Blue Collar Robots and Regolith

2025 IEEE International Conference on Space Mission Challenges for Information Technology and Space Computing Conference (SMC-IT/SCC)

Space Robotics Workshop 2025

“Unlocking the Off World Economy with Robotic Technologies”

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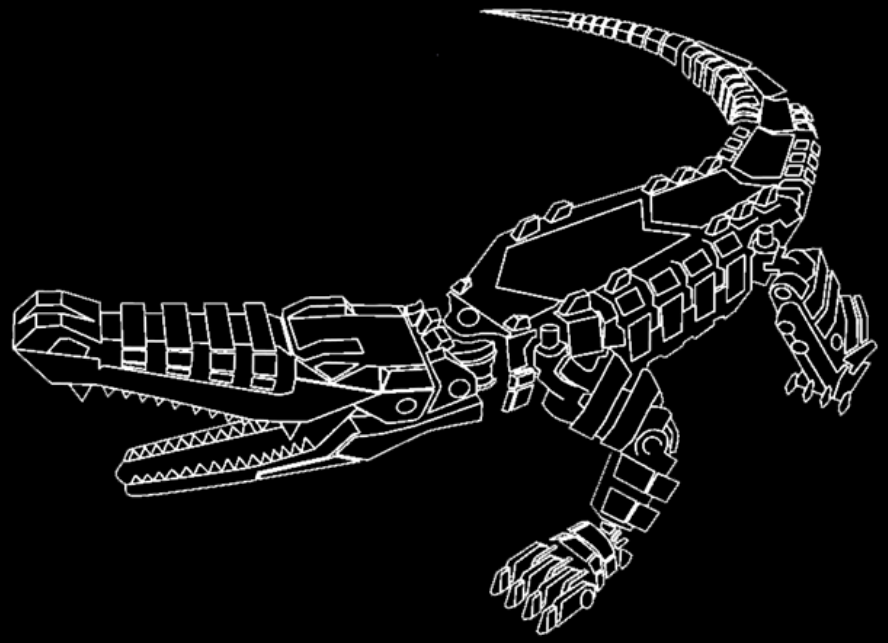
NASA, Kennedy Space Center, Swamp Works

7/26/25

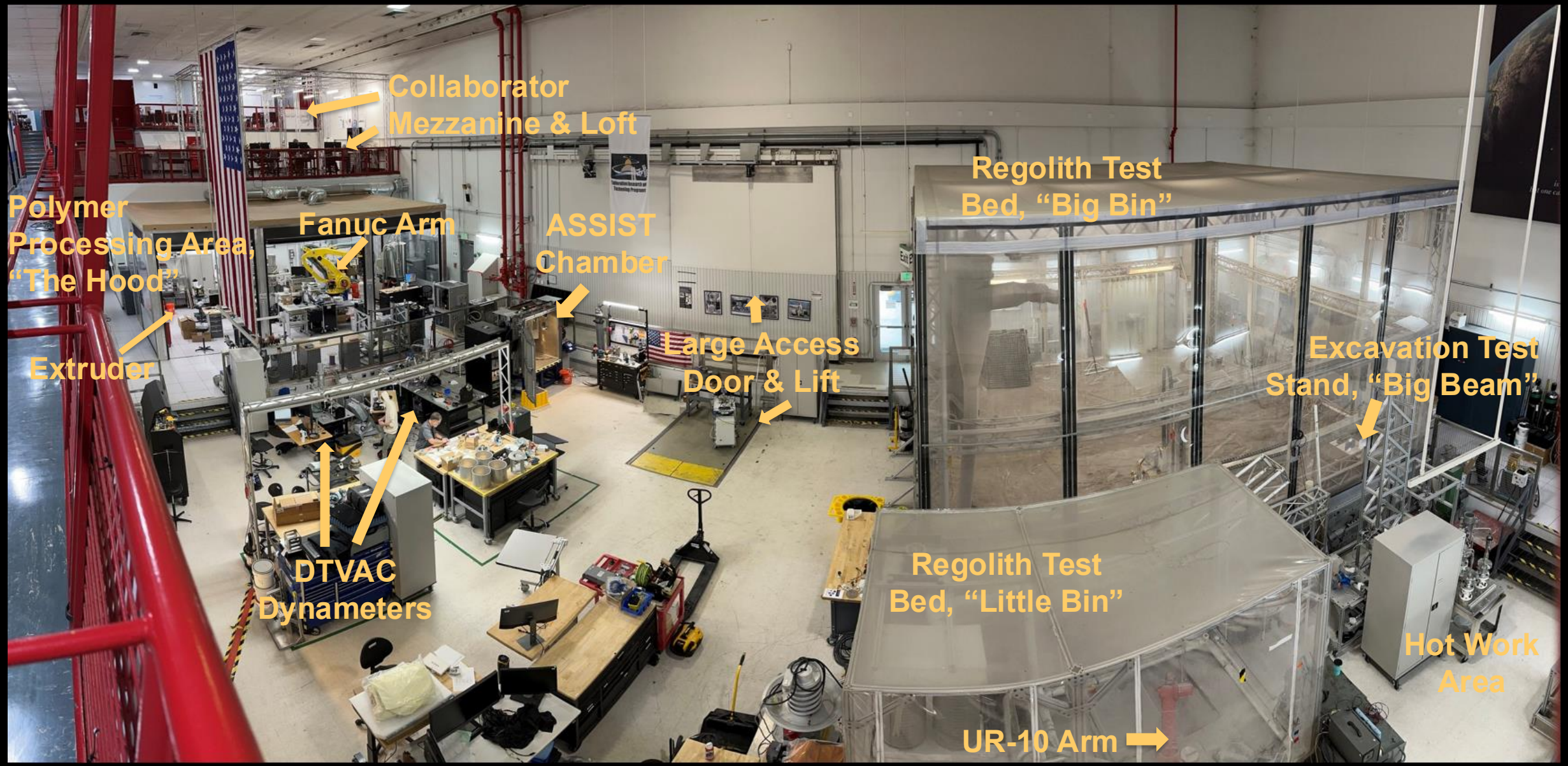
Swamp Works

Innovation Environment



- Philosophies aligned with those used in Kelly Johnson's Skunk Works and Werner von Braun's development shops.
- Helical development strategy - Testing performed in early stages and iterated. Start small and cheap to build momentum. Fail forward approach. "go do" mentality.
- Failure **IS** an option – if you never fail you are not pushing the boundaries hard enough.
- Swamp Works is not a place or a group of people, it is a philosophy for how to innovate.
- Leverage partnerships across NASA, government, industry & academia. 1 + 1 = 3

Granular Mechanics and Regolith Operations Laboratory



NASA imagery

Excavation Work - Autonomy Testbed

https://www.nasa.gov/isru-pilot-excavator/

What Does Blue Collar Mean?

- **In the US, Blue Collar and White Collar can describe different types of work**
  - Blue Collar – construction, manufacturing, agriculture, mining, maintenance, etc.
    - Typically, limited education, manual labor, with pay by hour or job
    - Historically wore blue collared shirts
  - White Collar – engineering, science, management, finance, executive, etc.
    - Typically, highly educated, office work, with salary-based pay
    - Historically wore white collared shirts, ties and/or suits
- **Sociocultural Factors**
  - There can be a perception that Blue Collar workers are lower paid and lower class than White Collar workers. It can be a derogatory term
  - In contrast, most Blue Collar workers are very proud of their work and believe it represents American values such as strong work ethic, honesty, sacrifice, and community
- **Intent of the phrase "Blue Collar Robots"**
  - To celebrate the ideals of Blue Collar workers and describe a new breed of space robotics designed to perform rugged, labor-intensive, tasks such as mining and construction, in a production environment

Blue Collar Tenants – Production Mindset

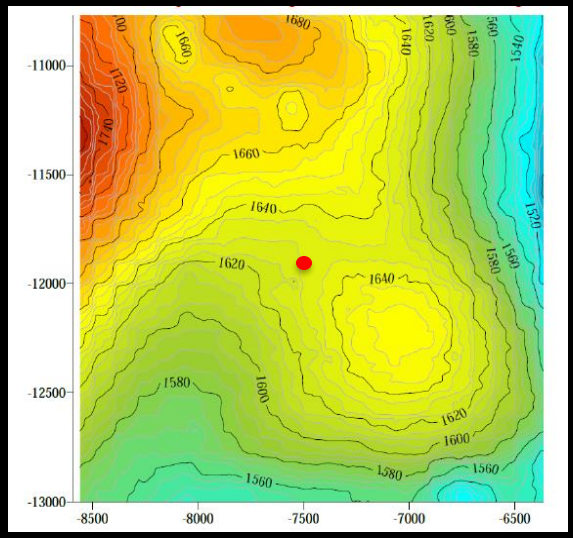
- **Production driven design and operations**
  - Production Environment:
    - Highest priority is efficient and reliable delivery of products/services (e.g., regolith delivery rate)
    - Rigid mission with explicit objectives (e.g., deliver 1000 kg of regolith 1 km from mine site to processing plant per day)
    - Delays/failures in production have significant downstream negative effects on subsequent activities (e.g., delays in H2O production affect rocket refueling capability)
    - Required production rates, communication time delays, and intentional terrain changes drive need for autonomy advancement beyond SoA
  - Science/Exploration Environment:
    - Highest priority is to maximize scientific return
    - Flexible mission typically designed to adapt to new information/findings
    - Delays/failures result in missed opportunity for new knowledge

Vehicle	Max Speed (km/h)	Distance Travelled (km)	Average Daily Travel (km/24 hr)
Sojourner	0.02	0.1	0.00
Ingenuity[1]	36.0	17	0.03
Viper[2]	0.80	20.0	0.20
Curiosity	0.14	32.1	0.01
LRV (Apollo 15)[3]	18.00	35.9	2.76
Lunakhod 2	2.00	42.1	0.36
Opportunity	0.18	45.2	0.01
Perseverance[4]	0.12	33.4	0.02
IPEx[5]	1.44	58.1	5.28

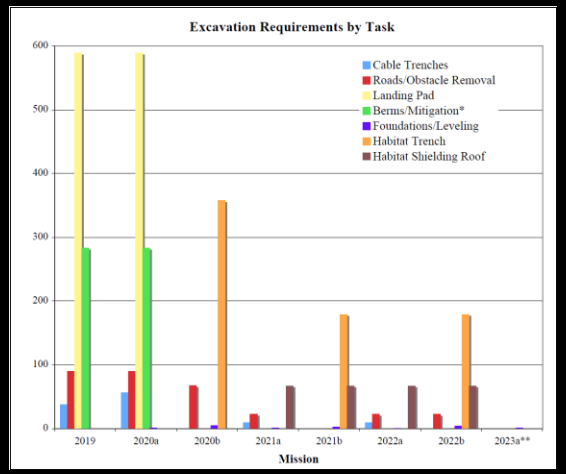
[1] Flights
[2] Design requirements
[3] Human operated
[4] Still operational
[5] TRL 5 ground demonstration

Blue Collar Tenants – Production Estimate

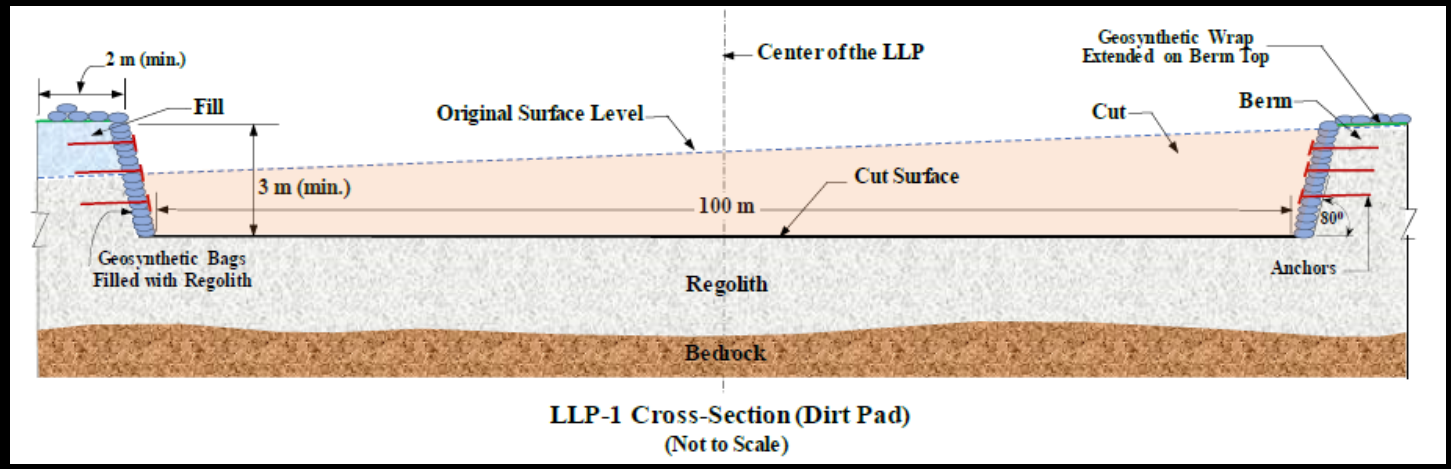
- Launch/Landing Pad Example
  - Excavation Requirements:
    - Initial 50 m diameter pad estimates were ~589 mt excavated regolith (equivalent to 2355 mt for 100 m)*
    - Newer estimates by Astroport Space Technologies Inc. using site specific elevation maps and a higher fidelity 100 m pad design resulted in ~40,000 mt excavated regolith (17x increase over previous estimate)
  - Operational Time Estimates
    - IPEx mission is for 10 mt over 11 days (scaled for 100 kg lander). Given this excavation rate it would take ~43,779 days
    - Scaling up and/or multiple excavators are necessary for a reasonable timeline



Connecting ridge pad location elevation map**



Initial excavation requirements in metric tons for a 50 m diameter pad and other tasks*



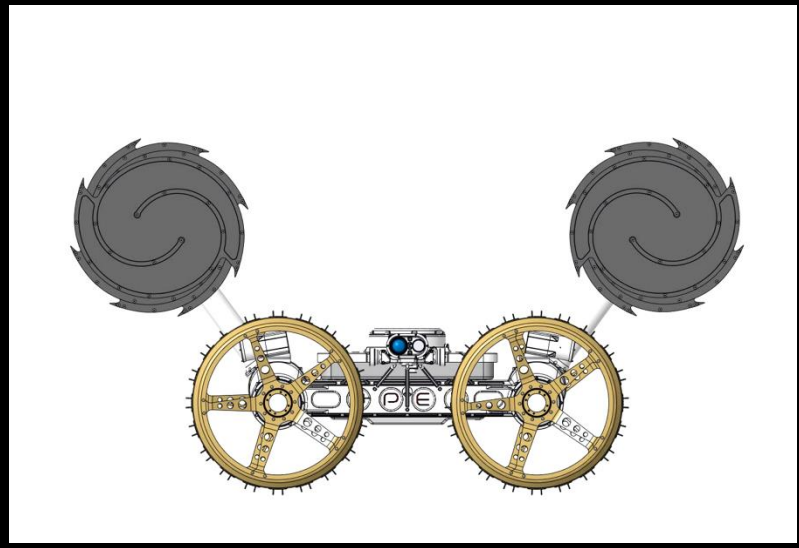
Regolith based launch and landing pad design**

*Mueller, Robert P. "Criteria for lunar outpost excavation." *Space Resources Roundtable IX* (2007).

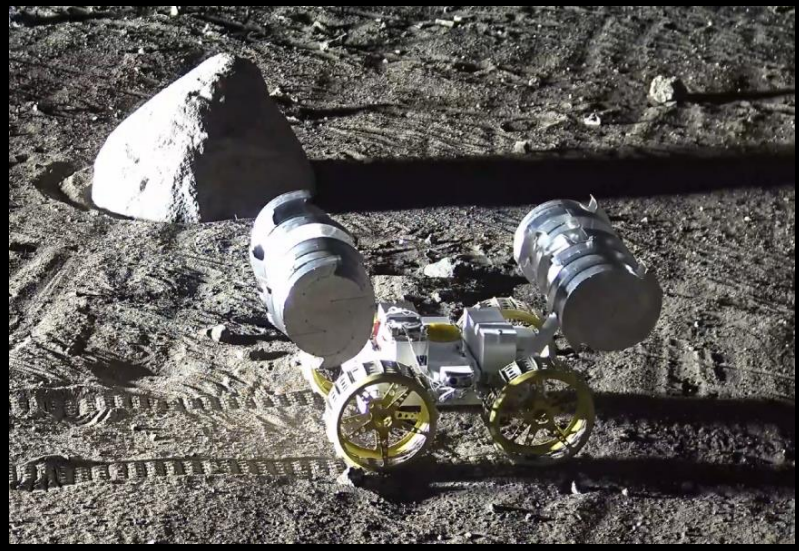
**Used with permission from Astroport Space Technologies Inc. Phase 2 STTR Research Contract No. 80NSSC24CA021 Quarterly Demonstration Report #4, "Bulk Regolith Handling Technologies for Landing/Launch Pad Site Preparation and Blast Shield Construction"

Blue Collar Tenants – Resiliency

- **Resiliency through layered failure tolerance**
  - Expect the worst-case failure scenarios
  - Design to not just fail safe, but fail operational
  - Hazard tolerance rather than hazard avoidance
  - Select extreme load cases and include judicious margin. IPEx is designed for Earth gravity conditions
  - Include features that allow for recovery from environmental hazards
    - Self rescue if stuck
    - Self righting if flipped over or on the side
    - Traverse slopes of up to 30 degrees by shifting center of gravity
    - Redundant mobility (wheels or bucket drums)
    - Redundant excavation implements (4x bucket drums x 4x excavation volumes)
  - Layered autonomy algorithms with weighted filter
    - Visual odometery
    - Wheel odometery
    - Sun tracker
    - Lander fiducials
    - Inertial Measurement Unit (IMU)



ISRU Pilot Excavator (IPEx) CAD rendering



IPEx Technology Readiness Level (TRL) 5 concept of operations testing

https://www.nasa.gov/gallery/isru-pilot-excavator/

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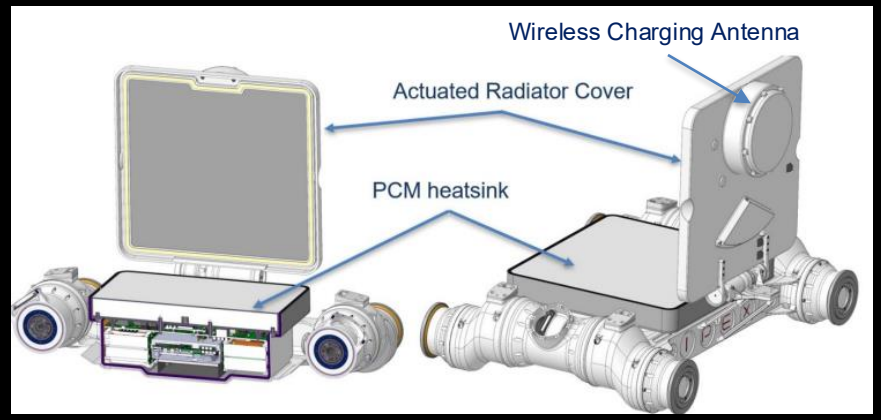
Blue Collar Tenants – Purpose Built

- **Design for single purpose**
  - Reject scope creep. Unnecessary instruments/systems distract from main purpose, add complexity, increase cost, and could introduce new failure mechanisms
  - Blue collar work (e.g., excavation, construction) is inherently challenging due to extreme dust exposure, rugged tasks, changing operational terrain, and complex construction processes. Balance reliance on external (e.g., lander) systems with on-board capability
    - Solar array efficiency can be significantly reduced by dust; landers have power generation capability; cycling interface connections can be risky in dusty conditions - offload power generation to lander and include wireless recharging
    - Direct to Earth (D2E) communications require precision pointing and are power intensive; landers have D2E communications systems – offload to the lander.
    - Thermal radiator efficiency can be significantly reduced by dust, landers have thermal management capability; but no existing dust tolerant thermal interfaces exist – keep radiators on IPEx but protect them from dust



IPEx themal management system and wireless charging antenna*

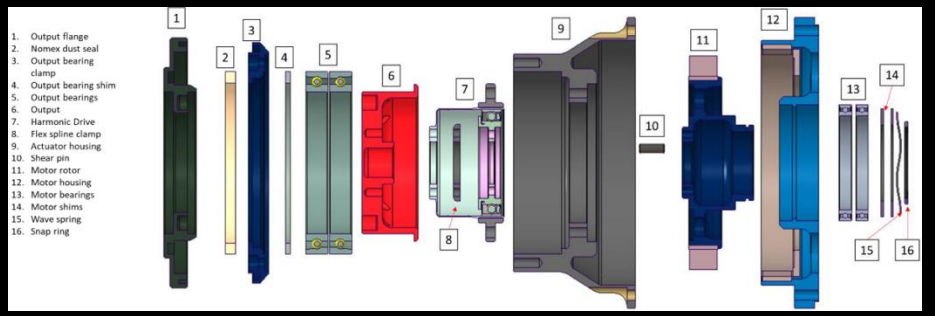
IPEx TRL 5 wireless charging concept of operations testing**

*Schuler, Jason, et al. "ISRU Pilot Excavator (IPEx) Technology Readiness Level 5 Design Overview." *AIAA AVIATION FORUM AND ASCEND 2024*. 2024.
**https://images-assets.nasa.gov/video/IPEx%20TRL%205%20Demo%20Narrated/IPEx%20TRL%205%20Demo%20Narrated~large.mp4

Blue Collar Tenants – Simplicity, Dust and Testing

- **Keep it simple**
  - Tracks and wheels were traded for mobility. Testing showed similar characteristics when using larger wheel diameters. Wheels were chosen due to inherent simplicity
  - Skid steer mobility was used in lieu of suspension or steering to minimize complexity
  - Use common actuators when possible. IPEx uses 9 actuators, the bucket drum and "shoulder" are common, the wheel actuators are similar but smaller scale, a COTS actuator was used for the radiator actuator. As a comparison, MSL used 31 actuators
  - Single style cameras and sensors
  - Reduce part count
- **Dust mitigation**
  - Expect dust in thin layers all over and piling up in prone areas
  - Rotary joints tend to be sealed easier than linear
  - Redundant dissimilar seals
  - Design areas where dust tends to build up with an exit path
  - Protect items that are particularly sensitive to dust (e.g., lenses, radiators)
- **Testing**
  - Test under extreme stressing conditions
  - Put hours on the hardware to tease out design weaknesses

Ejectable electrodynamic dust shield camera lenses*



Wheel actuator cross section view**

Dirty thermal vacuum actuator testing shows a small degree of regolith penetration that did not affect performance**

*https://www.nasa.gov/video-detail/ipex-eds-test1/

**Schuler, Jason, et al. "ISRU Pilot Excavator (IPEx) Technology Readiness Level 5 Design Overview." *AIAA AVIATION FORUM AND ASCEND 2024*. 2024.

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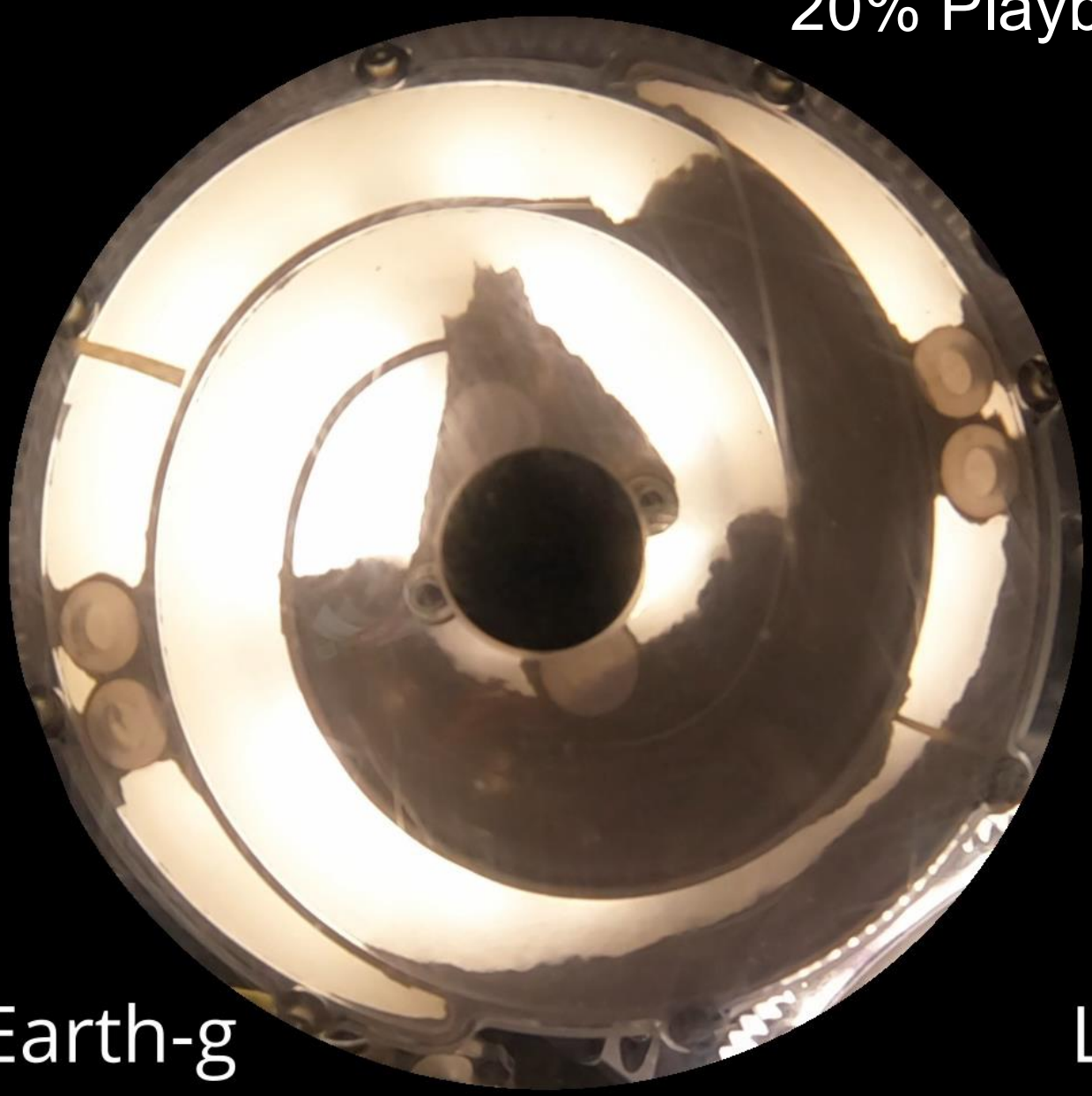
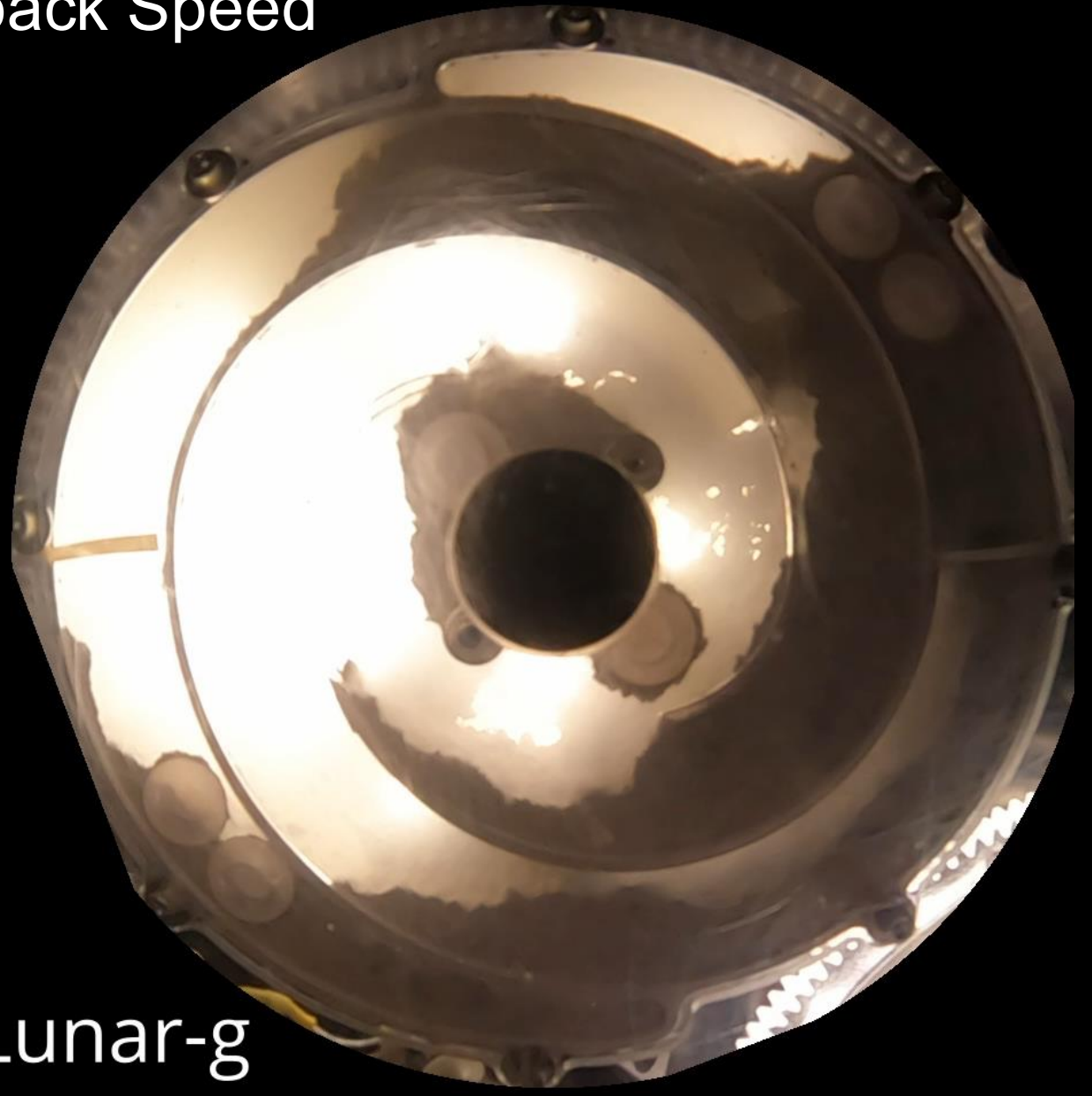


Earth-g



Lunar-g

https://www.nasa.gov/gallery/isru-pilot-excavator/

Regolith Risks and Rewards

NASA's Spirit Mars rover mission ended after becoming stuck in the regolith

Apollo 17 astronaut Gene Cernan covered in dust. Cernan stated "I think dust is probably one of our greatest inhibitors to a nominal operation on the moon. I think we can overcome other physiological or physical or mechanical problems except dust"

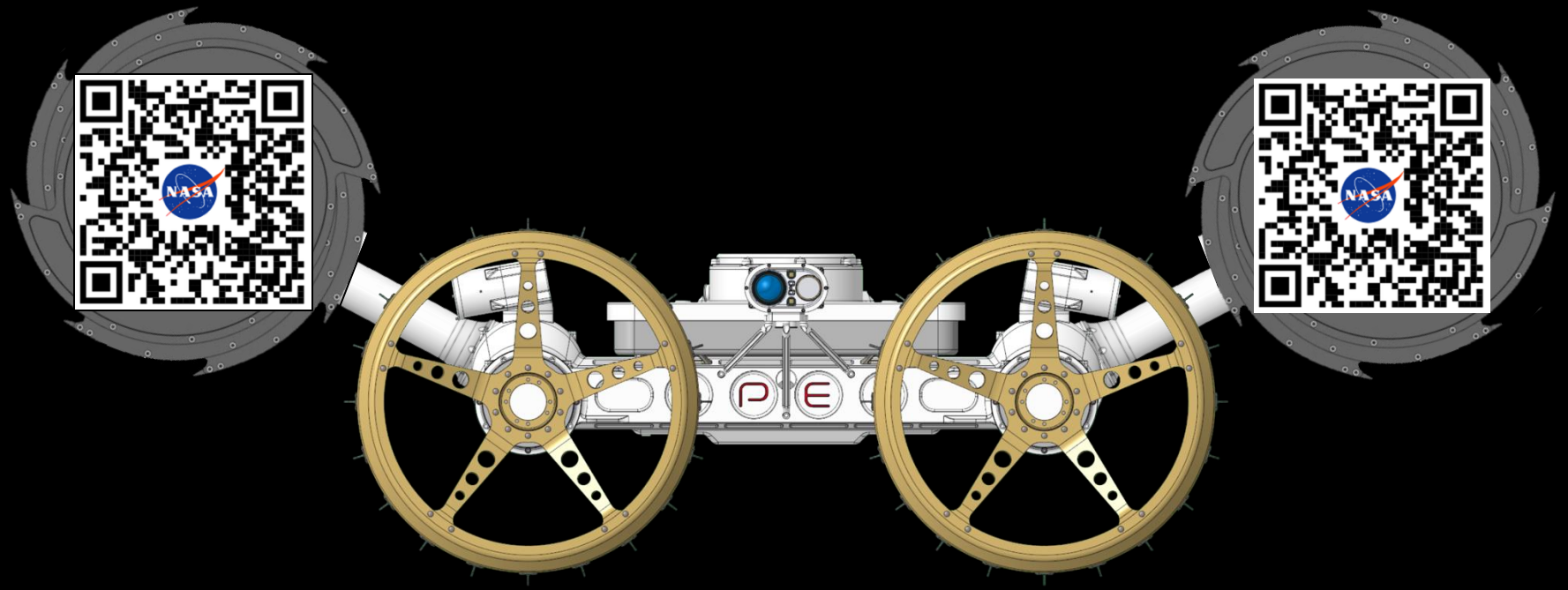
- Unsupported valuations of space resources (US Dollar)
  - The Moon's resources have been valued at $100's of billions to multi quadrillions
  - Single asteroids such as 16 Psyche have been valued at $10 quintillion
- Future national economic power will be defined by a nation's ability to access and use space resources*

Nothing less than a sustained lunar presence and the global balance of economic power depend very literally on… **Blue Collar Robots and Regolith**

NASA Imagery

*Goswami, N., Garretson, P., (2020). *Scramble for the Skies: The Great Power Competition to Control the Resources of Outer Space.* Lexington Books.

Thank you!



www.nasa.gov/isru-pilot-excavator