2024 NASA LUNABOTICS UNIVERSITY COMPETITION: SITE PREPARATION WITH BULK REGOLITH

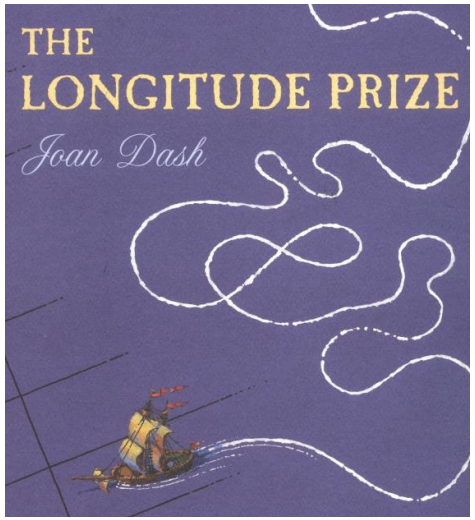
National Aeronautics and Space Administration

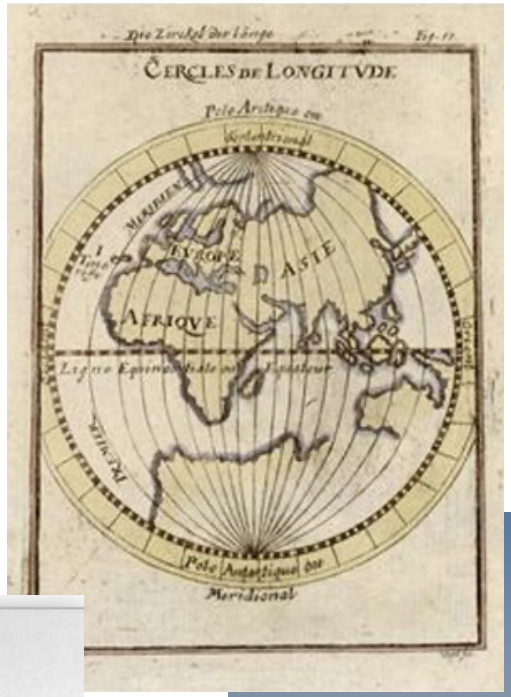
XXIV Meeting
Space Resources Roundtable
Colorado School of Mines
June 6, 2024

Rob Mueller
Senior Technologist
Swamp Works
Exploration Research and Technology Programs
NASA
Kennedy Space Center, Florida, USA

www.nasa.gov

Historical Leveraged Prizes





- Longitude Prize : 1714-1765
- Orteig Prize: 1919-1927
- Ansari X Prize: 1996-2004

NASA Regolith Excavation Challenge: 2007-2009

- In 2005 the United States of America congress funded a program of contests to stimulate innovation and competition in technical areas of interest to NASA.
- The Regolith Excavation Centennial Challenge was won in 2009 by Paul's Robotics, Worcester Polytechnic Institute, MA. - $500,000 prize

2010 - 2024

15th Anniversary of Lunabotics!

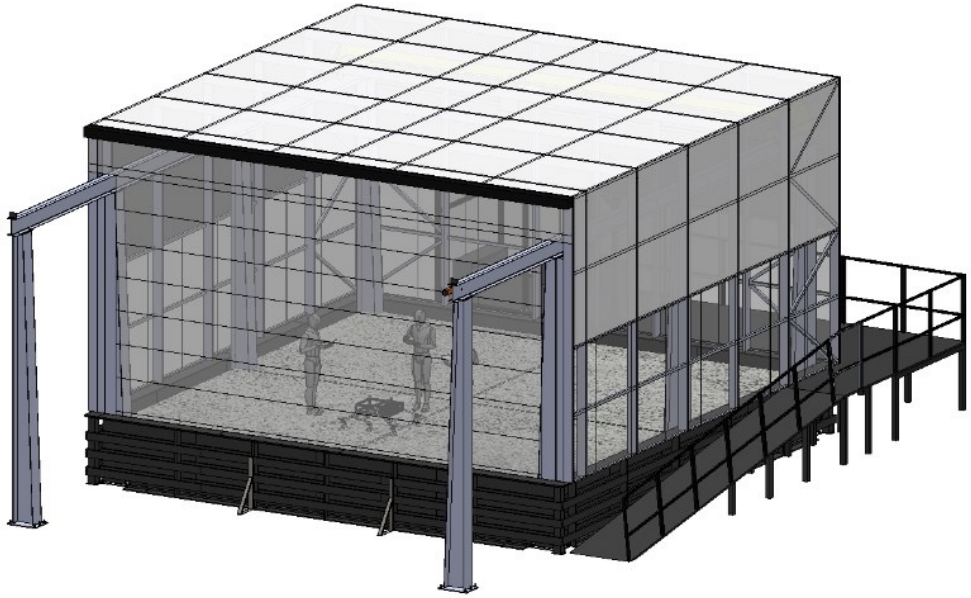
https://www.nasa.gov/learning-resources/lunabotics-challenge/

Lunabot Specifications

- ✓ **Robot Controlled Remotely or Autonomously**
- ✓ **Visual and Auditory Isolation from Operator**
- ✓ **Excavates Exolith Lunar Highlands Simulant (LHS) & Black Point 1 (BP-1) Simulant**
- ✓ **Builds a berm structure with excavated regolith**
- ✓ **Mass Limit - 80 kg**
- ✓ **Lunabot Dimension Limits - 1.5m x 0.75m x 0.75m**
- ✓ **Designed, Built, Tested and Operated by University Student Teams**
- ✓ **Must use NASA Systems Engineering methods**

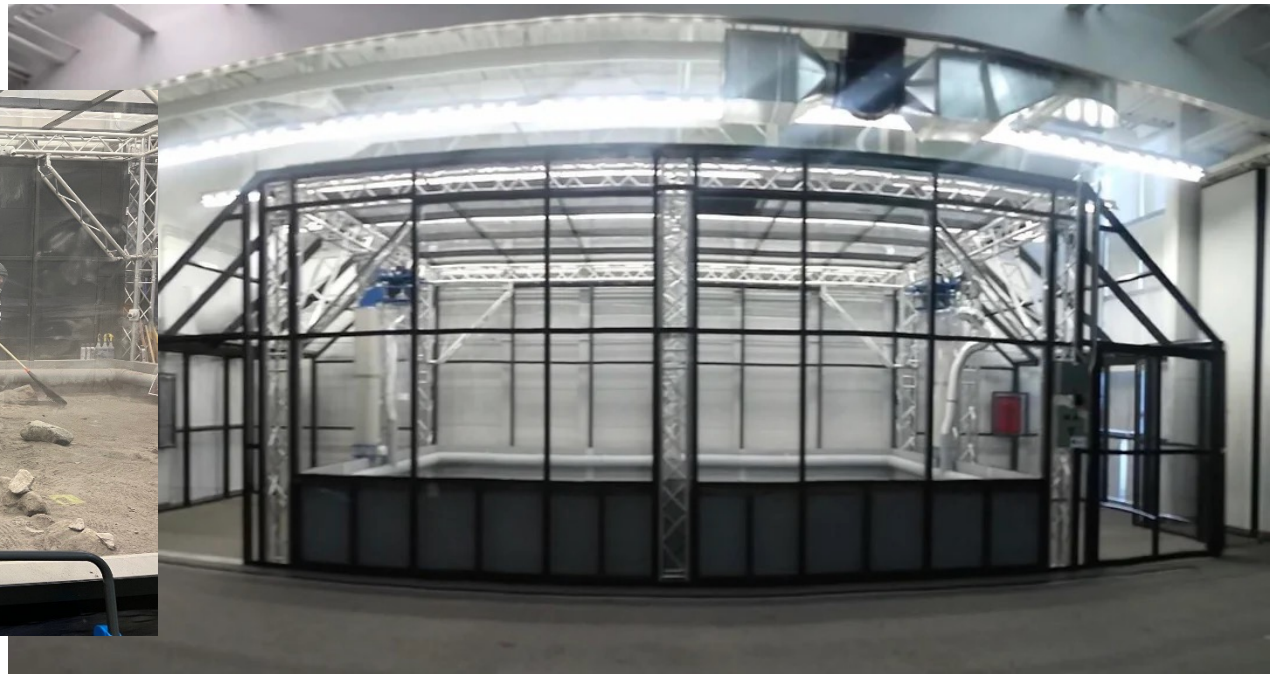
UCF Qualification Event

- A qualification event was held for 44 teams at the University of Central Florida (UCF) Exolith Lab in Orlando, Florida
  - 10m x 10m x 1 m deep
  - Lunar Highlands Regolith Simulant (LHS)



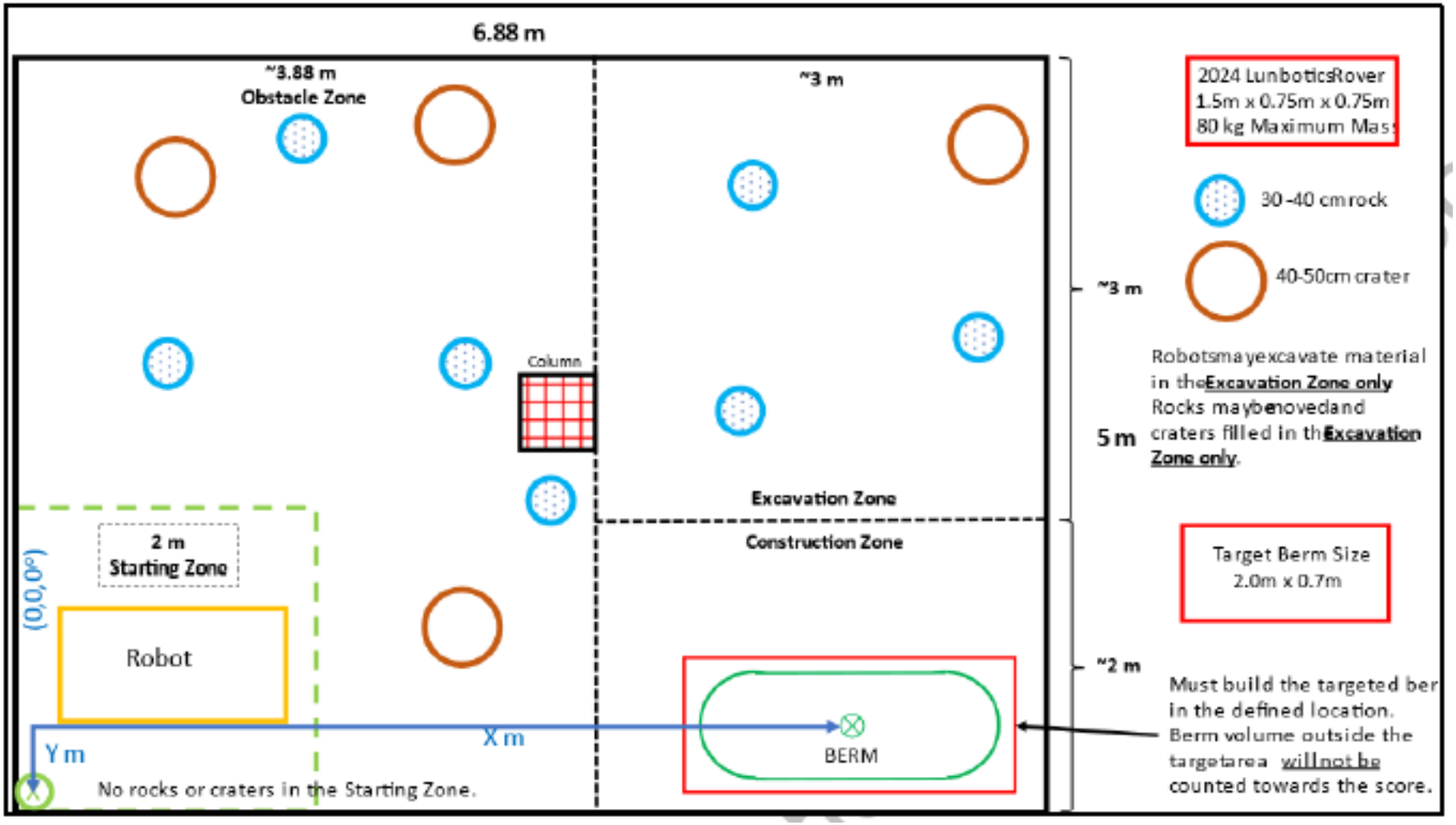
KSC Final Competition

- The top 10 teams advanced to the Lunabotics Challenge final event held at the NASA Kennedy Space Center (KSC) Center for Space Education
  - 6.9 m x 5 m x ~ 0.6 m deep
  - Black Point (BP) 1 regolith simulant



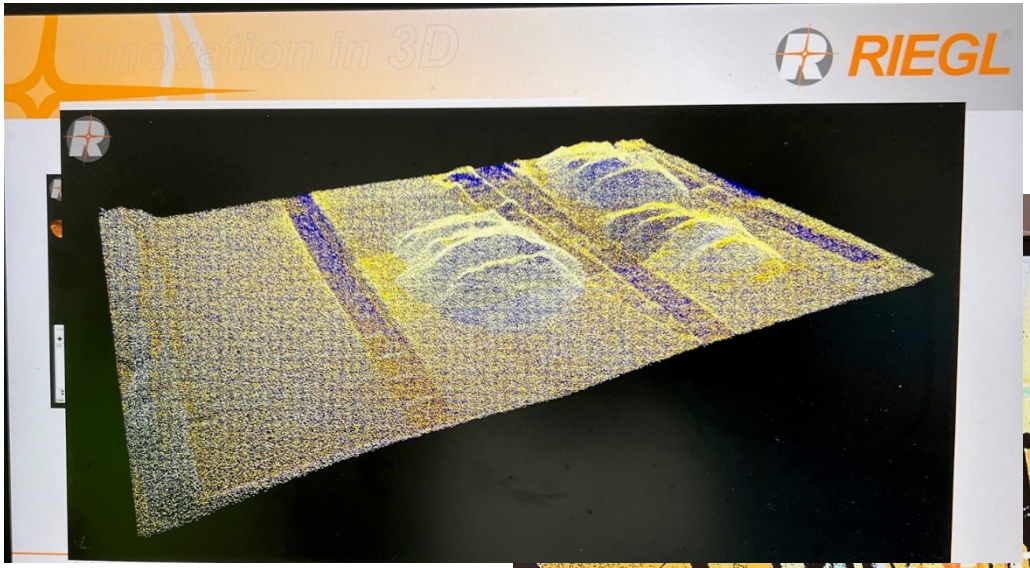
Lunar Like Regolith Behavior

Artemis Arena at KSC

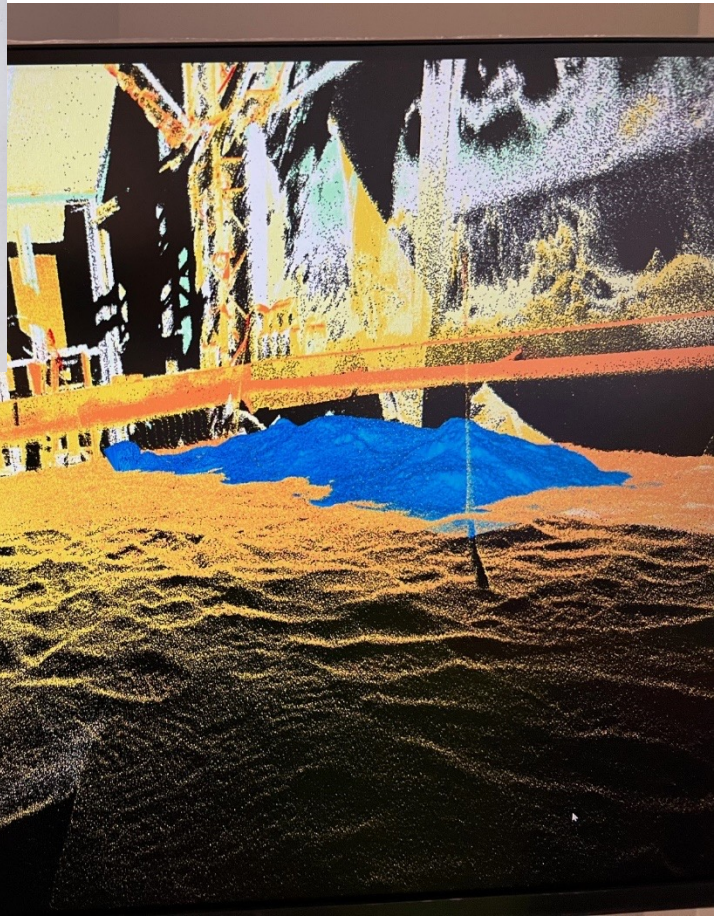


44 Universities from across the USA attended Lunabotics 2024

LIDAR Scanning of Berm



Goal was to build largest volume berm possible in 15-30 minutes



Types of Lunabots

Regolith Excavation Mechanism	# of machines employing excavation mechanism
Bucket ladder (two chains)	29
Bucket belt	10
Bulldozer	10
Scraper	8
Auger plus conveyor belt / impeller	4
Backhoe	4
Bucket ladder (one chain)	4
Bucket wheel	4
Bucket drum	3
Claw / gripper scoop	2
Drums with metal plates (street sweeper)	2
Bucket ladder (four chains)	1
Magnetic wheels with scraper	1
Rotating tube entrance	1
Vertical auger	1

Mueller, R. P., van Susante, P., Reiners, E., & Metzger, P. T. (2021). NASA lunabotics robotic mining competition 10th anniversary (2010–2019): Taxonomy and technology review. *Earth and Space 2021*, 497-510.

Terramechanics

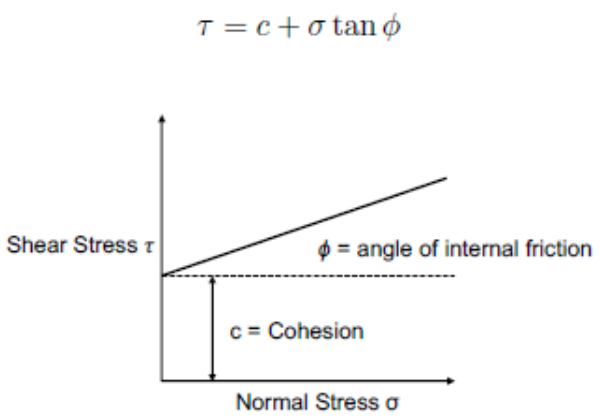
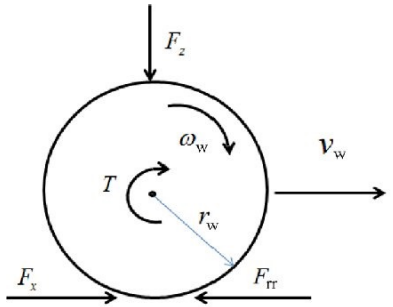


Figure 1: Relationship Between Shear Stress and Normal Stress



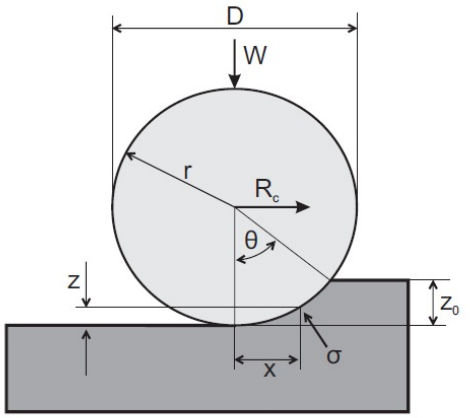


Fig. 1. Geometry and notation of the wheel-soil contact region.

- if $T_{motor} < T_{traction}$ and $T_{net} > T_{resistance}$, then the wheel will rotate without slipping and propel the vehicle forward
- if $T_{motor} < T_{traction}$ and $T_{net} < T_{resistance}$, then the wheel will not propel the vehicle and vehicle will remains at rest
- if $T_{motor} > T_{traction}$ and $T_{net} > T_{resistance}$, then the wheel will rotate (slip) and propel the vehicle forward
- if $T_{motor} > T_{traction}$ and $T_{net} < T_{resistance}$, then the wheel will spin while $V = 0$ and the vehicle will remains at rest

Where T_{net} is the net torque from wheel motor and gravitational effect.

NASA White Paper - Terramechanics for LTV Modeling and Simulation

Zu Qun Li and Lee K. Bingham

Lunar Regolith Properties

- To predict the wheel performance analytically these lunar regolith properties need to be measured or derived (preferably in-situ):

Symbol	Description	Lunar Soil Value	Used in
n	Exponent of sinkage	1.0	Everything
k_c	Cohesive modulus	$1400N/m^2$	R_c, R_b, H
k_ϕ	Frictional modulus	$820,000N/m^3$	R_c, R_b, H
ϕ	Angle of inertial friction	$30-40degree$	$N_q, N_c, N_\gamma, K_c, K_\gamma, R_b, H$
c	Cohesive strength of soil	$170N/m^2$	R_b, W_s, H
γ	Soil weight density	$2470N/m^3$	R_b, W_s, H
K	Coefficient of soil slip	$0.018m$	H
N_q	Terzaghi's bearing capacity factor	32.23	W_s
N_c	Cohesive bearing capacity factor	48.09	W_s, K_c
N_γ	Density bearing capacity factor	33.27	W_s, K_γ
K_c	Cohesive modulus of soil deformation	33.37	R_b
K_γ	Density modulus of soil deformation	72.77	R_b

Table 2: Wheel Parameters

Symbol	Description	Used in
b	Wheel width	R_c, R_b, H
D	Wheel diameter	R_c, R_b, H
c_f	Coefficient of rolling friction	R_r
r	Wheel radius	s, H
N	Number of wheel grouser	H
h_g	Grouser height	H

NASA White Paper - Terramechanics for LTV Modeling and Simulation
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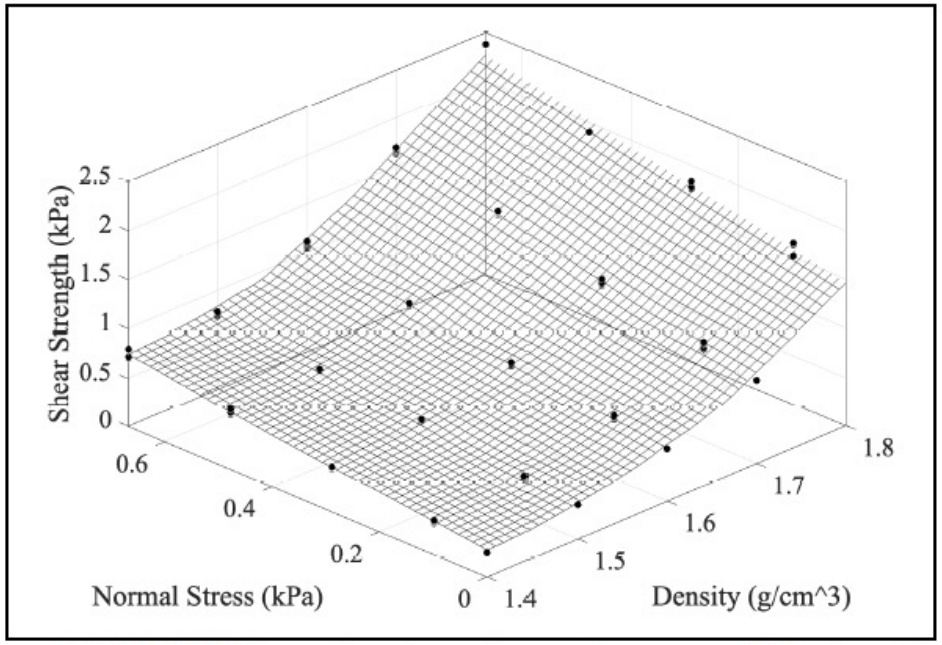
Analysis

$$DP = H - R$$

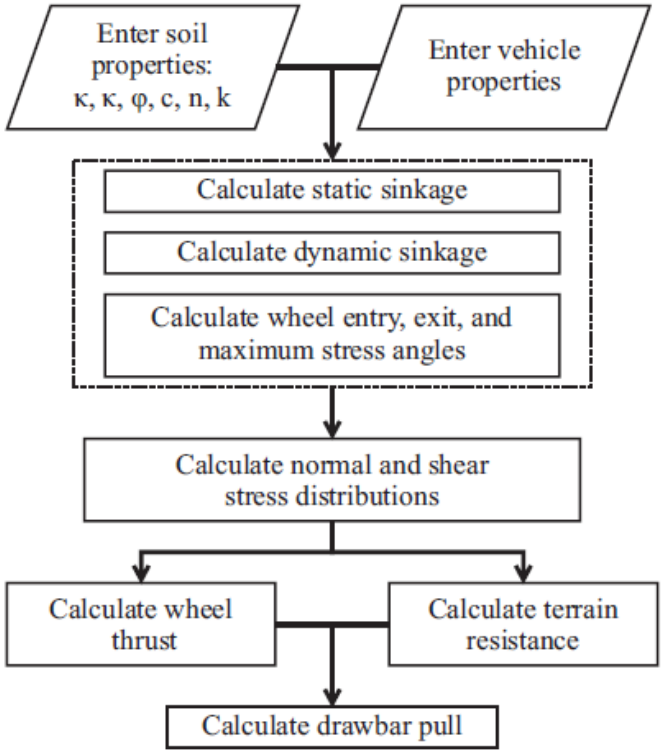
$$H = blc + W \tan \phi$$

DP= Draw Bar Pull
H = Thrust
R-= Resistance



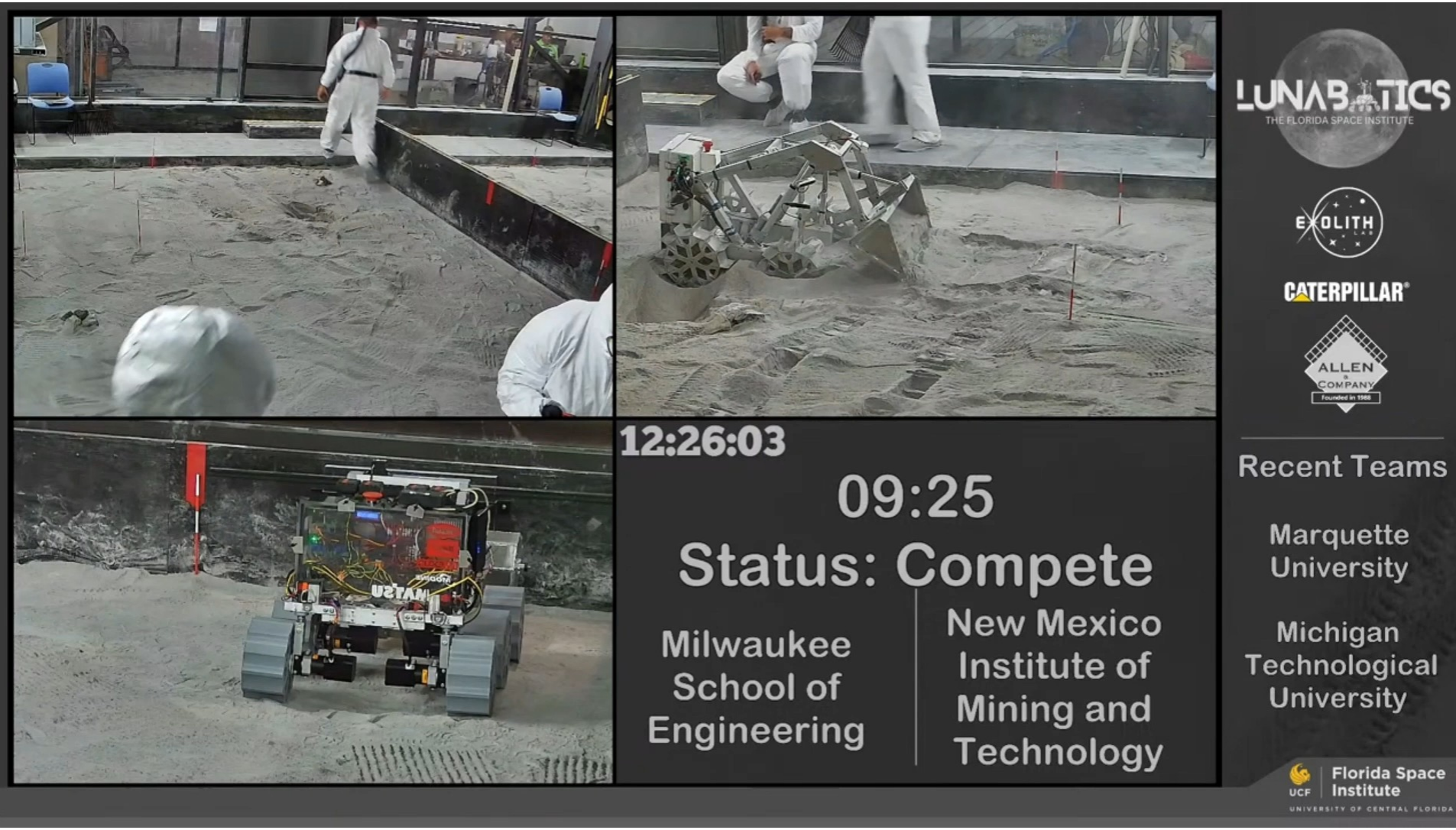
Cohesion and Shear Strength of Compacted Lunar and Martian Regolith Simulants.

B. Dotson, D. Sanchez Valencia, C. Millwater, P. Easter, J. Long-Fox, D. Britt, and P. Metzger, University of Central Florida, Department of Physics, 4000 Central Florida Boulevard, Orlando, FL 32816; email: bdotson@knights.ucf.edu.



Meirion-Griffith, Gareth, and Matthew Spenko. "Application of a diameter-dependent terramechanics model to small-wheeled unmanned ground vehicles operating on deformable terrain." 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE, 2011.

Example Traction Video



Evidence

Good traction = clean tracks = no shear

2024 Results

Robotic Construction Award

Robotic Construction Award 1st Place - Iowa State University

Robotic Construction Award 2nd Place - The University of Alabama

Robotic Construction Award 3rd Place - University of Utah

The Artemis Grand Prize

First Ever Tie:

Iowa State University

The University of Alabama

The Caterpillar Autonomy Award

6th Place – Purdue University
5th Place – University of Illinois at Chicago
4th Place – Iowa State University
3rd Place – University of Utah
2nd Place – Vanderbilt University
1st Place – University of Alabama

Systems Engineering Award

Systems Engineering Paper Award 3rd Place - Purdue University - Main Campus
Systems Engineering Paper Award 2nd Place - The University of Alabama
Systems Engineering Paper Award 1st Place - College of DuPage
Systems Engineering Paper Award Leaps & Bounds Award - New York University
Systems Engineering Paper Award Nova Award for Stellar Systems Engineering by a First Year Team - Ohio State University

Summary

- 58 teams applied and 42 Universities from across the USA were able to attend Lunabotics 2024
- The competition format changed from regolith mining for In-Situ Resource Utilization (ISRU) to berm building for lunar construction
- A qualification event was held at the University of Central Florida Exolith lab in a 10 m x 10 m x 1 m deep regolith simulant bin
- The finals were held at the NASA KSC Center for Space Education and the top 10 teams were invited from the UCF qualifier
- Excavation for construction requires more traction than ISRU mining surface excavation which will be challenging in $1/6^{th}$ G on the Moon

Thank you to all supporters!
Looking forward to next year

Announcements

TELEPRESENCE Field Competition and Demos

November 15, 2024

The 2024 Field Telepresence Competition will focus on demonstrating telepresence capabilities aiding robotic vehicles navigate difficult high desert terrain.

A **$5,000 Prize** for the winning team will be provided by the **IEEE Telepresence Initiative.**

Open to all. We also welcome **Telepresence Demos**, to be presented during the Conference.

IEEE Telepresence

California Institute of Technology, Pasadena, California

November 16-17, 2024

Mojave Desert, Peterman Hill, in Lucerne Valley, California

Announcements

TELEPRESENCE Field Competition and Demos

November 15, 2024

Off World Robot – will be available

Announcements

CATERPILLAR

ISRU Pilot Excavator (IPEX) Autonomy Student Competition

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