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# SPACE-DRUMS® A COMMERCIAL FACILITY FOR THE ISS

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## ABSTRACT

Space-DRUMS® was developed to satisfy an internationally agreed science requirement for a containerless processing facility that could handle large objects, 5 to 10 cm in diameter. There were three approaches investigated by the international community:
Electrostatic by Japan, magnetic by Europe and acoustic by Canada, NASA researched all three. Guigné, (GIL) through the Canadian Space Agency proposed an acoustic solution based on a dynamically responding acoustic matrix system that only applied controlling forces when an object moved out of a control zone.
Guigné in discussions with the Colorado School of Mines, (CSM), formed a joint interest in trying to make glass, glass ceramics and metal ceramics using Self-Propagating High Temperature Synthesis, (SHS), (Combustion Synthesis). Guigné became the industrial partner for CSM and together founded the Center for Commercial Applications of Combustion in Space. This Center was one of 15 centers set up under the NASA Space Product Development, (SPD) Program. These centers had to reorganize to meet the NASA Exploration agenda through the Innovations Partnership Program (IPP). The NASA Innovation Partnership Program is now sponsoring Space-DRUMS®. With the new NASA Programs Space-DRUMS is searching for a new Sponsor and is working with BioServe, U of Colorado, Boulder.

## INTRODUCTION

Space-Dynamically Responding Ultrasonic Matrix System (DRUMS™), Space-DRUMS™ was conceptualized to process materials of a commercial size and quantity a containerless environment on the International Space Station. In the past Scientists and Industry reported that they required containerless processing of baseball sized materials before they could see the benefits of conducting such experiments in space. Guigné responded by developing the technology that can process and/or control up to a three-inch diameter solid mass and up to 4.5-inch diameter liquid (1.5Kg). Guigné met the challenge in a pathfinder role providing this capability as the first commercial facility on the ISS. As such they have been developing a client base. Guigné having initially designed the facility for containerless experiments and processing made a few modifications that have adapted Space-DRUMS™ to also accommodate container experiments. In addition, the facility has been developed for an EXPRESS rack and built in functional modules, such that, other payloads can use each module without having to down mass the Space-DRUMS™ module. The concept of plug and play was used.
Lighter, stronger, higher temperature resistant materials are critical for advanced developments in the automotive and space industries. Fuel and energy costs have refocused attention for these types of advancements. As identified in the 21st Century Truck program [15], reductions in weight as high as 20% are targeted as goals

Guigné, since 1996, in order to understand the science associated with containerless processing, investigated the use of combustion synthesis for the manufacture of glass, glass ceramics and porous ceramics. Over the past 12 years while waiting for the launch of Space-DRUMS® Guigné chose to investigate several materials that could not be made on earth. Since starting down this path they have been able to unlock some of the mysteries through ground research and KC-135 flights and file several patents. The larger gains are still expected when the Space-DRUMS™ is functioning in the ISS. Guigné in collaboration with the NASA Space Product Development Program and then the Innovative Partnershiop Program, the Colorado School of Mines, and Bioserve have supported the facility. It has been ready since the fall of 2002 and is now waiting for ULF-2 this fall. It will be one of the US facilities destined for the JEM module on the ISS and uses one EXPRESS rack. It is the first commercial facility scheduled for the ISS. The facility will be used for processing glass, glass ceramics and porous ceramics in a containerless environment using Self Propagating High temperature Synthesis or combustion Synthesis. The facility is also capable of hosting other experiments relating to colloids, granular studies and out reach education initiatives involving high schools and universities all over the world for a variety of pure physics experiments.

Guigné owns 100% of Space-DRUMS assets and over the past four years has developed a business case for Space-DRUMS. The modular design of Space-DRUMS® will accommodate commercial and pure research applications within the limitation of the EXPRESS rack. It is one of the facilities that will be available on the ISS and will be operated on a TREK station from the ground with minimum interface with the astronaut.

Space-DRUMS® is an acoustic positioning system designed for containerless processing and the study of self-propagating high temperature synthesis (SHS) on the International Space Station (ISS). The long duration microgravity environment of the ISS is ideally suited for containerless processing experiments since samples can be positioned without the effect of gravity. Isolation from the chamber walls of a furnace or experimental vessel can be achieved eliminating unwanted interactions between the container and the high temperature liquid state of the material being processed. Generally, such interactions include contamination of the melt and catalysis of unwanted reactions or nucleation induced reactions of the melt.[1] An additional issue for experimenters is the potential for heterogeneous nucleation including crystallization of material on the walls of the container.

**Strategic Objective Mapping:** Space-DRUMS® will facilitate research and materials processing in a manner that can only be accomplished in the microgravity environment aboard the ISS. The benefits of Space-DRUMS® will include not only further scientific understanding of processes like combustion synthesis and self-propagating high temperature synthesis, but also direct commercial benefits from materials processing. Advanced ceramics, polymer, and colloids can be processed in Space-DRUMS®.

Other areas that Space-DRUMS® can support include:

1. Radiation and radiation shielding materials studies.
2. Materials science processing for lunar/Martian In-Situ Resource Utilization over 90% of the materials used in the Guigné studies can be found on the moon.
3. Microwave sintering of lunar regolith.
4. Resource extraction.
5. Aerosol physics including lunar dust behaviour, charge state, chemical hazard, settling/dispersion rates.
6. Sample sterilization.
7. Thermal vacuum chamber development for:

a) development of lightweight advanced structural materials (this was your idea I believe)

b) thin film solar cell fabrication

c) RCC repair using slurry or weld tapes

8. Structural material fabrication.
9. Certifying materials being transported for processing over long periods of time.
10. IR glasses using lunar regolith
11. Aircraft engine noise abatement
12. Ceramic filters (foam)
13. Capilliary pumps
14. Abraisve foams, porous metals

## COMBUSTION SYNTHESIS

SHS or combustion synthesis is a novel technique for producing high temperature ceramic and composite materials. A typical SHS process involves mixing of the reactant powders, preparation of the powders into the necessary mold and density and initiation of the exothermic chemical reaction with an ignition source. Once the molded pellet is ignited, the reaction ignites adjacent layers on its own, thereby generating a self-sustaining combustion wave propagating throughout the material in a few seconds. Combustion synthesis has undergone extensive study in the laboratories of Guigné and their associates at the Colorado School of Mines.[11] The process requires minimal amounts of energy and is a candidate for manufacturing on other planets or the moon. The SHS reactions under study for the Space-DRUMS® program are extremely versatile as evidenced by the variety of materials that can be produced, such as:

Ceramic-Metal Composite

$$(y+z)\ \mathrm{Ti} + xz\ \mathrm{B} = y\ \mathrm{Ti} + z\ \mathrm{TiB_X}$$

$$(x+y)\mathrm{Ti} + y\mathrm{C} = x\mathrm{TiC} + y\mathrm{Ti}$$

Bioceramic

$$3CaO + P_2O_5 = Ca_3(PO_4)_2$$

Intermetallic

$$Ni + Ti = NiTi$$

$$x\mathrm{Ni} + (x+y)\mathrm{Ti} + y\mathrm{C} = x\mathrm{NiTi} + y\mathrm{TiC}$$

Intermetallic-Ceramic Composite

$$2Ti + 2B + 3Ni = Ni_3Ti + TiB_2$$

Glass Ceramic Composite

$$3TiO_2 + (a+3)B_2O_3 + 10\ Al + bMgO = 3TiB_2 + aB_2O_3 \cdot 5Al_2O_3 \cdot bMgO$$

Materials produced by the SHS technique are inherently porous. The porosity results from existing pores in the reactant powder mix of the unprocessed pellet, pores generated due to density differences between the reactant powders and the products and finally evolution of gaseous products during the reaction. Product porosity is typically about 50%. However, product samples can be engineered for a specified porosity and pore distribution to meet a number of applications. For example, to obtain high porosity, a gasification substance is added to the reactive system that decomposes at the combustion wave front thereby generating pores. Ceramic foams with porosity as high as 90% have been generated using this technique.

One of the advantages of SHS is the simple production of samples with near net shape processing (Figure 1). This is accomplished not only through moulding of the reactant powders but also control of the reaction parameters such as reactant powder density, reaction stoichiometry and product porosity.

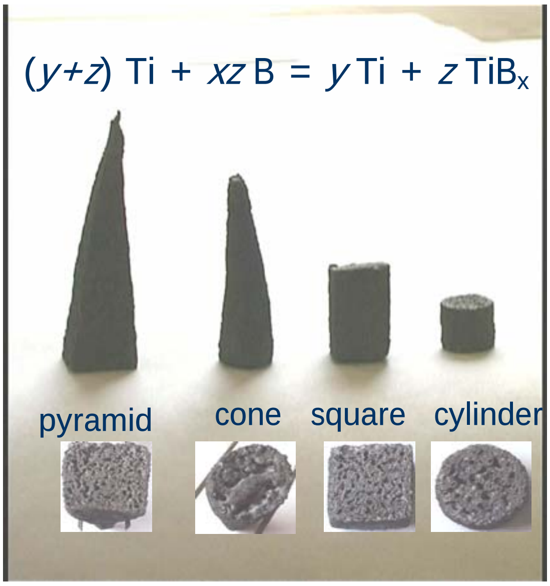


**Figure 1 - near net shape processing of a ceramic-metal composite using SHS.**

Materials to be processed using SHS on Space-DRUMS® will be in not only a microgravity environment but containerless as well. The purpose of containerless processing is the removal of heat sink and nucleation effects. Contact with a container has been shown to initiate early crystallization (nucleation) of the glass (oxide) matrix in the glass ceramic SHS systems. It is paramount that the pellet sample in its molten state, after the combustion reaction has been completed, remain out of contact with any materials, other than the inert gas atmosphere, until solid again. If the hot molten sample contacts the walls, then,

- the area of contact would be cooled at a faster rate than the rest, thus affecting the vitrification characteristics of the whole sample;
- the area of contact would also promote heterogeneous nucleation, thus defeating the objective of the research.

Thus, the sample must remain within a defined control zone for a period of up to 30 minutes during the cooling down (molten) period.

SHS performed in microgravity provides products with different structures and properties than if performed in a 1-g environment, mainly a more homogeneous structure. Even if the object would remain stable within the microgravity environment of the ISS, it would still be necessary to support the molten sample without contacting it – in this case acoustically. The generation of heat, gas and particles during the SHS reaction would result in movement of the reacting SHS system, and these forces must be opposed by the acoustic forces. In addition, thermal or mechanical effects on the ISS or inadvertent actions of the crew can cause extraneous accelerations on the payload which must be corrected for by applying acoustic positioning to the pellet, should an experiment be underway.

## CONCEPT OF ACOUSTIC CONTROL

The original concept for Space-DRUMS® was to use a standing wave pattern for an acoustic beam to levitate an object. The plan for this object was to undergo combustion synthesis without being contaminated by other materials – hence containerless processing. It was immediately obvious that acoustic levitation using standing wave patterns would not work. There was little confidence that this technique would have the necessary ability to levitate larger objects (up to 75 mm diameter and 100 grams mass) or be able to maneuver or manipulate such objects to maintain them within the confines of a restricted control zone. The control zone for an acoustic levitator is only mm in diameter. Thus the standing wave technique was rejected.

The technique adopted instead was to use, not a static and continuous standing wave pattern, but a dynamic multiple acoustic beam approach. In this concept the acoustic beams would push or force the object into a confined control zone.

The dynamic field approach inherent in Space-DRUMS® uses calculated force impulses only from required directions as dictated by an intelligent vision system to restore a sample to its prescribed position in the processing chamber. What is unique in the operation is that when the sample is centered, there are no forces applied and the best uncoupled microgravity conditions can prevail. The design of the Space-DRUMS® ISS facility is directed at minimizing contact with the sample as much as possible during processing yet maintaining a rigorous ability to restore the sample position even under high temperature combustion conditions and extreme station g-jitter.

## MODULE FUNCTIONS

The payload consists of five separate modules (refer to Figure 3):

- Processing Module (PM) – quad locker (bottom of rack) where samples are stored and processed.
- Payload Computer & Electronics Module (PCEM) – the main payload computer (middle right) which controls and automates all processing using custom software.
- Acoustic Positioning Electronics Module (APEM) – (middle left) contains the frequency tracking function generators and power amplifiers to run the acoustic projectors.
- Ignition Power Module (IPM) – (top right) contains batteries to supply the ignition pulses to ignition coils for initiating combustion of a sample.
- Argon Gas Module (AGM) – (top left) contains and controls ultra high purity argon for flushing and purging the processing chamber so that a combustion process may be performed in an inert atmosphere.

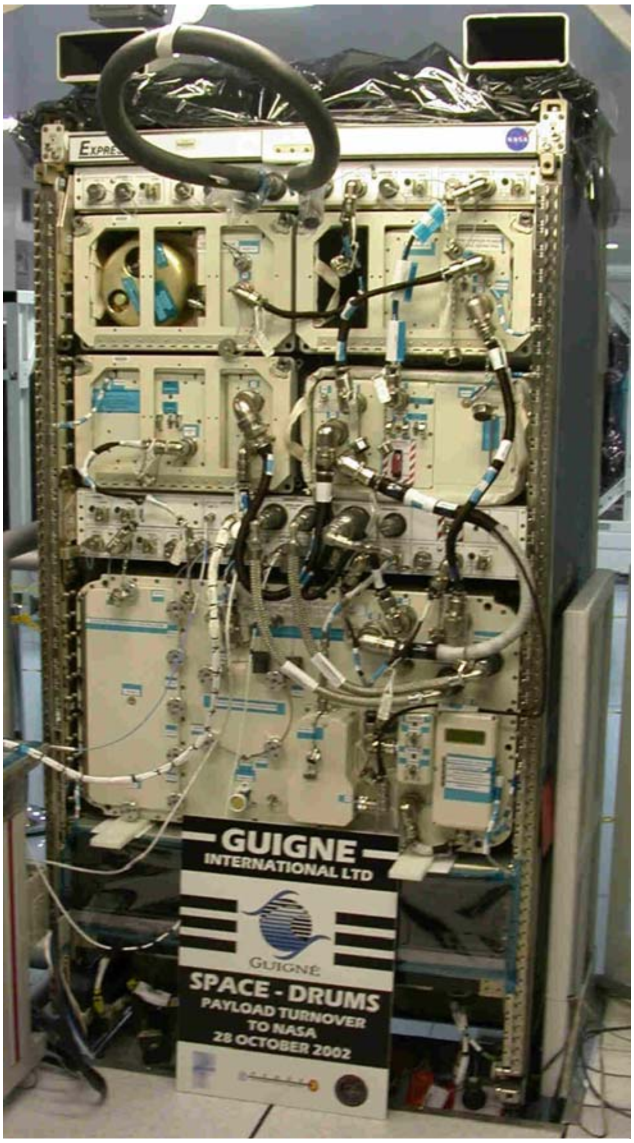


**Figure 3 - Space-DRUMS payload mounted in an EXPRESS rack for online testing at Kennedy Space Center.**

The core of the payload is the processing chamber within the Processing Module. Twenty acoustic projectors are evenly distributed around a 30 cm diameter spherical chamber. Infrared cameras relay the position of a sample within the chamber to the payload computer which in turn calculates the necessary force to apply to the sample to return it to chamber center. This force is translated into parameters for five acoustic projectors to fire the necessary acoustic pulses to nudge the sample back to the center. Visible light CCD cameras are also available for optional visual feedback. Samples up to 5 cm in diameter may be stored in a carousel. A robotic arm is used to remove a sample from the carousel and position it at the center of the chamber prior to release. Once a sample is released the cameras, acoustic projectors and computer along with software control algorithms keep the sample from hitting the chamber walls. For combustion synthesis studies, ignition coils are also stored in the carousel which can be removed by the robotic arm and placed inside a central hole in a sample. An electrical pulse is supplied to the ignition coil sufficient to ignite a sample and initiate the combustion. Combustion for glass ceramic samples typically takes a 4 or 5 second ignition pulse, a 2 to 5 second combustion at peak temperatures ranging up to 2000°C and then a 20-30 minute cool down. The sample is released during combustion at the end of the ignition pulse at which point it is held in containerless mode by acoustic forces until re-acquired by the robotic arm after the cool down period.

## PAYLOAD OPERATIONS

On-orbit operations follow a defined procedure. Integration of the payload into EXPRESS Rack 5, setup of the payload and subsequent operations will follow the Experiment Operations Checklist. Any proposed deviation from this procedure must go through Space-DRUMS® personnel and

subsequently the NASA crew office. To summarize the checklist, the steps are as follows:
1. Install modules in EXPRESS Rack 5.
2. Connect all electrical cables and fluid hoses.
3. Install argon gas bottle in AGM; sample storage carousel and debris trap into PM.
4. Establish coolant flow and airflow and enable telemetry.
5. Power up EXPRESS Rack.
6. Close all power circuit breakers on payload.
7. Boot-up PCEM.

At this stage the payload is totally automated and under software control. Only one command is required from the ground – a GO command to start sample processing once the PCEM and software have initialized all modules and readied the payload according to a defined sequence. Any off-nominal readings from sensors or other feedback will negate any ground commands except for specified software or engineering troubleshooting and analysis commands. The following sequence occurs after boot-up of the PCEM.

1. Computer initializes all parameters in a normal boot-up sequence.
2. Software initializes all payload component parameters according to a defined sequence:
- start sending Health & Status data to Rack Interface Computer (RIC)
- power up all necessary components
- accurate science data is now sent along with Health & Status data
- check status of PM interlocks and all sensors and relay any warnings to PM status display
- go to *WAIT* state

In the *WAIT* state, software waits for some input as an indication to what step to take next. Generally this will be a *Start Processing* command to initiate the combustion sequence for a pellet but it could also be an analysis command to start troubleshooting or to go to manual sequence commanding.
The *Start Processing* command starts the following sequence:
3. Check for presence of storage carousel and debris trap in PM. If both present, continue.
4. Establish PM second level of containment - lower pressure inside PM with respect to ISS cabin.
5. Purge the Processing Chamber with argon.
6. Rotate carousel to the next un-used ignition coil position and retrieve ignition coil with robotic arm.
7. Rotate carousel to next target pellet compartment and retrieve pellet with robotic arm.
8. Position pellet, ignition coil correctly at center of Processing Chamber which enables IPM battery circuit.
9. Enable APEM.
10. Select two cameras to provide feedback for target positional control. Select third camera for transmittal to Ethernet video.
11. Check IPM battery status.
12. Apply a continuity check to coil by applying low current pulse. Alternatively, use visible camera video feedback to verify presence of coil in shuttle.
13. Apply an ignition pulse of 600 Watts for required ignition time.
14. Precisely at end of ignition pulse time, retract robotic arm shuttle (opens end-effector fingers and releases pellet) and retract arm. At the same time start APEM control of pellet to maintain it at center of Processing Chamber.
15. Combustion normally finishes in a few seconds. APEM retains control of pellet position for up to 30 minutes. Infrared thermometer will measure temperature of pellet surface as long as it remains above 1000°C. Thermal cameras can measure temperature of pellet from about 200°C to 750°C with lower accuracy.
16. Once the pellet reaches 200°C to 400°C, the robotic arm retrieves the pellet.
17. APEM control is turned off.
18. Pellet is held by robotic arm for an additional 30 minutes to enable pellet to cool sufficiently to be returned to storage carousel.
19. While pellet is cooling, the Processing Chamber is evacuated and purged with argon again. This step is to remove combustion by-products from the chamber and filter them through the debris trap.
20. The robotic arm returns the pellet to its compartment in the carousel and then returns the used ignition coil to its slot in the carousel.
21. IPM battery is recharged.

All pertinent science video is stored on the hard drive primary unit and mirrored onto the secondary unit. Health & Status data has been transmitted continuously at a 1 Hz rate to the RIC along with Science data. Ethernet video (third IR camera) has been sent to the ground as telemetry is available.

At this stage the software will assess the status of the payload and determine whether any change-outs are required of consumables. If not, the payload is ready to process again.

## COMMERCIAL OPPORTUNITY

There are many benefits arising from the materials that will result from Space-DRUMS® studies on the ISS and possible subsequent studies:

- The SHS process requires very little power consumption, especially when compared with combustion furnace techniques. The SHS process is inherently simple and straight-forward, again especially when compared with the complexity of a combustion furnace.
- Development of viable techniques for fabrication or manufacture of these materials – either to make them affordably in space or learn how to make them in a reduced gravity environment. First and foremost is the discovery of these materials that have the necessary properties and will allow these manufacturing processes.
- Discovery of new, advanced materials with properties of low density coupled with high strength and high heat resistance to help improve vehicle safety.
- Lower density materials with high strength will reduce up-massing requirements which will in turn require less fuel to raise to various orbits.

Space-DRUMS addresses all of the above. It is innovative since it can conduct containerless processing and handling of large economically sized materials. It provides a capability that never flew on MIR, Shuttle or Spacelab. Plus Space-DRUMS™ can provide a volume for a container experiment that is larger than that available in a typical single or double locker sized payload. It is re-configurable on orbit. Each of the four supporting modules fit a mid-deck locker and can support other payloads.

In order to define the many possibilities of a company/partnership that would be focused on the support of Space-DRUMS™ we will first look at the initiatives.
There are several initiatives that can be followed to get a return on investment.

1. Use the lessons learned in Microgravity to advance the discovery and reduce the development time of materials on earth. The ISS CCACS configuration is designed to do this. Guigné has developed a full process for combustion synthesis that is being referenced as the standard way forward. It includes ground testing hardware and KC-Hardware (COSYM). The use of ground testing and parabolic flights (KC-135) to reduce the number and qualify the compositions of materials to be processed in space. Guigné earns 1.5 pellet-resources for every pellet flown for NASA. One carousel is required for every 5 pellets additional consumable items (Gas, debris traps, cleaning gloves).

2. Conduct pure physics Experiments. Space-DRUMS can be used to conduct experiments that are investigating the effects of microgravity on combustion processes. The facility can accommodate both container and containerless handling of materials. Space-DRUMS would be leased by NASA, ESA, NASDA, and CSA in support of universities and government institutions, for incorporating an experiment into Space-DRUMS™. The experiment can be integrated into Space-DRUMS® very easily.

3. Lease or sell facility and modules, sell allocated lockers. payload developers.

4. A service will also have to be provided to house or warehouse and deliver payloads to KSC and in the KSC area. This service would track the payload through MSFC and KSC. In addition the handling of simulators and other equipment required for Astronaut training at JSC. The number of lockers that will be sent to Space-DRUMS™, or assigned to partners for compensation, will also be a significant percentage of the total number being sent to the ISS. The handling, storage and delivery of these lockers will be a sizable step to offering the service as a commercial enterprise. Space-DRUMS™ is the only commercial facility, all the other facilities on the ISS are owned by the ISS Partner governments.

5. Developing a specialized facility for conducting a wide range of experiments in space. The development would focus on generic experiment support. The subject is proprietary and will not be discussed further.

6. Manufacture in Space: The most desired scenario for the International Space Station/National laboratory is to be able to identify some product or process that can make it economically feasible to manufacture in space.

## APPLICATIONS

The original concept of the Space-DRUMS® payload was for a facility to be used on the International Space Station in order to process new, advanced materials. The two main attractions of this facility would be the manufacture of materials in microgravity and in a containerless mode. In other words, the manufactured material would not be influenced either by gravity or by its surroundings, other than the use of an inert atmosphere. The containerless process used by Space-DRUMS® avoids contaminants and physical defects typically seen in conventional systems by enabling large samples to be positioned and held stable in a microgravity environment with acoustic energy.

Initial investigations employing this payload will examine combustion synthesis of glass ceramics. A proprietary formulation of inorganic reactant powders in a solid sphere (a 5 cm diameter pellet sample with a 1.4 cm through hole) is released into the center of a processing chamber after being ignited at a temperature of 600-800°C using a tungsten ignition coil. In microgravity, this pellet floats in the chamber, with its position being controlled by highly focused acoustic energy beams from acoustic projectors situated about the periphery of the chamber. Further investigations will be performed on porous ceramic formulations and high hardness materials.

The possibility of in-space repairs using Space-DRUMS® as a fabrication facility coupled with special SHS ribbons which quickly and easily weld two pieces of ceramic-metal composite has been examined and can be developed further. This is a potential repair scenario for exotic materials such as the reinforced carbon-carbon heat shield panels on the Space Shuttle.

Space-DRUMS® is more than just a containerless facility. This payload is easily adapted to container experiments, either housed within its full rack complement or supported by its individual modules. Such flexibility and adaptability allows the facility to be re-configured for any number of experiments. Guigné is currently investigating the benefits of using this system in areas such as particle and granular physics and g-jitter as well as manufacture of glasses, ceramics, polymers and colloids.

The materials that Guigné has experimented with for Space-DRUMS operations have been Moon regolith to look at the feasibility of reducing materials that have to be launched to the moon and reduce the power required to manufacture these materials.

Guigné sees the trucking industry as the natural partner for the acceptance of these new materials. The rugged testing in over the road conditions will tell us how the new materials will perform in rugged conditions prior to launching them into space. The Trucking industry also provides an early market to fund these new materials while they are being vetted for space. Designed to operate with minimum astronaut support using TREK commanding and making functional changes by simple ground-based software commands.

Availability to ground-based equipment to universities and laboratories, GIL Stairwell approach for ground studies to space includes: Ground based chambers, COSYM™ facility: Parabolic Aircraft Single Axis Levitator: Ground based, parabolic flights; and Space-DRUMS® on ISS

Instrumentation includes:
Temperature measurement to 2500°C
Video data: visible (CCD) and thermal infrared
Triple containment, Independent modular construction with standard connectors; each unit can be shared by other ISS payloads. Designed to produce lighter, stronger, harder and higher temperature resistant materials, dense or porous, and/or functionally graded.
Develop processes that reduce spacecraft weight and power consumption and use in-situ resources
Perform experiments with high scientific merit
Involve students and industry to participate

The list of possible candidates- both process and advanced materials in space, focus has been based on the use of Moon regolith:
•Glass, IR Glasses, Glass ceramics
•Ceramic foams, Metal-Ceramic foams for structures
•Filters
•Acoustic abatement in high temperature applications • safety through advanced materials
•Bone replacement
•Drug delivery systems. (Diabetes, schizophrenia, osteoporosis)
•Cutting tools• Wear resistant parts• Armor
•Farm machinery (related to cutting and wear)
•Automotive (Brakes, ball joints, hubs, coatings, weight reduction program)
•Crack repair• Brazing• Coatings •Fire extinguishing

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