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Test Based Microgravity Analysis for the Fluids and Combustion Facility

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ABSTRACT
The Fluids and Combustion Facility (FCF) is a two rack facility dedicated to combustion and fluids science in a microgravity (near zero-g) environment on board the International Space Station (ISS). An important aspect of performing on-orbit research is maintaining the rack microgravity environment by minimizing vibroacoustic disturbances generated within the science payload. This paper discusses recent rack-level acoustic emission testing to characterize the science payload microgravity environment. Measurements are compared with FCF microgravity science requirements.

1. INTRODUCTION

The Fluids and Combustion Facility (FCF) is a modular, multi-user, two-rack facility that consists of the Fluids Integrated Rack (FIR) and the Combustion Integrated Rack (CIR), which will be used to accommodate microgravity science experiments on board the US Laboratory Module of the International Space Station (ISS). The FCF will be a permanent facility aboard the ISS, and will be capable of accommodating up to ten science investigations per year. It will support the NASA Science and Technology Research Plans for the ISS, which requires sustained systematic research of the effects of reduced gravity in the areas of fluid physics and combustion science. The Microgravity Science Division at the NASA Glenn Research Center is developing the FCF.

The ISS provides a quiescent vibration environment (on the order of 10^{-6} g rms) for microgravity scientific research. Acoustic and mechanical sources inside a rack can generate vibration disturbances that can contaminate the science microgravity environment. In order to characterize the FIR microgravity environment near the science payload, rack-level acoustic emission testing was performed and acceleration test data was acquired on the optics bench.

A first order analysis was performed to adjust the acceleration level measured during this ground test to account for the differences in the FIR on-orbit boundary conditions and thus predict the accelerations levels that will be seen on-orbit. The ground test configuration represented the FIR rack in the launch configuration. The differences between the launch and on-orbit rack boundary conditions are the constraints at the rack interface to the module, and optics bench boundary conditions. For the launch configuration, the rack interface constraint with the module is pinned, while the on-orbit rack interface constraint is free-free. The optics bench boundary condition is fixed during launch and is pinned on-orbit.

2. FIR EM RACK ACOUSTIC EMISSION TESTING

An acoustic emissions test of an Engineering Model (EM) of the FIR was conducted in February 2003 at the Acoustical Testing Laboratory at the NASA Glenn Research Center[1,2] as shown in Figure 1. The ATL test chamber was in a hemi-anechoic configuration. The FIR EM rack was installed in the Rack Handling Adapter (RHA) as shown in Figure 1 and Figure 2. The Fluids rack hardware included the composite flight rack, optics bench, Air Thermal Control Unit (ATCU) fan assembly, Input/Output Processor (IOP) package, Electrical Power Control Unit

(EPCU) package, rack door, and an engineering unit of the Light Microscopy Module (LMM) science payload. Hardware mounted on the back side of the optics bench included the White Light Package, FSAP, two IPSU packages and the Nd: Yag Laser. The total weight of the FIR EM rack was approximately 1,500 pounds. The total weight of the FIR EM rack and the RHA was approximately 3,000 pounds.

The main vibroacoustic disturber in the FIR was the ATCU. The ATCU is comprised of two 8.5 inch diameter centrifugal fans isolated at the four corners of the fan assembly. The ATCU isolator fundamental frequency is approximately 14 Hz. A secondary vibroacoustic disturber in the rack is the 5 inch diameter IOP muffin fan. The IOP fan nominal operating speed was 2,850 rpm.

The primary purpose of this test was to characterize FIR rack acoustic emission characteristics and investigate the effect of various acoustic treatments for given ATCU fan speeds. The ATCU fan speed was varied from 1,600 rpm to 2,700 rpm. The nominal operating speed of the ATCU fans is approximately 1,800 rpm based on thermal control requirements for the LMM science payload. The sound pressure levels were measured at a distance of 2 feet from the front, top, and right side of the FIR EM. The International Space Station rack continuous noise requirement is NC-40 at these locations.

A secondary objective of the FIR EM rack test was to characterize the microgravity acceleration environment near the science payload due to the operation of the IOP and ATCU fans. The FIR microgravity science requirement was developed based on the envelope of seven classes of fluid physics science experiments. In order to assess whether the FIR satisfies the microgravity science requirement, measurements of the optics bench were made and a spatial average response calculated. The optics bench spatial average response was then compared to the FIR microgravity science requirement as shown in Figure 3. The microgravity science requirement was exceeded for the ATCU fan speeds tested.

The FIR EM rack had it launch restraints on the optics bench engaged during testing. The ATCU isolators were active. The FIR EM rack was instrumented with twenty-six accelerometers mounted normal to the surface of the optics bench and ATCU frame. Acceleration time histories were acquired with MTS Ideas Test software with a sampling frequency of 1280 Hz. The acceleration time histories were post processed into narrowband power spectral density functions with frequency resolution of 0.625 Hz and a frequency range from 1 to 500 Hz. These narrowband power spectral density functions were further reduced into 1/3 octave band acceleration level spectrums.

Ambient background acceleration levels were measured and used to assess the valid frequency range for the response acceleration measurements. The criteria chosen for determining the valid frequency range was a minimum of 6dB separation between the response and the ambient background acceleration levels. For the ATCU operating at 1800 and 2000 rpm, the test data was valid from 50 to 400 Hz; for the operating speeds of 2200, 2400, and 2680 rpm, the test data was valid from 40 to 400 Hz. Due to the noise floor considerations, only a portion of the microgravity science requirement frequency range could be evaluated. The microgravity science requirement has a frequency range from 0.01 to 315 Hz.

3. MICROGRAVITY ANALYSIS METHODOLOGY

A first order analysis of the on-orbit microgravity environment was predicted based on the measured ground test data. The ground test configuration represented the launch configuration. Differences between the launch and on-orbit boundary conditions of the FIR rack and optics bench were accounted for in this analysis. The rack interface constraint with the module is pinned for launch, and the on-orbit constraint is free-free. The optics bench constraint is fixed for launch and pinned on-orbit. A NASTRAN Finite Element Model (FEM) of the FIR rack on-orbit configuration was used for the microgravity analysis prediction using 0.25% modal damping. Northrop Grumman Information Technologies (prime contractor for the Fluids and Combustion Facility) created this FEM in November 2002. The FEM contains 36,829 grids and 220,974 degrees of freedom and was updated to represent the as-tested hardware configuration of the FIR EM rack. Modifications included updating the mass of the LMM science payload (engineering unit weighs 172 pounds) and removal of the Active Rack Isolation System components (115 pounds) to represent the as-tested configuration. The ATCU isolators were also included in the model with a spring rate of 50 pounds/inch in the x, y, and z directions.

The FEM of the on-orbit configuration of the FIR has 10,868 modes between 0 and 500 Hz, which were computed in NASTRAN. These modes were then used in NASTRAN to compute nine frequency response functions (FRF) with reference location chosen to be on the ATCU frame, which is shown in Figure2. The nine response locations coincided with the nine optics bench accelerometer measurement locations from the FIR EM rack acoustic emissions test. The nine optics bench FRF were averaged yielding a single spatially averaged FRF. The narrowband FRF's were post processed into 1/3 octave center band frequencies.

The analytical transmissibility between the spatial average optics bench FRF and the ATCU FRF was computed based on the following equation:

$$\text{Transmissibility}(\text{g / g}) = \frac{\text{FRF}_{\text{Optics Bench}}\,(\text{g / unit force})}{\text{FRF}_{\text{ATCU Reference}}\,(\text{g / unit force})}$$

The individual FRFs used to derive the transmissibility is shown in Figure 4. In the frequency range from 2 to 100 Hz, the FRF's are comparable. From 100 to 315 Hz, the optics bench FRF is significantly less than the ATCU FRF. The resulting transmissibility values become small for frequencies greater than 100 Hz.

The transmissibility values are post-multiplied by the ATCU test measured response (Figure 5) to obtain the first order estimate of the on-orbit Fluids rack microgravity environment (Figure 6). The test based microgravity analysis estimate for the ATCU operating at 1,800 rpm indicates that the Fluids rack microgravity environment satisfies the science requirements. The estimate has a limited frequency range from 50 to 315 Hz due to noise floor considerations.

In order to make test measurements for a wider frequency range of the microgravity environment, additional isolation from the background disturbances must be provided. The Microgravity Emissions Laboratory (MEL) at the NASA Glenn Research Center is a pendulum isolation system that has the capability of making acceleration measurements as low as 0.2 Hz in frequency.[3] Analytical predictions of the FIR microgravity environment[4] have been made for the frequency range from 0.01 to 315 Hz using an on-orbit FIR rack NASTRAN finite element model and Matlab/Simulink simulation software.

4. CONCLUSIONS

Test based microgravity analysis can be used to augment vibration test data obtained from FCF rack acoustic emissions testing to provide a first order estimate of the on-orbit microgravity environment. The prediction has a limited frequency range (50 to 315 Hz) due to noise floor considerations. Therefore, the entire microgravity science requirement frequency range from 0.01 to 315 Hz cannot be completely evaluated using this method. In order to extend test measurements into a lower frequency range, additional isolation from background disturbances is required. The Microgravity Emissions Laboratory provides an alternative test based method to obtain microgravity measurements down to 0.2 Hz.

Based on this first order analytical method, the FIR rack is below the microgravity science requirements from 50 to 315 Hz.

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3. A.M. McNelis, "Microgravity Emissions Laboratory Testing of the Physics of Colloids in Space Experiment," NASA/TM—2002-211901 (2002).
4. M.L. Just, "FIR Microgravity Analysis Update for CDR," ZIN Technologies Report Number ARIS_INT-002_MEM1001, November 27, 2002.

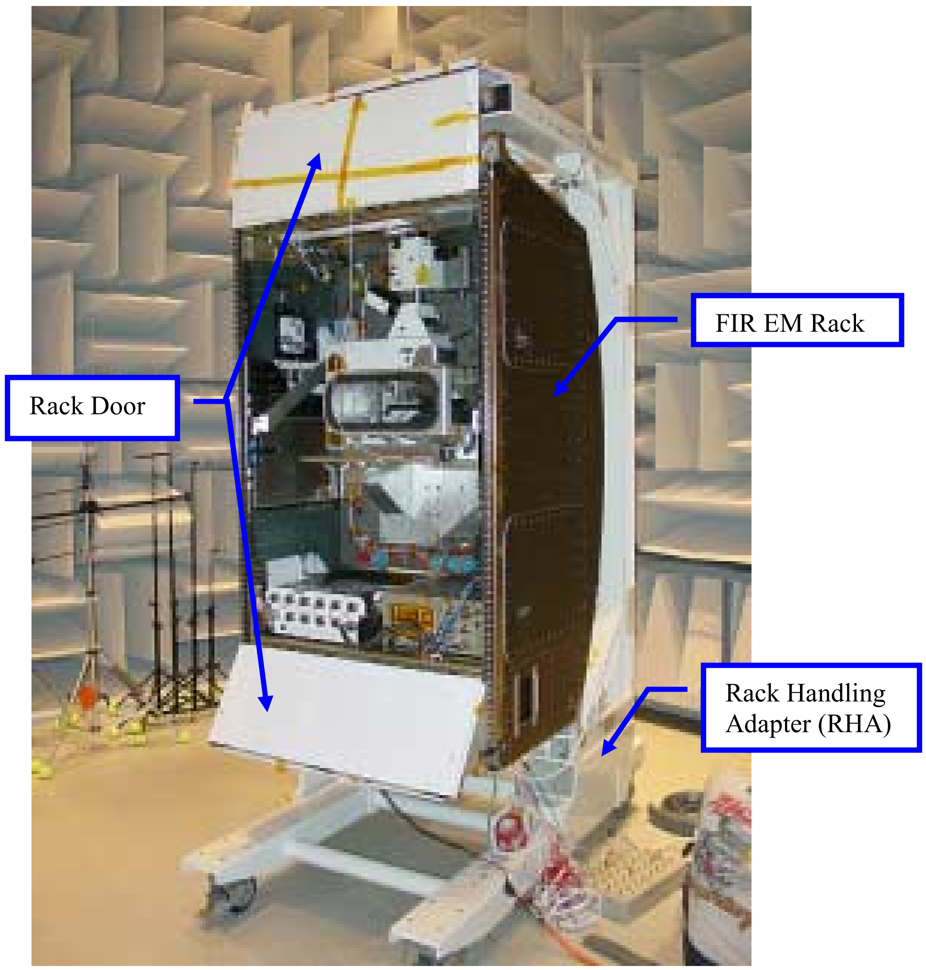

Figure 1. FIR EM Rack with Front Doors Open in the ATL Test Chamber.

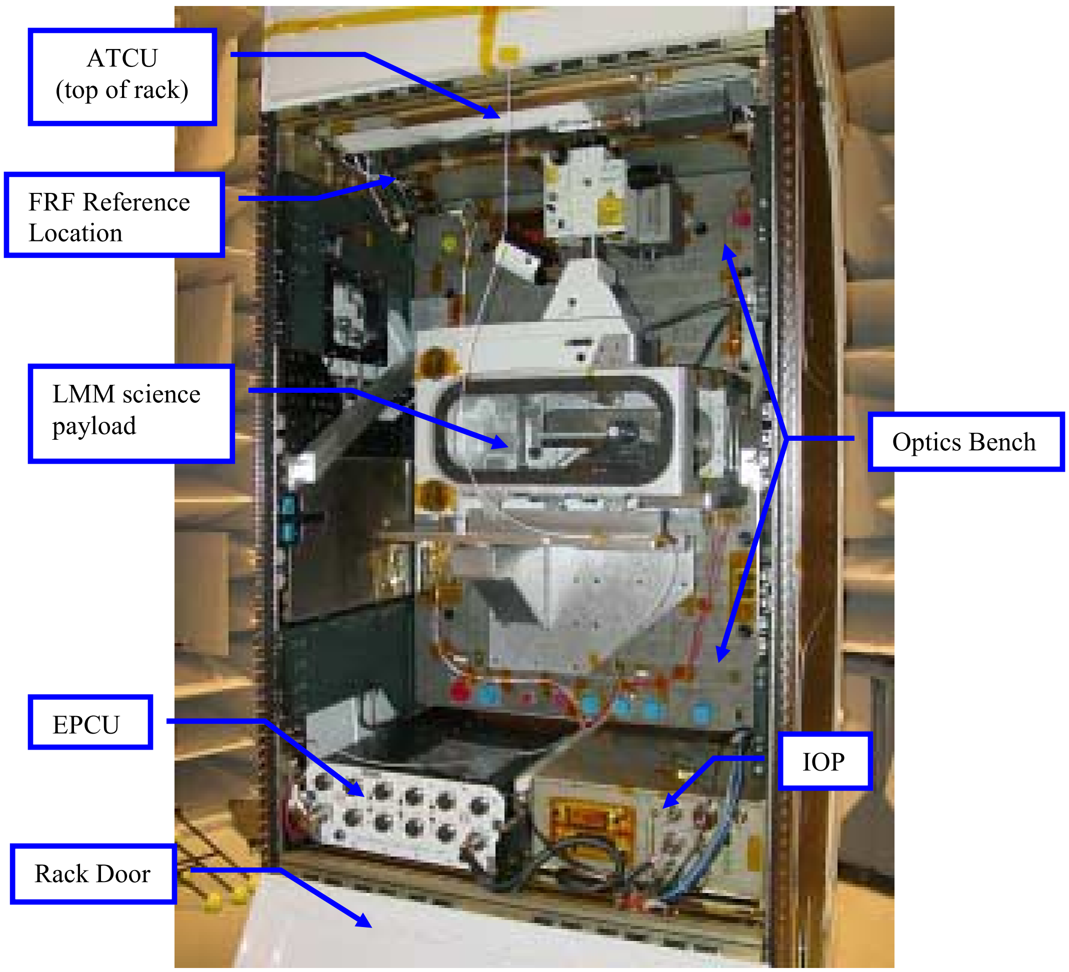

Figure 2. FIR EM Rack Hardware.

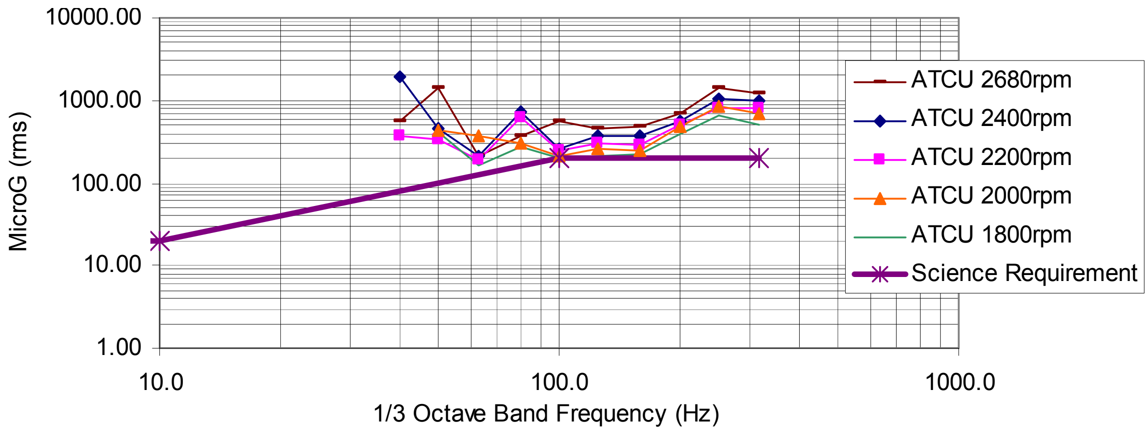

Figure 3. FIR EM Rack Acoustic Emission Testing in the Launch Configuration
Optics Bench Response Compared to the FIR Rack Science Requirement
(IOP and ATCU fans operating).

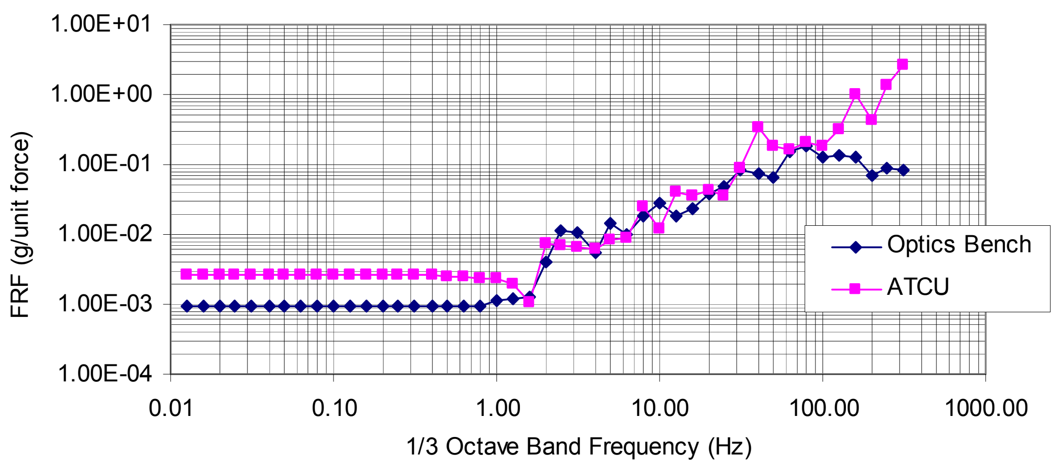

Figure 4. Optics Bench and ATCU On-Orbit Configuration
Analytical Frequency Response Functions.

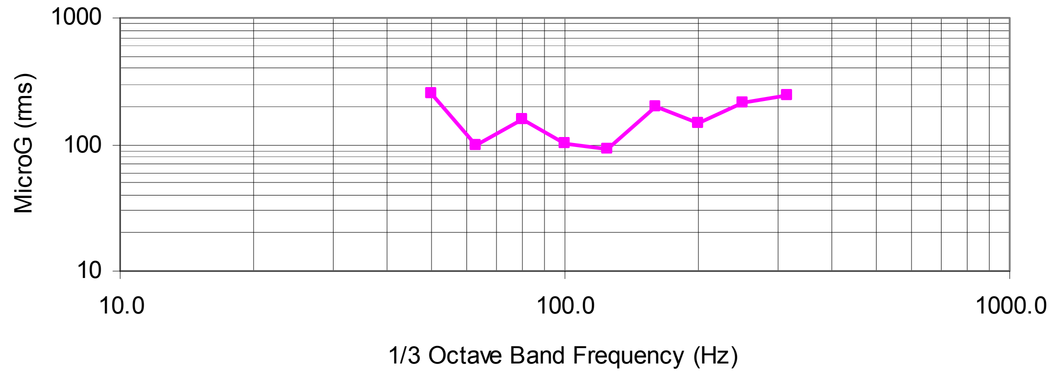

Figure 5. FIR EM Rack Acoustic Emission Testing in the Launch Configuration
Measured ATCU Reference Response Location
(ATCU Operating Speed at 1800 rpm).

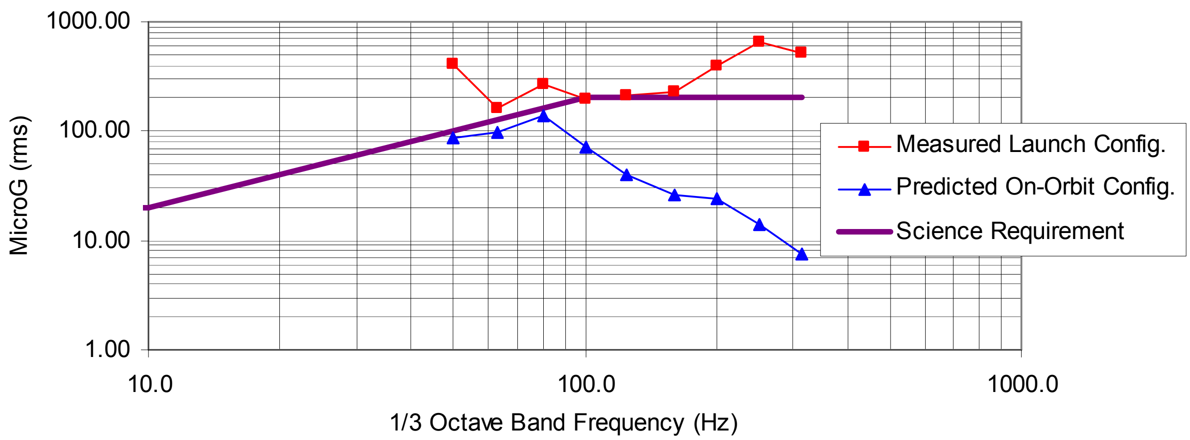

Figure 6. Comparison of Optics Bench Response Predicted On-Orbit versus
Test Measured Launch Configurations.

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13. ABSTRACT ***(Maximum 200 words)***

The Fluids and Combustion Facility (FCF) is a two rack facility dedicated to combustion and fluids science in a microgravity (near zero-g) environment on board the International Space Station (ISS). An important aspect of performing on-orbit research is maintaining the rack microgravity environment by minimizing vibroacoustic disturbances generated within the science payload. This paper discusses recent rack-level acoustic emission testing to characterize the science payload microgravity environment. Measurements are compared with FCF microgravity science requirements.

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