National Aeronautics and Space Administration

NASA In-Situ Resource Utilization (ISRU) Pilot Excavator (IPEX) Digital Twin Autonomy Challenge for Universities

2024 Machine-Ground Interaction Consortium Meeting (MaGIC)

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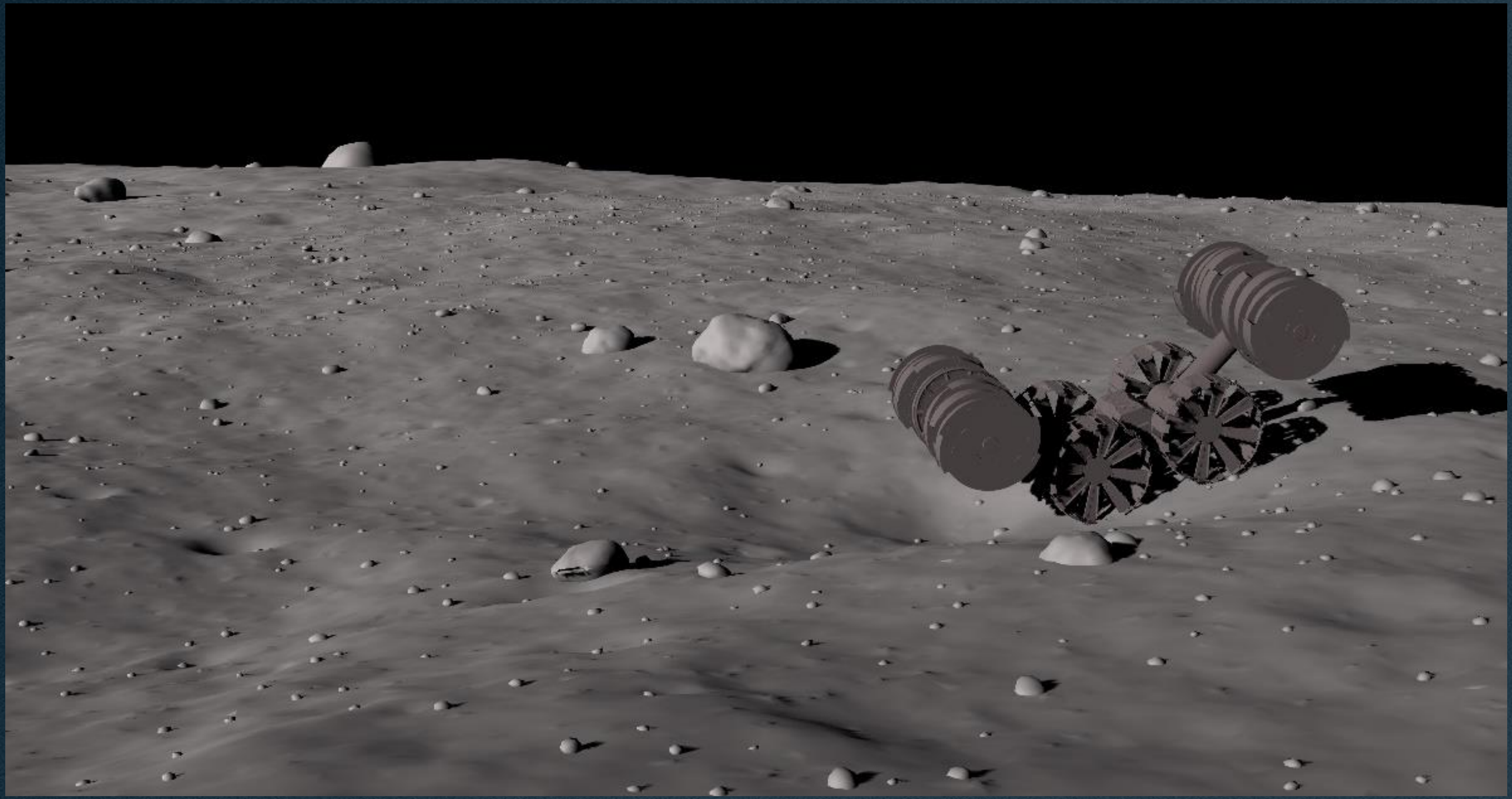
What is IPEx ?

Why do we need Digital Twin Simulations?



In Situ Resource Utilization (ISRU) Pilot Excavator (IPEx)

TRL 5 Dual Bucket Drum Excavator Prototype

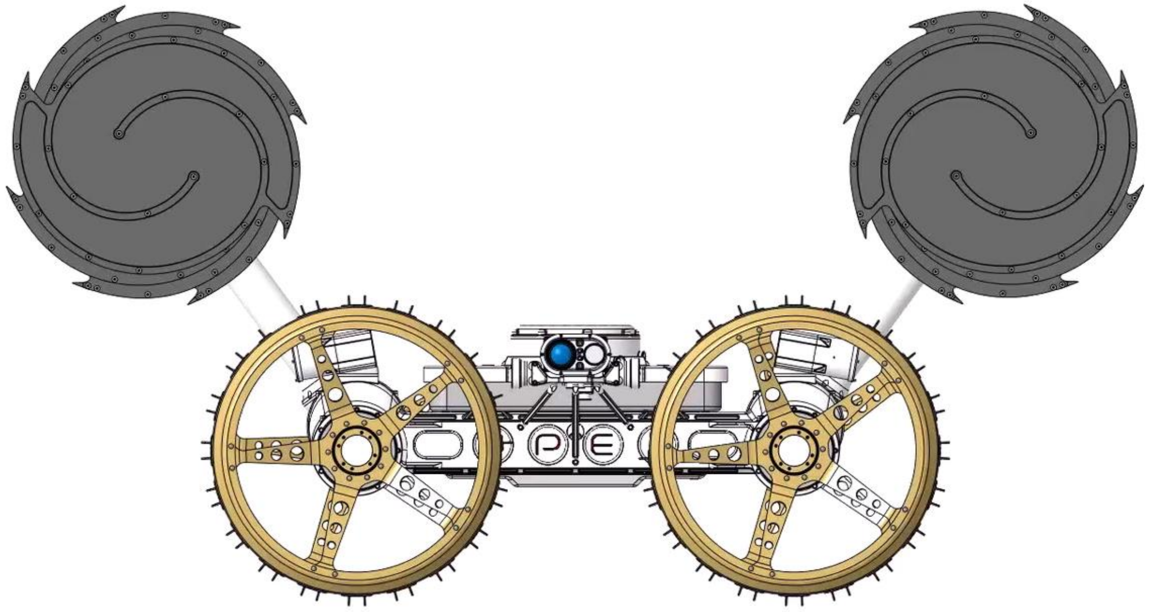
Quantitative Impact

- Traverse total of **70km** in Lunar environment (1.5x current SOA)
- Traffic over same terrain **350x** (70x current SOA)
- Move a total of **10t (metric tons)** of regolith **100 meters** over **11 days** (200x current SOA)

- Proof of Concept Results
  - Simulating the lunar regolith
  - Simulating IPEx
- Caterpillar inc. Collaboration
- University Competition
- Next Steps

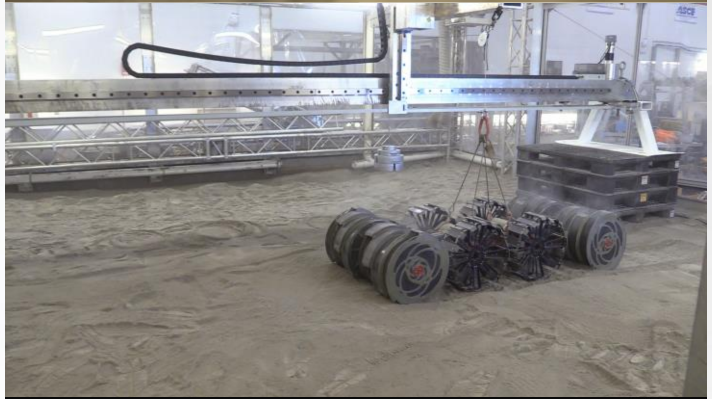
IPEx Project

- **I**SRU **P**ilot **Ex**cavator
- Game Changing Development (GCD) project under the Space Technology Mission Directorate (STMD)
- Design and build a TRL 6 robotic excavator ready for lunar demonstration
- Demonstrate capability to excavate, transport, and deliver 10 metric tons (ISRU Pilot Plant need) of lunar regolith during an 11-day mission.
- Enabling technologies:
  - Low gravity excavation system
  - Robust Lunar surface system reliability
  - Dust tolerant battery charging
  - Dust tolerant thermal control
  - Supervised autonomous operation
  - High-cycle mobility



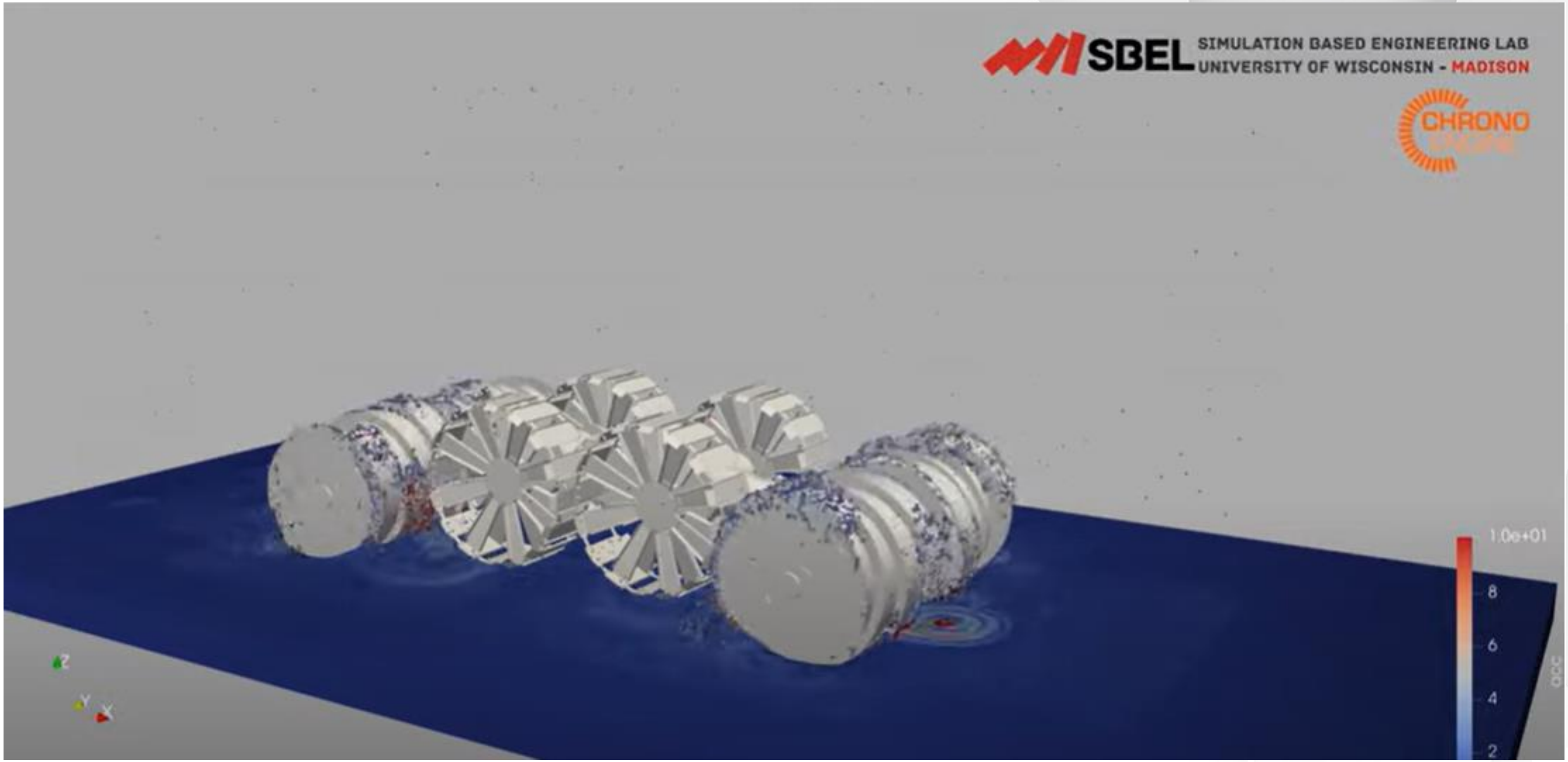
IPEx Project

- Need: Required testing of subsystem and system level interactions with regolith.
- Problem: Terrestrial testing challenges for a Lunar Excavator:
  - Effect of reduced gravity
    - Reduced gravity flights are suited to short and small experiments
  - Regolith conditions
    - Lack of geotechnical data from Lunar South Pole region and variability depending on landing site selection.
    - Numerous geotechnical configurations to test
    - Repeatability between tests is hard to achieve and labor intensive
- Solution: Simulations grounded in limited terrestrial tests
  - Regolith flow inside a bucket drum (DEM) validated by reduced gravity experiment.
  - Vehicle response to excavation in various regolith conditions
  - Ability to tune parameters within the autonomy stack
  - “Playbook” of mission scenarios

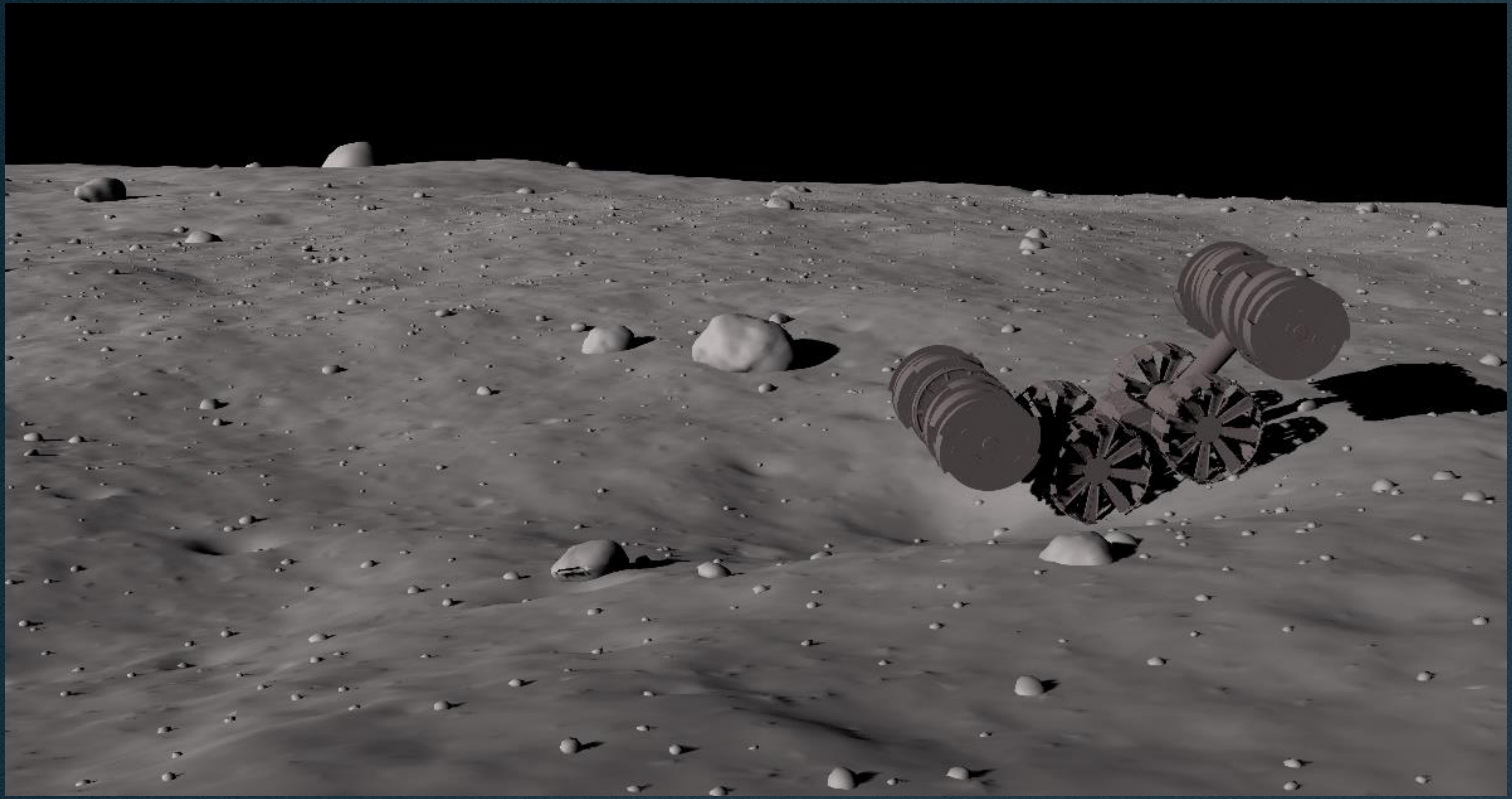


University of Wisconsin Simulation of RASSOR 2.0 in Chrono

https://www.youtube.com/watch?v=uuF-jHwcfcY

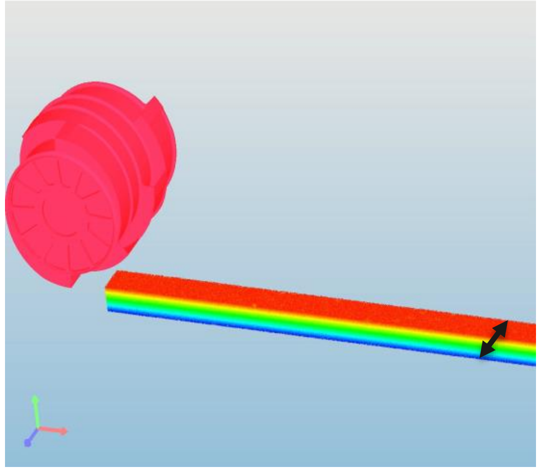


Proof of Concept Results – Lunar Regolith

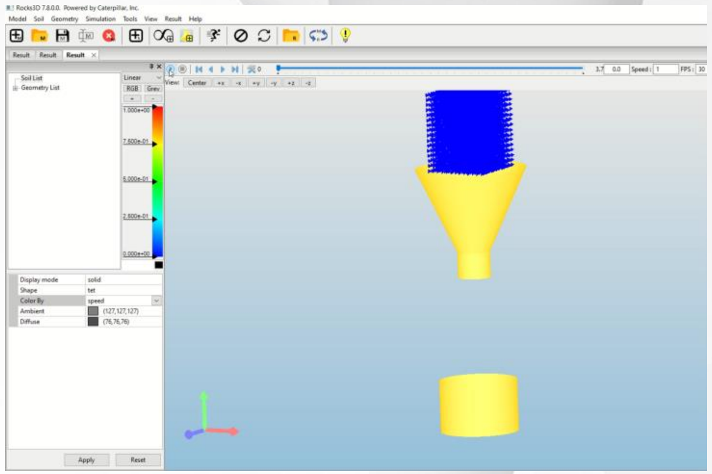


Calibration Approach

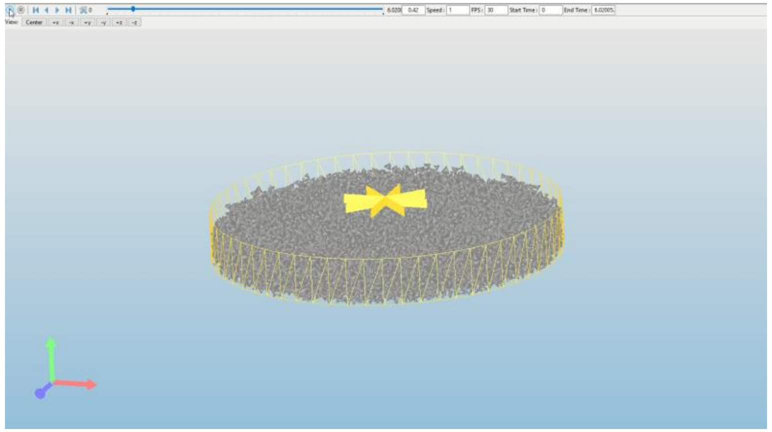
Grain Size $r\min = 1mm\,, \frac{rmax}{rmin} = 2.5$



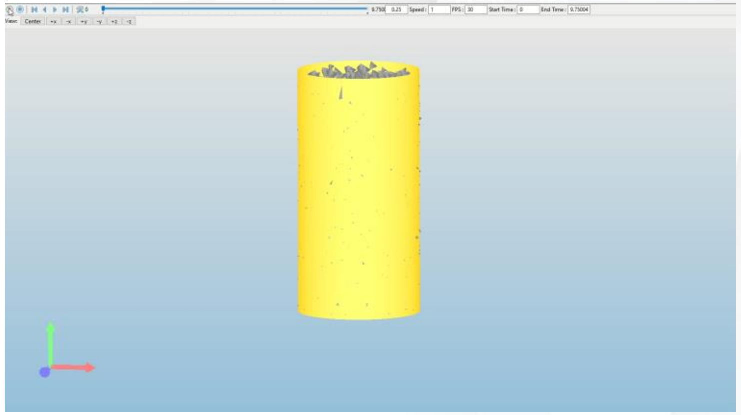
Angle of Repose - 0.9% error.



Pocket Vane-Shear



Triaxial Compression - 0.3% to 11.8% error at various densities



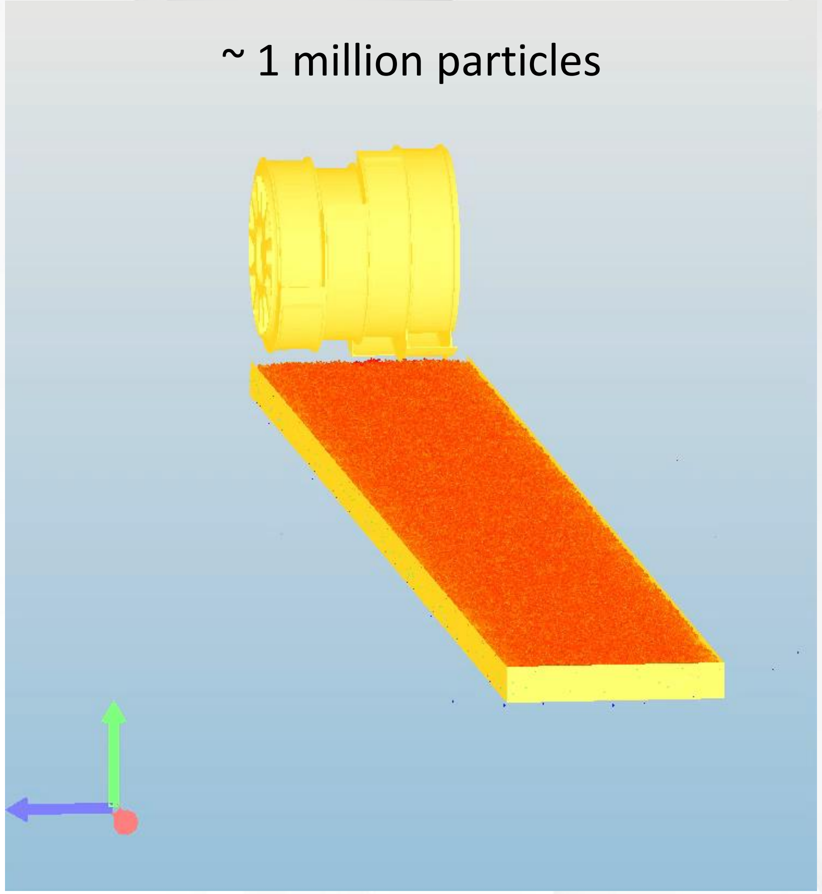
System Tests - Excavation

Single Bucket Drum

- Four sets of controlled experiments at two linear velocities (10 mm/s and 30 mm/s) and two cut depths (10 mm and 16 mm).
- Compare experimental force and torque results with DEM results.

Processor	Total Threads	Compute Time (mins) / Mission Simulation (secs)
3.00 GHz	48	12.5

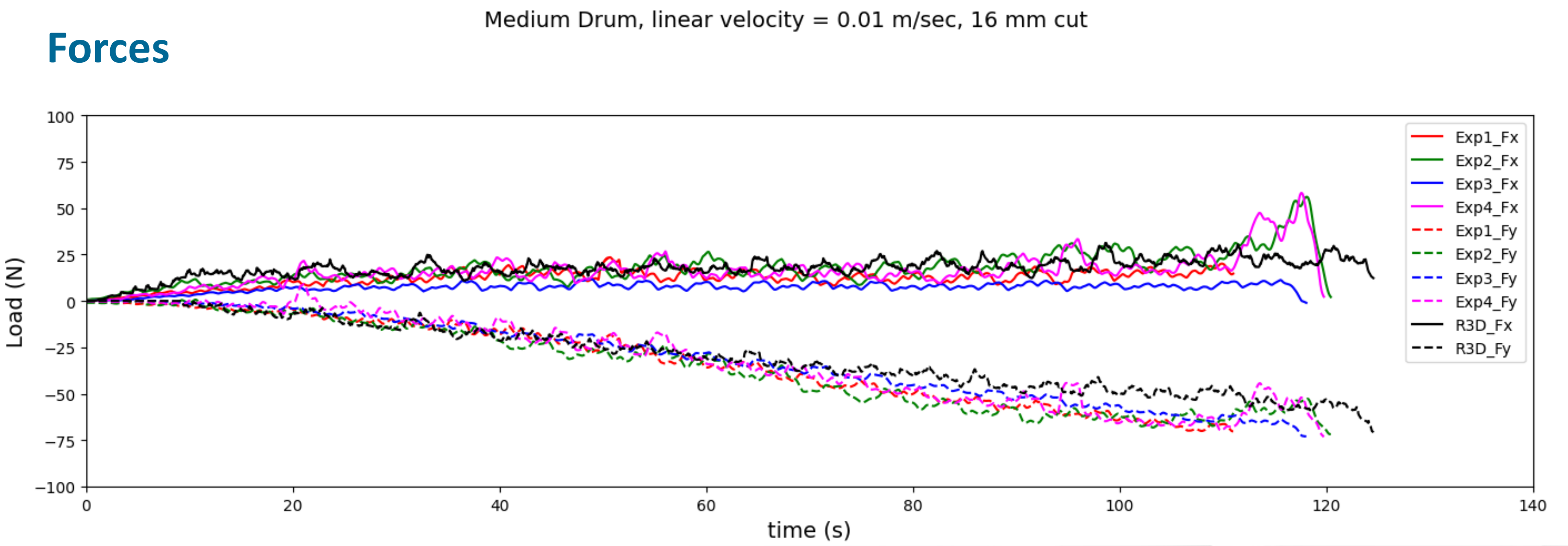
Schuler et al. (2022)



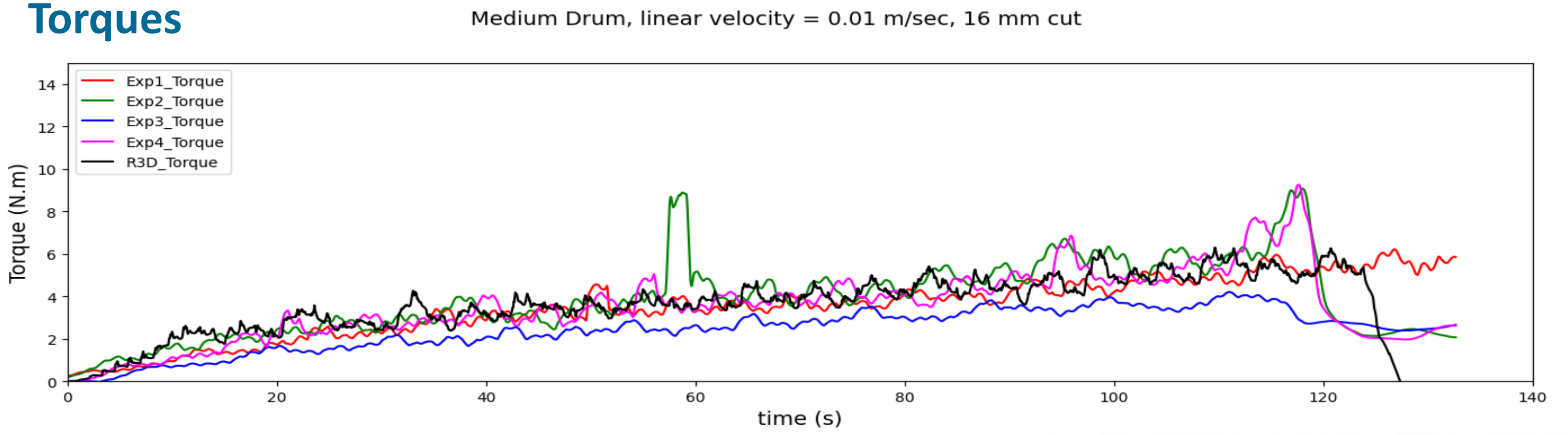
Bucket Drum Results

- **10 mm/s** velocity, **16 mm** cut depth.
- Simulation aligns within the scatter of physical test data

Forces



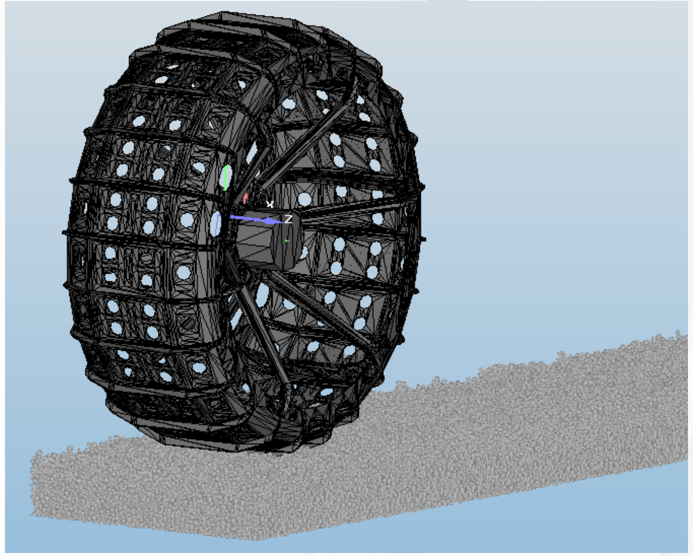
Torques



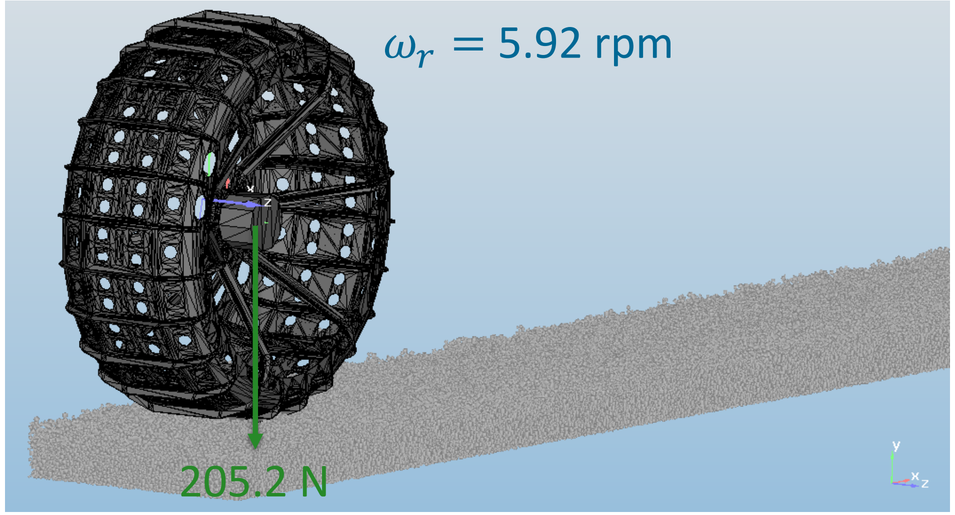
System Tests - Mobility

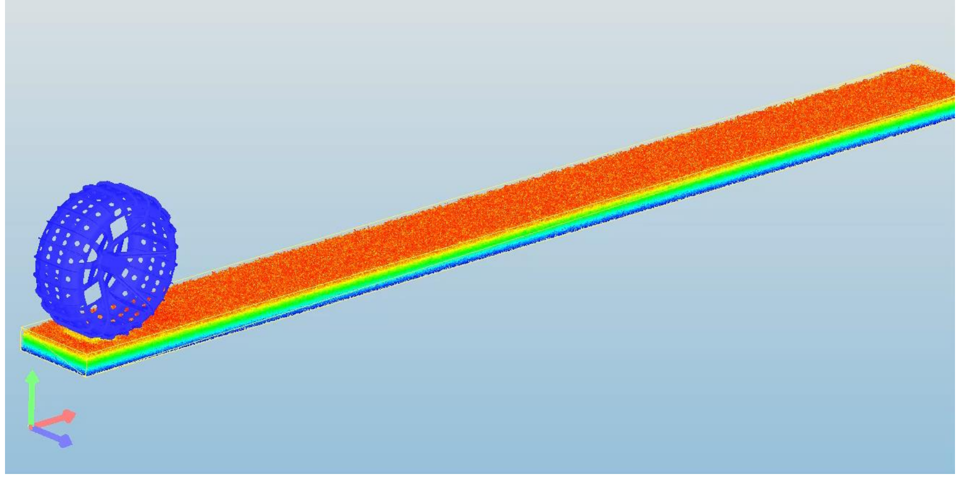
- Mobility / Drawbar
  - Experiment: weights were added incrementally to the sled as the robot is commanded to move at 0.1 m/s velocity. Pull force was measured using a single-axis load cell.
  - DEM: single tire model with a vertical load equal to ¼ of the total weight of the robot, and a variable horizontal load equal to ¼ of the experimental pull force.

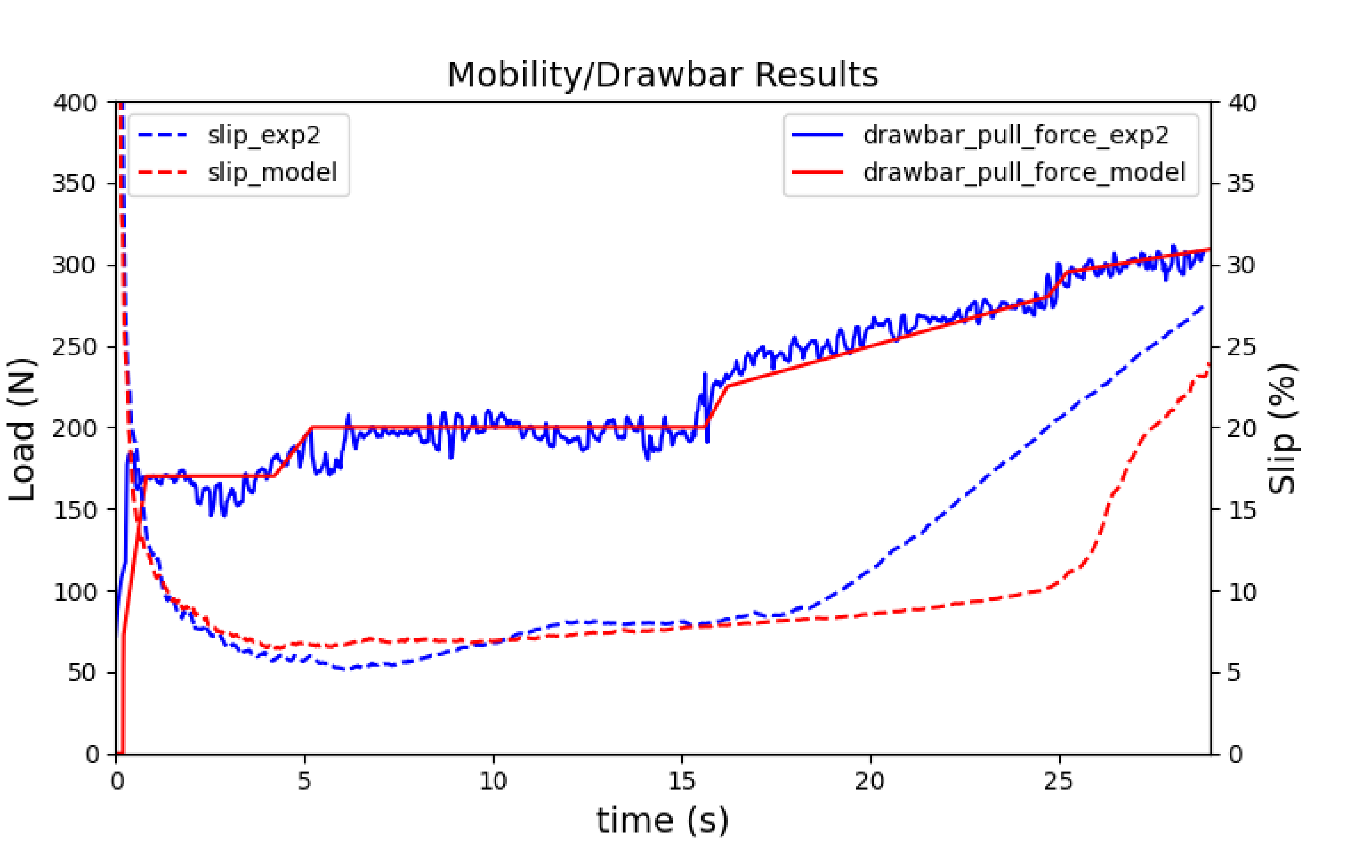
Provided by NASA (2023)



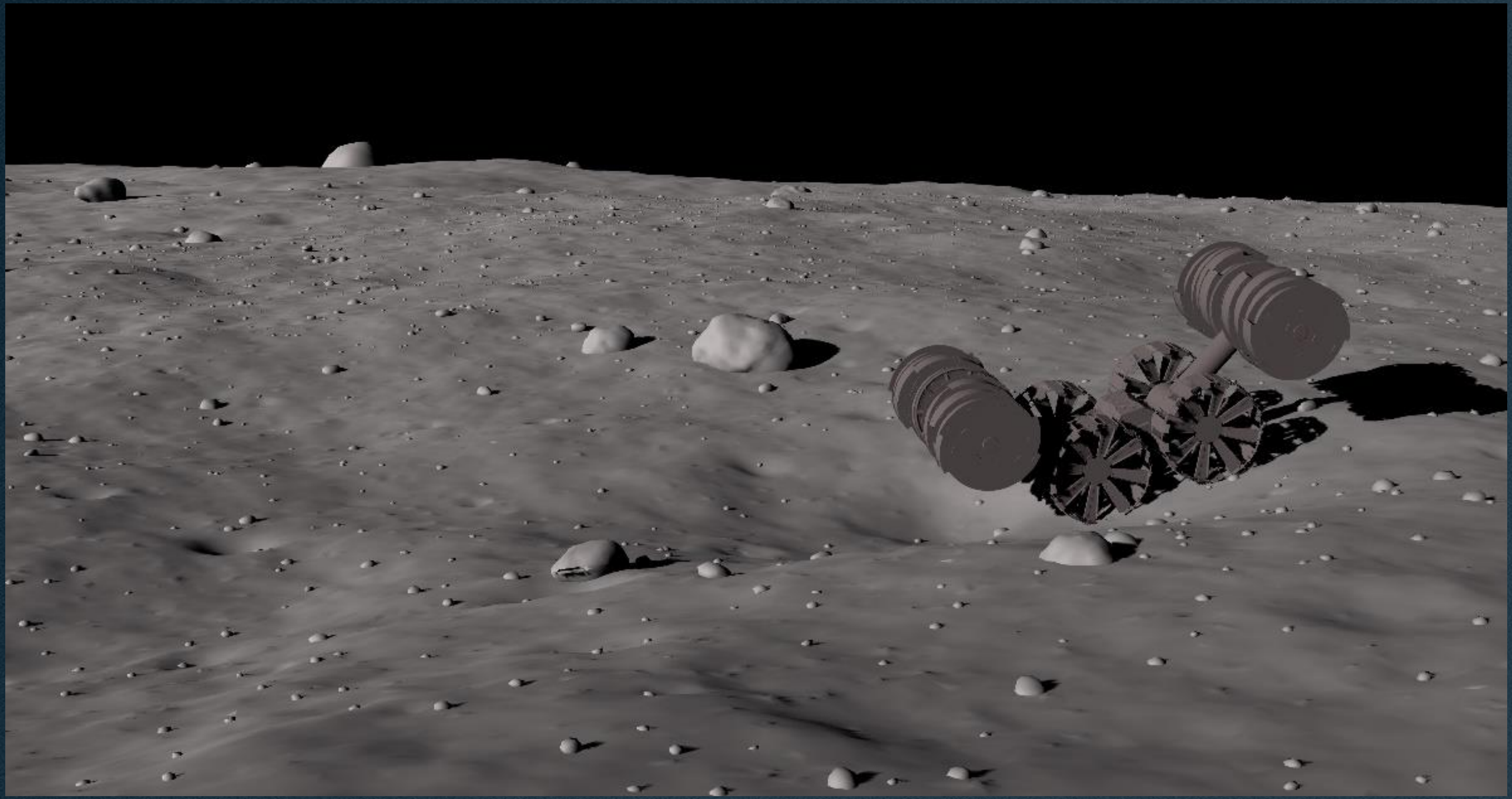
Mobility / Drawbar Results





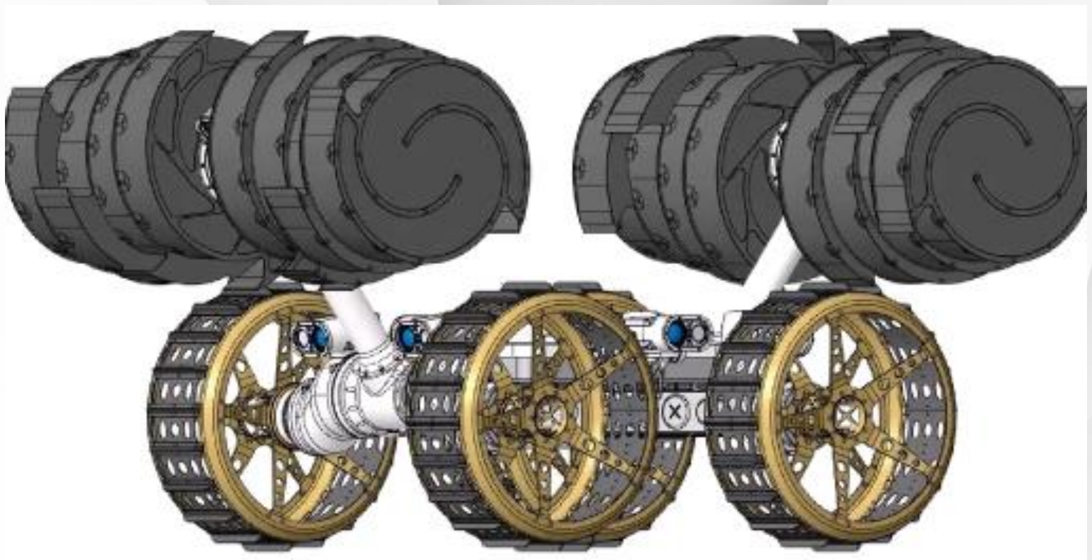


Proof of Concept Results – IPEx



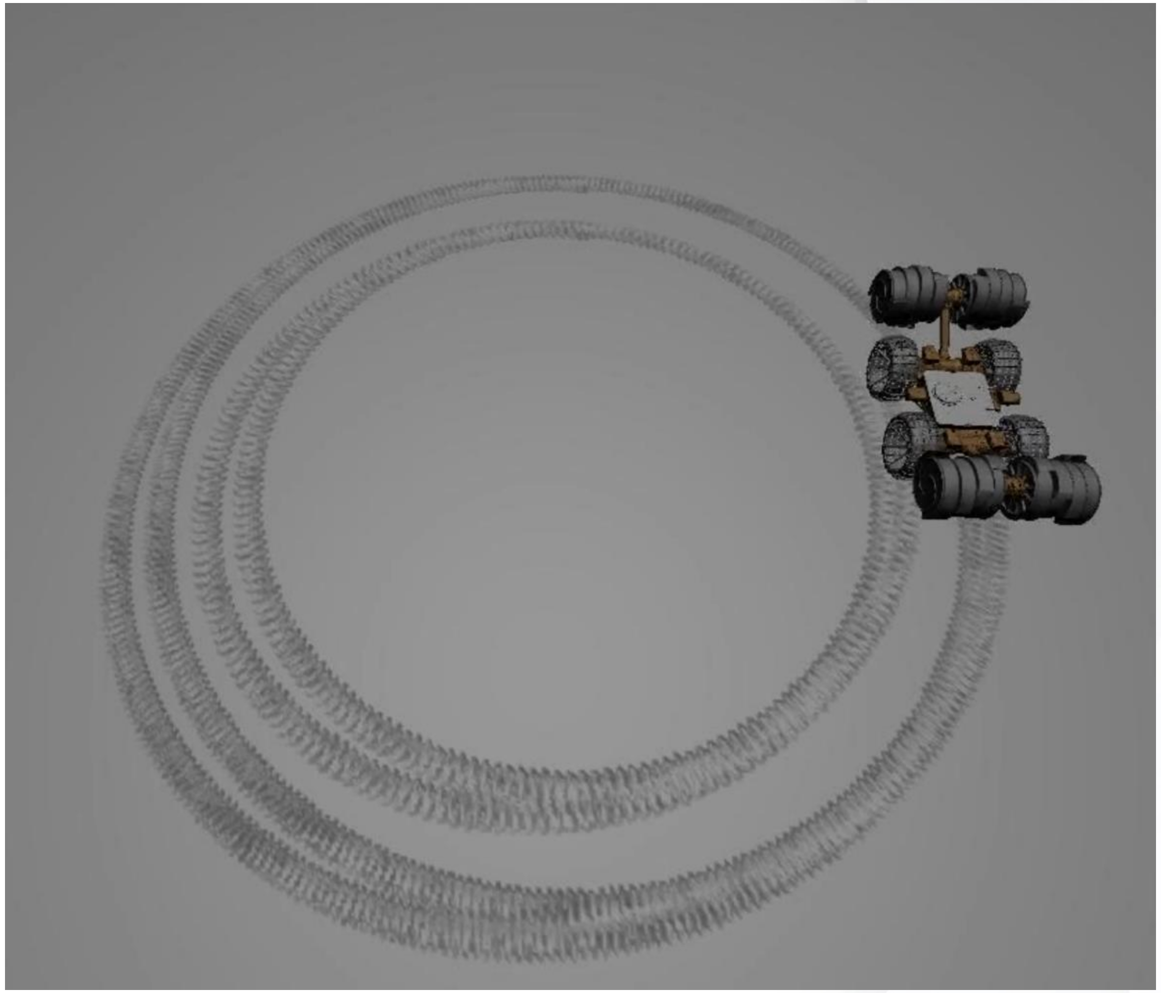
IPEx Physics - Chrono

- Generic component models for chassis, arms, drums, wheels, and radiator cover
  - mass, inertia, etc.
- Motor and Gear Train modeled with efficiency
- Battery State of Charge

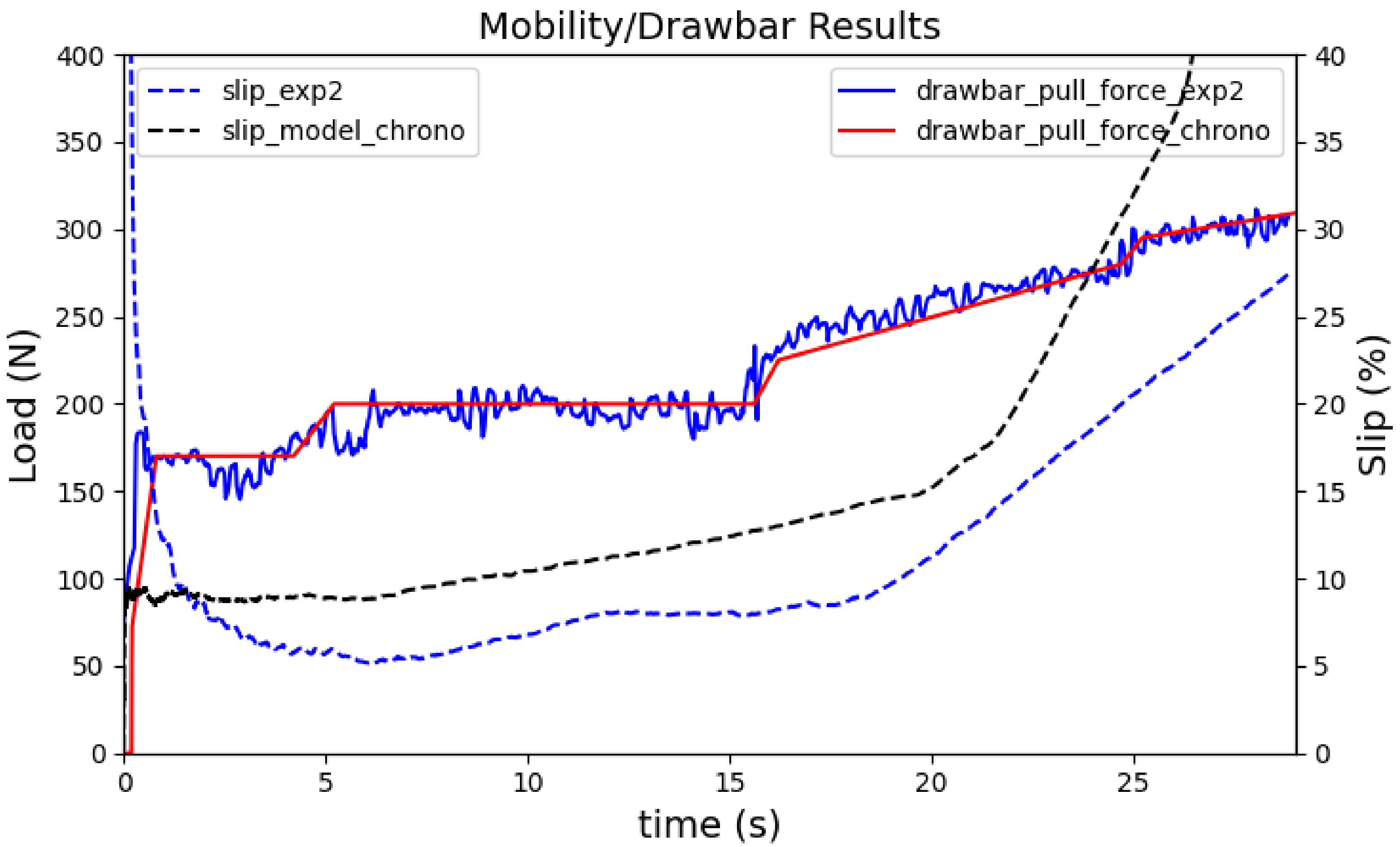


IPEx Modeling in Chrono: Terrain Model

- Utilizing Chrono SCM (Soil Contact Model) for ground deformation, with Bekker equations and soil properties from Lunar Sourcebook and other research
  - SCM supports bulldozing effect and realistic deformation, but not excavation

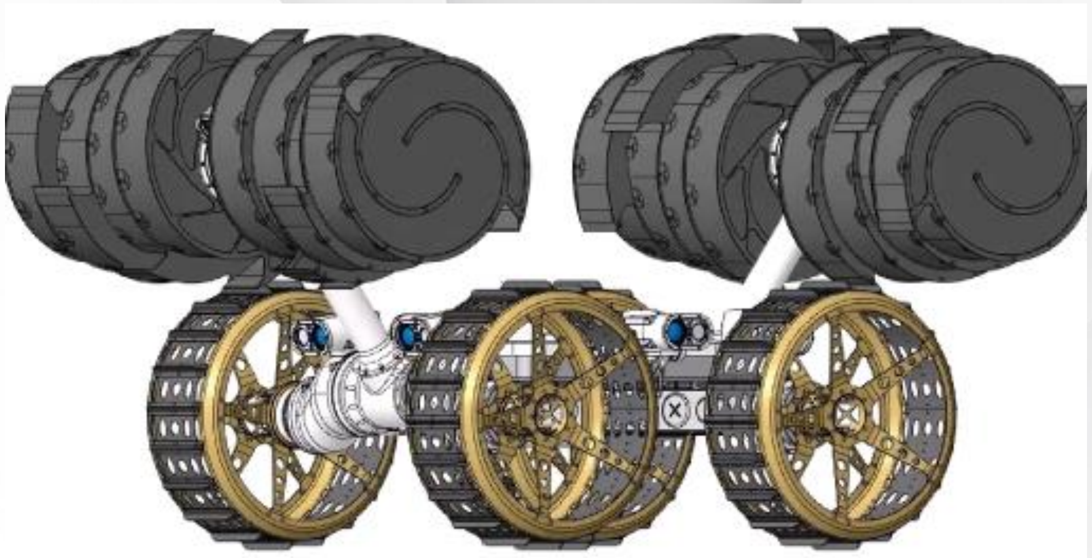


IPEx Modeling in Chrono: Drawbar pull

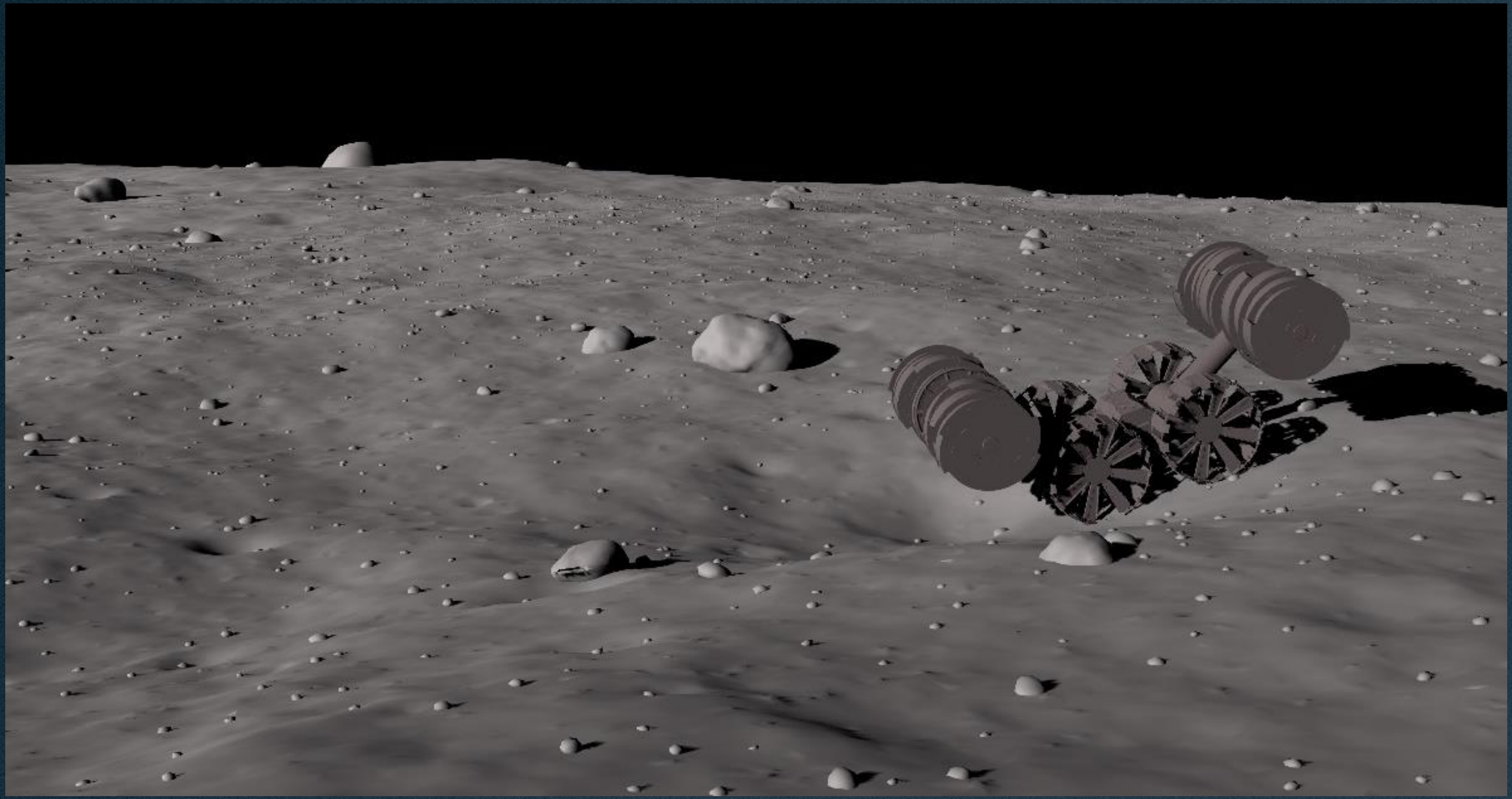


IPEx Autonomy & Lunar Surface - CARLA

- 8 cameras w/ LED Lights
- IMU
- Lunar surface
  - South Pole Location
  - Craters / Rocks
  - Lighting conditions



Lunar Autonomy Challenge



LUNAR AUTONOMY CHALLENGE

SCAN TO LEARN MORE

LAC.JHUAPL.EDU

Challenge Team

APL | CATERPILLAR | EMBODIED AI
With technical assistance provided by **NASA**

The Lunar Autonomy Challenge is a competition for university students to develop algorithms to autonomously control systems in a realistic lunar environment

- Map a simulated lunar surface using IPEx's digital twin
- Develop terrain height maps and identify rocks given power and data budgets
- Real-world problem solving contributes to the knowledge base for autonomous lunar operations
- Summer 2024 Pilot
- Official announcement and challenge details in Fall 2024

NASA LUNAR AUTONOMY CHALLENGE