Regolith-Derived Heat Shield for Planetary Body Entry and Descent System with In-Situ Fabrication

Michael D. Hogue, NASA Kennedy Space Center
Robert P. Mueller, NASA Kennedy Space Center
Laurent Sibille, QNA ESC Kennedy Space Center
Paul E. Hintze, NASA Kennedy Space Center
Daniel J. Rasky, NASA Ames Research Center

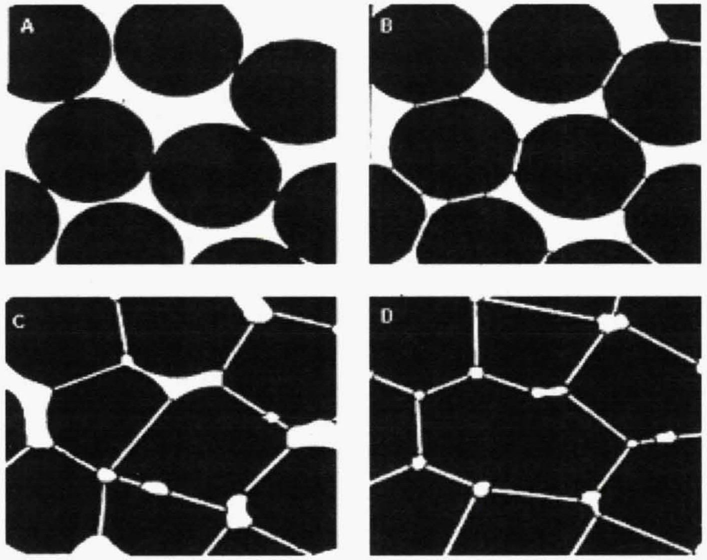
Introduction

- High-mass planetary surface access is one of NASA's Grand Challenges involving entry, descent, and landing (EDL).
- Heat shields fabricated in-situ can provide a thermal protection system for spacecraft that routinely enter a planetary atmosphere.
- Fabricating the heat shield from extraterrestrial regolith will avoid the costs of launching the heat shield mass from Earth.
- This project will investigate three methods to fabricate heat shield using extraterrestrial regolith.

Fabrication Methods Being Investigated

- Sintering of regolith
  - Furnace sintering
  - Solar sintering
- Hot post-process regolith from in-situ resource utilization (ISRU) devices.
  - ISRU processes to derive O_2 and other materials from regolith leaves a hot slag or glassy melt as a waste stream.
  - This hot regolith can be poured into a heat shield mold form.
- High temperature polymer binder

Sintering Process



Temperature and heating time are crucial factors in resulting structure.

Rocket plume exposed JSC-1A sintered tiles (Courtesy Dr. Phil Metzger/NASA KSC)

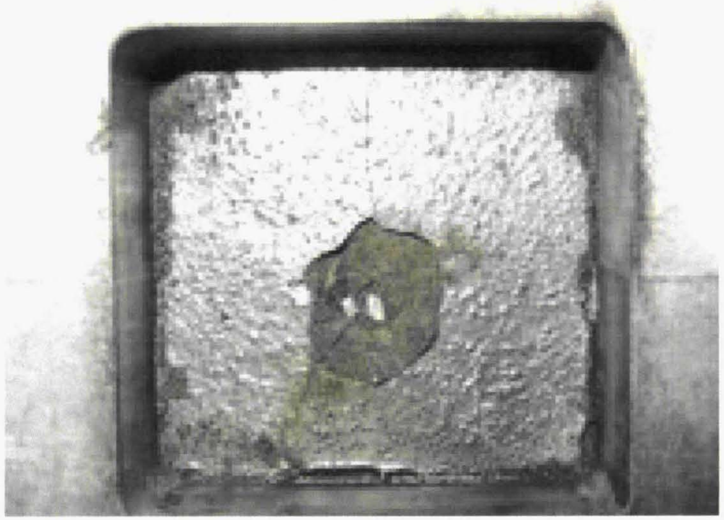
ISRU Process Waste

Use of waste stream from ISRU processes.

- Hot regolith can be poured into a heat shield mold.
- Saves energy by combining processes.

Hot Hawaiian tephra output from the ROxygen generation I oxygen production reactor.

High Temperature Polymer Binder



Regolith block made using a polymer resin.

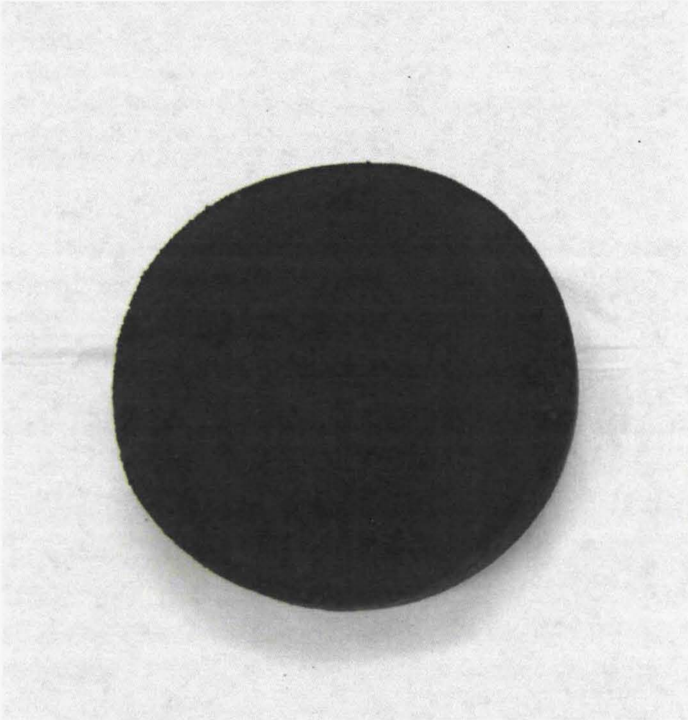
High temperature silicone based polymers are being investigated as binding agents for the regolith.

Progress to Date

- KSC is preparing to furnace sinter several 6” x 8” x 1” test tiles using both JSC-1A Lunar and JSC-1 Martian regolith simulants. Solar sintering experiments have been deferred until summer when sunlight is stronger.
- These tiles will be evaluated by physical testing and subjected to flame impingement tests (via a welding torch).
- A high temperature, space rated, silicone based polymer has been identified for use as a binder agent. Regolith to binder ratios will be tested for strength and heat resistance.

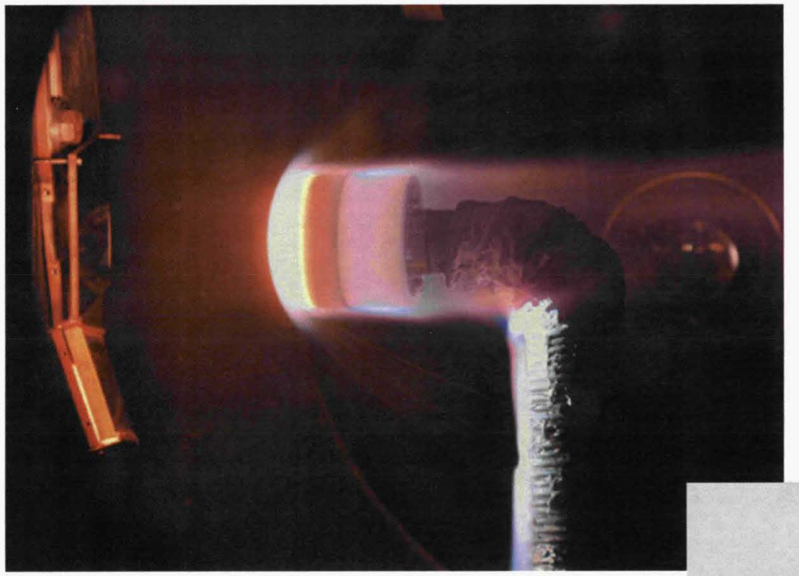
KSC Internal Torch Testing

- KSC is making three inch diameter test tiles of all three fabrication methods from both lunar and martian regolith simulants.
- These tiles, as well as final arc-jet test coupons will be subjected to high temperature flame impingement from a welding torch.
- Both rear face and front face temperatures will be recorded via a thermocouple (back face) and an IR camera (front face).

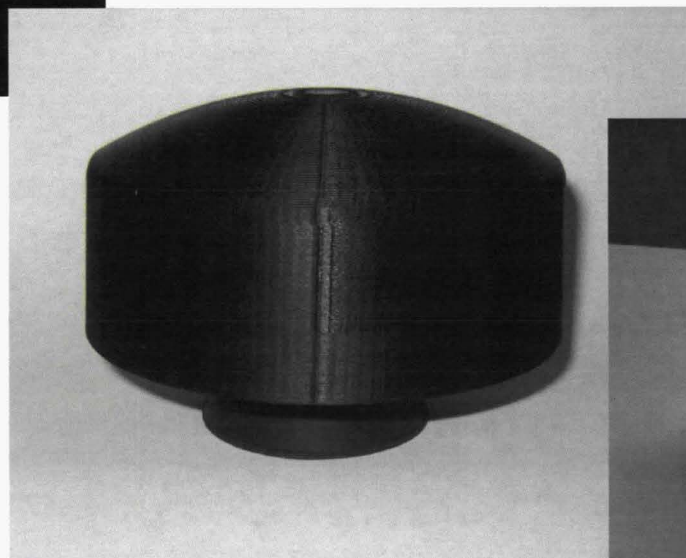


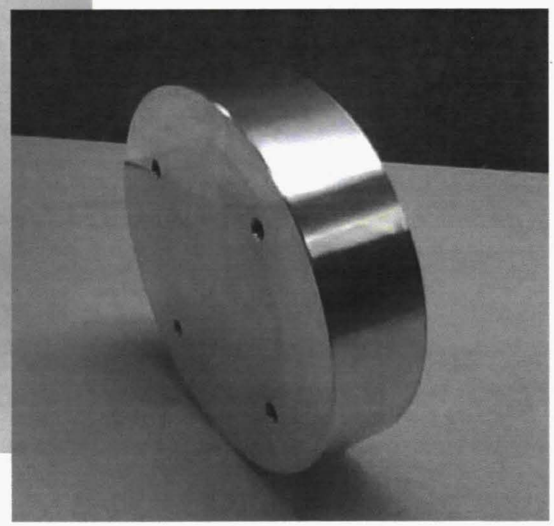
3" diameter sintered JSC-1AC lunar regolith simulant (1125°C).

Arc-Jet Testing



- KSC will fabricate multiple regolith simulant coupons for testing at the arc-jet facility at ARC.
- The arc-jet facility can model the thermal and kinetic environment of atmospheric entry.





- Test coupon and back plate designs are complete.
- Mold plugs were fabricated to create molds for the coupons.

Architecture

- Architecture benchmark is the Mars NASA Design Reference Architecture, DRA 5.0, modified to use Mars entry heat shields fabricated on Phobos or Deimos.
- With a TPS mass of 40.7 metric tons and a gear ratio* of 5, the LEO to **Mars Mass savings is 203.5 metric tons**.
- Using expendable launch vehicles (~$8,800/kg) the cost savings per Mars mission is $1.79 Billion.
- With 10 crew rotations (20 missions) in a Mars campaign using the regolith heat shields, the total cost savings would be **about $35.8 billion.**

* Gear ratio is the ratio of mass required in LEO to deliver one mass unit to Mars orbit.

Mars Moons Taxi Architecture

Deimos Operations Orbit:

20,063 km circular orbit
0.9 deg, 1.26 day period

Phobos Operations Orbit :

5981 km circular orbit
1 deg, 0.32 day period

Notional Deimos Heat Shield Additive Fabrication Strategy OR Notional Phobos Heat Shield Additive Fabrication Strategy

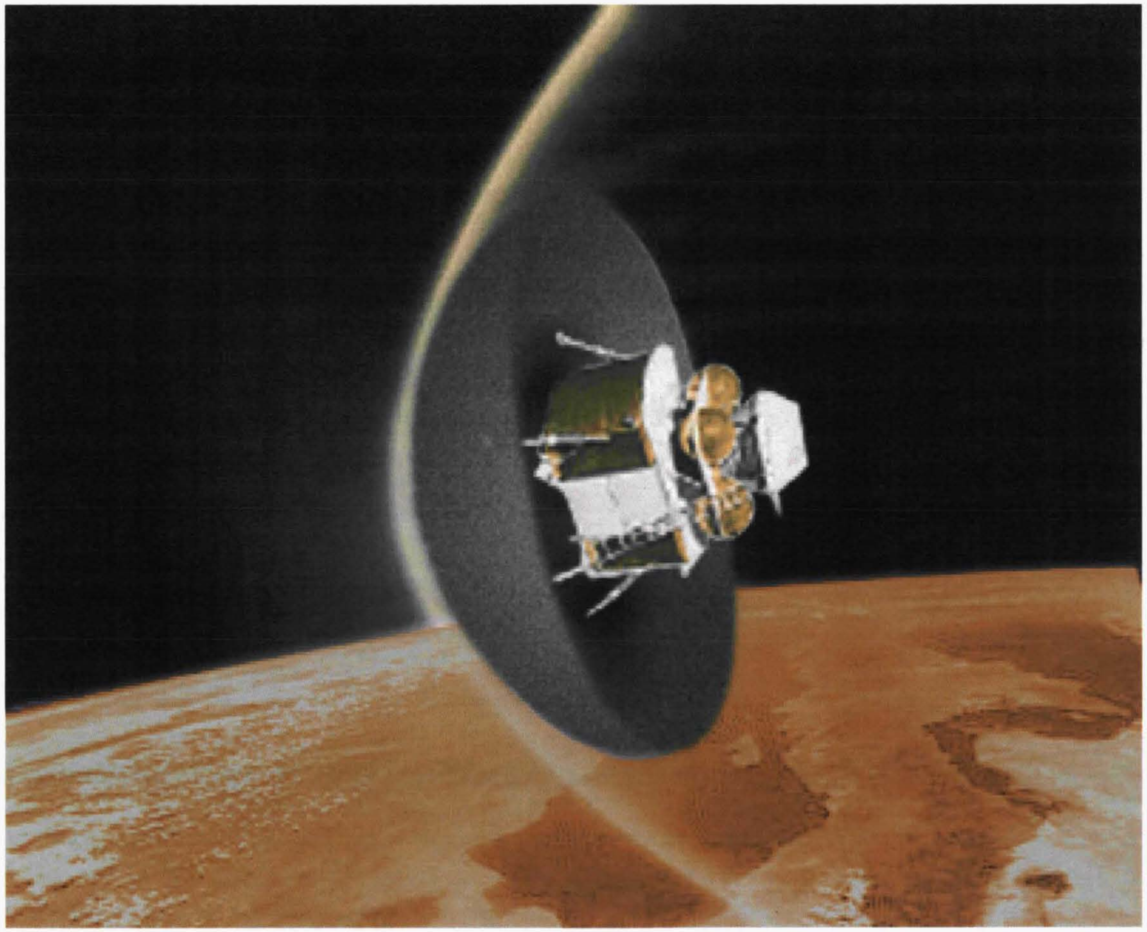
Notional Deimos Heat Shield Additive Fabrication Strategy

1. Capture into a 1-sol parking orbit with proper plane change to Deimos inclination
2. Lower Mars Transfer Vehicle to Deimos orbit (653 m/s delta-v required)
3. Prepare for orbital operations
4. Utilize a spacecraft to explore Deimos numerous times with an orbital survey and surface sampling
5. Spacecraft inserts four hard point anchors into the regolith
6. Counter Rotating Bucket Drum Surface Contour Excavator prepares an elliptical surface
7. One surface layer of regolith is hardened by spacecraft ops
8. Surface Excavator repeats step 6 to deposit another layer of loose regolith
9. Repeat Step 7
10. Repeat Steps 6-10 until Regolith Heat Shield thickness is achieved
11. Remove Heat Shield from the surface by attaching to hard point anchors, releasing anchors and thrusting off with the spacecraft
12. Install onto Mars Entry, Descent and Landing (EDL) Vehicle in Orbit
13. Proceed to Mars EDL with a De-Orbit Burn
14. Release Heat Shield after hypersonic entry, during Descent operations
15. Land on Mars
16. Launch from Mars to Deimos using ISRU propellants
17. Repeat steps 5-16

Notional Phobos Heat Shield Additive Fabrication Strategy

1. Capture into a 1-sol parking orbit with proper plane change to Phobos inclination
2. Lower Mars Transfer Vehicle to Phobos orbit (1,437 m/s delta-v required)
3. Prepare for orbital operations
4. Utilize a spacecraft to explore Phobos numerous times with an orbital survey and surface sampling
5. Spacecraft inserts four hard point anchors into the regolith
6. Counter Rotating Bucket Drum Surface Contour Excavator prepares an elliptical surface
7. One surface layer of regolith is hardened by spacecraft ops
8. Surface Excavator repeats step 6 to deposit another layer of loose regolith
9. Repeat Step 7
10. Repeat Steps 6-10 until Regolith Heat Shield thickness is achieved
11. Remove Heat Shield from the surface by attaching to hard point anchors, releasing anchors and thrusting off with the spacecraft
12. Install onto Mars Entry, Descent and Landing (EDL) Vehicle in Orbit
13. Proceed to Mars EDL with a De-Orbit Burn
14. Release Heat Shield after hypersonic entry, during Descent operations
15. Land on Mars
16. Launch from Mars to Phobos using ISRU propellants
17. Repeat Steps 5-16

Artist's Concept of a Regolith-Derived Heat Shield



Summary

- Building a viable heat shield in-situ from regolith will greatly reduce the transport costs of Missions to Mars or other bodies where atmospheric entry is required.
- Three in-situ fabrication techniques are being investigated to build the heat shields.
- Optimal methodology, shield structure, density, and thermal conductivity are being developed.
- This technology can be applied to other regolith based structural components such as habitats, berms, and landing pads.