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Testing and Noise Control for FCF Project
Fluids and Combustion Facility (FCF): FIR and CIR

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1.0 BACKGROUND

The Fluids and Combustion Facility (FCF) is a modular, multi-user facility designed to accommodate fluids and combustion experiments on board the US Laboratory Module (US Lab) of the ISS. The primary mission of FCF is to support accomplishment of NASA Glenn Research Center Microgravity Science Division (GRC/MSD) Program objectives requiring sustained, systematic microgravity fluid physics and microgravity combustion science research on board the International Space Station (ISS). The extended duration microgravity environment of the ISS will enable microgravity research to enter into a new era of increased scientific and technological data return. The FCF is being designed to increase the amount and quality of scientific and technological data, while decreasing the development cost of individual experiments relative to other avenues of performing such experiments.

1.1 Fluids Integrated Rack

The Fluids Integrated Rack (FIR) accommodates a wide variety of microgravity fluid physics experiments on board the ISS. The FIR concept has evolved over time to provide a flexible “optics bench” approach to meet the wide variety of anticipated research needs. The FIR’s system architecture is designed to meet the needs of the fluid physics community while operating within the constraints of the available ISS resources. The FIR concept is based on a “carrier” approach that provides common services needed by nearly all fluid physics researchers to minimize the hardware required to be developed and launched for each experiment. Since a majority of hardware is reused, the FIR concept saves development costs, total up mass, and crew time required to perform the experiments.

1.2 Combustion Integrated Rack

The Combustion Integrated Rack (CIR) is the first FCF element to be launched. The CIR will provide sustained combustion physics research in the microgravity environment of the ISS. Investigators use this microgravity environment to isolate and control gravity-related phenomena and to investigate processes that are normally masked by gravity effects and thus are difficult to study on Earth. Combustion microgravity experiments can provide a unique insight into the control of the generation of combustion by-products (pollution) and the increased efficiency of fuels.

2.0 REQUIREMENTS

Noise requirements for the ISS are defined in terms of continuous and intermittent sources. The limits for continuous noise sources and intermittent noise sources at 0.6 m from the test article are defined by NC-40 and are summarized in Tables I and II.

3.0 INTRODUCTION TO ACOUSTIC APPROACH FOR THE RACKS

As part of the development of the CIR and FIR rack design, numerous acoustic tests were conducted. The purpose of the initial tests was to determine the levels of the various components thought to be contributors to the rack total noise. Based on the results from these previous tests and analyses of the effects of installation of the components in the rack and acoustic transmission through the rack, estimates were made of the total emitted noise of the integrated rack. These estimates indicated that the noise from the CIR and FIR rack would exceed the NC 40 noise requirement at high ATCU fan speeds and that the ATCU fans were the dominant contributor to the total rack noise and its exceedence. However, this analysis was based on invalidated analytical models for the installation and transmission loss effects. In addition to component level testing, packages were tested. The packages were installed into the racks to obtain total noise level of the packages in the rack. Both the CIR and the FIR have been tested at the NASA Glenn Acoustical Testing Laboratory two times each. Rack level testing of the CIR and the FIR helped to confirm and improve the validity of the analytical models.

During the development phase of the program, the ATCU fans were changed from McLean fans to EBM fans to allow the fans to operate at higher speeds and to provide more airflow for adequate cooling of rack components. Rack level acoustic tests performed on the CIR and FIR with design changes provided a more accurate assessment of the noise from the racks with the new fans and an opportunity to assess the noise reduction resulting from more acoustic treatment within the racks. The testing also provided an opportunity to again validate/improve the analytical models used to predict the levels of the flight rack.

4.0 MICROPHONE LOCATIONS

All acoustic rack tests are performed in a hemi-anechoic chamber. The total number of microphones and their locations vary during testing, depending on the acoustic emissions characteristics of the rack under test. A typical test consists of nine external microphones two feet forward of the front of the rack. Microphones are also placed two feet above the center of the rack, below the rack, two feet to the right of center of the right side of the rack, and internal to the rack in front of the optics bench. See Figure 2. Prior to testing each day, each microphone is calibrated with a piston phone calibrator.

5.0 NOISE REDUCTION FEATURES

5.1 Addition of Acoustic foam to racks

1-inch white melamine flat foam was attached to side and rear panels of rack for acoustic absorption shown in Figure 3. Figure 4 shows the application of the melamine foam to the door panels.

5.2 Addition of Aluminum close out panel to bottom of racks

Through testing it was apparent that the noise levels from the rack would not meet NC-40 requirements unless there was blockage of noise transmitted from the rack bottom. This was accomplished by addition of an aluminum closeout panel to the bottom of the rack as pictured in Figure 5.

5.3 Reduction of ATCU Fan Speed

The Air Thermal Control Unit (ATCU) Fans were identified as the primary source of acoustic noise. Testing showed both acoustic treatment and reduction in ATCU fan speed are needed to meet NC-40. Lowering the RPM of the ATCU fans reduces the airflow used for cooling the rack hardware. In order to improve the acoustic signature without affecting its component reliability additional coolant was requested to improve the performance of the ATCU Heat Exchanger (HX). Based on extrapolated results from the ATCU package testing, a 10% to 15% reduction in Fan CFM corresponds to a 7% to 12% reduction in Fan RPM, which corresponds to a 3.5 to 5.0 dB reduction in the acoustic signature of the ATCU. Analysis shows that this increase in coolant flow rate, when coupled with acoustic treatment, will allow the CIR to successfully meet the NC-40 Acoustic Requirement for continuous noise. See Figure 6.

6.0 RACK TEST RESULTS AND ANALYSIS

6.1 CIR Acoustic Results

CIR acoustic testing results in Figure 7 showed that with acoustic treatment the NC 40 requirement could be met with ATCU fans operating at 2200 RPM, barely met at 2400RPM and not met at 2640 RPM. Addition of thicker door foam to the rack with ATCU fans at 2400 RPM resulted in the rack noise level meeting NC-40 as shown in Figure 8.

6.2 FIR Acoustic Results

FIR met the NC-40 noise requirement at an ATCU fan speed of 1825 rpm with ½ inch foam on rack side and rear panels and with noise radiation from below the rack door blocked with transmission loss material.

7.0 FLIGHT CONFIGURATION

7.1 Analysis for the estimate of compliance with NC-40

To estimate the noise levels from the flight racks, adjustments need to be made to the levels measured with the Engineering Model (EM) rack to account for the differences between the racks. The major difference is the rack material, i.e. Aluminum for the EM rack and composite for the flight rack. In addition, adjustments need to be made for noise producing components that were not present during the tests of the EM rack.

The net effect of the difference in rack material is to allow slightly more acoustic energy to be radiated through the composite rack rear and sides and thus reduce the reverberation within the composite rack. The resulting calculated reverberation effects are given in Table III. As can be seen, this effect is only significant at low frequencies where the main energy loss from inside the rack is transmission through the rack wall. At high frequencies, energy loss from absorption by the acoustic treatment within the rack dominates.

Noise levels from components not present during the rack test are also accounted for in the estimation of the levels of the flight rack. Estimated noise levels from the various hard drives within the rack are obtained by adjusting measured levels from an isolated hard drive for the number of drives within the rack and for the effect of installing these drives within the rack. Levels for all other components such as water flow, were assumed to have uninstalled levels 10 dB below NC-40. These levels were then adjusted for installation effects. Noise associated with the scientific package was included separately and was not a part of the “other” sources. Radiated levels associated with the maximum permitted levels of the scientific package were included in the estimated flight rack levels. Table IV summarizes the radiated levels for hard drives, scientific package and other sources that are included in the flight rack noise estimate. The Table also shows the estimated levels for the flight rack and the measured levels for the EM with the ATCU fan speed of 2400 RPM.

8.0 CONCLUSIONS

With the addition of foam to the rack door and the blockage of noise transmitted from the rack bottom, measured CIR rack levels exceeded the NC 40 requirement by only 0.9 dB at 2400 RPM and 2.4 dB at 2600 RPM. The requirement was met at speeds below 2400 RPM.

Estimated levels for the CIR flight rack were only slightly different then those measured with the EM, except at high frequencies where permitted noise from the scientific package increased the total rack levels. The flight levels accounted for the difference in rack material and other components, including the scientific package.

FIR meets NC 40 at 1825 rpm with noise from below rack blocked and ½ inch thick foam on side and rear panels. Increasing foam thickness on panels to 1 inch and adding 1 inch thick foam to door increases margin at 1825 RPM to from 0.4 to 4.4 dB. At 2200 RPM NC 40 is exceeded by 0.2 dB with 1 inch foam on panels and door and front blocked. At 2300 RPM the exceedence increases to 1.3 dB.

FIGURE 1. FCF Containing CIR and FIR

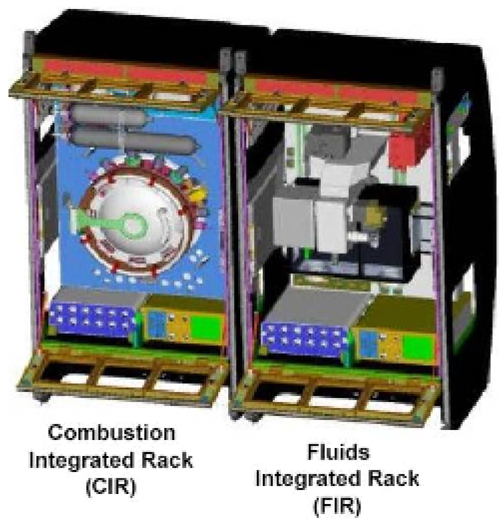

FIGURE 2. External microphone locations

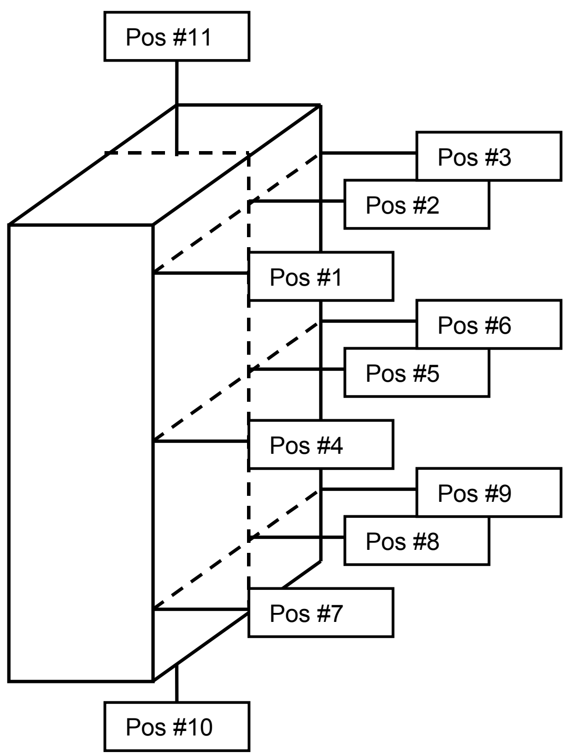

FIGURE 3. **Removable side and back rack panels with Melamine foam**

FIGURE 4. **Addition of foam to door panels**

FIGURE 5. **Aluminum close out panel for bottom of rack**

FIGURE 6. **Octave-band levels for microphone position 5 at 2400 RPM for CIR rack configurations**

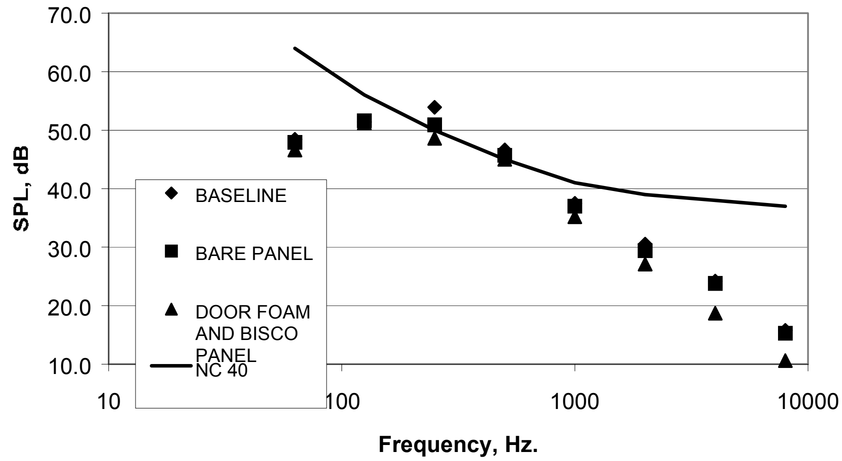

FIGURE 7. **Predicted acoustic noise for CIR composite rack.** With 1 Inch Foam on Rack Panels and Door Noise From Rack Bottom Blocked
(All Continuous Sources + Maximum Levels from Scientific Package Included)

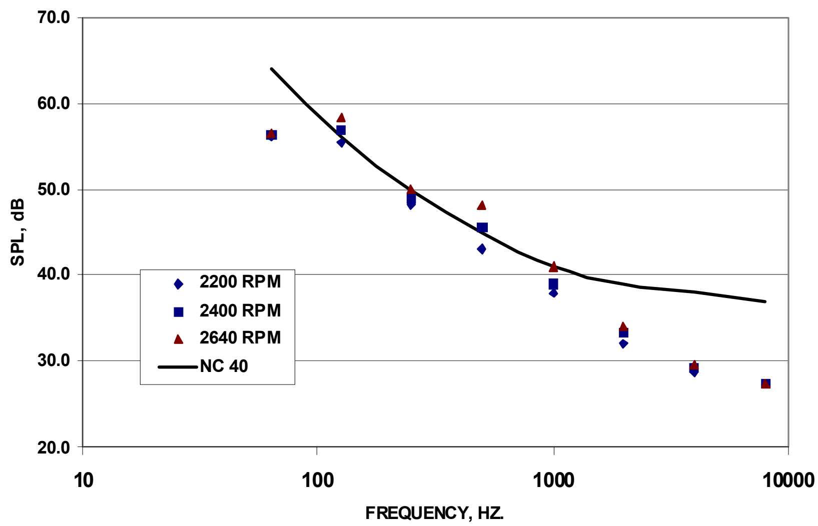

FIGURE 8. Predicted acoustic noise for CIR composite rack effect of thicker foam on doors.

Noise From Rack Bottom Blocked All Continuous Sources + Maximum Levels from Scientific Package Included ATCU Fan Speed 2400 RPM

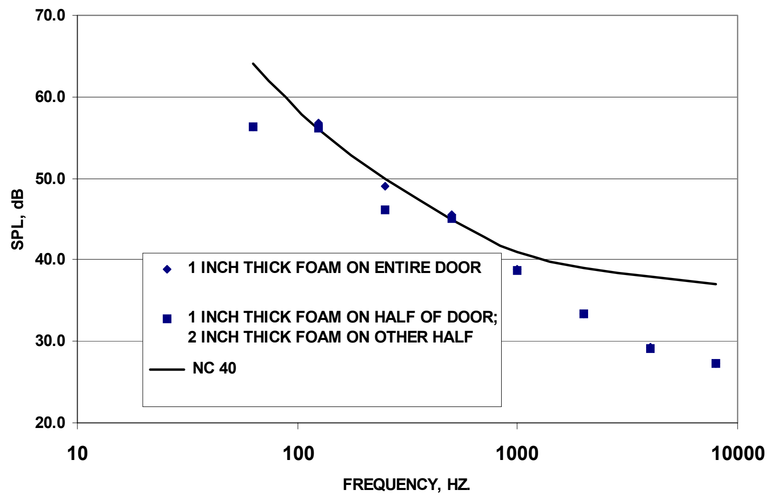

FIGURE 9. FIR noise levels ATCU fan speed=1825 RPM

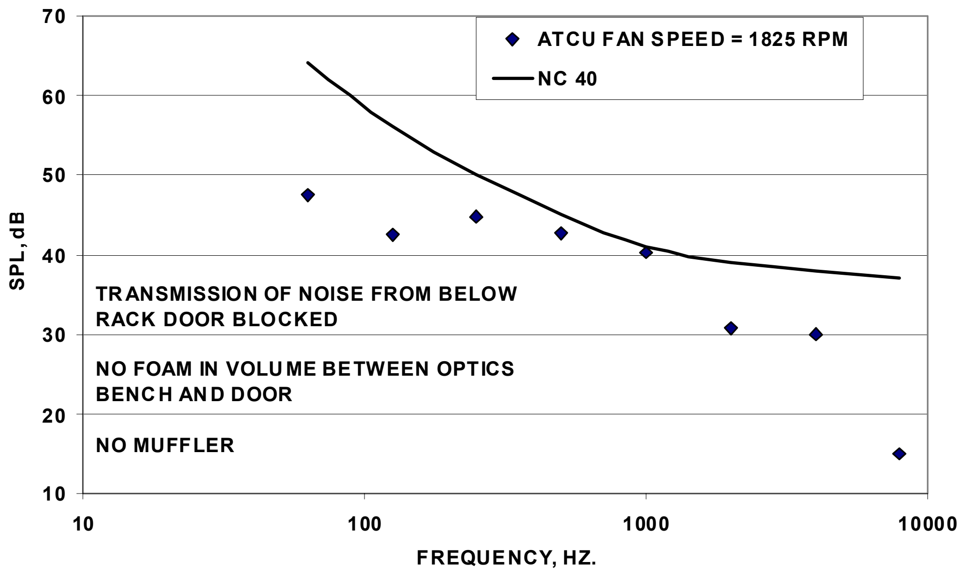

TABLE I. Rack noise limits for continuous noise sources at 0.6 m from the noisiest part of the article (for rack testing)

Frequency	63	125	250	500	1000	2000	4000	8000
SPL	64	56	50	45	41	39	38	37

TABLE II. **Rack noise limits for intermittent noise sources at 0.6 m from the test article**

Maximum Rack Noise *Duration Per 24 Hour Period	Total Rack A-weighted SPL (dBA)
8 Hours	49
7 Hours	50
6 Hours	51
5 Hours	52
4.5 Hours	53
4 Hours	54
3.5 Hours	55
3 Hours	57
2.5 Hours	58
2 Hours	60
1.5 Hours	62
1 Hour	65
30 Minutes	69
15 Minutes	72
5 Minutes	76
2 Minutes	78
1 Minute	79
Not Allowed	80

***The Rack Duration is the total time that the rack produces noise above the NC-40 limit during a 24 hour time period.**

TABLE III. **Comparison of the reverberation effect for the composite rack with that of the Aluminum rack**

Frequency Hz.	Net Reverberation Aluminum Rack dB	Net Reverberation Composite Rack dB
63	9.8	8.7
125	13.8	12.8
250	13.9	13.6
500	7.8	7.8
1000	6.5	6.5
2000	5.8	5.8
4000	5.0	5.0
8000	4.5	4.5

TABLE IV. **Estimated component noise levels, measured and calculated rack noise levels ATCU Fan speed 2400 RPM**

Frequency Hz.	Hard Drives dB	Other Sources dB	Scientific Package dB	Measured EM dB	Flight dB	NC-40 dB
63	4.2	51.5	54	50.4	56.3	65
125	28.7	41.6	46	56.9	56.8	56
250	0	29.7	40	48.8	49	50
500	5.4	13.8	35	45.1	45	45
1000	14.1	8.5	31	38.1	38.9	41
2000	11.1	5.8	29	31.3	33.4	39
4000	19.6	4	28	21.8	29.2	38
8000	0.9	-5	27	14.3	27.3	37