Zero-G Corp.
August 2011 Campaign

August 25 – September 2, 2011

Ellington Field, TX

Manifest

- 004-PS Printing the Space Future – Jason Dunn/Made in Space
- 007-P Radio Frequency Mass Gauge on Parabolic – Greg Zimmerli/NASA GRC
- 008-P Indexing Media Filtration – Juan Agui/NASA GRC
- 011-P Cryocooler – Ben Longmier/Ad Astra

004-PS

Printing The Space Future

Adapting Additive Manufacturing Technology for Zero-Gravity

STATUS QUO

Additive Manufacturing in Zero-G

- Limited zero-gravity testing and physical analysis of 3D printing in zero-g on micro/macro scale
- No testing of building extended structures
- Experimental box is flight ready

NEW INSIGHTS

Technology Focus Area:
Additive Manufacturing (AM)

Specific Benefits of Technology:
Enables In-Situ Manufacturing

All current space missions depend on Earth. AM will enable in-space manufacturing of parts, spacecraft and large extended structures. Rather than transporting the final part from Earth, only printers and feedstock need to withstand launch stresses.

MAIN ACHIEVEMENT:

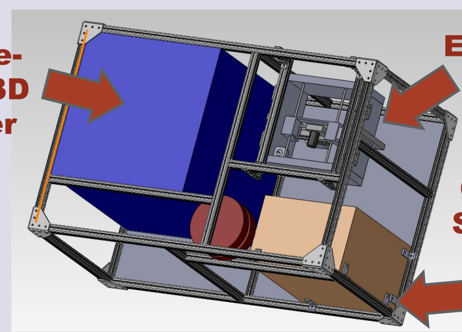
This experiment will test the underlining physics of additive manufacturing (AM) in zero-g. Parts will be built in zero-g. Post-flight stress tests and micro/macro analysis will then be compared to parts built on Earth. Using a newly conceptualized Extended Structure Additive Manufacturing Machine (ESAMM), this experiment will also test the concept of building extended structures in zero-gravity. The current ESAMM prototype builds structures several feet long, while a future scaled up model could build in-space structures kilometers in length.

HOW IT WORKS:

AM "prints" parts by adding material layer by layer, causing an efficient use of material. Two OTS AM machines will build cross sections of functional parts. The ESAMM uses worms gears to provide travel in the third direction allowing for a theoretical unlimited amount of layers to be built. The worm gears ride along teeth built into the structure by the AM process.

Off-the-Shelf 3D Printer

ESAMM



Off-the-Shelf 3D Printer

QUANTITATIVE IMPACT

Flight Experiment Requirements

- ESAMM builds "core sample", a part printed continuously during flight.
- Two OTS FDM printers will fly to test fundamental physics of AM and compare results with ESAMM

Experiment Specifications

- Dimensions: 44in x 22in x 24in

END-OF-PHASE GOAL

Analyze functionality and physics of AM in zero-g environment

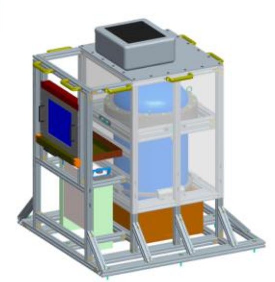
- Demonstrate key in-space manufacturing technology
- Flight qualify 3 total AM machines
- Post flight non-destructive and destructive testing of machined parts from flight

Additive manufacturing (often called 3D printing) is an efficient, fast and increasingly automated manufacturing method that will enable the development of in-space infrastructure.

Low-g Testing of the Radio Frequency Mass Gauge (RFMG) *PI: Dr. Greg Zimmerli, NASA GRC*

Flight Opportunities Program

STATUS QUO



- Propellant quantity gauging in low-gravity typically requires settling burns and the use of level sensors.
- The Radio Frequency Mass Gauge (RFMG) is capable of gauging in zero-g.
- RFMG rig is ready for flight.

NEW INSIGHTS

Technology Focus Area:
Low-g cryogenic propellant quantity sensor

***Specific Benefits of Technology*: Enables fast low-g gauging**

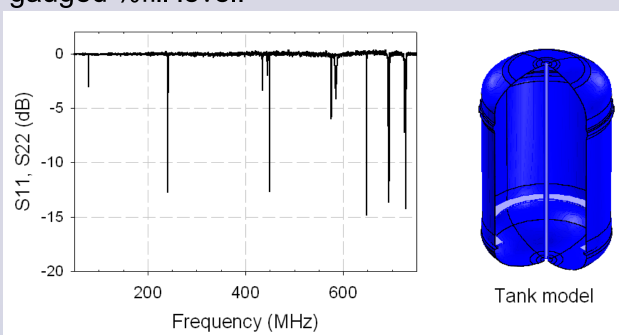
Tests on the low-g aircraft will provide critical test data to measure the accuracy of the gauge in low-g and in the presence of fluid sloshing. A different fluid fill level will be tested each flight day.

MAIN ACHIEVEMENT:

Low-g testing of the RFMG in 2010 showed that the gauge works well when the data is filtered and averaged to mitigate the effects of sloshing. Tests in 2011 will incorporate a slosh baffle and mock "spray bar" hardware elements inside the tank to increase the fidelity of the tests. A digital RC filter will also be applied to the real-time gauge output to smooth the effects of sloshing.

HOW IT WORKS:

The natural electromagnetic modes of the tank are excited by pinging the tank with an RF chirp signal via two small antennas mounted inside the tank. An RF electronics unit measures the RF power spectrum, and software identifies the peaks or mode frequencies. These frequencies are compared to a large database of RF simulations, and a best match occurs at some %fill level which is then reported back as the gauged %fill level.



SPEC'S/ IMPACT

Test Fluid: Fluorinert FC-77

Rig Mass/Dimensions: 465 lbs; 45" x 43" x 53"

RF power: < 1 mW

Frequency: 50 – 750 MHz

Antennas: Z-dipoles (2)

Gauging operations: Once per second, continuously

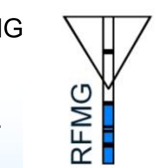
Simulation database: Over 3,000 fluid configuration, fill level combinations

IMPACT: The RFMG provides a way to quickly gauge a tank in low-gravity without having to apply a settling thrust.

END-OF-PHASE GOAL

Demonstrate zero-g gauging at four different fluid fill levels

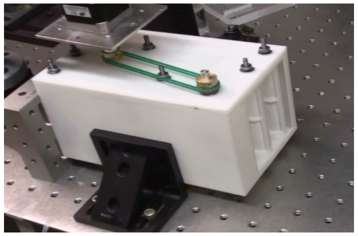
- Advance elements of the technology to TRL-6 through low-g flights
- **Future:** Infuse RFMG technology into commercial launch vehicles and space-based payloads



The Radio Frequency Mass Gauge enables low-gravity gauging of cryogenic propellants.

008-P Indexing Media Filtration System for Long Duration Space Missions

STATUS QUO



Indexing Media Filtration System for Long Duration Space Missions

- Development of advanced particulate filtration systems for long duration missions that feature long service life, regenerability, and require minimal to no crew-tended maintenance
- Replacing filters is typical for 1-g systems but impractical in space.
- Laboratory tested.

NEW INSIGHTS

Technology Focus Area:
Life Support Systems
Specific Benefits of Technology:
Long life cabin filtration

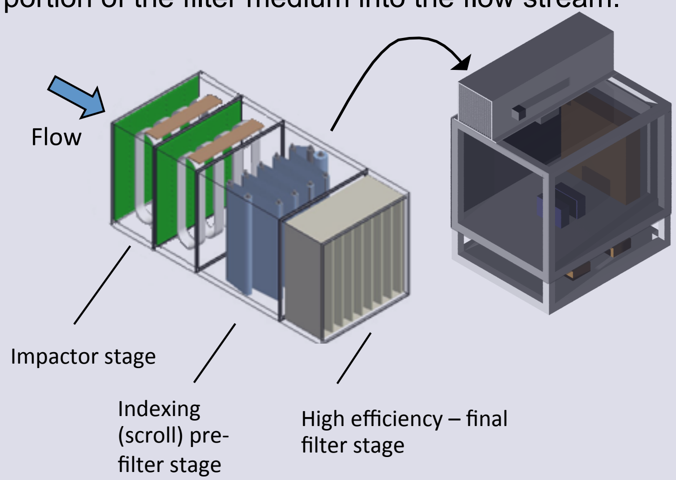
- **Indexing media increases filter area and efficiency.**
- **Indexing reduces filter replacement need.**
- **Indexed media may be regenerated.**

MAIN ACHIEVEMENT:

Develop sustainable regenerable dust mitigation techniques appropriate for space environments.

HOW IT WORKS:

Indexing Media Filtration System uses an advancing web mechanism to advance a fresh portion of the filter medium into the flow stream.



Large particles are separated by impactor plate.

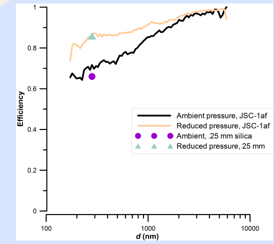
Majority of particles are filtered by indexing media.

Fine particles captured by HEPA filter.

ASSUMPTIONS AND LIMITATIONS:

- Adequate filtration for long duration space missions is unavailable in industry.

QUANTITATIVE IMPACT



Collection efficiency

Flight testing will address the effect of gravity on:

- dust separation capability.
- Collection of large particulates (that tend to settle out in 1-g).
- Dust collection efficiency.
- In-place media indexing..
- Reduced or microgravity operation of the system.

Expected outcome: A prototype filtration system with at least an order of magnitude longer life than state of the art filters, and a particle size filtration range that can be tuned to mission requirements.

END-OF-PHASE GOAL

Particulate removal in spacecrafts, habitats, airlocks and pressurized rovers.

- *Enhance the life of filtration systems*
- *Reduce launch requirements*
- *Reduction of system maintenance.*

Filter system components may be renewed, thus extending life and decreasing maintenance

011-P Cryocooler Vibration Analysis for VF-200

Ad Astra Rocket Company

STATUS QUO

Sunpower CryoTel™ (CT) cryocooler testing to date.

- Prior µg campaigns, SEED 2010 and FAST 2010, establish commercial technology at TRL 6.
- Thermal testing of CT cryocooler testing in-situ with High Temperature Super Conducting (HTSC) magnet presented need for vibration mitigation at CT-HTSC interface.

Significance of Study:

Vibration characterization

NEW INSIGHTS

Ad Astra's VF-200, VASIMR® (Variable Specific Impulse Magnetoplasma Rocket) Flight - 200 kW, scheduled for testing aboard the ISS in 2014, nozzles plasma propellant via a core of mechanically sensitive HTSC magnets, conduction cooled by CT cryocoolers. Investigation of CT vibration modes will advance TRL of cryocooler technology while simultaneously down selecting mounting interface design.

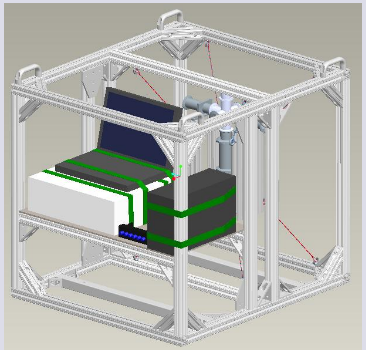
VIBRATION ANALYSIS ACHIEVEMENT

OVERALL OBJECTIVE:

The SunPower CryoTel™ (CT) model cryocooler is a compact Stirling engine device capable of rejecting 10-15 Watts at 40K, ideal for the baseline VF-200. Significant vibrations induced by CT operation pose a hazard to system integrity by degradation of the High Temperature Superconducting (HTSC) magnetic field. The study will advance a solution to mitigate this problem by furthering understanding of CT vibrational characteristics. The experiment is designed to isolate the CT mass system from the experiment frame, reducing the uncertainty associated with vibration transfer.

TEST METHOD:

3-axis accelerometers strategically instrumented throughout experiment provide comprehensive vibration responses at varying cryocooler power levels. Cryocooler operation monitored by current and temperature measurements.



CAD model of experiment rig

QUANTITATIVE IMPACT

Flight Requirements:
40 parabolas/flight x 4 flights

Vibration Measurement:
Accelerometer specifications:
Adjustable sensitivity: +/- 3g or +/11g
Supply voltage: 2.2V-16V
Supply current: 0.5 mA

Experiment interfaces:
Mode of Operations:
Autonomous, LabVIEW controlled.
Power requirements: 115 VAC.

Experiment Specifications:
Mass/Dimensions:
220 lbs. 33in x 33in/ x 37.5in.

END-OF-PHASE GOAL

Measure vibrational characteristics of cryocooler operation.

- Determine natural frequency and intensity of vibrations as a function of test parameters (cryocooler power, g-load, mounting arrangement)
- Offer initial design solution for vibration mitigation.

Sunpower Cryotel™ platform will provide lightweight and compact cryocooling capabilities for the VF-200 test flight aboard the ISS in 2014.