National Aeronautics and Space Administration



2024 NASA LUNABOTICS UNIVERSITY COMPETITION: SITE PREPARATION WITH BULK REGOLITH

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



NASA Regolith Excavation Challenge: 2007-2009





CENTENNIAL CHALLENGES

- 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/







- 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





- 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)









- The top 10 teams advanced to the Lunabotics Challenge final event held at the NASA Kennedy Space Center (KSC) Center for Space Education
 - $6.9 \text{ m x} 5 \text{ m x} \sim 0.6 \text{ m deep}$
 - 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







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.





SWAMP WORKS

NASA KENNEDY SPACE CE





Figure 1: Relationship Between Shear Stress and Normal Stress

- 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





 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	30-40 degree	$N_q, N_c, N_\gamma, K_c, K_\gamma, R_b, H$
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	Н
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 Zu Qun Li and Lee K. Bingham



Poor Traction Video



Video not included due to file size





Video not included due to file size





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







- 44 Universities from across the USA attended 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

