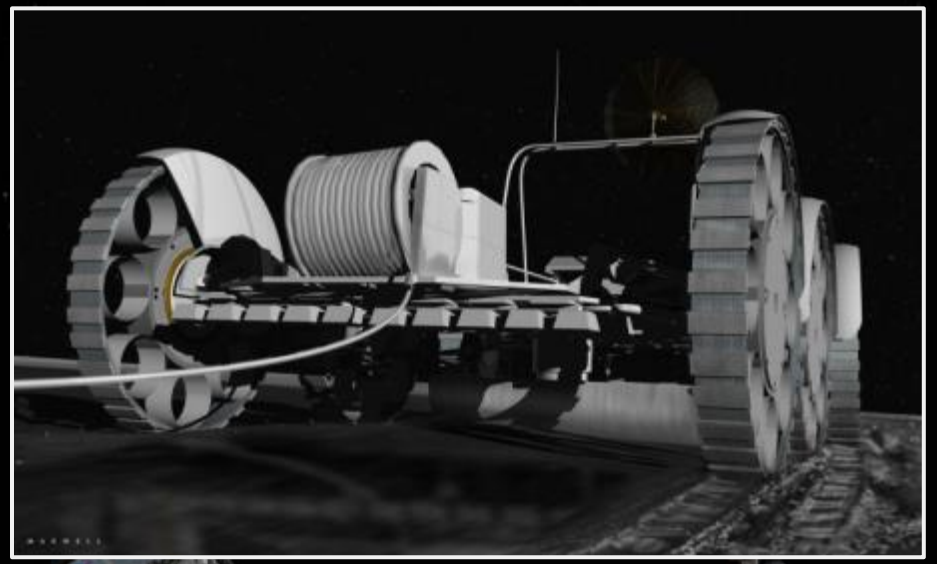
Planetary Basalt Construction & Material Science

PISCES / NASA KSC

Briefing to LEAG

Lunar / Mars Industrial Base



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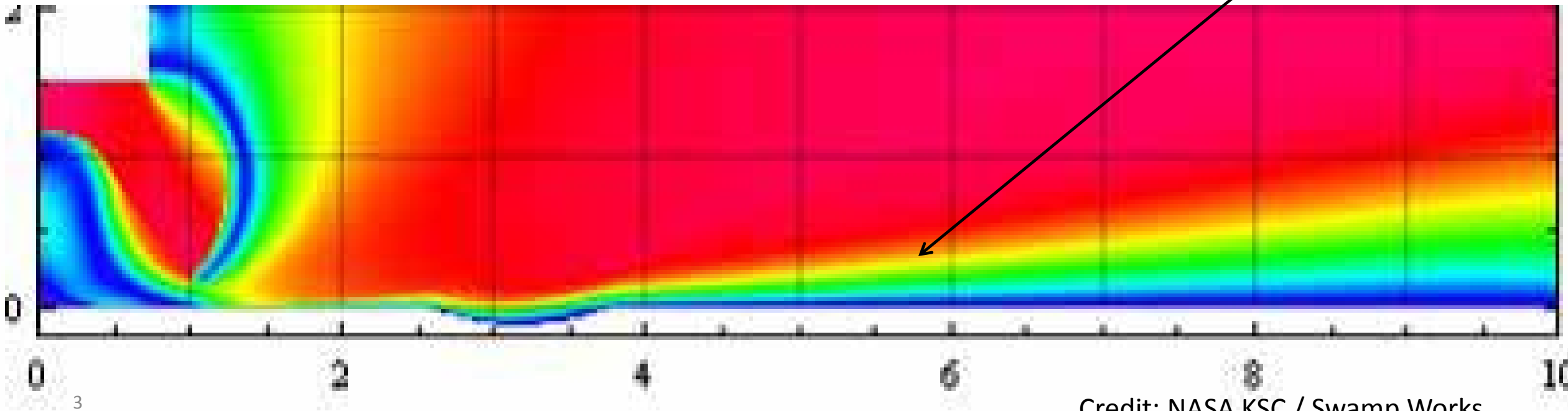
Material Science of Dust on the Lunar Surface

- Lander descent engines create high velocity / horizontal flow across surface
- Relatively flat sheet of dust (1-3 deg to surface)
  - Particles lifted by aero forces
- Total eroded and scouring volume: ~2MT
- Dust velocities can reach as high as 2000 m/sec

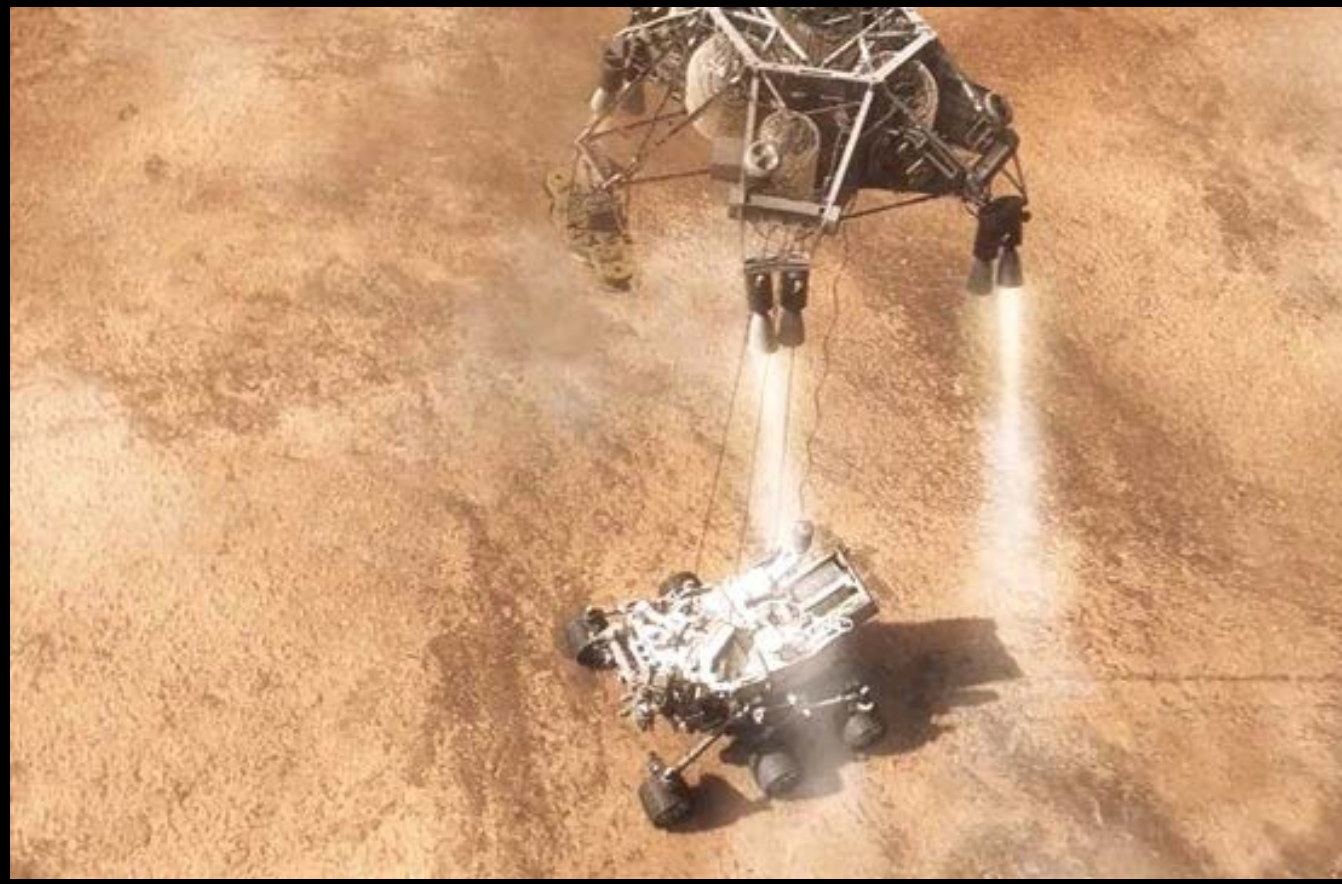


Credit: NASA KSC / Swamp Works

Skycrane / Curiosity Lander - Kicking up dust just prior to landing (60 meters)

EROSION

CONCLUSION - Need to sinter/stabilize the surface of Moon/Mars for VTVL pads



Planetary Construction Phase I – Basalt “lunar” sidewalk construction project – March 2015

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Basalt Rebar

PISCES PACIFIC INTERN EXPLORATION .GOV

COUNTY OF HAWAII

STATE OF HAWAII

UNIVERSITY of HAWAI'I MĀNOA

SWAMP WORKS
NASA KENNEDY SPACE CENTER

Planetary Construction Phase 2 – 2015 VTVL Basalt Pad Construction Demonstration

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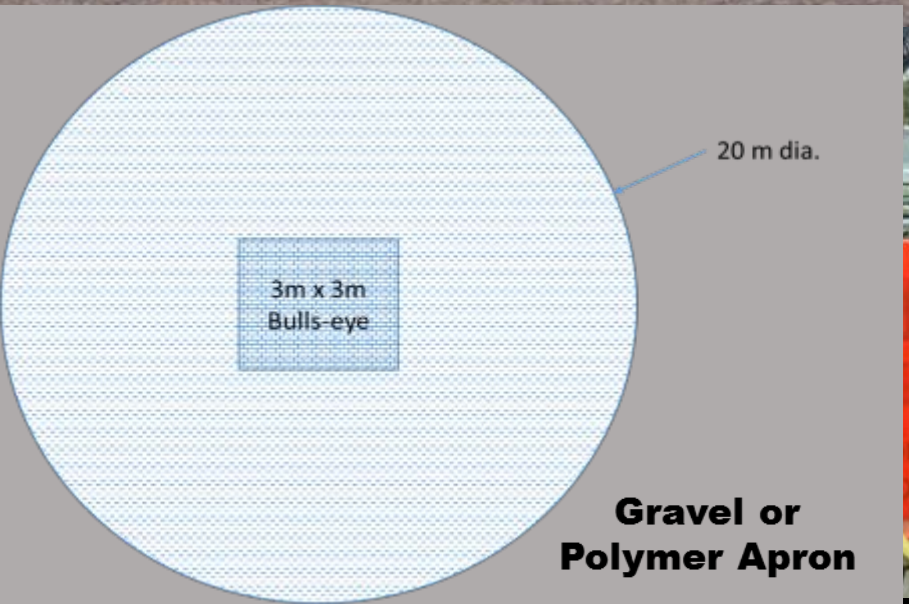
Credit: NASA Morpheus/JSC landing at KSC Hazard Field



Strategic Partners for ACME Landing Pad

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SWAMP WORKS
NASA KENNEDY SPACE CENTER

PISCES

Argo®

COUNTY OF HAWAII
OLA NA MOKU
STATE OF HAWAII

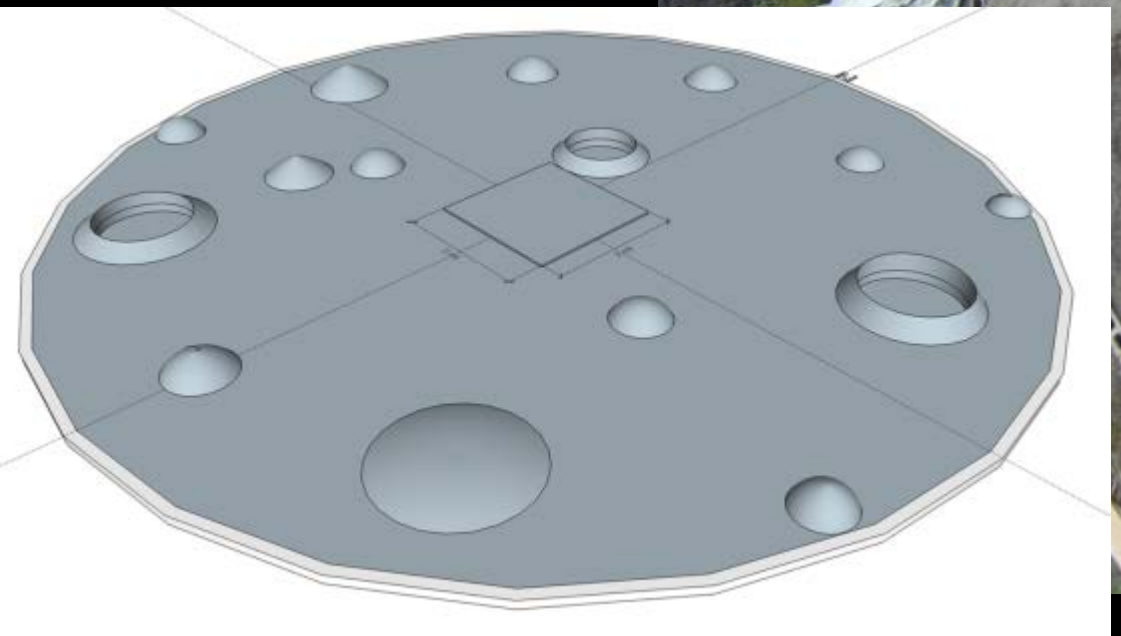
HONEYBEE ROBOTICS

End Goals for VTVL Pad Construction

1. **Be the first demonstration of robotic landing pad construction using planetary analogue material**
2. **Investigate construction materials made from basalt**
3. **Advance the TRL of robotic VTVL pad hardware and processes**
4. **Provide a gateway to fabricating VTVL pads in precursor space missions (prior to humans arriving) with in-situ resources**

Aerial view of the PISCES VTVL basalt lunar landscape

Sept 2015



60 ft

VTVL pad area before grading.

3m x 3m bullseye

“Lunar” crater in foreground

PISCES rover / KSC blade removing crown from bullseye pad

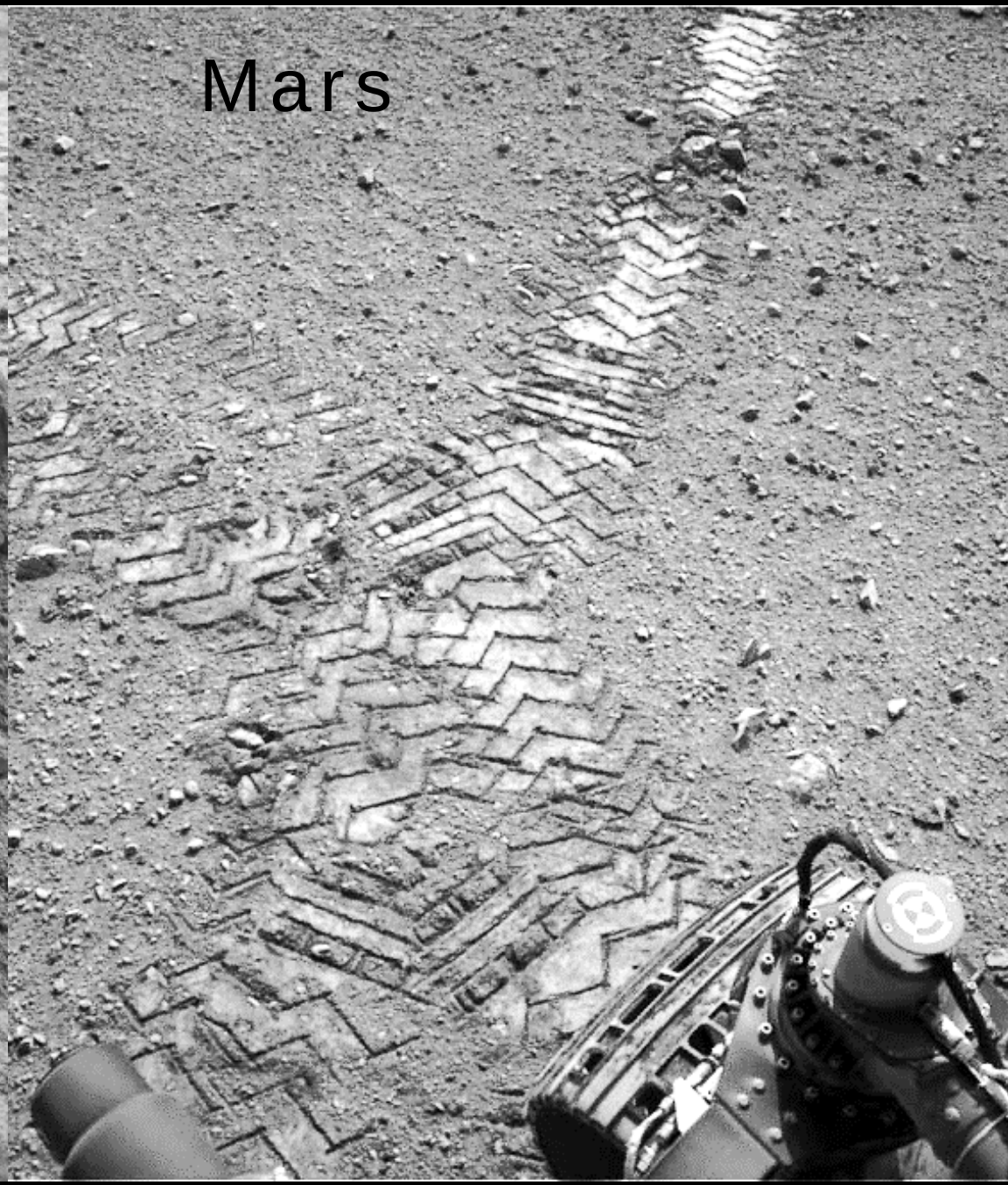
PISCES rover / KSC blade compaction operations of bullseye

Completed Technical Milestone #1

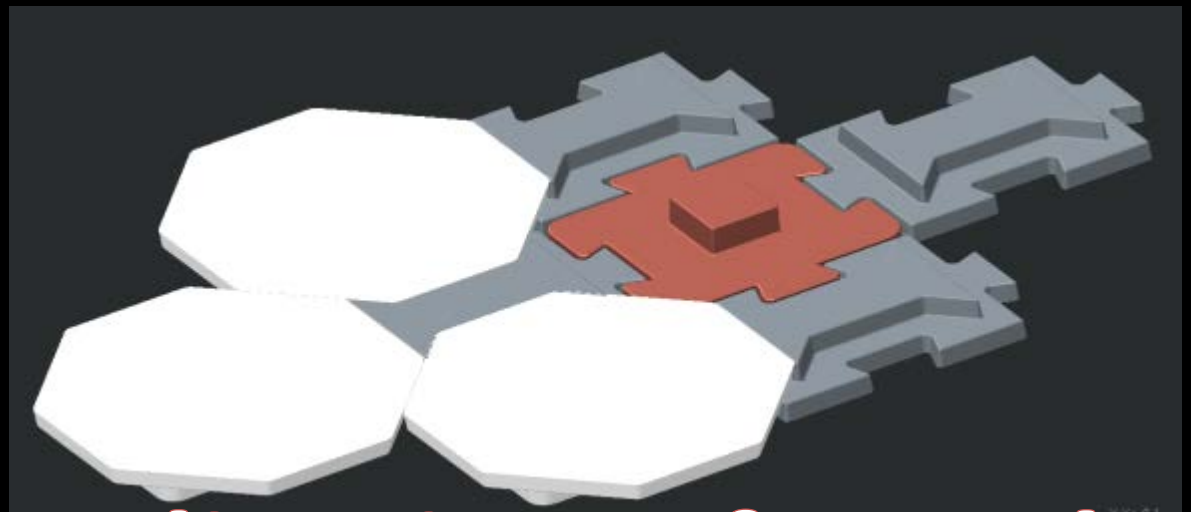
30 Sept 2015

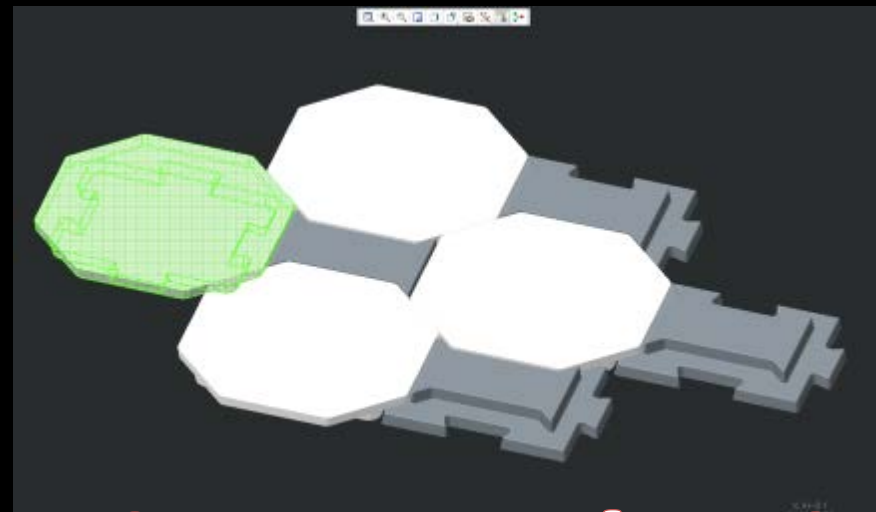
Tire imprints in the basalt fines.

Similar to prints on lunar / Mars surface



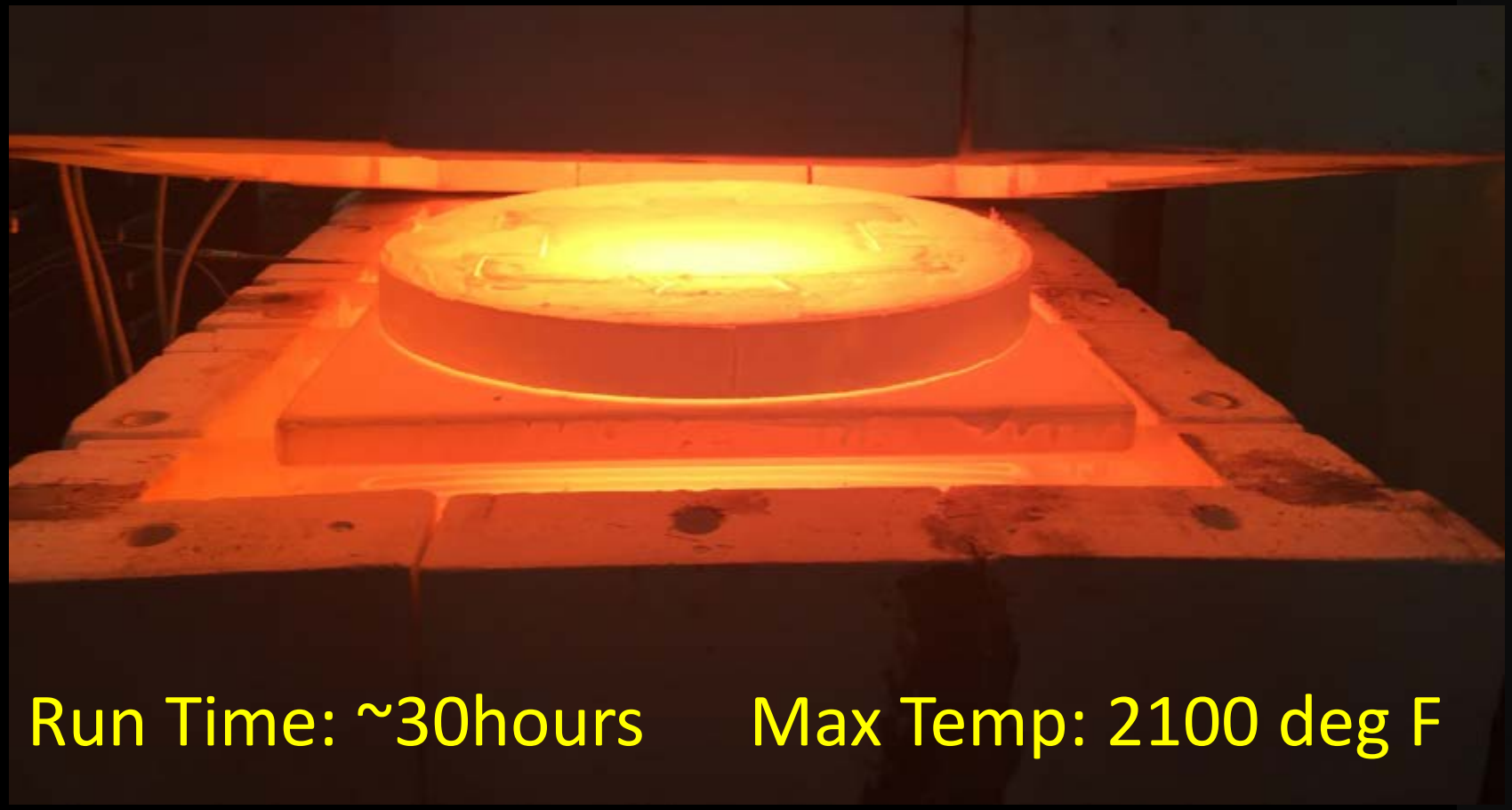
VTVL Landing Pad
Interlocking Paver System





Application of *Combustion Synthesis* for bonding/joining interlocking pavers?

VTVL Landing Pad Paver Fabrication



Run Time: ~30hours Max Temp: 2100 deg F

Landing pad paver April / May 2015

Material: Hawaii basalt fines

- **Nice defined edges**
- **Solid material**
- **Hot spot in oven at KSC**

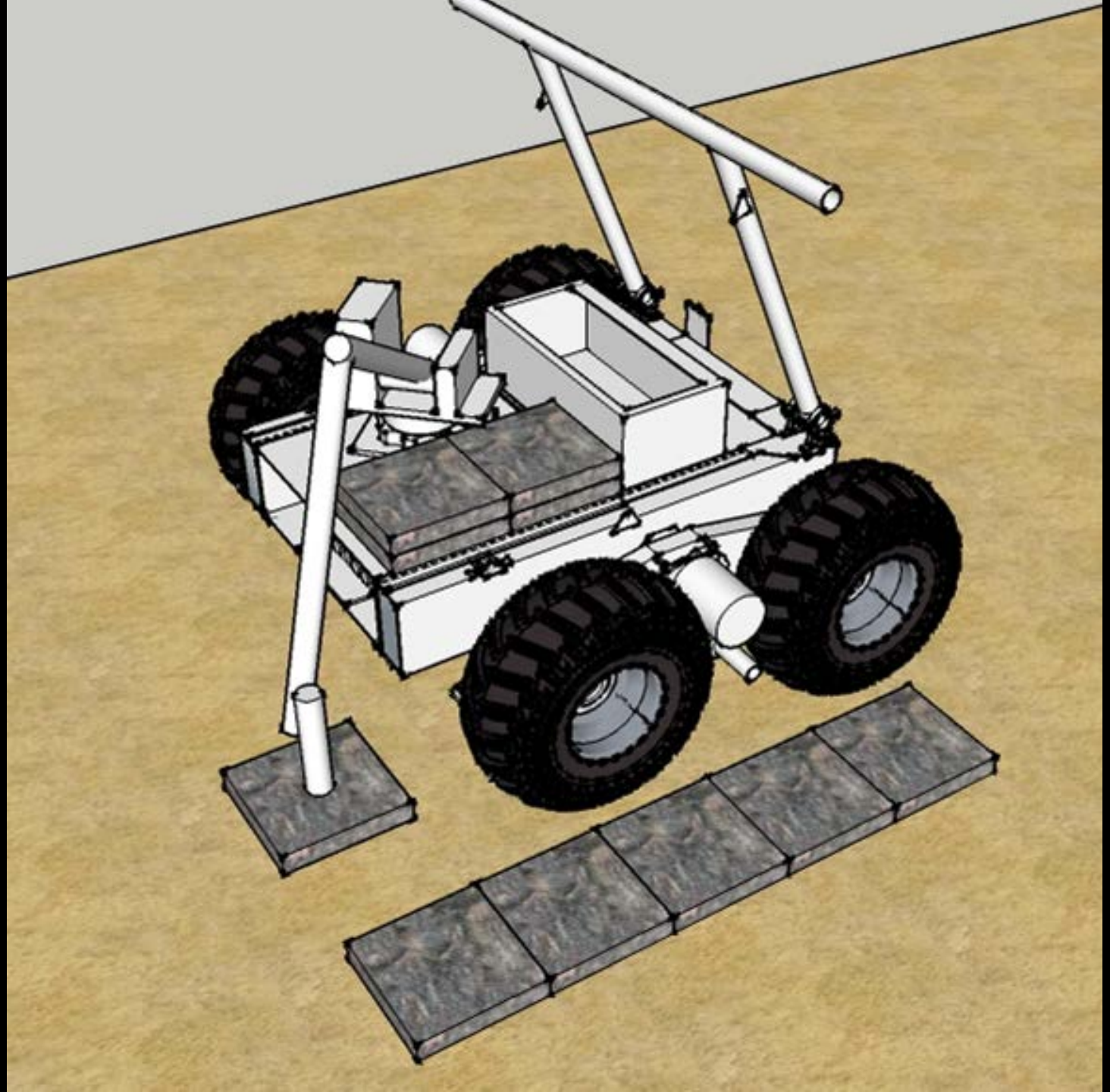
Landing pad paver June 11, 2015

SUCCESS!

Major breakthrough in paver development process

Paver Deployment Mechanism

Concept of Operations



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VTVL PAD TEST SCHEDULE

September:

- leveling, grading and compression of the bullseye pad

October:

- Data analysis from Sept tasks
  - ASTM nuclear gauge testing for density of compression
- PDM/robotic arm integration/test onto PISCES rover

November / December:

- tele-op, robotic paver construction

January:

- Ablation/erosion tests: cold gas, hot gas engine firings


Questions?

Payload / Instrument Processing

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Small-Sat Launch

Goal: A Thriving Commercial Aerospace Industry

Commercial Cis-Lunar

(NASA/Eagle Engineering artist Mark Dowman)

Planetary Sustainability (Basalt)

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PACIFIC INTERNATIONAL SPACE CENTER
EXPLORATION SYSTEMS | PISCES.HAWAI

Landing Pad Construction Phases

PHASE 1 – Prep the "lunar" site. Leveling and grading with PISCES rover/KSC blade. 50' x 50' area

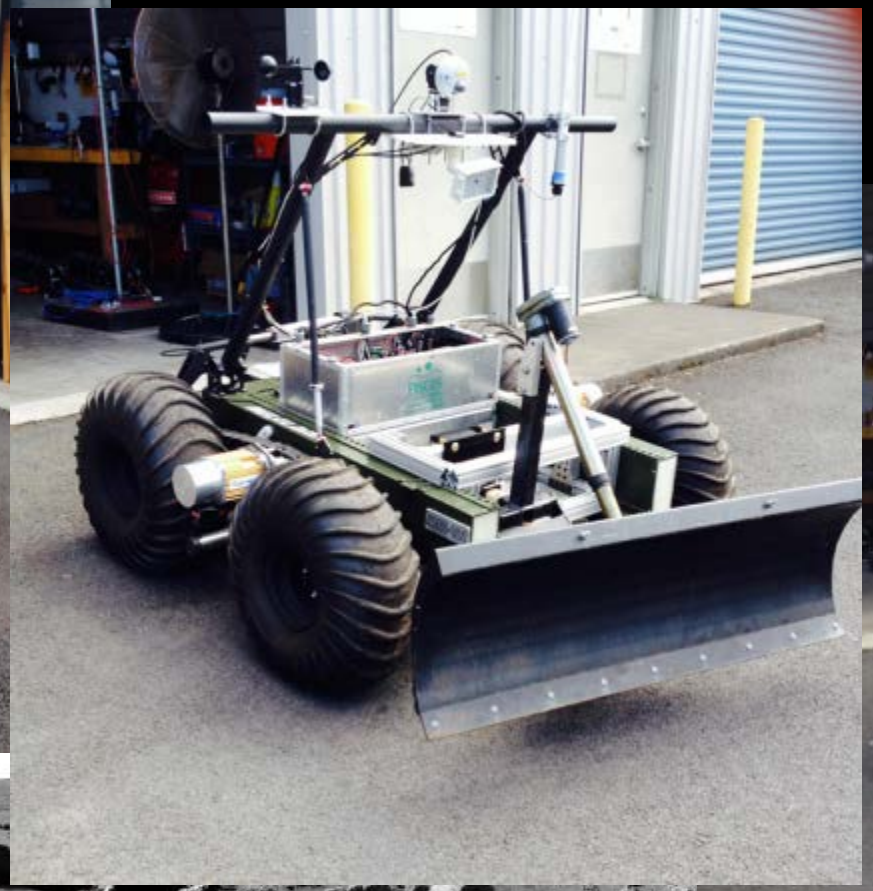
PHASE 2 – Compaction and fine finish. PISCES' blade on rover with sod roller attached. 10'x10' area

PHASE 3 – PISCES rover emplaces pavers using KSC PDM

PHASE 4 – PISCES rover/roller compact outer apron

PHASE 5 - Rover places/levels additional gravel on apron

Roles of the PISCES' Rover



Pioneering Space

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Goal – create economic development and hi-tech workforce by providing research and development in planetary surface systems for maturing technologies for sustainable operations on the Moon, Mars and asteroids.

Credit NASA NIAC / University of Southern California / Contour Crafting Corp

PISCES Strategic Plan Objective

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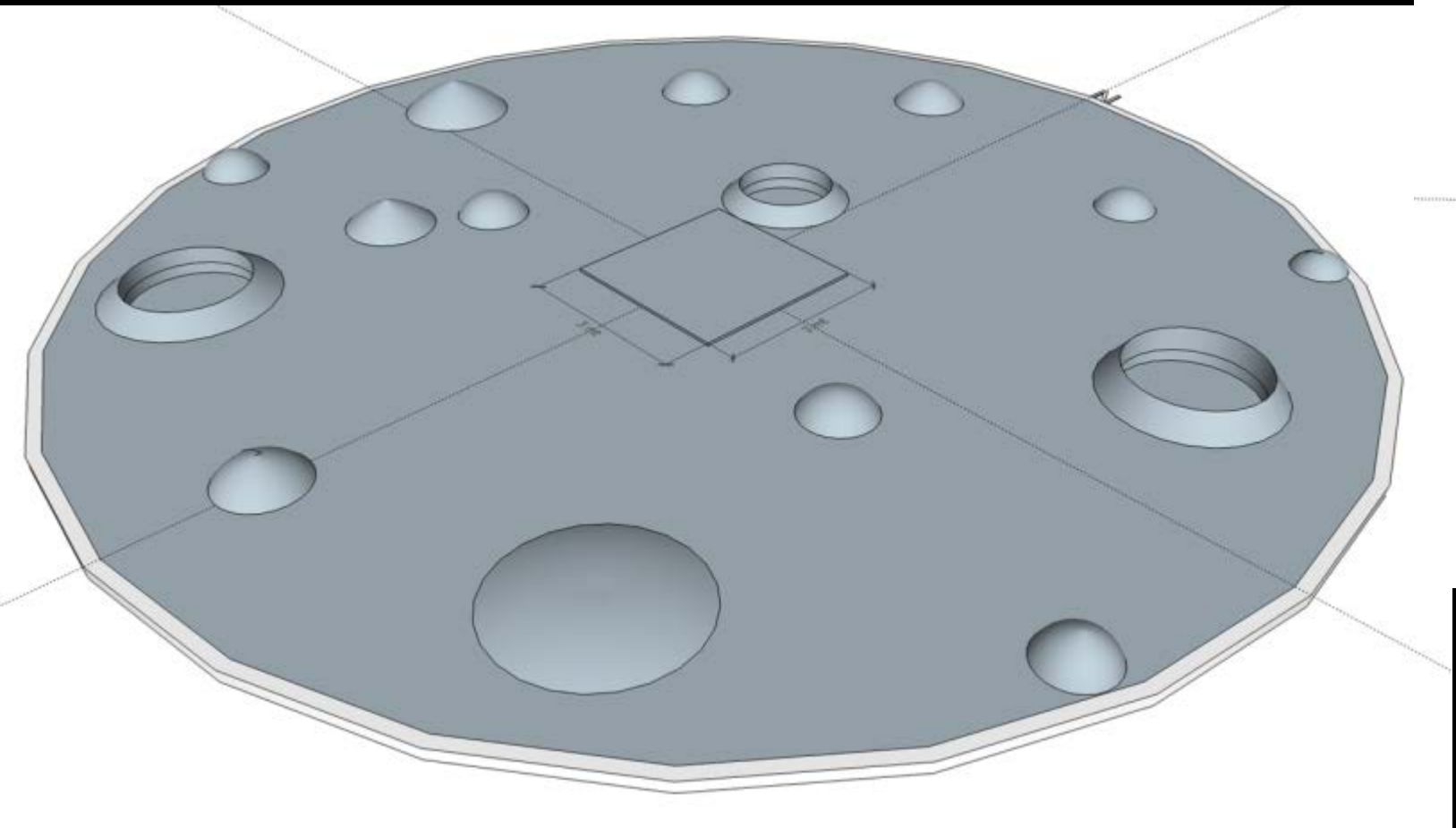
TECHNOLOGY DEVELOPMENT / DUAL-USE TECHNOLOGY IN:

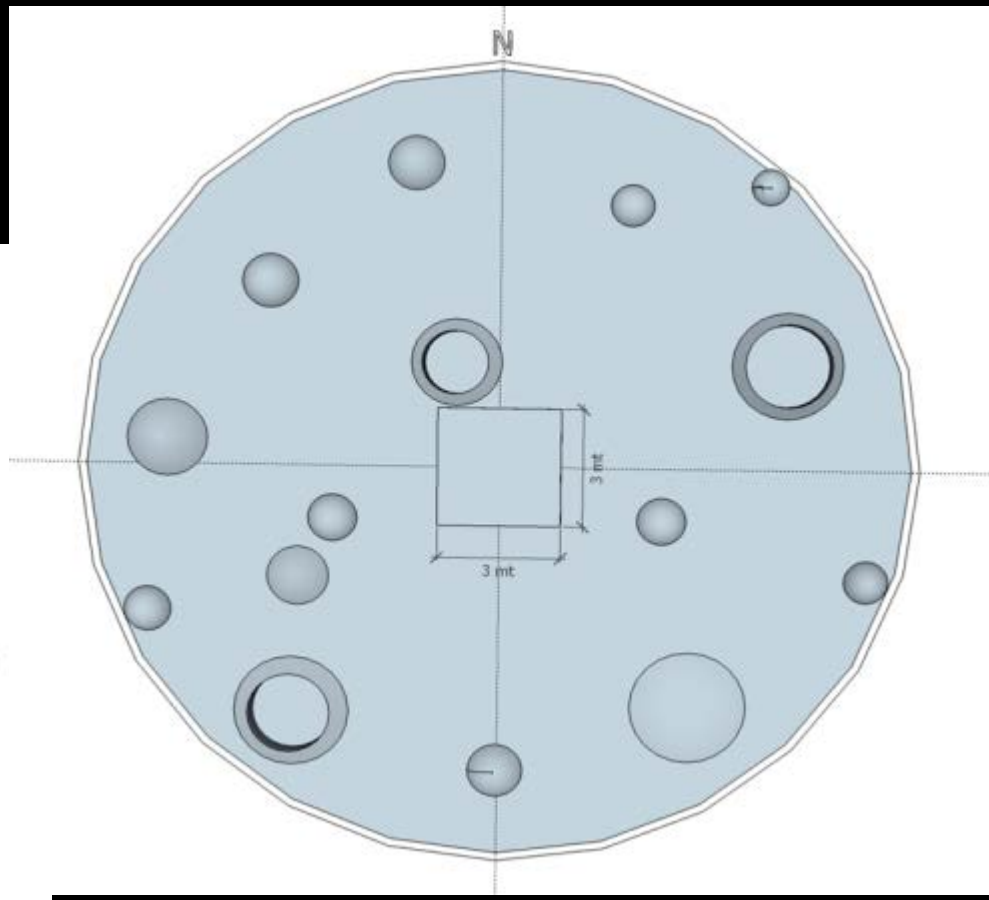
1. Basaltic construction (R&D)
2. PISCES Planetary Rover systems upgrade/integration
3. Expand the PISCES Planetary Analogue Test Site (PPATS)
4. PISCES lunar surface flight experiment – MoonRIDERS
5. International Robotics Mining Competition in Hawaii - PRISM
6. NASA Laser Communications Relay Demonstration (LCRD) and ground terminal
7. Workforce Development – Intern and Coop Program

Ceramic mold for interlocking paver

April 2015 –initial tests with interlocking pavers– but stress concentrations were causing cracking.

VTVL Lunar Analogue Site





Planetary Surface "Systems of Systems"

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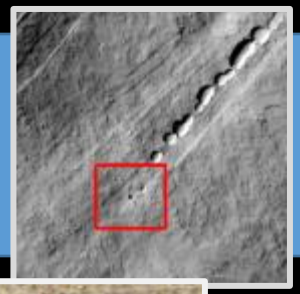
Planetary Site Characterization



Planetary Mobility

Planetary Construction

Operations/Flight Communications Network

PREPARE FUTURE MISSIONS