General Information

Title of Technology Development: 3D Additive Construction with Regolith for Surface Systems

Responsible NASA Mission Directorate or Office: Center Innovation Fund

NASA Lead Center or Facility: Kennedy Space Center

NASA Supporting Centers and Facilities: Jet Propulsion Laboratory

NASA Program: Center Independent Research & Developments: KSC IRAD

NASA Project: 13733

NASA Program Executive: Karen Thompson

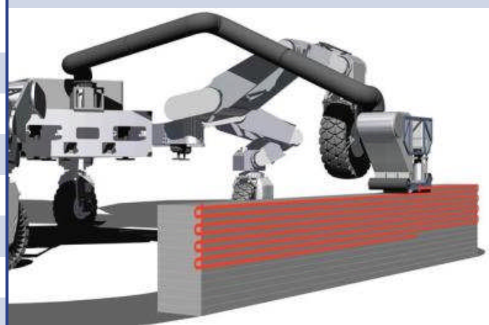
NASA Program Manager: Nancy Zeitlin

NASA Project Manager: Robert Mueller

Principal Investigator: Robert Mueller

States with Work: FL, CA

Contractors Performing Work: QinetiQ North America/ ESC



Sources of Funding

NASA Mission Directorates or Offices Providing Funding/Resources: Center Innovation Fund

NASA Centers and Facilities Providing Funding/Resources: Kennedy Space Center

Other U.S. Government Agencies Providing Funding/Resources: No data provided

U.S. External Partners Providing Funding, Academia or Commercial: University of Southern California

International Partners Providing Funding/Resources: No data provided

Technology Project's Mappings

Primary Space Technology Roadmap - Technology Area: TA 7: Human Exploration Destination Systems

– Detailed Primary Space Technology Roadmap - Technology Area: TA 7.2: Sustainability & Supportability

Secondary Space Technology Roadmap - Technology Area: TA 4: Robotics, TeleRobotics & Autonomous Systems

Additional Space Technology Roadmap - Technology Area: TA 6: Human Health, Life Support & Habitation Systems, TA 14: Thermal Management Systems, TA 9: Entry, Descent & Landing Systems, TA 12: Materials, Structures, Mechanical Systems & Manufacturing

Project Details

Project Start Date: May-01-2013 **Project End Date:**Jun-01-2014

Project Start TRL: 2 **Project End TRL:** 3

Brief Description (abstract) of Technology Project: Planetary surface exploration on Asteroids, the Moon, Mars and Martian Moons will require the stabilization of loose, fine, dusty regolith to avoid the effects of vertical lander rocket plume impingement, to keep abrasive and harmful dust from getting lofted and for dust free operations. In addition, the same regolith stabilization process can be used for 3 Dimensional (3D) printing, additive construction techniques by repeating the 2D stabilization in many vertical layers. This will allow in-situ construction with regolith so that materials will not have to be transported from Earth. Recent work in the NASA Kennedy Space Center (KSC) Surface Systems Office (NE-S) Swamp Works and at the University of Southern California (USC) under two NASA Innovative Advanced Concept (NIAC) awards have shown promising results with regolith (crushed basalt rock) materials for in-situ heat shields, bricks, landing/launch pads, berms, roads, and other structures that could be fabricated using regolith that is sintered or mixed with a polymer binder. The technical goals and objectives of this project are to prove the feasibility of 3D printing additive construction using planetary regolith simulants and to show that they have structural integrity and practical applications in space exploration.

Technical Performance Measures:

Measure	Unit	Quantity

Description of Capability This Technology Provides: Surface Systems applications on Asteroids, the Moon, Mars and Martian Moons will require the stabilization of loose, fine, dusty regolith to avoid the effects of rocket plume impingement, to keep abrasive and harmful dust from getting lofted and for dust free operations. In addition, the same regolith stabilization process can be used for 3 Dimensional (3D) printing, additive construction techniques by repeating the 2D stabilization in many vertical layers. This will allow in-situ construction with regolith so that materials will not have to be transported from Earth. Examples of extra-terrestrial infrastructure that can be constructed using this technology are: landing pads, blast protection berms, roads, dust suppression surface stabilization, parking lots, radiation and micro-meteorite shelters, thermal shade structures, thermal wadis, hangars and habitats.

Anticipated Benefit to NASA for Funded Missions: 3D Additive Fabrication is already planned to be demonstrated on the International Space Station (ISS). Polymer parts will be printed on ISS by Made in Space inc. This will prove the feasibility of "Massless Exploration" where parts can be made on the ISS with zero mass transported from Earth. The European Space Agency also plans to 3D print parts on ISS but made from a metallic powder feedstock. The possibilities and benefits are tremendous, so these initial steps are important to learn how to deal with the unique space environment especially micro-gravity. Future feedstocks will include raw planetary regolith and feedstocks derived from the regolith such as aluminum, iron, titanium, platinum and magnesium. The lessons learned from the ISS efforts will be rolled into this technology development effort and vice versa.

Anticipated Benefit to NASA for Unfunded/Planned Missions: The logistics required to set up a human outpost on another planetary surface are vast and prohibitively expensive. Space transportation costs are high, so the corresponding value of In-Situ Resource Utilization (ISRU) to make structures and spare parts using local materials is also high. By developing new technologies to transport, position, emplace, bind and from a net shape with regolith, parts and structures can be built on Asteroids, the Moon, Mars and other moons so that a robust logistics space mission architecture will result which means higher reliability and safety. 3D printing is a game changer due to it's efficiency and digital manufacturing methods which allows electronic computer files to be uploaded from Earth to a space destination and then structures and parts can be constructed or fabricated using local resources.

Anticipated Benefit to Commercial Space Industry or Other Government Agencies: In addition terrestrial spinoffs are also possible. The state of Hawaii has expressed interest in using this sustainable technology to build structures and roads using locally available in-situ volcanic lava basalt as a spin-off technology to build Hawaiian civil infrastructure such as sidewalks, roads, bridges, support structures and housing. By avoiding the importation of raw materials such as asphalt, Portland cement, pavers and bricks, the state of Hawaii will gain economically and reduce its dependence on good imported from the mainland. Raw basalt materials from the volcanic Hawaiian islands could be exported world wide, making Hawaii a net exporter of construction materials. Currently houses cost hundreds of thousands of dollars to construct. By using 3D additive construction, it will be possible to reduce the construction cost of the primary structure by a factor of ten. Affordable housing will result in an increased standard of living for billions of people worldwide. Rapid deployment of 3D Additive Construction robots will make it possible to quickly and efficiently build disaster relief housing using locally available granular materials such as sand or crushed rock.

Detailed Description of Technology Project

This project uses the knowledge gained from several NASA SBIR contracts (Ceralink, Adherent, Honeybee), USC NIAC, and the KSC NIAC Regolith Derived Heat Shield project that was tested in the Ames Arc Jet Test Facility. These results indicate that the unique properties of granular planetary regolith are well suited for use as a construction material with high insulation values, low densities and good manipulation characteristics. Examples of regolith manipulation processes are solar heat sintering, microwave sintering, laser sintering, polymer binders, compaction, regolith paste extrusion and waterless concrete forming . Methods of transferring regolith to a “3D Print Head” mounted on a robotic arm will be developed to investigate the feasibility of adhering the regolith particles together in successive 2D layers to achieve a 3D printing additive manufacturing proof of concept process with net shape characteristics of useful structures such as blast walls, landing pads, habitats, bricks, roads, antenna towers, heat shields and even propellant tanks. This will result in high mass savings as local in-situ regolith is without transporting material and equipment from Earth. Power consumption per product kilogram is determined for each transfer method.