Effects of Regolith Simulant Properties on an Experiment:

ROxygen Phase I Input Hopper
Reduced Gravity Flight – Houston, TX

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Outline

- ISRU Oxygen Production
- ROxygen Phase II System Configuration
- Regolith Feed System
- Regolith Input Hopper Design
- RGF Experiment Configuration
- RGF Experiment Data – JSC-1A
- RGF Experiment Data – NU-LHT-2M
- RGF Experiment Data – OB1
- Opportunistic Testing Techniques
- Flow Effects of Different Simulants
- Conclusions
- Q&A

ISRU Oxygen Production

In-Situ Resource Utilization (ISRU)
Mission Consumable Production:

- Complete Life Support/Extra Vehicular Activity closure for Oxygen (O2) and water (H2O)
- Regenerate and storage life support and fuel cell power consumables (in conjunction with Life Support and Power)
- Gases for science and cleaning
- Propellant production; O2 and methane (CH4) for robotic and human vehicles

How Do We Plan To Produce O_2 From Lunar Regolith?

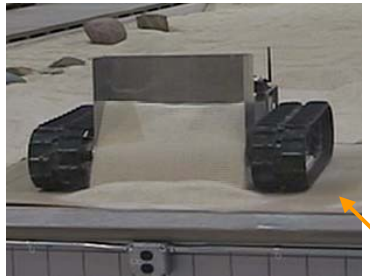
Numerous Chemistries Have Been Proposed And Studied Since Apollo.

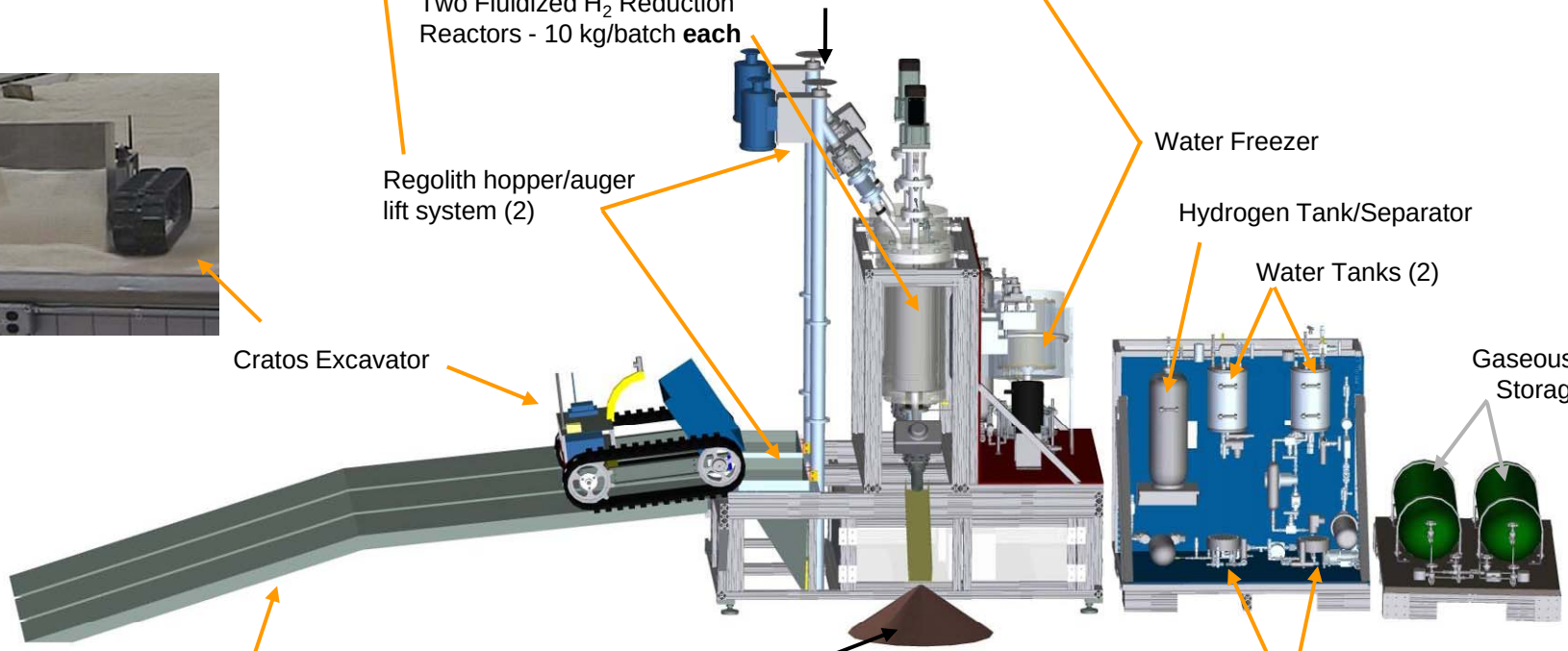
- **H_2 Reduction of Ilmenite**
- **Carbothermal Reduction**
- Hydrogen Extraction
- Hydrogen Sulfide Reduction
- Carbochlorination
- Fluorine Exchange
- Hydrofluoric Acid Leach
- **Direct Electrolytic Reduction**
- Electrolytic Reduction of Oxide/Caustic Solution
- Electrolytic Reduction of Oxide/Ionic Liquid
- Reduction by Lithium or Sodium
- Reduction by Aluminum
- Vapor Phase Reduction
- Ion Separation

Source: Eagle Engineering Report: Lunar O2 Pilot Plant

1st Gen ROxygen H_2 Reduction System Field Test Hardware

Water Electrolysis Units (2)





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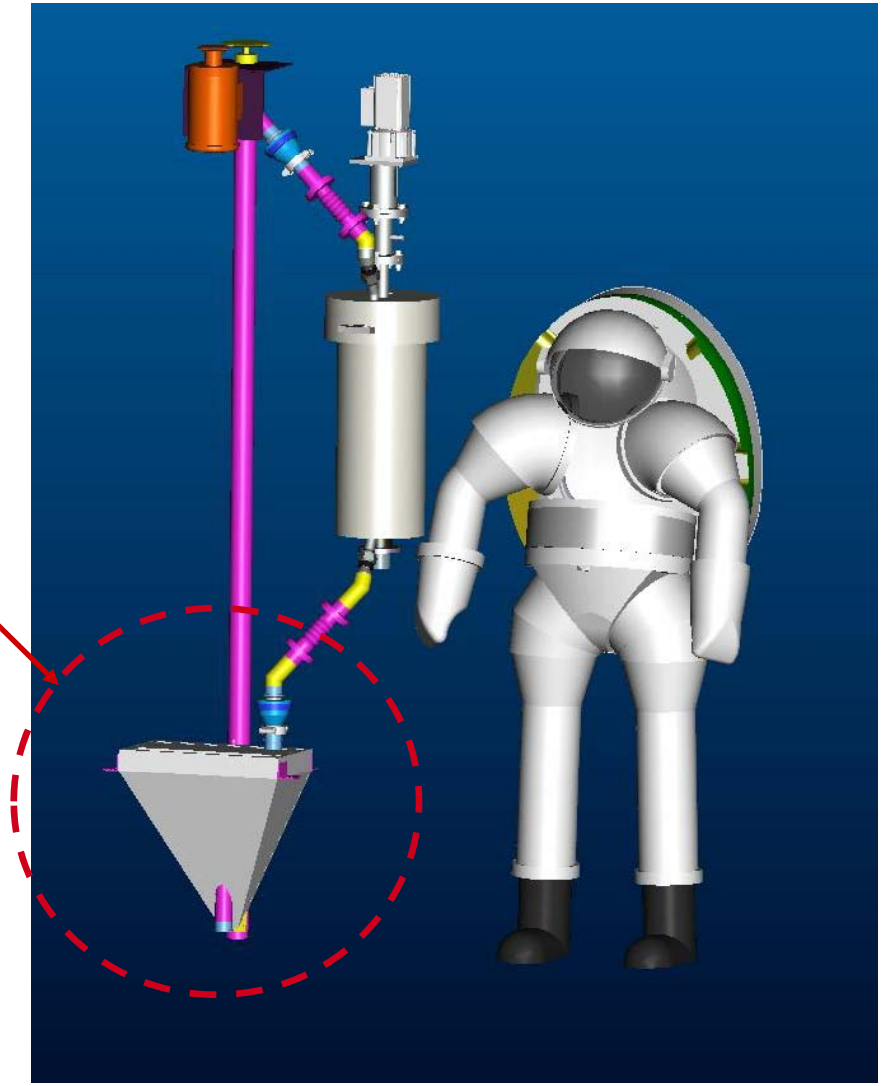
Regolith Feed System

Regolith Input Hopper



Hopper Flow Mock Up: JSC-1A

The hopper hourglass was constructed from clear acrylic plates and consisted of two inner hopper/outer hopper assemblies mated exit flange to exit flange.

RGF REGOLITH FLOW TESTING
REDUCED GRAVITY FLIGHT TESTING

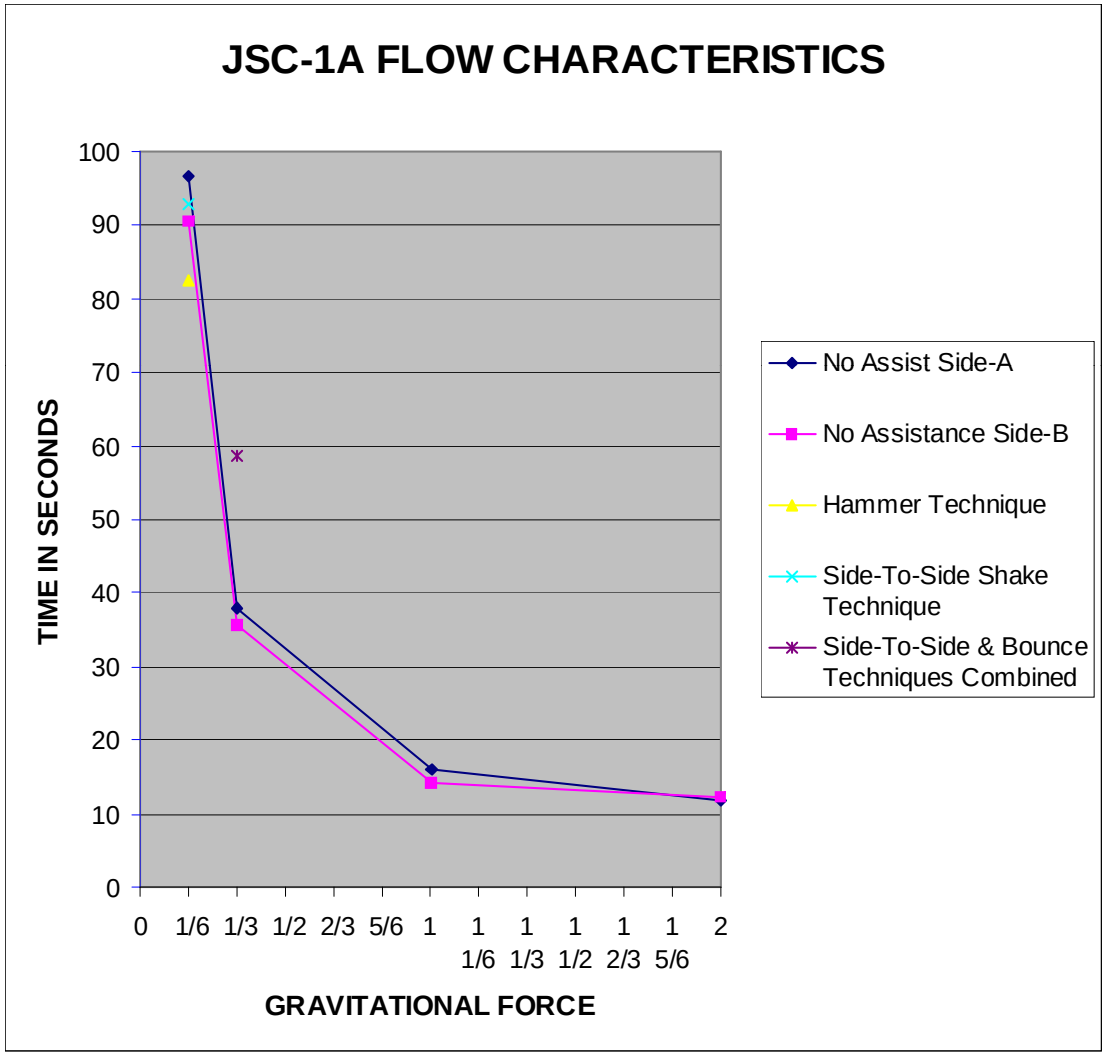
1/6G Hopper Flow Testing without flow enhancing assistance

RGF REGOLITH FLOW TESTING
REDUCED GRAVITY FLIGHT TESTING

Hopper Hourglass Assembly Testing on the NASA Reduced Gravity Flight using the hammer flow

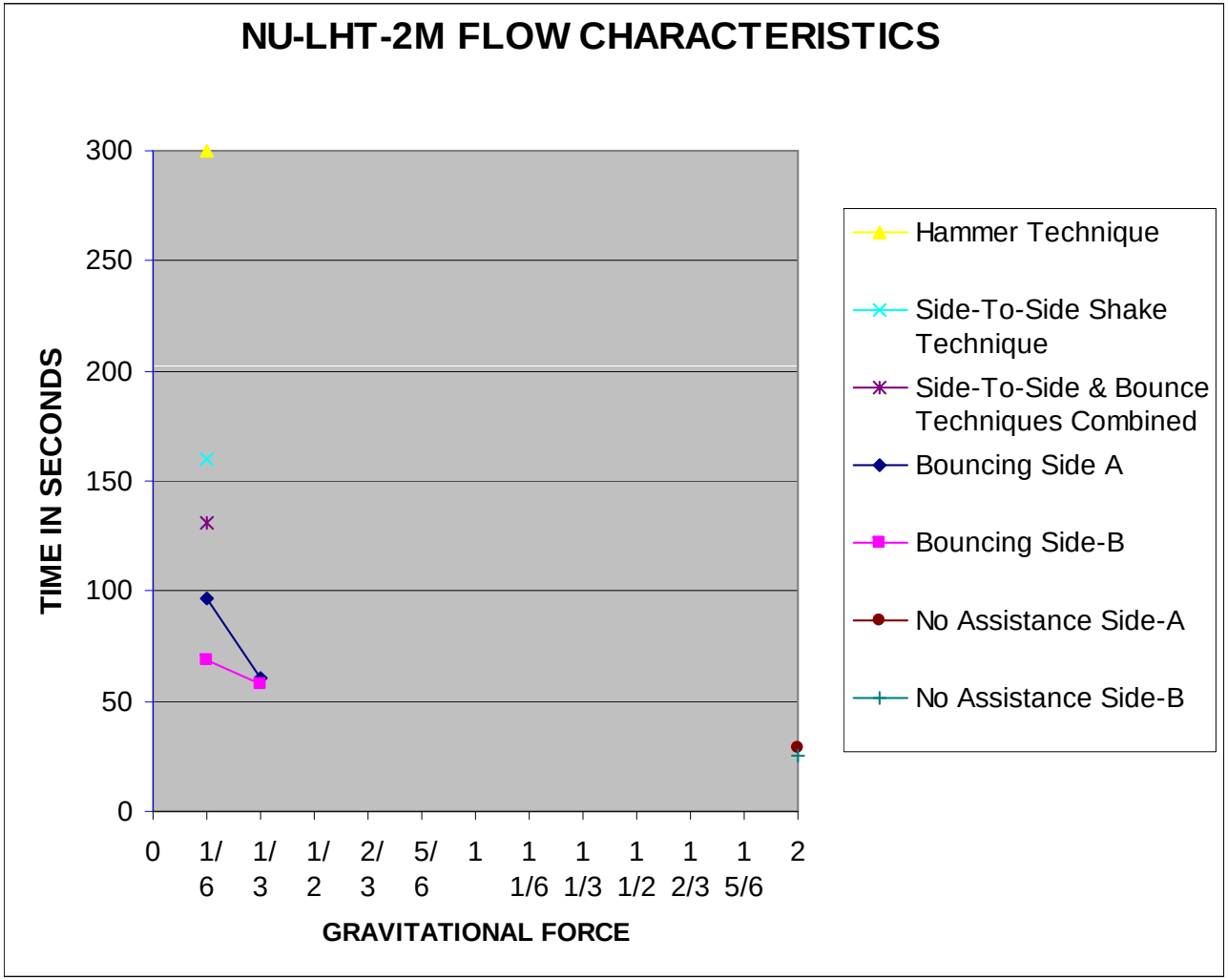
enhancement method. -Run Video

RGF REGOLITH FLOW TESTING
JSC-1A Lunar Simulant



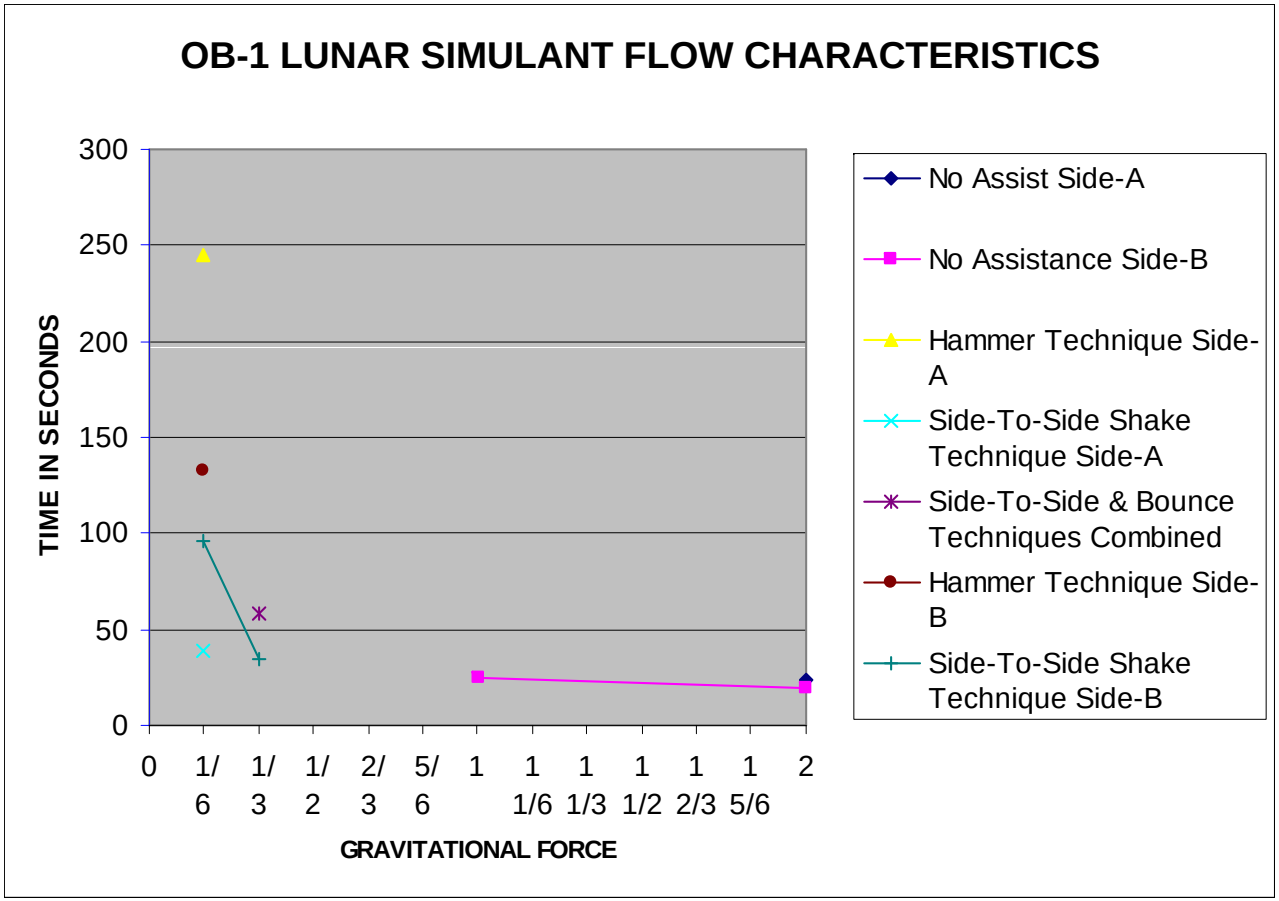
Flow characteristics of JSC-1A during Earth, Lunar, and Mars gravity force simulations on the C-9 Reduced Gravity Simulator Aircraft October 2008. The graph only shows points for the Side-To-Side Shake Technique and the Side-To-Side Shake & Bounce Techniques Combined because there was no data collected at other force levels. Side-A flowed faster than Side-B in each test. The difference in the hoppers is that Side-A has heat conduction fins installed where Side-B does not.

RGF REGOLITH FLOW TESTING
NULHT-2M Lunar Simulant



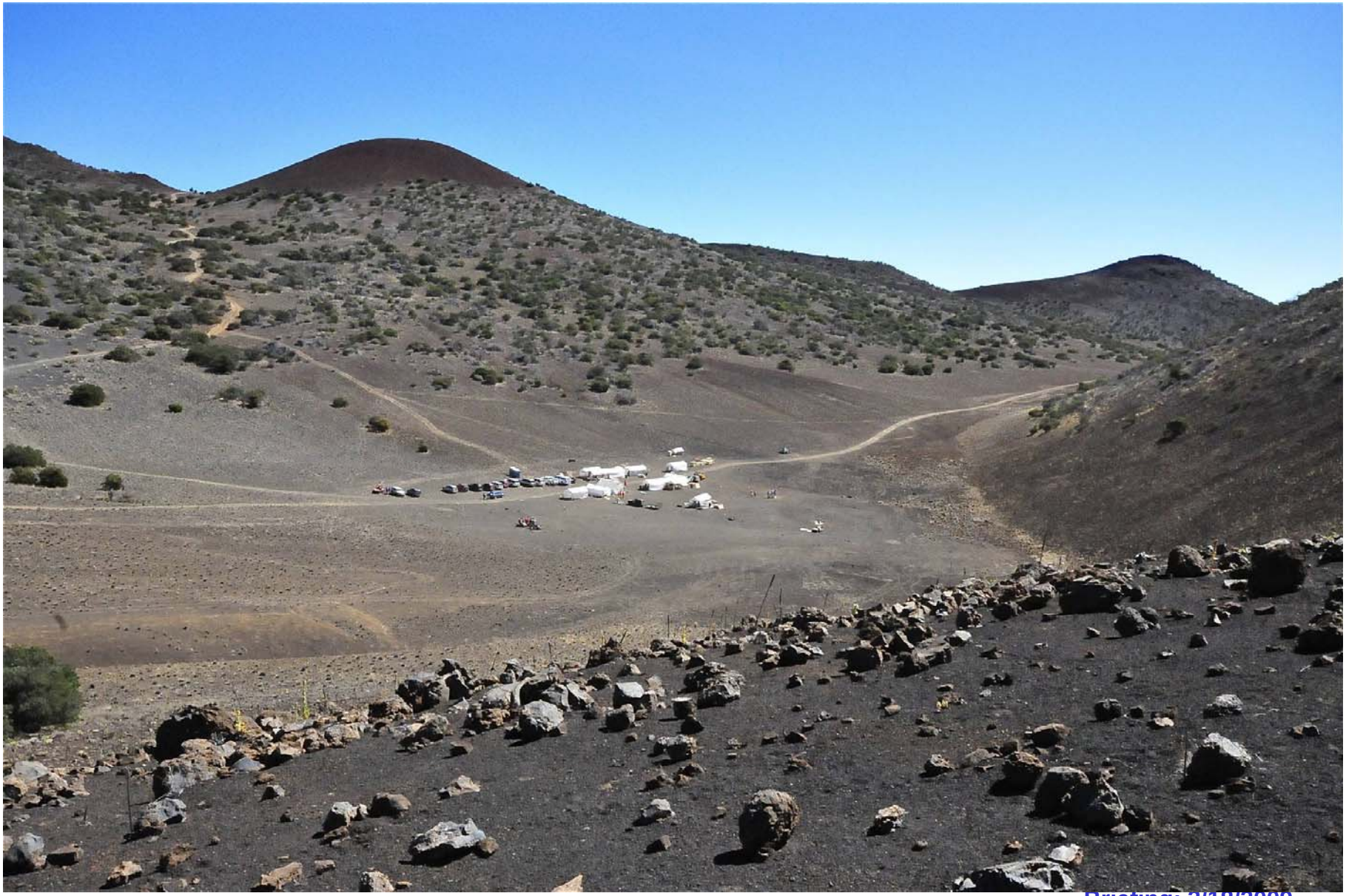
Flow characteristics of NU-LHT-2M lunar simulant during Earth, Lunar, and Mars gravity force simulations on the C-9 Reduced Gravity Simulator Aircraft October 2008. The graph only shows points for the Hammer Technique, Side-To-Side Shake Technique, and the Side-To-Side Shake & Bounce Techniques Combined because there was no data collected at other force levels.

RGF REGOLITH FLOW TESTING
OB-1 Lunar Simulant

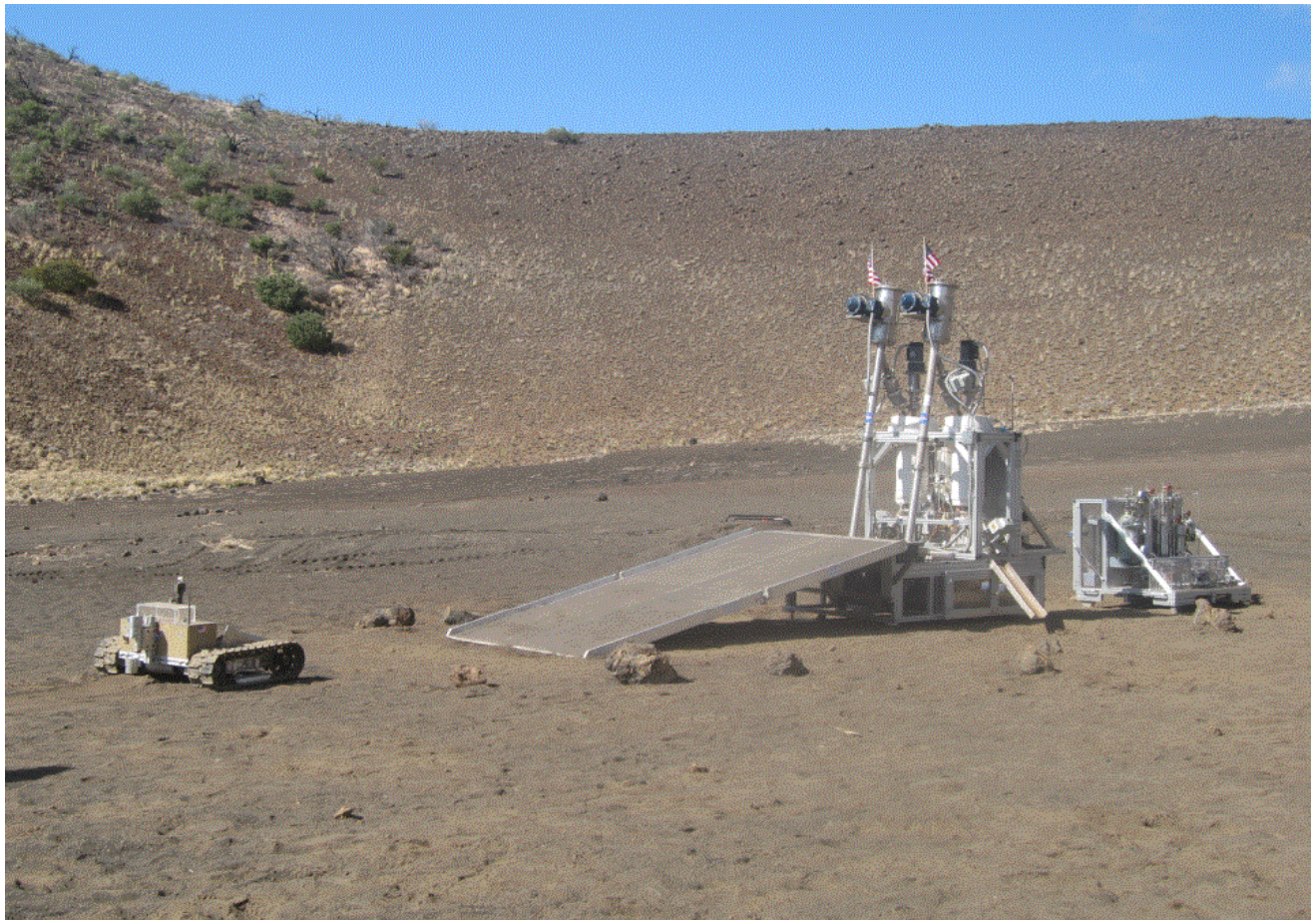


Flow characteristics of OB-1 lunar simulant during Earth, Lunar, and Mars gravity force simulations on the C-9 Reduced Gravity Simulator Aircraft October 2008. The graph only shows points for the No Assist Side-A, Hammer Technique Side-A, Hammer Technique Side-B, and the Side-To-Side Shake & Bounce Techniques Combined because there was no data collected at other force levels for that technique

Mauna Kea Volcano - Hawaii



Roxygen I at Field Test



The NASA ROxygen fluidized bed and auger hydrogen reduction reactor makes oxygen at approximately 660 kg/yr, which is about 2/3 of the scale required for the initial stages of a Lunar Outpost being designed for the NASA architecture (1000 kg/year).

Conclusions

- JSC-1A, OB1 and NU-LHT-2M simulants flow through the Roxygen hopper all behaved differently
- JSC-1A flow was intermittent but acceptable (with tapping) at all G levels tested
- OB1 and NU-LHT-2M did not flow at reduced gravity and needed flow assistance with a more aggressive bouncing technique (~ 3 Hz)
- Reduced Gravity Flight was very useful in accelerating development and discovering items needing improvement
- Opportunistic experiments on board the flight allowed new promising techniques to be developed
- Availability of various simulants from ETDP project collaborations were critical to flying this experiment – Thank you!
- Further analytical techniques are being developed to allow future design methods to evolve

Acknowledgements

- Exploration Systems Mission Directorate (ESMD) - Lunar Surface Systems Office (LSS)
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- ETDP – In Situ Resource Utilization Project
- ETDP – Dust Project
- NORCAT – OB1 Simulant
- Orbitec – JSC-1A Simulant
- MSFC / USGS – NU-LHT-2M Simulant
- Kennedy Space Center Prototype Shop
- JSC Reduced Gravity Flight Office – Ellington Field
- Zero G Corp.
- ETDP KSC POC – Karen Thompson
- KSC Leads - Dr. Carlos Calle, Nancy Zeitlin

Roxygen I RGF

- Backup Slides

RGF REGOLITH FLOW TESTING
NULHT-2M Lunar Simulant

- NU-LHT-2M Lunar Simulant Testing at 1/6G Using the Hammer Technique

  Testing showed that quicker taps with the hammer at approximately 1” amplitude and approximately 4 strikes per second enhanced flow better than slow hard strikes. This hammering technique took 15 parabolas to empty the B-Side hopper for a total time of 300 seconds at 1/6G.

  NU-LHT-2M Lunar Simulant Testing at 1/6G Using the Front-TO-Back Shake Technique

  Front to back vigorous shaking worked better than hammering. This shaking technique took 8 parabolas to empty the A-Side for a total time of 160 seconds.

  NU-LHT-2M Lunar Simulant Testing at 1/6G Using the Bounce Technique

  Bouncing the entire assembly off the floor of the aircraft worked better than both hammering and shaking with an amplitude of approximately 2” and frequency of approximately 3 bounces per second. A-Side took approximately 97 seconds on average to empty its contents. B-Side to approximately 69 seconds to empty its contents. Testing clearly showed that the bouncing technique was the best flow enhancing technique for this simulant.

RGF REGOLITH FLOW TESTING
OB-1 Lunar Simulant

Lunar Simulant at 1/6G
Both Side A and Side B did not flow without employing flow enhancement techniques.

OB-1 Lunar Simulant at 1/6G Using the Hammer Technique
Side A would flow until the hopper was empty using the Hammer technique in approximately 245 seconds. Side B would flow until the hopper was empty in approximately 133 seconds.

OB-1 Lunar Simulant at 1/6G Using the Side-To-Side Shake Technique
Side A would flow until the hopper was empty using the Side-To-Side Shake technique in approximately 102 seconds. Side B would flow until the hopper was empty using the Side-To-Side technique in approximately 96 seconds on average. This simulant showed that is would not flow without using flow enhancement techniques and that the Side-To-Side Shake technique allowed the simulant to flow more consistently and faster than the Hammer technique.

OB-1 Lunar Simulant at 1/3G
Side A simulant flow would randomly stop and require flow enhancing assistance but flowed well during most tests without assistance and displayed an average 38 seconds to empty the hopper. Side B simulant flow would occasionally stop flowing but flowed well for the majority of tests and displayed an average time of 34 seconds to empty the hopper.

RGF REGOLITH FLOW TESTING
OB-1 Lunar Simulant

OB-1 Lunar Simulant at 1G

The hopper hourglass assembly has heat transmitting fins on Side A and no fins on Side B. This simulant would begin to flow but would stop and did not flow reliably flow at 1G from side a without the use of flow enhancing techniques (Suspect the simulant was wet because it flowed better at 1/3G than at 1G, we should repeat the 1G testing). The flow would stop normally after approximately 25 seconds and would not re-start without the use of a flow enhancement technique.

OB-1 Lunar Simulant at 1G Using the Hammer Technique

Hammering did help the flow characteristics allowing the simulant to flow from the hopper in approximately 41 seconds. Hammering would allow constant simulant flow but the flow would stop if the hammering technique was not maintained. Side B without the heat transfer fins did exhibit simulant flow during most of the tests. The simulant flow would occasionally slow but did not stop allowing the hopper to empty its contents in approximately 25 seconds on average.

OB-1 Lunar Simulant at 2G

Both Side A and Side B flowed well during 2G runs and did not require flow enhancement techniques. Side A would empty the hopper in approximately 24 seconds. Side B would empty the hopper in approximately 20 seconds.