Microwave Sintering Lunar Landing Pads & Horizontal Infrastructure

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Microwave Structure Construction Capability Element Lead

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Agenda

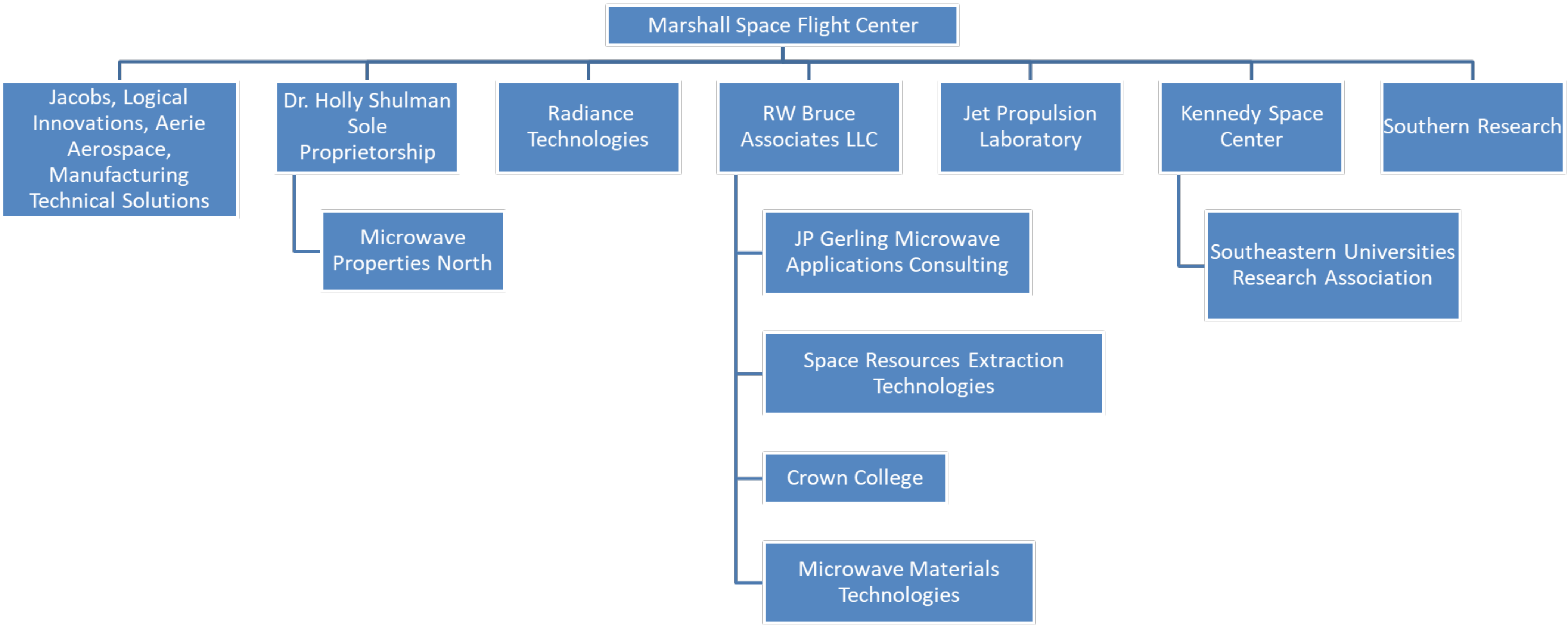
- Overview
- Technical Challenges
- Current status
- Forward Work
- Summary

Microwave Structure Construction Capability (MSCC) Overview

- **Goals**
  - Mature the technology and capability to emplace in-situ-based construction materials on the Moon to form infrastructure elements (horizontal infrastructure, e.g., landing pads, roads, etc.)
  - Develop and demonstrate microwave sintering of lunar simulants that can be used to form infrastructure on the Moon for a mid-sized payload (e.g., 2mT microwave paver vehicle)

- **Objectives**
  - Develop microwave sintering protocols/processes and horn/applicator designs
  - Demonstrate microwave sintering construction of subscale structures

MSCC Team Partners



Technical Challenges

- **ConOps**
  - Initial system concept of operations (ConOps) definition that have high specific area sintered/power in reasonable time with functional simplicity and robustness
- **Simulant & Synthetic Minerals**
  - The number of variables in the lunar regolith that might affect microwave absorption characteristics & resulting ceramic properties is very large (e.g., distributions of particle size, shape, composition, etc.)
  - Simulants needed to perform the necessary tests are too limited in specifications and availability
  - Parameter space can not be explored directly and definitively via large scale experiments
  - Lack of lunar highland type and other simulants

Technical Challenges

- **Site Prep**
  - Terrain surveying in high light contrast conditions
  - Lunar regolith typically compacts less than terrestrial simulants, with larger void ratios
  - Degree of uniformity of prepared regolith layers to meet microwave sintering requirements
  - Dust generation during site preparation may lead to navigation, positioning errors and consequently construction errors
- **Design**
  - System that can survive lunar night
  - Accurate temperature dependence of lunar simulant permittivity and other physical parameters (thermal conductivity and specific heat)
  - Thermal management system for paver vehicle
  - Power available with respect to construction time
  - Design of a applicator that can work continuously in a lunar environment while exposed to an 1100C radiant surface and volatiles

Technical Challenges

- **Microwave Sintering**
  - Regolith is a super insulator that prevents conduction of heat from the surface
  - Develop accurate method for determining temperature when sintering takes place for ground testing
  - Gain understanding of the heating profile and depth of penetration of the microwaves into the regolith
  - Development of procedures for applicator such that it can withstand the heat and volatile generation without significant degradation
  - Determine (and develop optimized energy efficient process) mass sintered simulant densified per hour with magnetron from -200C to sintering temperature, accounting for porosity, and mitigating thermal runaway

Technical Challenges

- **Testing**
  - Obtaining vacuum capability for certain testing (e.g., thermal & mechanical properties)

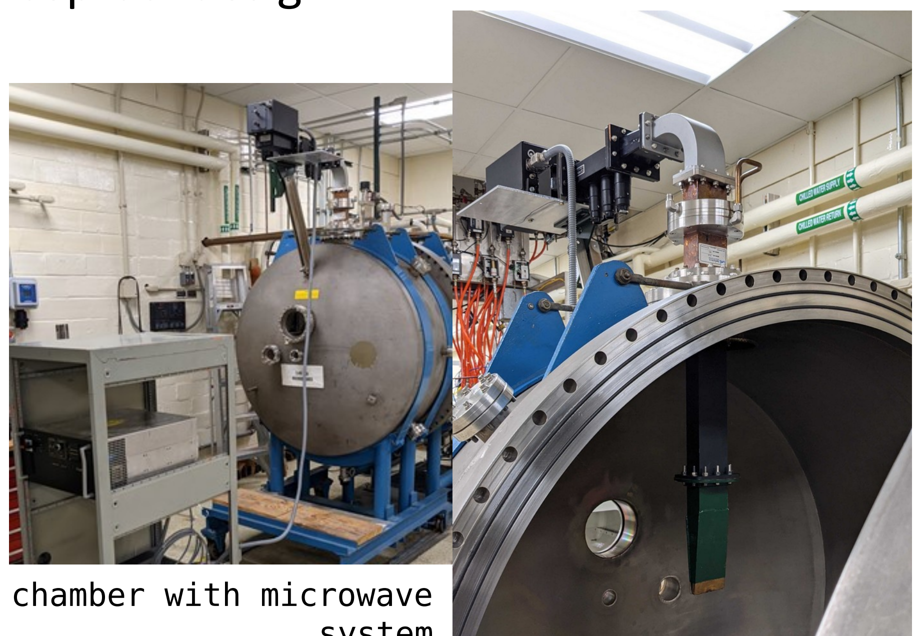
- **Ancillary Instruments**
  - Ceramic product verification with non-uniform porosity, thickness, and graded density
  - High temperature measurement of off-gas products from a sintering operation

(20 ft. diameter x 28 ft. long), Existing vacuum chamber system
Credit: NASA

2006 1kW microwave heater before vacuum chamber testing
Credit: NASA

Current Status

- Three contracts awarded
- Building up and activating microwave sintering testing facilities at Alfred University, JPL, Radiance Technologies & MSFC
- Initiated simulant heating modeling using HFSS and COMSOL (JPL, Space Resources Extraction Technologies, & MSFC)
- Initiated microwave sintering vehicle conceptual design



4’ diameter TVAC chamber with microwave system
Credit NASA

Forward Work

- **Known Gaps**
  - Generating process monitoring instrumentation
- **Forward leveraging planned**
  - Flight site preparation vehicle (rock removal, leveling, etc.)
  - Tailor mass spectrometer and other existing flight volatile identification systems to MSCC needs
  - Tailor microwave radiometer and/or thermography for temperature measurements
  - Tailor terrain mapping and applicator positioning instruments
- **Solar power amplification and transmission to solar cells**
- **Flight microwave sintering vehicle PDR, CDR, fabrication, assembly, testing, software, automation, con-ops, mobility system, guidance navigation and control, and delivery**

- **Not required to complete paving job, but useful for increased lunar human sustainability**
  - Integration of any volatile collecting systems from OTHER projects (likely on 2nd generation paver)
  - Apply principles to the beneficiation/extraction of minerals and other lunar resources
  - Apply principles to vertical structure fabrication

Summary

- MSCC is a broad & deep industry, academia, and multi-NASA Center team with extensive microwave and site preparation experience that will enable TRL 6 achievement for process and hardware that will ultimately yield a microwave sintered landing pad on the Moon
- MSCC has multiple design and testing paths to achieve optimal solution (i.e., competition within)
- MSCC has two design and test cycles for multiple technologies (i.e., design, test, incorporate lessons learned in redesign)
- MSCC is developing some ancillary technology necessary to enable landing pad fabrication (i.e., site preparation, volatile characterization on ground, & ceramic landing pad in-situ verification)