder.wustl.edu), [2]MIT, Cambridge, MA [3]JPL/Caltech, Pasadena, CA

Objectives and Approach

•Develop ARTEMIS, a multi-element dynamic model of Opportunity rover interacting with realistic terrain elements
•Include digital elevation models from orbital and rover-based data
•Include spatially variable deformable soils and bedrock
•Test with single wheel model and experiments
•Test with “Mars Yard” engineering rover drives
•Reproduce selected Opportunity drives
•Use validated model for path planning when Opportunity has to cross soil-covered slopes to get to Endeavour’s rim

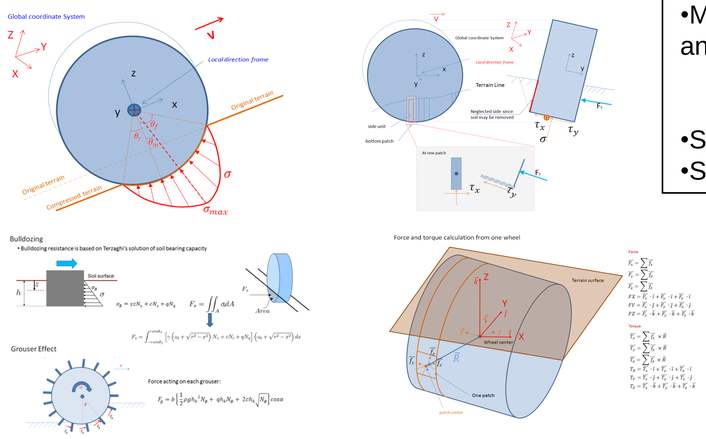
Modeling and Analysis Overview



Summary and Future Work

•Artemis has been developed and is being tested with lab and flight data
•Able to model ripple-crossing slippage and sinkage, along with downhill skid on soil covered slope, and uphill slippage on bedrock thinly covered by soil
•Conducting detailed testing and stream-lining code to be ready to model risky drives (high slippage and sinkage expected) associated with traversing soil-covered slopes (10 to 20° tilts) to get to Noachian outcrops on Endeavour’s rim (Cape York, Solander Point, and Cape Tribulation)

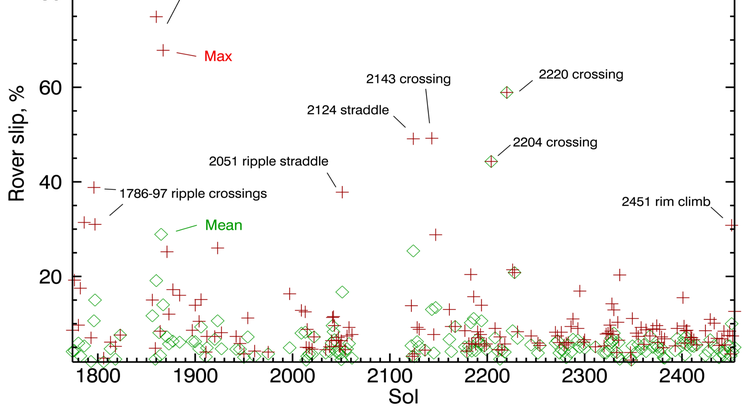
Model Wheel-Soil Interactions



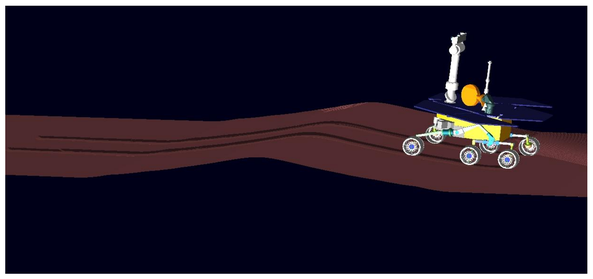
•Original rover model developed and tested by MER Project
•Wheel-soil interactions in our model include normal and shear stresses along both longitudinal and lateral directions, with wheel sinkage and slippage
•Employed classical Bekker-Wong relationships
• Our innovation is modeling the rover dynamical system and how that system responds to realistic terrain models

Opportunity Mobility Issues

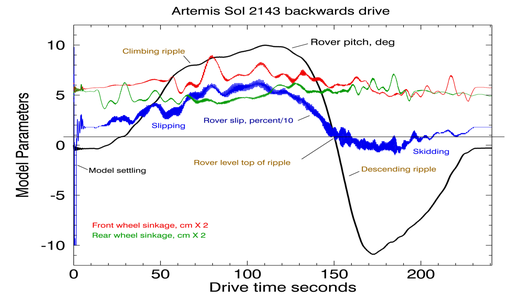
•Opportunity has successfully driven over 26 km across the plains of Meridiani
•Mobility issues have been associated with increased soil sinkage, compaction resistance, and slippage when:
  Driving over large ripples when all six wheels were climbing ripple flanks
  Driving up or down steep, soil-covered slopes (interiors of Endurance and Victorian craters)
•Significant slip encountered on uphill drives on bedrock (Santa Maria rim)
•Skidding has been observed on downhill drives



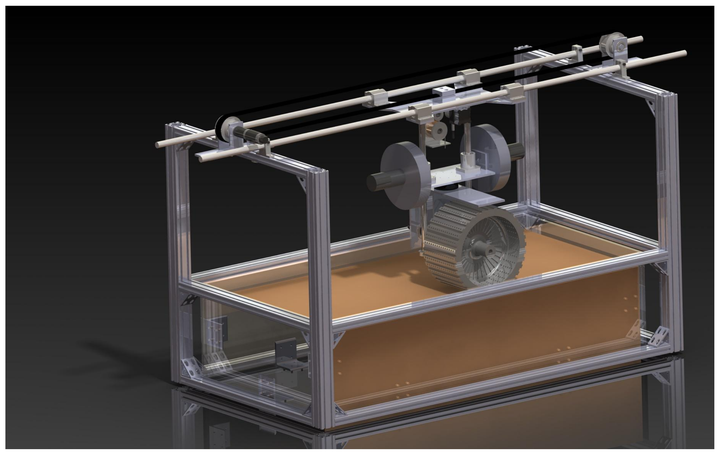
Example Model and Analysis

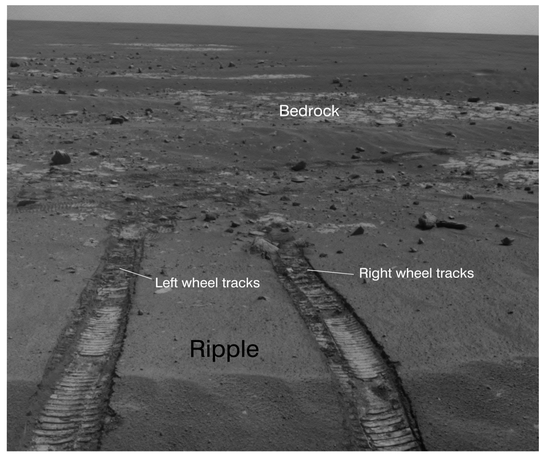


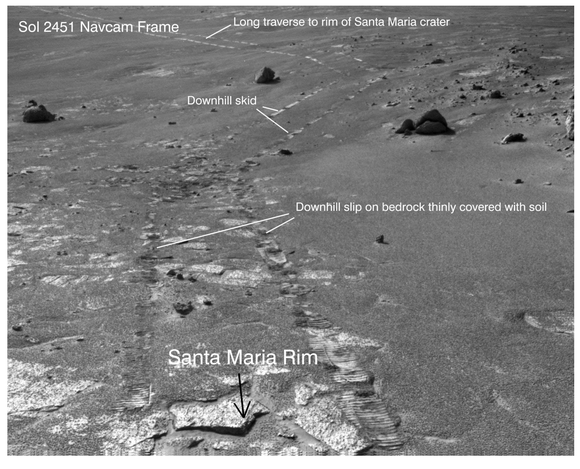
Sol 2143 ripple crossing simulation using Artemis in which Opportunity drive backwards



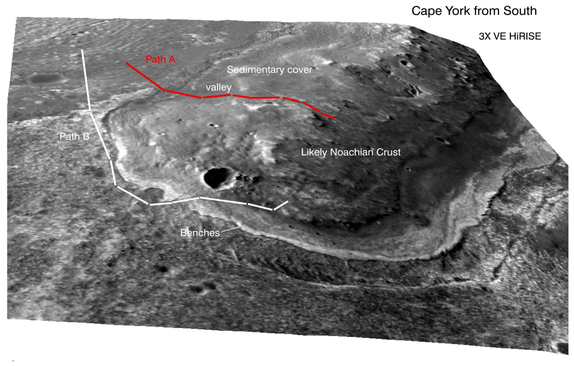
•Model telemetry reproduces flight patterns in rover pitch, sinkage, and slip, including increased sinkage and slippage for wheels on downhill side while climbing ripple.
•Soil parameters consistent with loosely consolidated, poorly sorted, dry silty sand.







How to get to Noachian crust on Endeavour’s rim?



HiRISE draped over DEM from stereo pairs

Left: Wheel-soil laboratory rig at MIT to be used to test single wheel model. Middle: Navcam view of tracks associated with the Sol 2143 ripple crossing drive. frames. Right: Tracks from the sol 2451 ascent to the rim of Santa Maria crater. Visual odometry indicates up to 58% slippage for the ripple crossing, and modest downhill skid and uphill slippage for the ascent to the Santa Maria rim.