NASA Quiet, Efficient Fans for Space Flight Workshop

Fan Acoustic Issues in the NASA Space Flight Experience

Christopher S. Allen (JSC/SF22 Acoustics Office)
Jerry Goodman (JSC/SF Habitability and Environmental Factors Division)

NASA Glenn Research Center
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Outline

- General Concerns
- Apollo Command Module & Lunar Module
- Shuttle Orbiter
- ISS Hardware
- Cx Acoustic Requirements

General Concerns

- **Emphasis needs to be placed on choosing quiet fans compatible with systems design and specifications that control spec levels**
  - Sound power
  - Choose quiet fan or plan to quiet it, early in program
  - Plan early verification that fan source allocations are met

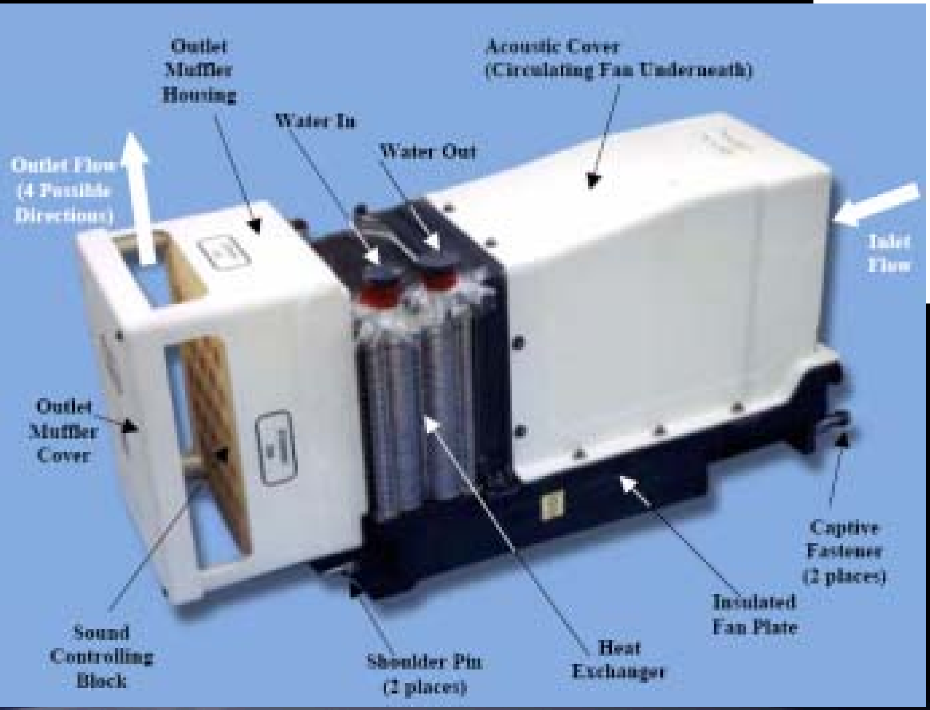
- **Airborne noise**
  - System design should function/play together with fans used (flow passages, restrictions, bends, expansions & contractions, and acoustics) vs. fan speed understood (nominal, worst case, & unplanned variances)
  - Fan inlets treated, as required
  - Fan Outlets treated, as required
  - Ducted system inlets are outlets designed for acoustic compliance compatibility & designed so some late required modifications can be made without signicant impacts

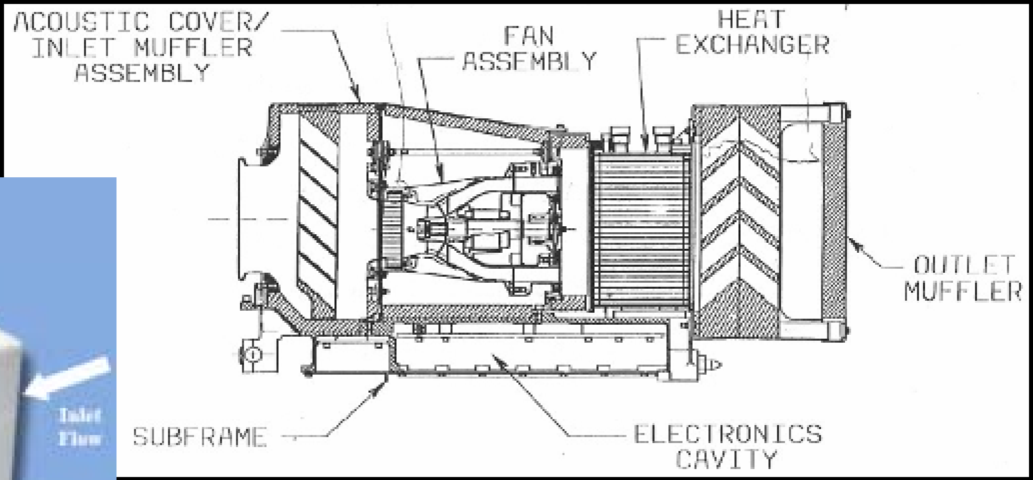
- **Structure Borne Noise**
  - Structure borne noise dealt with as part of fan package or installation
  - Duct attachments and lines isolated

- **Case Radiated Noise**
  - Treatment added as much as possible to fan package (see example)

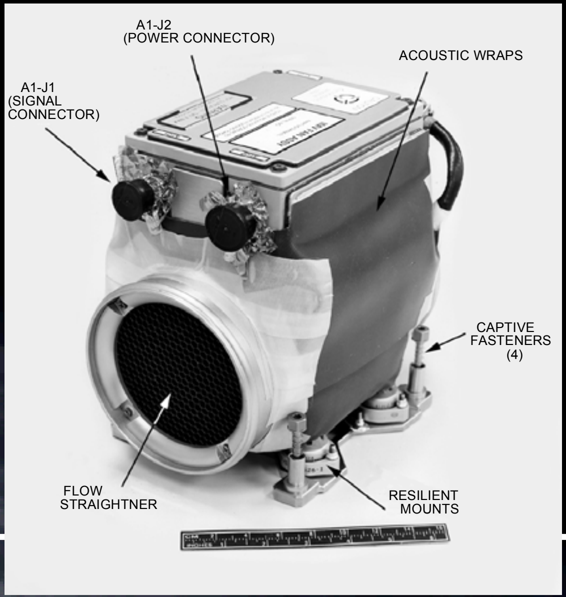
Good Examples of Integrated Fan Features

- ISS AAA fan and packaging
(Integrated muffler & covers)





- **ISS IMV fan** (Integrated barrier and isolators)



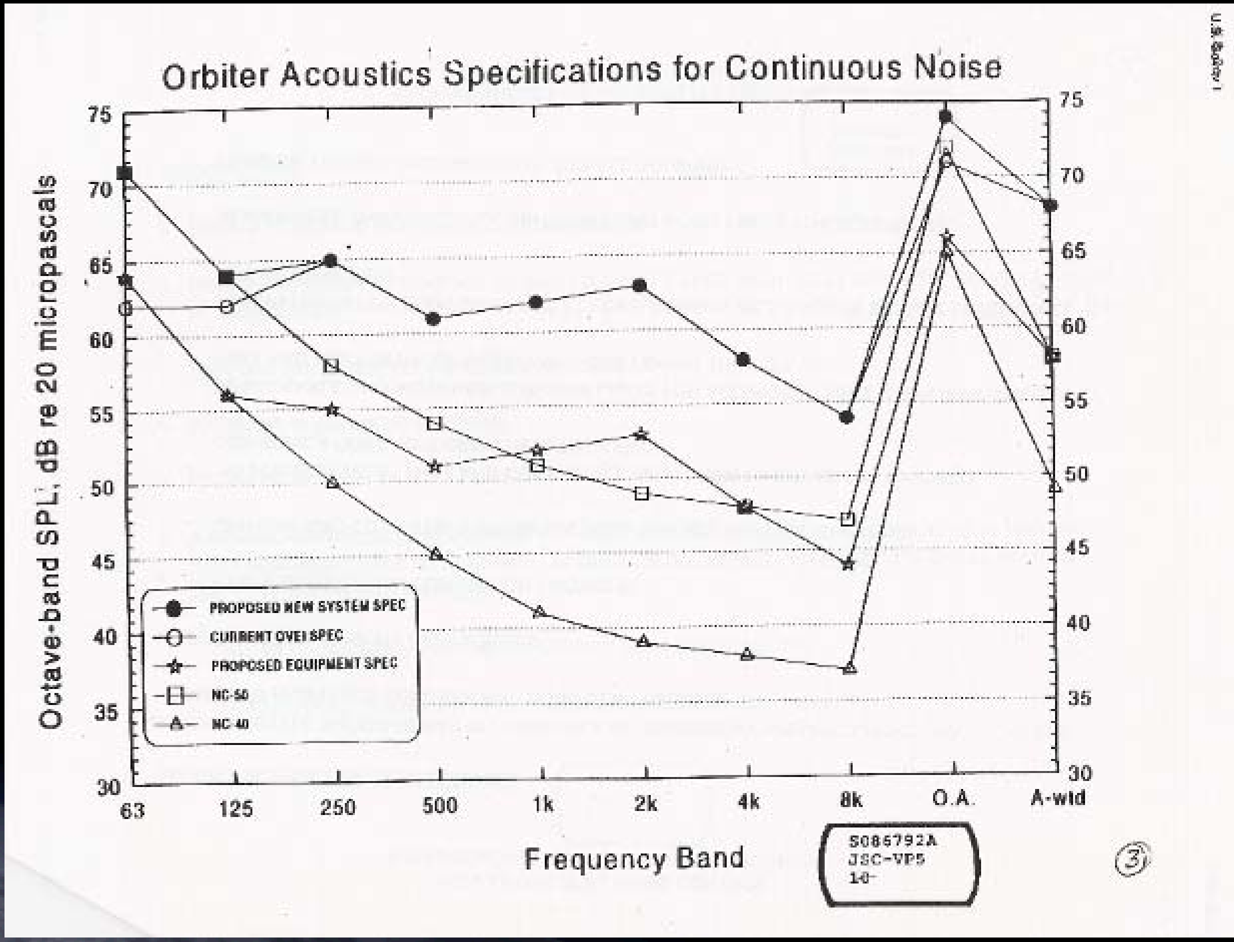
Apollo Command Module & Lunar Modules

- **Apollo Command Module (CM)**
  - Crews did not operate the cabin fans except during short specified periods and relied upon suit heat exchanger for the total thermal control of the cabin gas. This was because of the fan noise and because the noise passing through the cabin heat exchanger was amplified by the cabin structure

- **Apollo Lunar Module (LM)**
  - Fan use was mostly discontinued because of excessive noise

Space Shuttle Orbiter

- **Fans were dominant noise source in Orbiter. Late acceptance of NC-55 as Orbiter limit, although NASA technical inputs were NC-50. Lost time: long debate over "goals" vs. requirements and NC-50 vs. 55. Orbiter levels were 68 dBA after IMU muffler fixes (see Figure)**



Space Shuttle Orbiter (Continued)

- **RFP requested Orbiter ECS use of "quiet fans" developed by NASA-JSC in RTOP contract with Hamilton Standard. Rockwell carried fan through early development as baseline, but deleted them in deference to "off-the shelf fans". NASA technical objected, and costs/schedule to re-implement quiet fans was prohibitive**

- **IMU Fans**

  -Unacceptably high levels prior to Orbiter acceptance and shipment. Incorporated NASA GFE mufflers on three inlets and outlet at Palmdale-this demonstrated levels could be reduced to acceptable levels. Later incorporated integrated muffler for inlets/outlets

- **Cabin Fans**

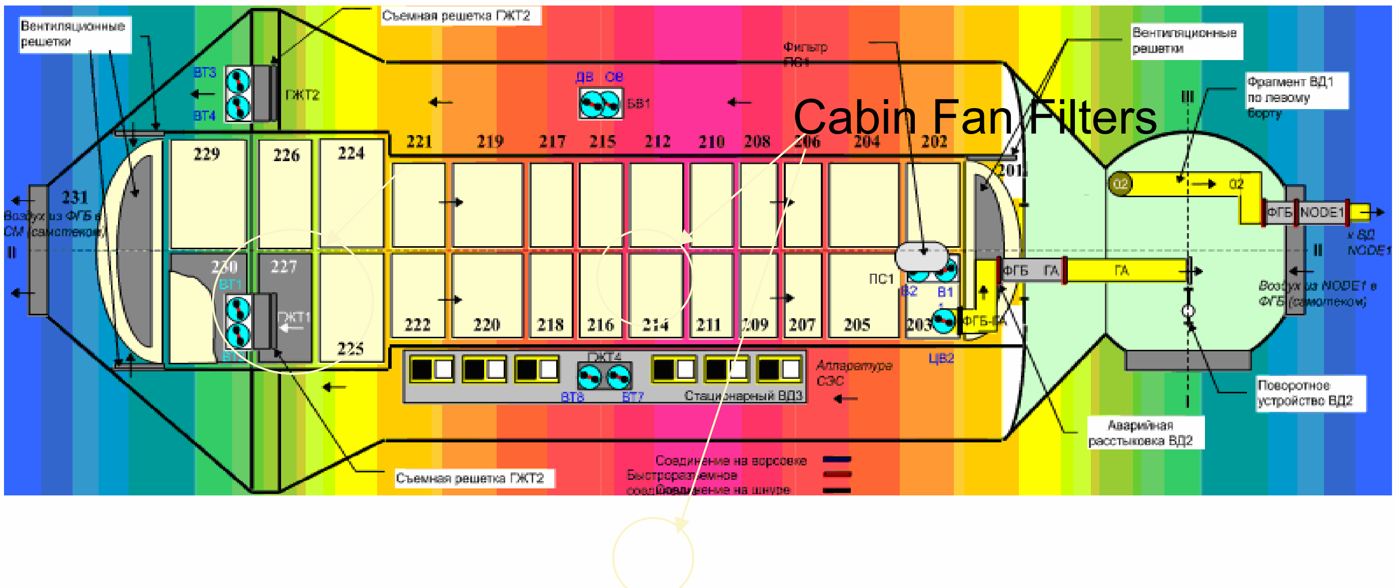
  - Mufflers considered, but impacts were too significant because of costs & schedules and late identification

- **Avionics Bay Fans**

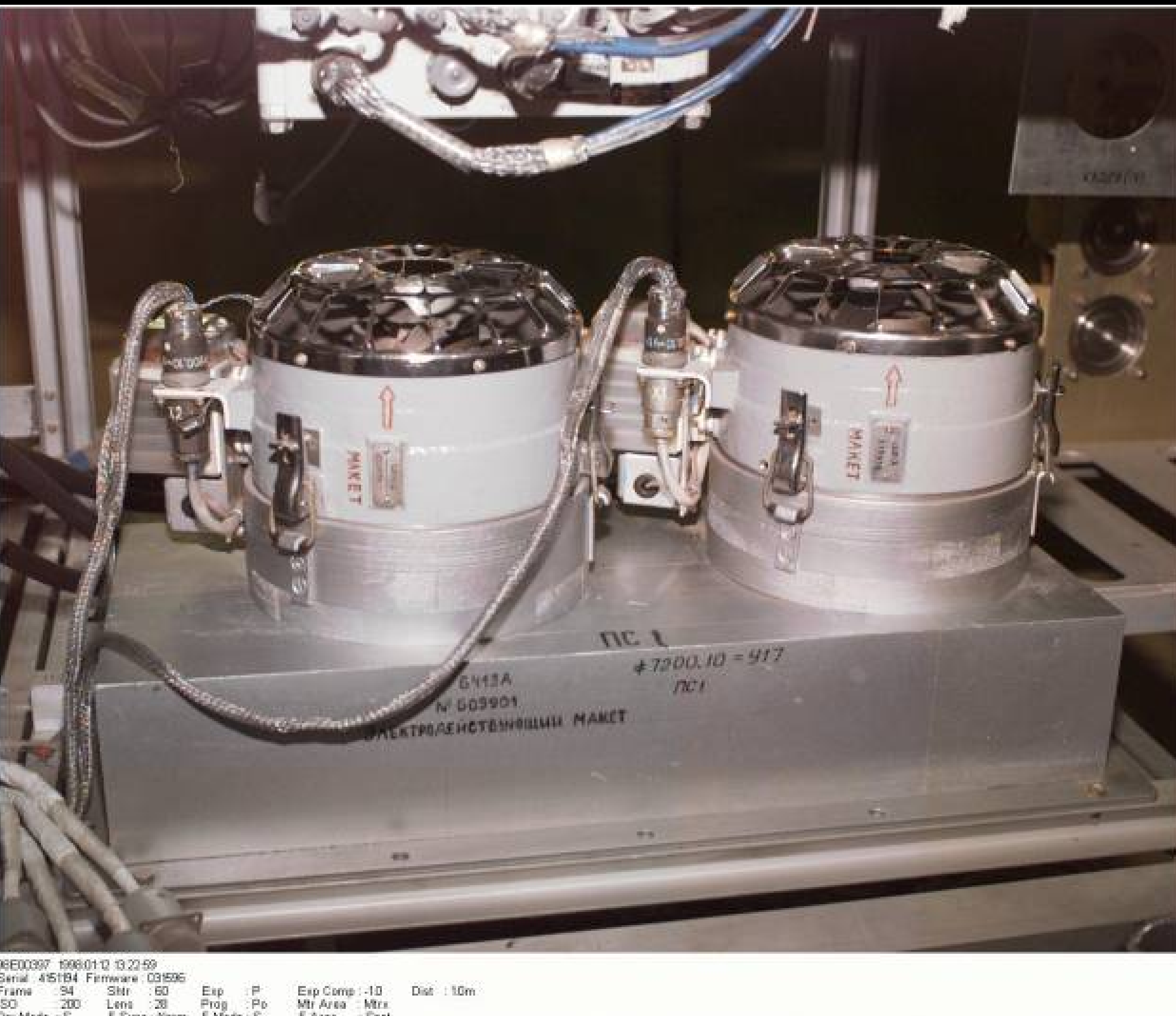
  - Were loud but located in isolated avionics bays which were treated

FGB Module Ventilation System

Cabin Circulation Fans



FGB Air Filtration Fans



- Two encased fans (each side of vehicle)
- Diameter 170 mm
- 3000 RPM
- Rotational frequency 50 Hz
- Two blades
- Blade passage frequency 100 Hz
- Inlet dimensions ~ 550 mm x 230 mm
- Inflow area 18644 sqmm

FGB Air Filtration Fan Rotor Hub

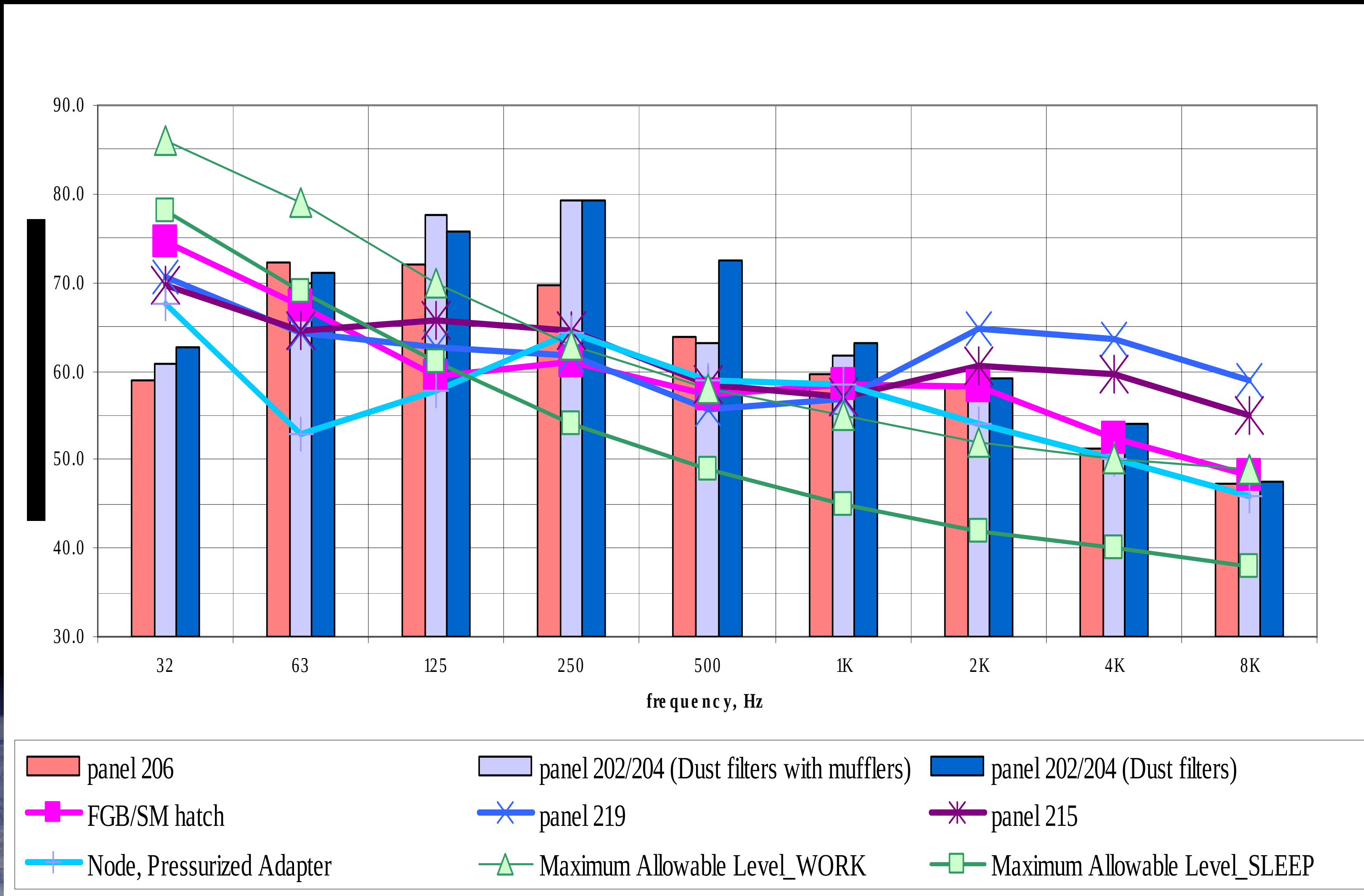
Aerodynamic Noise

- Blade passage frequency (# blades
- Support strut wake/blade interactio
- Inlet turbulent flow
- Blade pressure fluctuations
- Blade-vortex interaction
- Exhaust

Structureborne Noise

- Motor
- Rotor unbalance
- Bearings

Noise spectra in FGB



FGB Fans
Noise control options

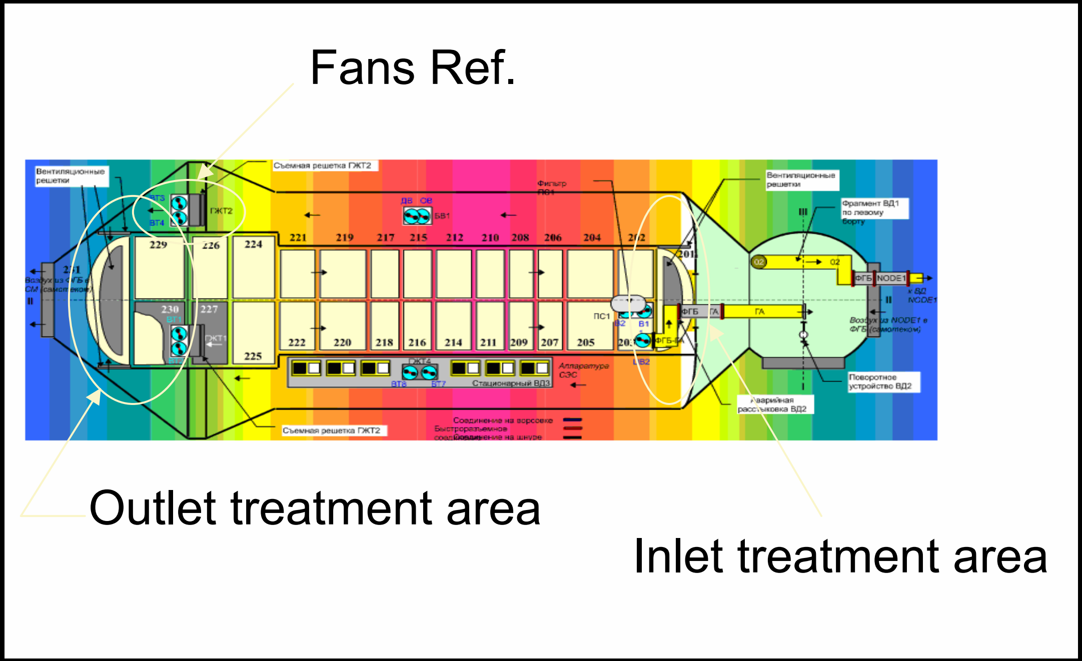
- Aerodynamic fairing
- Unobstructed inflow
- Blade design
- Motor/bearing design
- Helmholtz resonator
- Enclosure/duct
- Plenum
- Muffler
- Barrier
- Absorptive lining
- Damping

Solutions worked:

1. NASA Muffler (photo below). Incorporated Helmholtz resonators, inlet with blocked direct field of view, and incorporated foam absorption.
2. Russian mufflers, also utilized Helmholtz resonators

Ref. Noise-Con Paper

FGB Cabin Circulation Fans

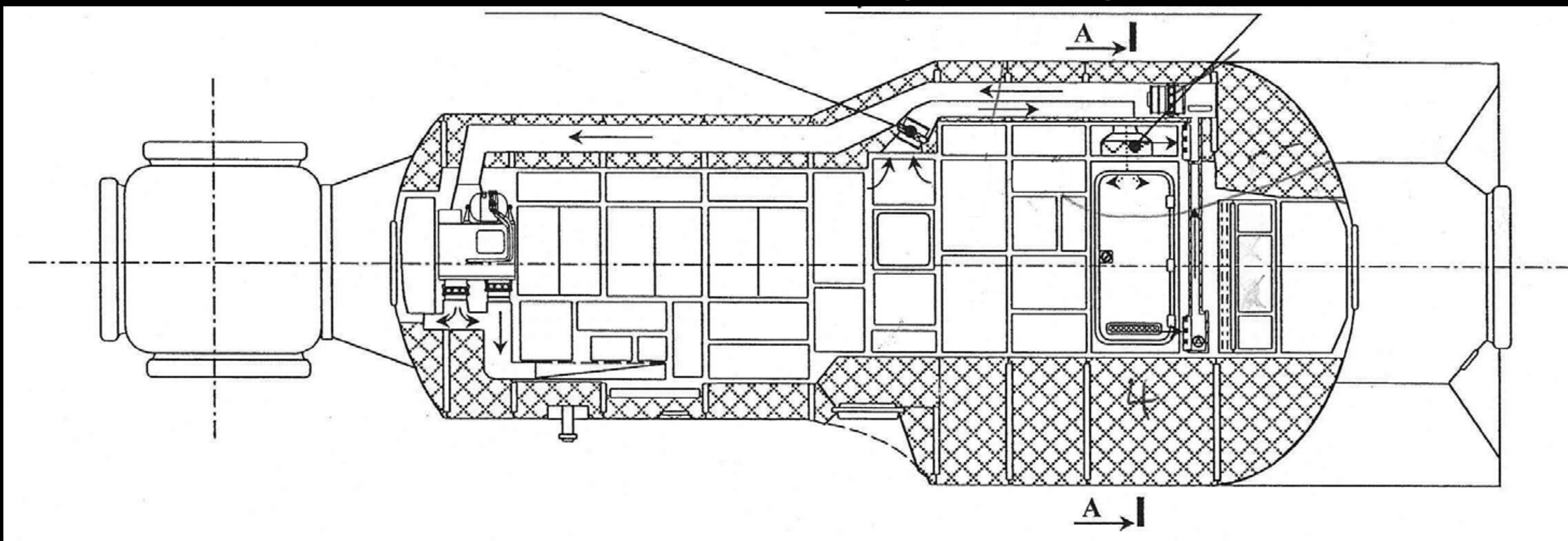


- Could not change fans to quieter ones or put isolators on them. Also, they couldn't accept absorbing liners in outboard flow areas
- Inlet & outlet crew compartment areas circled were used to quiet resultant noise. Significant hardware items, weight, & infringement into habitable volume was the result

FGB Quieting Equipment

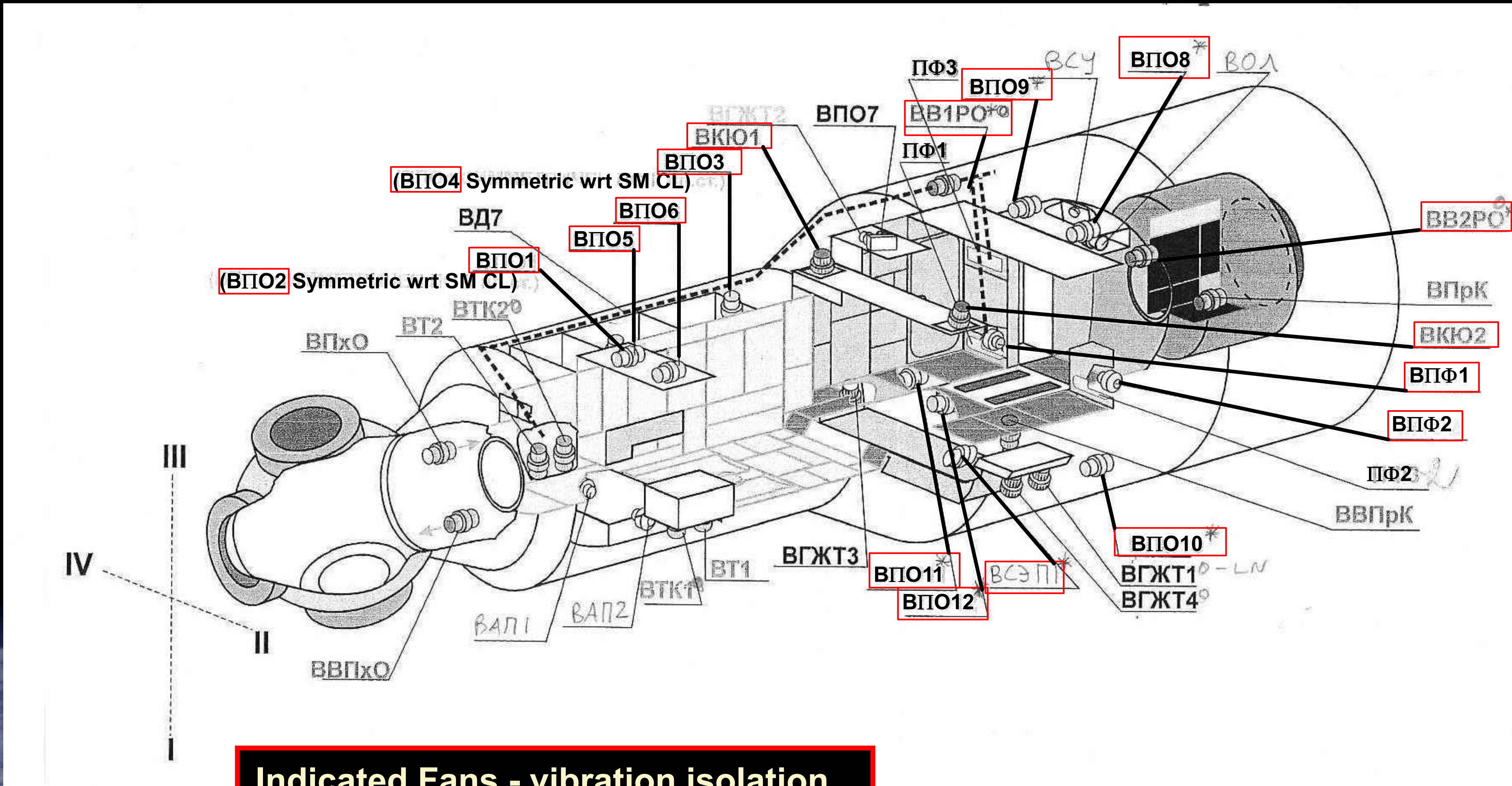
Profile Cross-Section of Service Module

Kayuta Inlet Fan **Kayuta air register**



Kayuta Acoustic Treatments

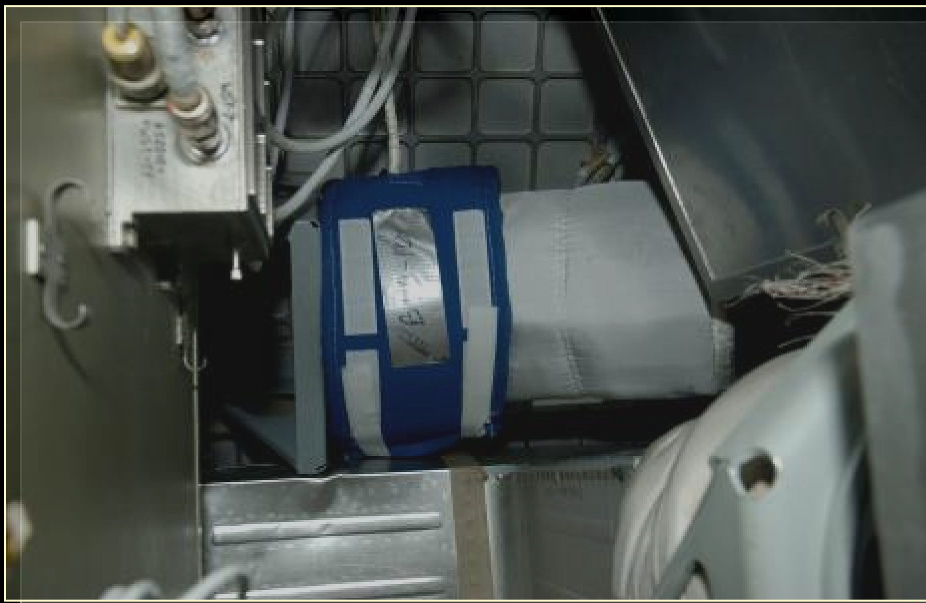
Service Module Ventilation System Fans



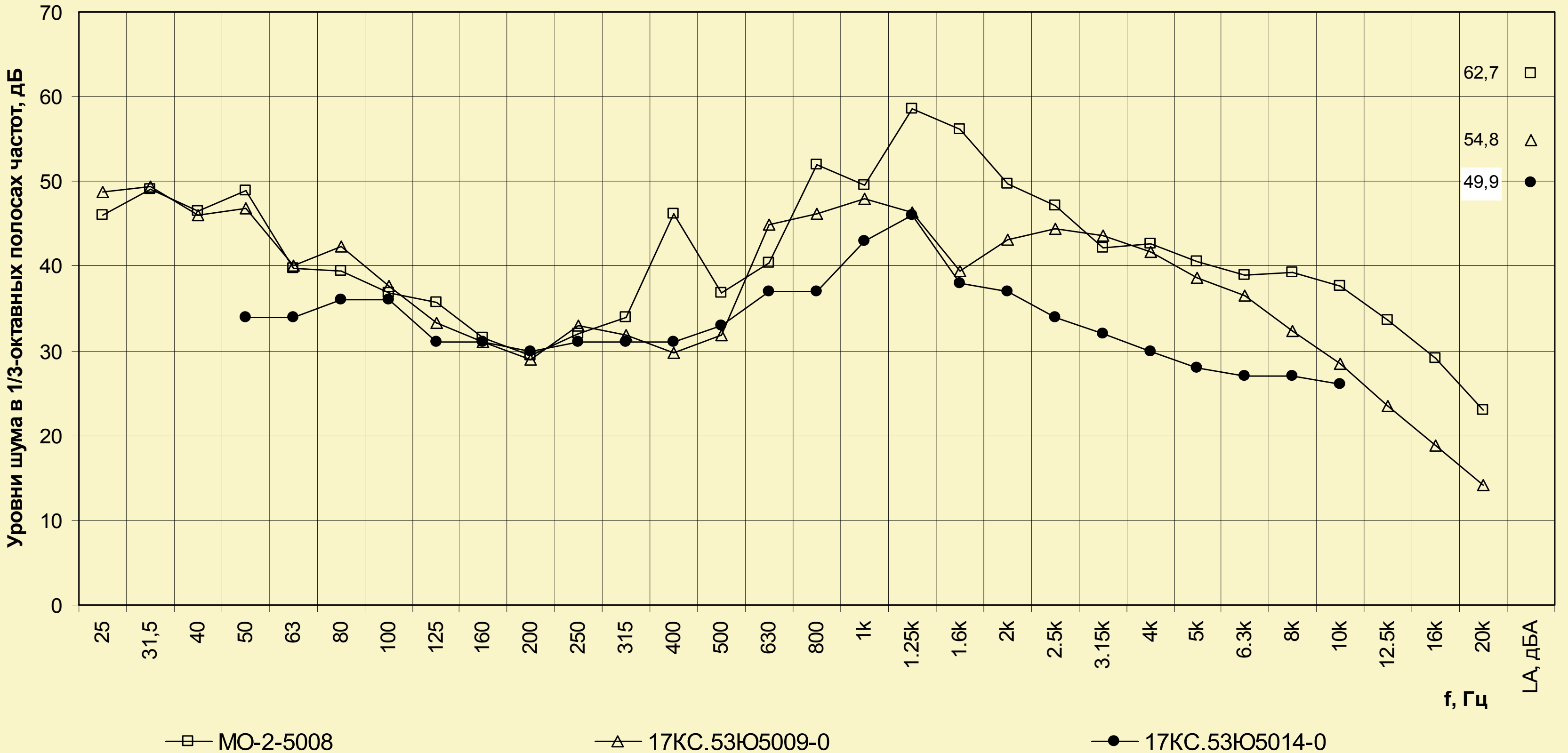
Indicated Fans - vibration isolation
- acoustic lined duct

Ventilation Subsystem

Installation of soundproofing device on ВПО10, ВПО11, ВСЭП1



SM Acoustic Contract
Quiet Fan Development



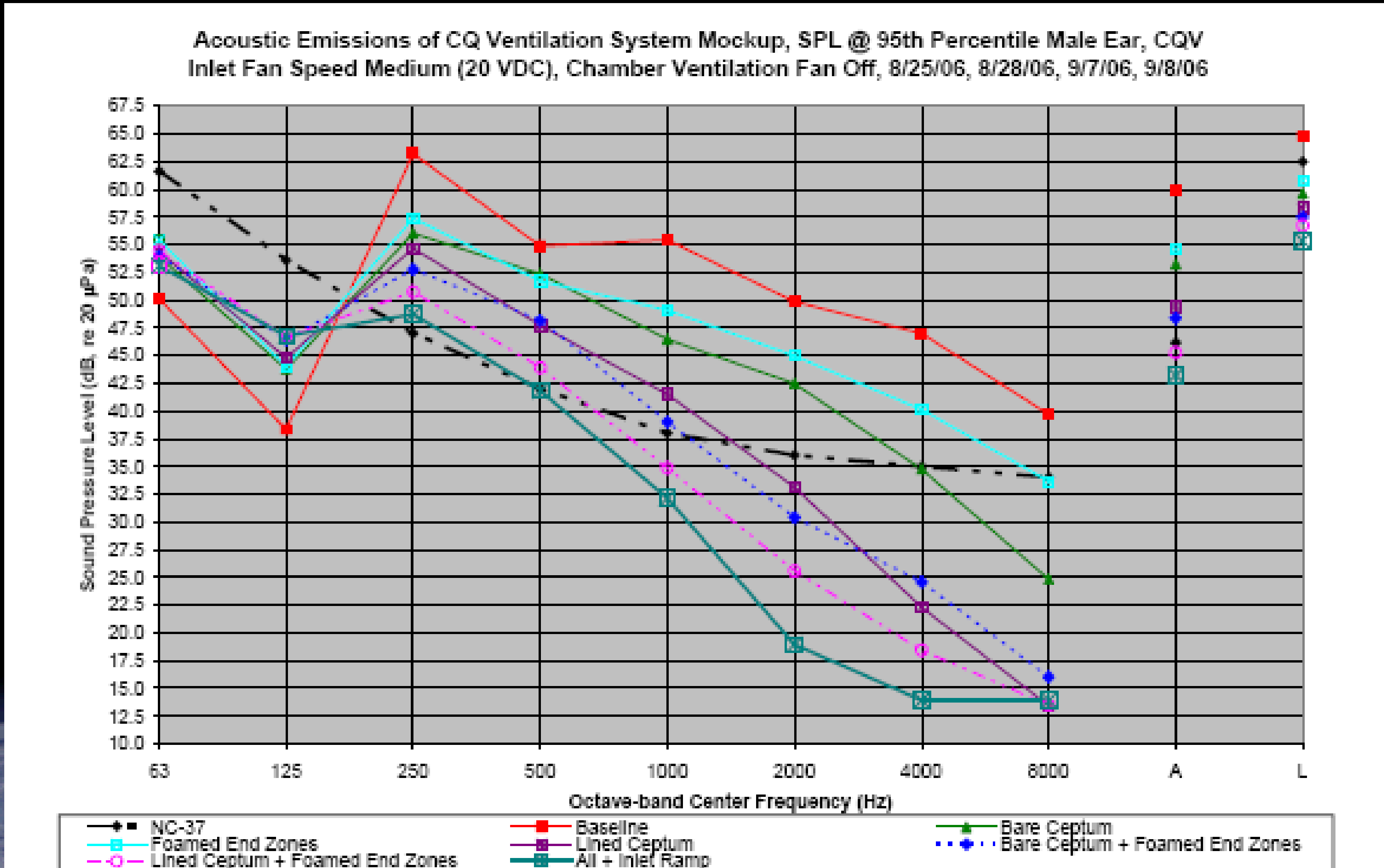
WHC

- Given a fan because it was spaceflight qualified
- Problem with voltage settings and MTL software

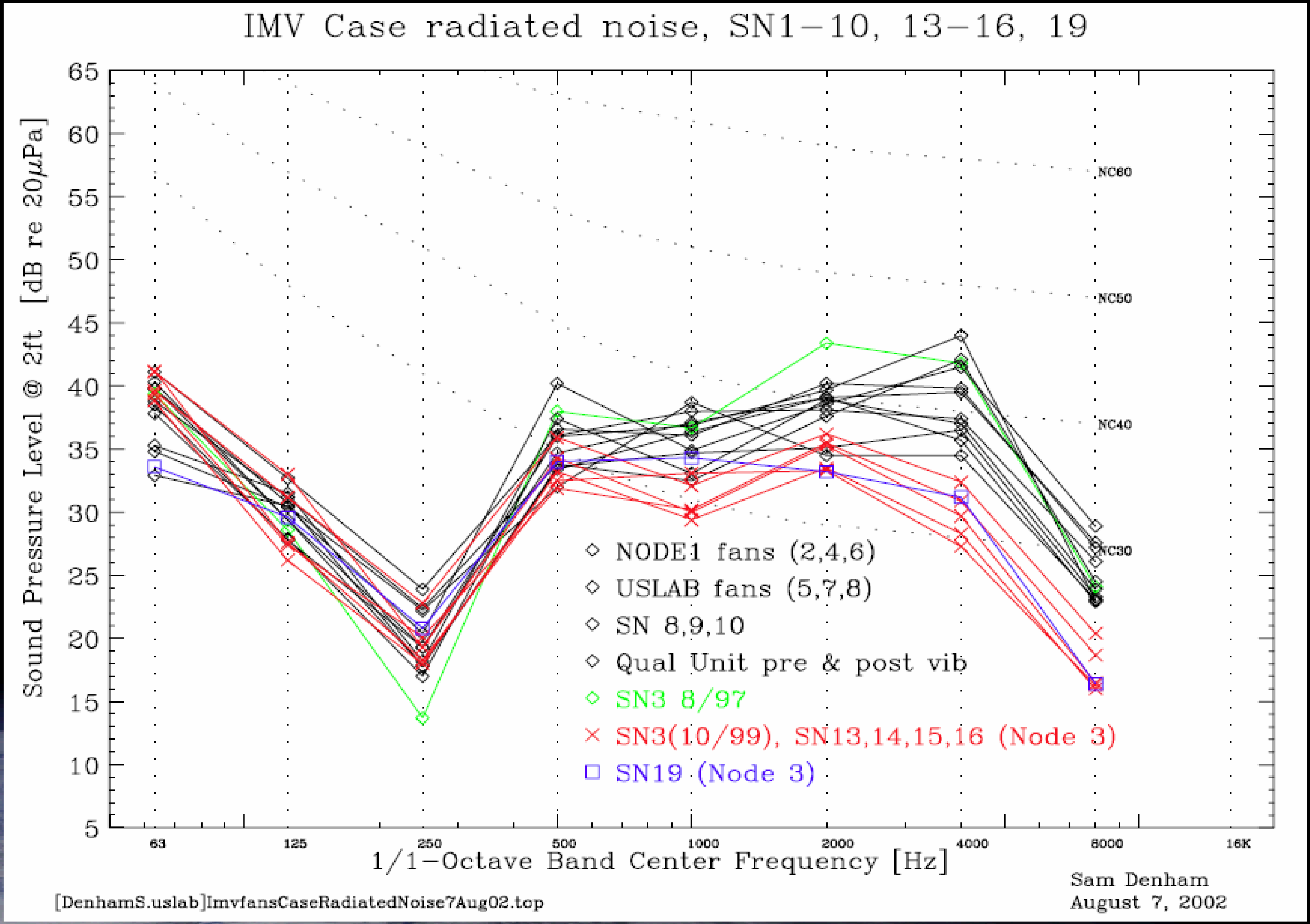
Crew Quarters

- Did not have time to choose a fan
- Vibration isolation problem
- Beating phenomenon
- Mockup testing was very helpful
  - Wooden mockup
  - Intermediate mockup

Noise Reduction of Airborne Path

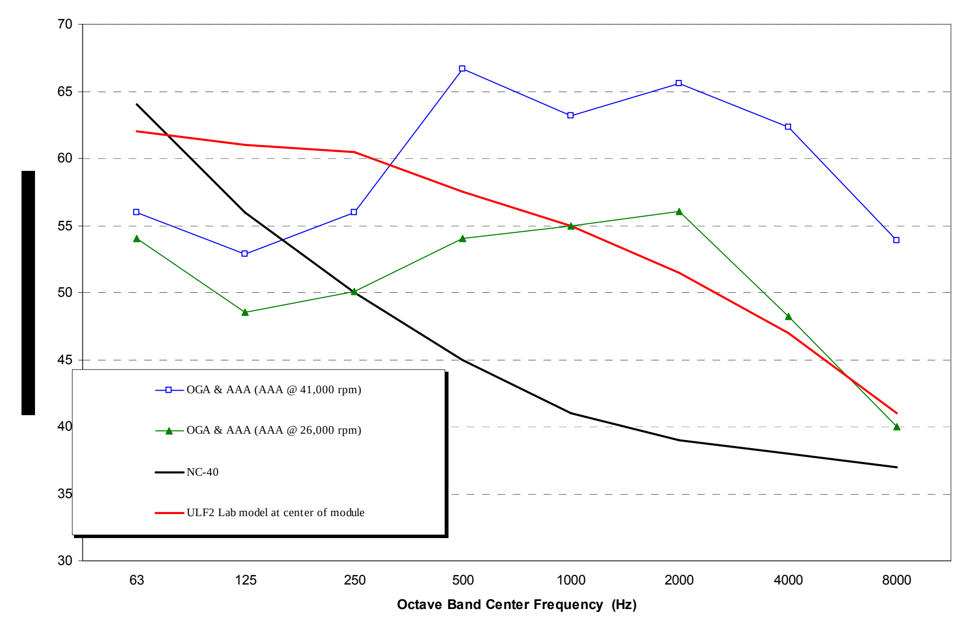


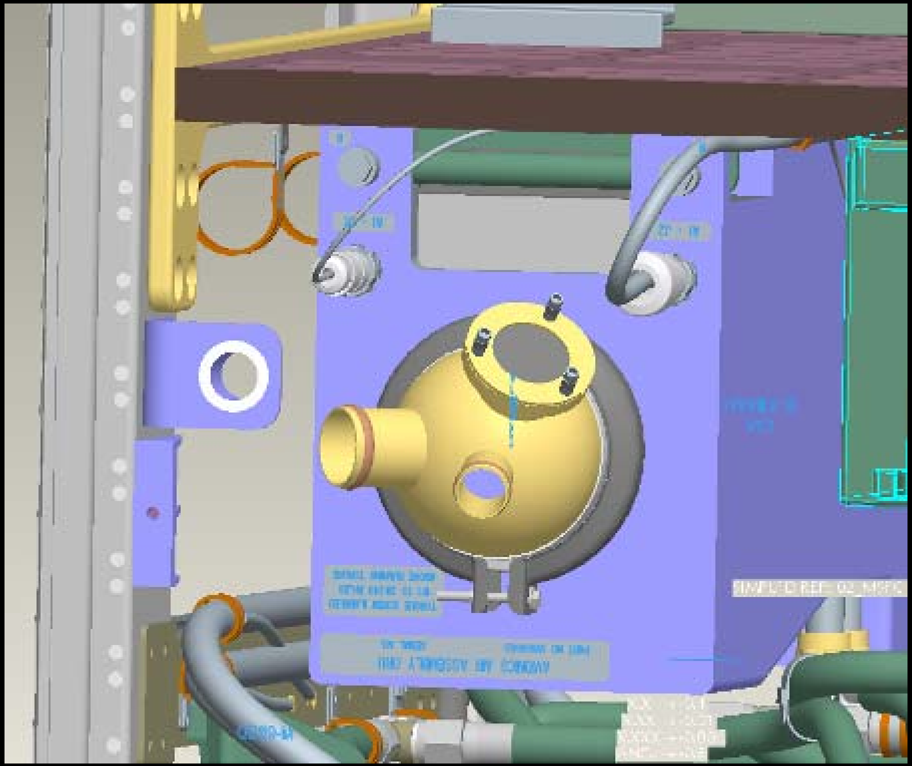
Fan to Fan Differences



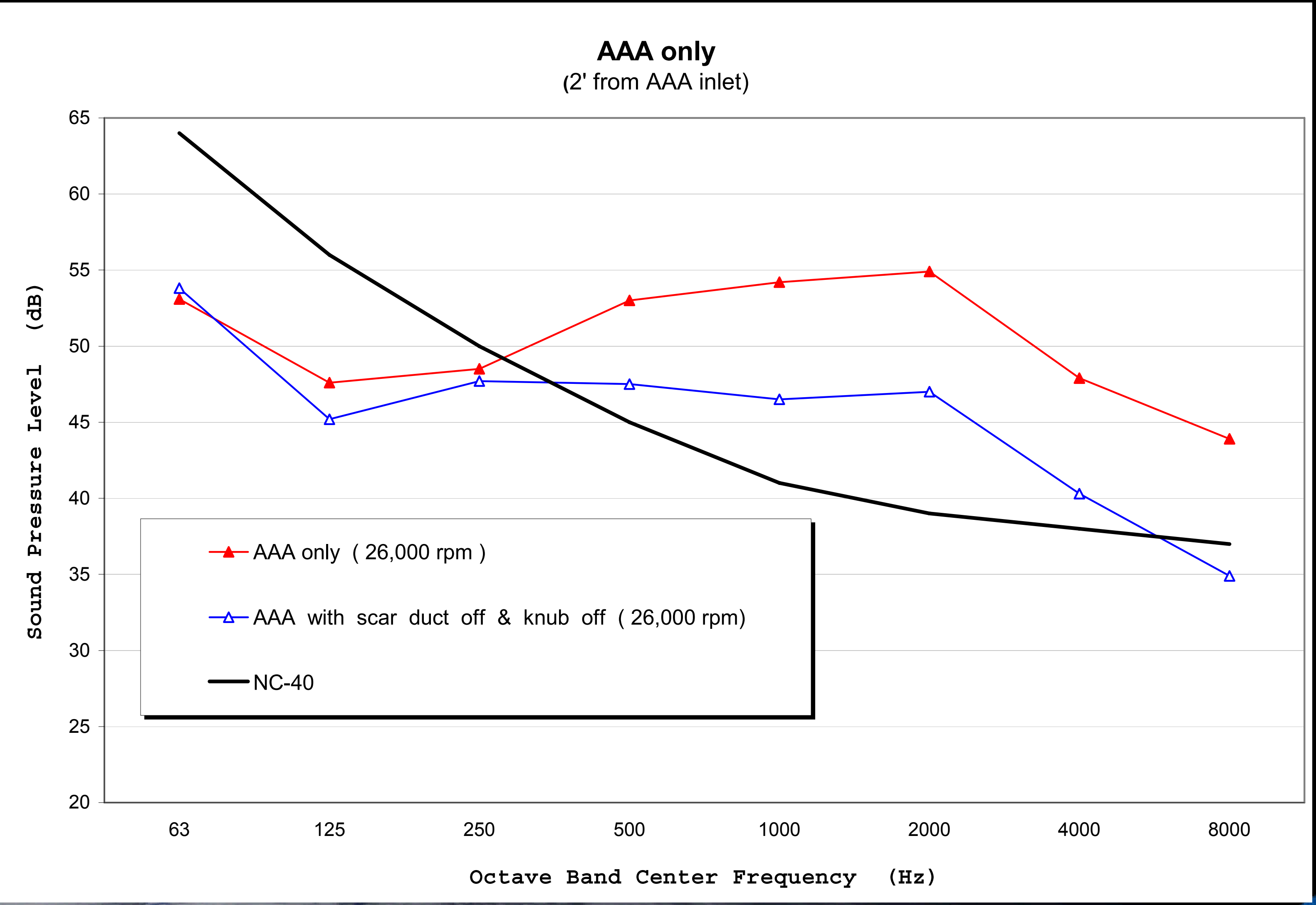
OGS

- Problem with manifold causing the fan to stall
- Show levels before and after choke





Effect of Reducing Backpressure



40x80 Noise at Different Rotational Speeds

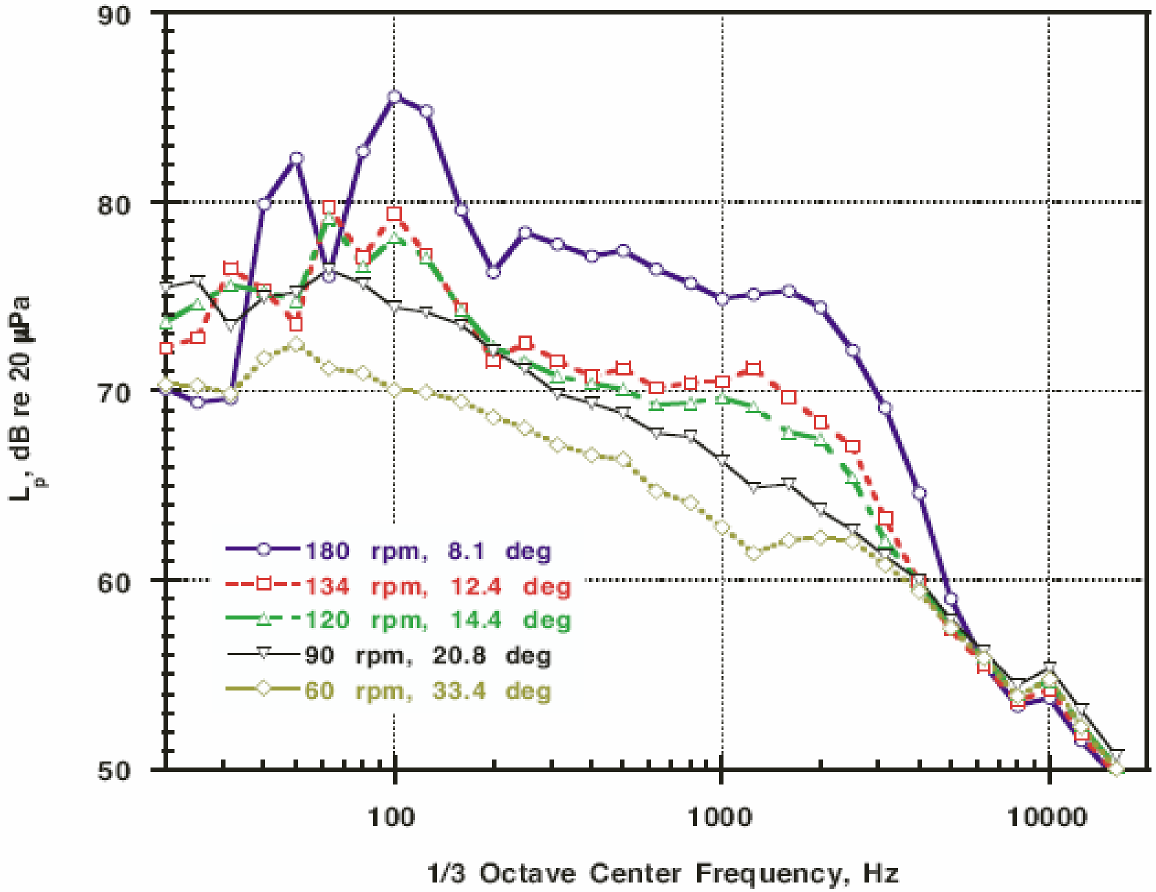
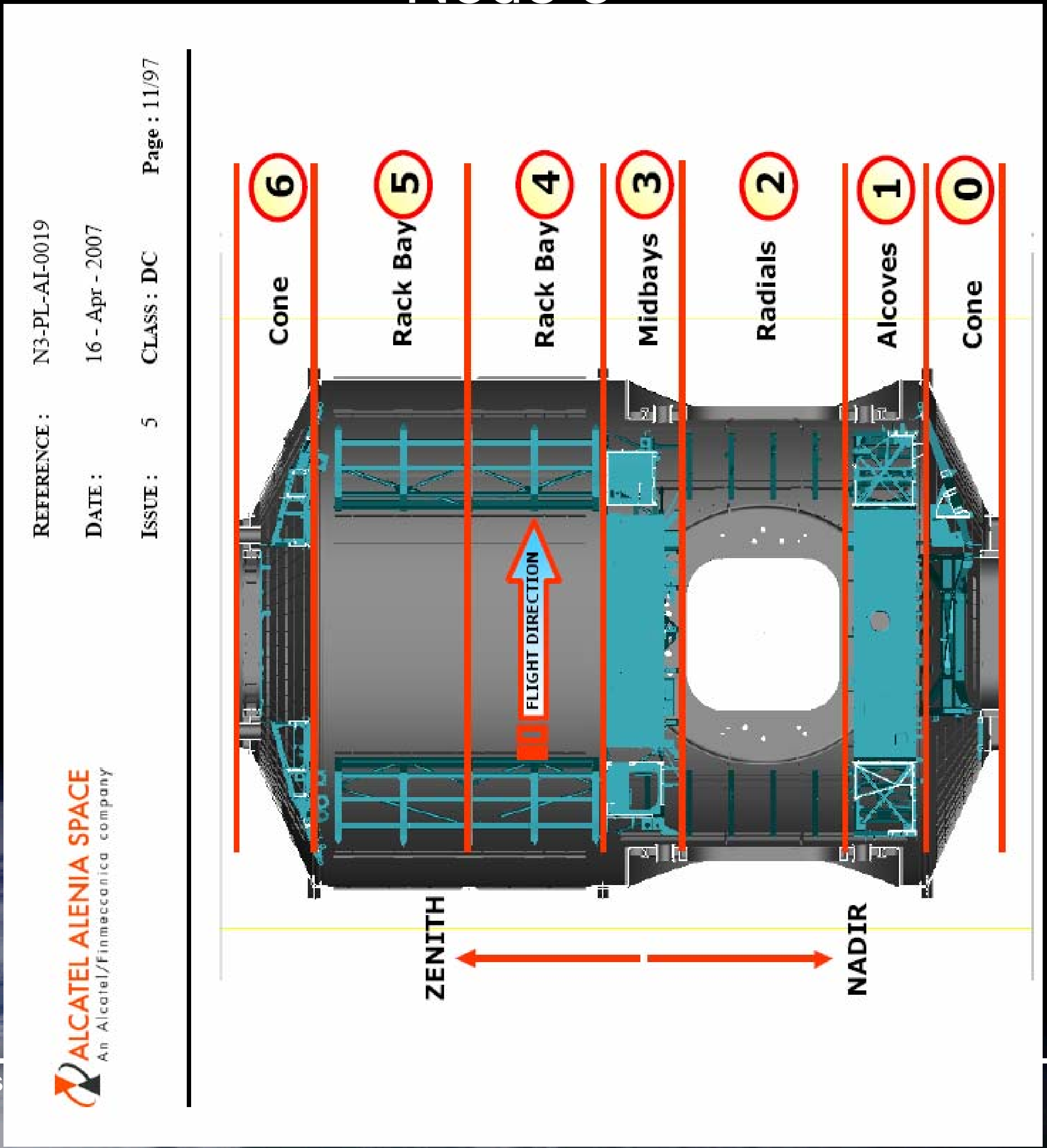


Figure 27a. Noise level variation with changing fan rotational speed, N, but with constant test section flow velocity of M=0.1 (34.5 m/s, 67 kts).

Node 3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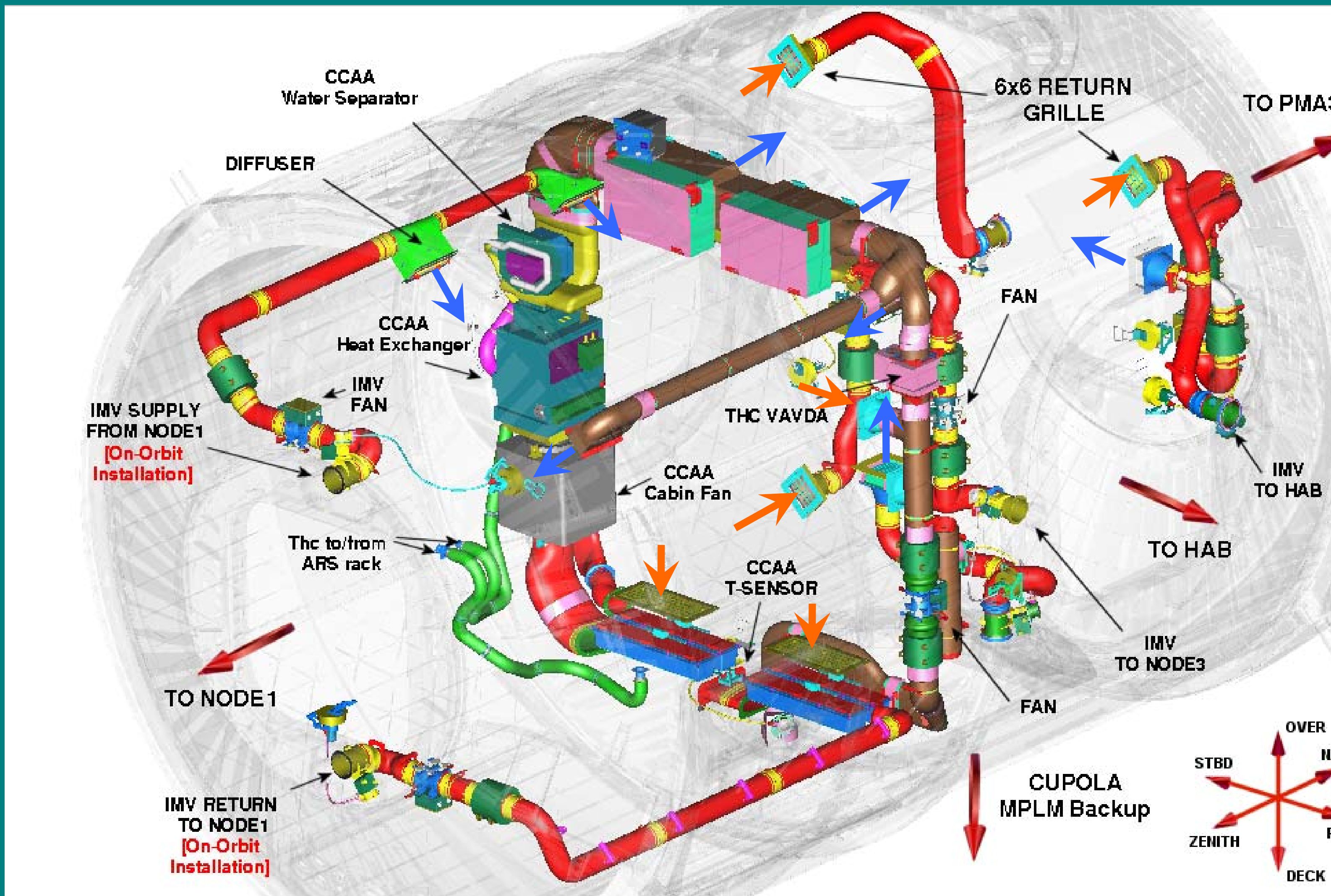
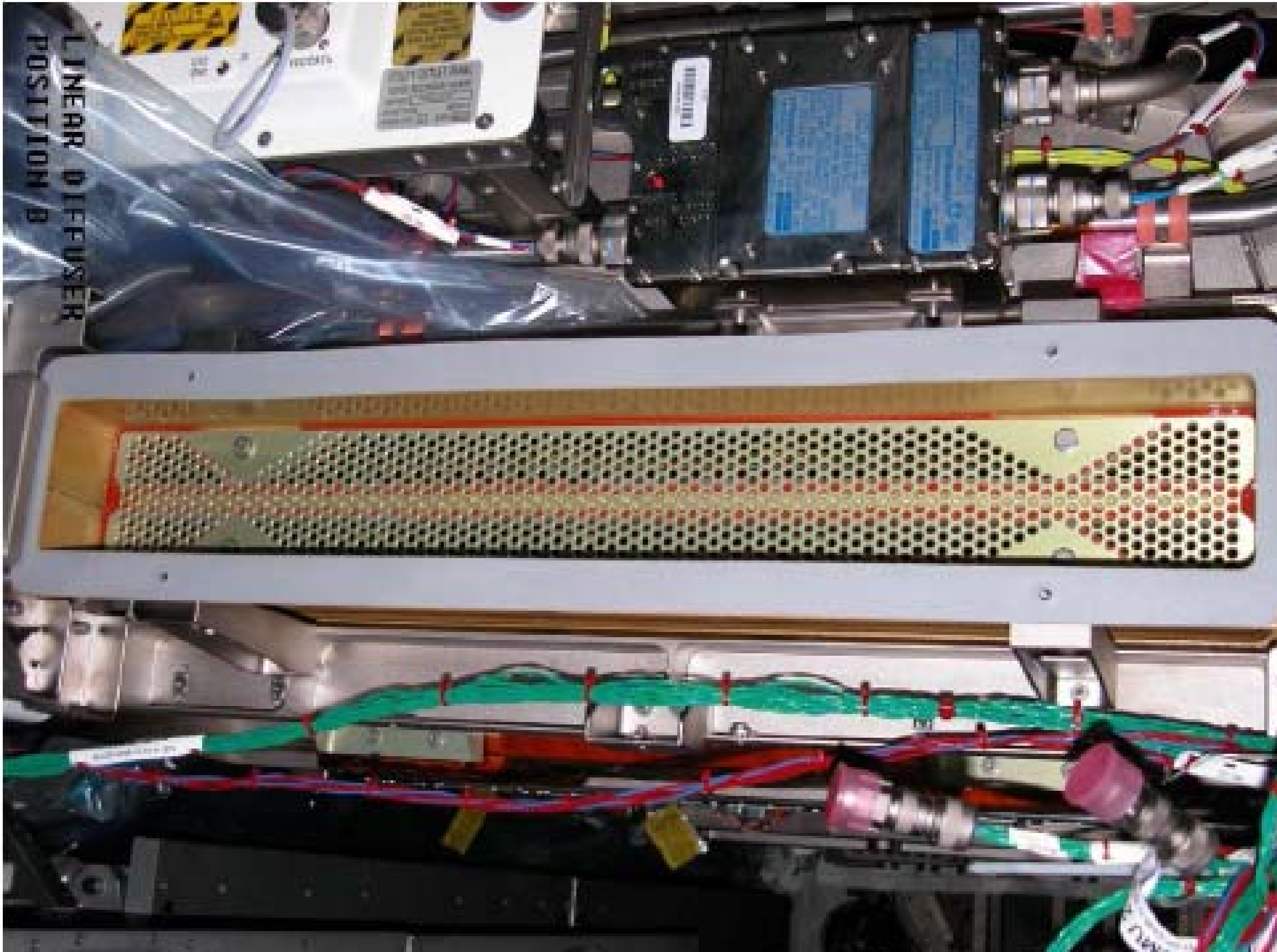
DATE : 16 - Apr - 2007
ISSUE : 5
CLASS : DC
Page : 11/97
ALCATEL ALENIA SPACE
An Alcatel/Finmeccanica company
6 Cone
5 Rack Bay
4 Rack Bay
3 Midbays
2 Radials
1 Alcoves
0 Cone
FLIGHT DIRECTION
ZENITH
NADIR

Node 3 Ventilation System





Linear diffuser Port side (position B, see annex A)

- Test Performed on May, the 17th 2007 (ACOUSTICS)
  - Alternative Perforated Plates tested

Common Midbay Diffuser (22 slots out of 31 open, as per picture above) – Plate No. 1F70849-1B Rev. NC MFG8Z095

Common Zenith Diffuser (all slots open) – Plate No. 1F70849-1

Alternative Plates installed as per pictures above.

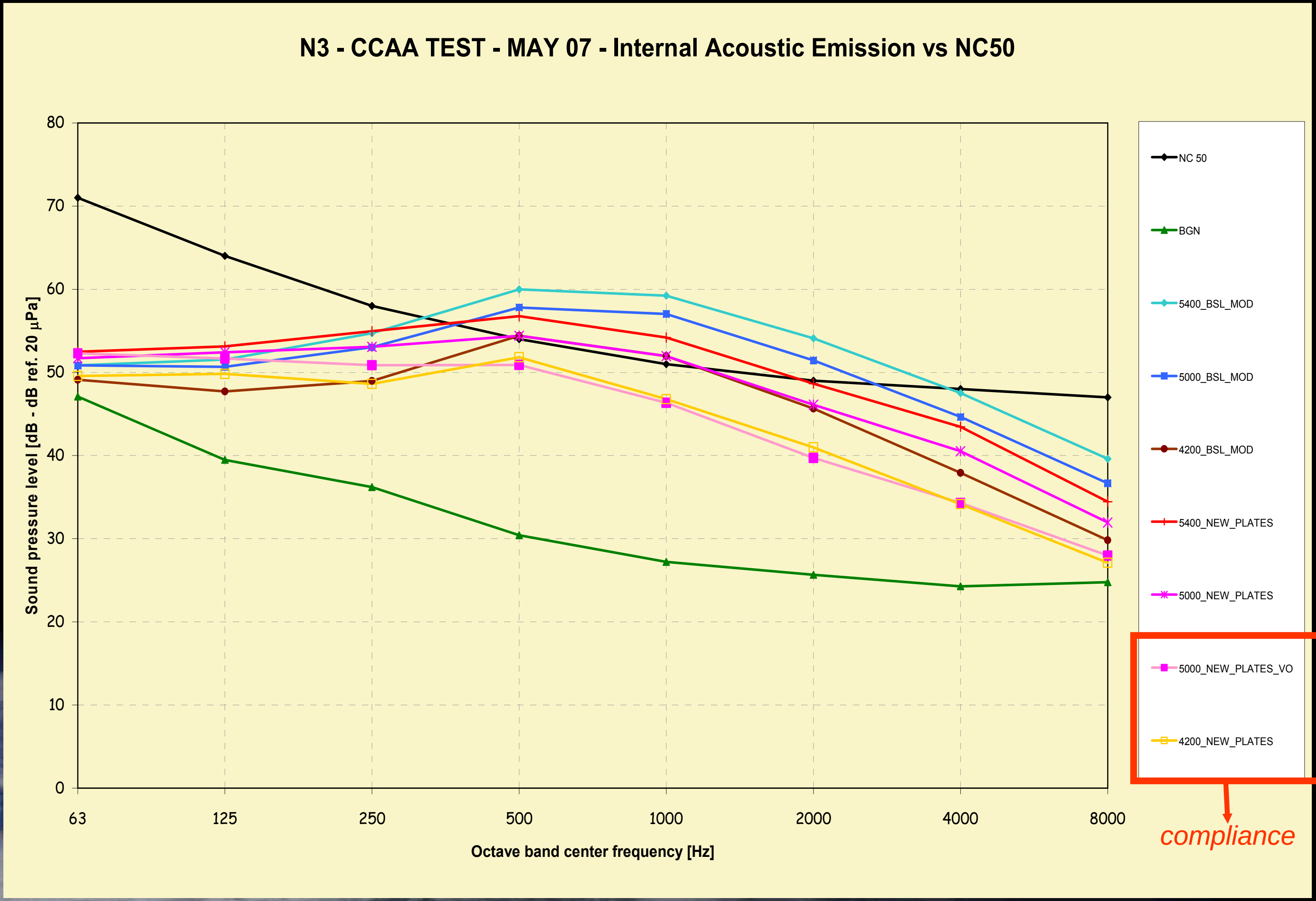
Increase of passage area:

75% on common zenith perforated plate

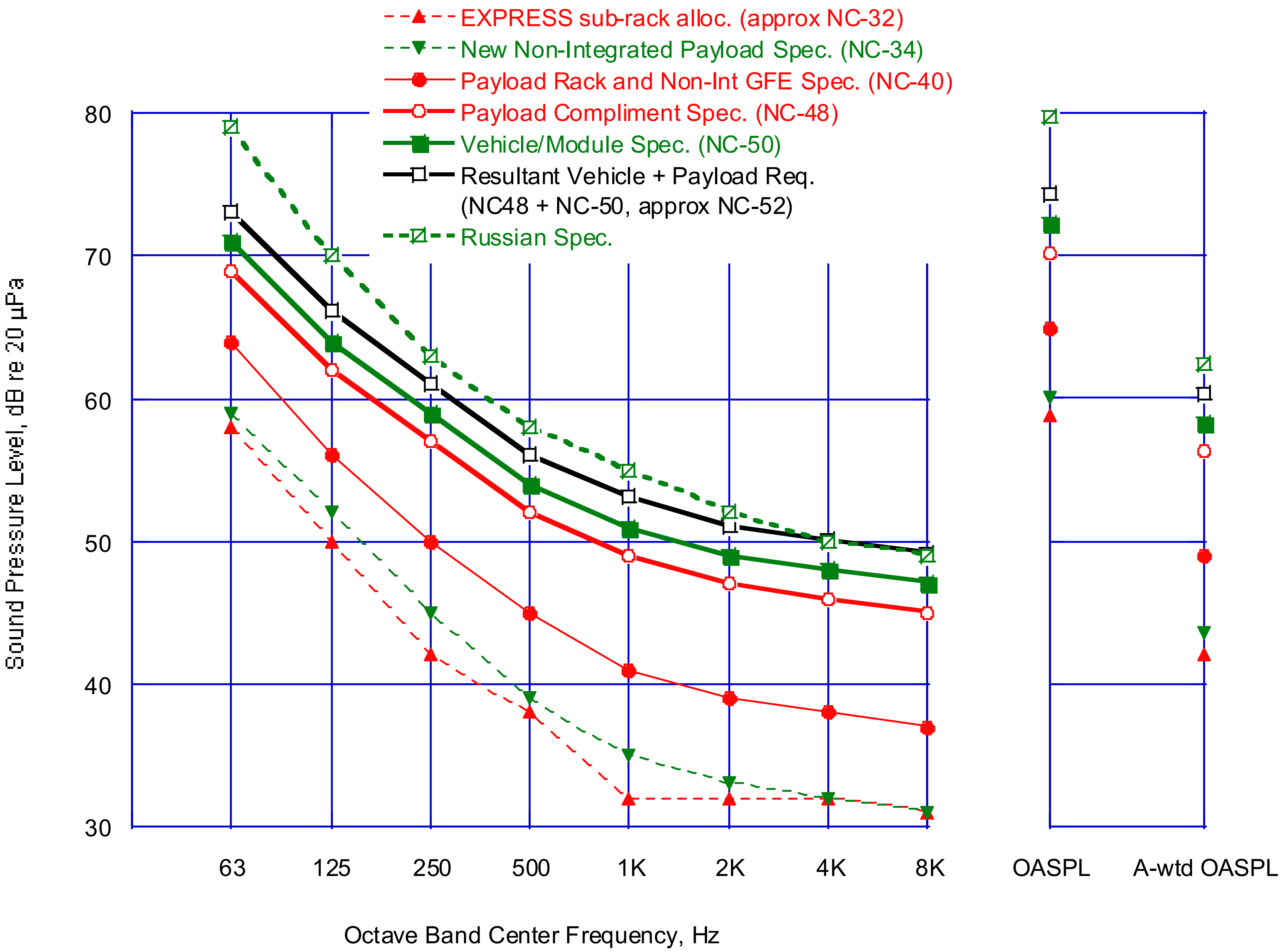
100% on common midbay perforated plate

THC/Acoustic troubleshooting

- Test Performed on May, the 17th 2007 (ACOUSTICS)

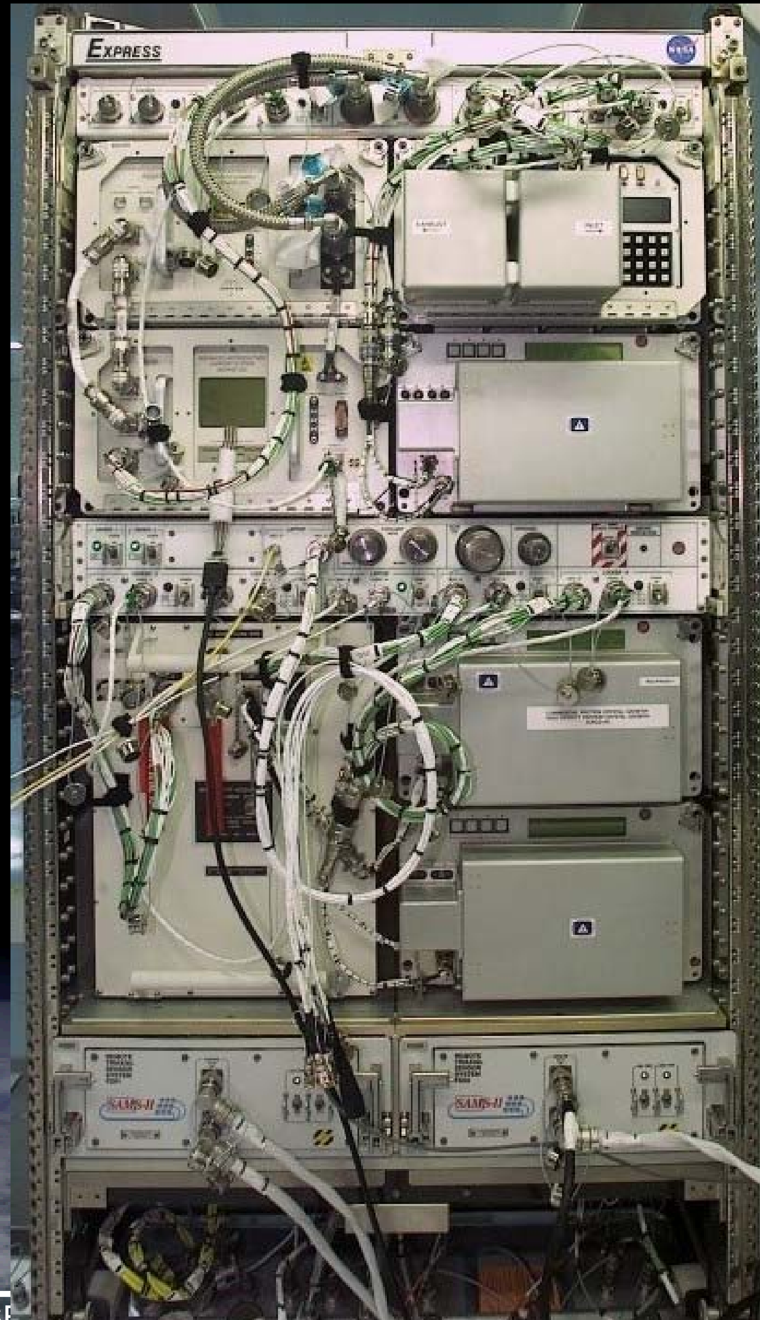


ISS Noise Requirements



CGBA

ADVASC



PCG-STES

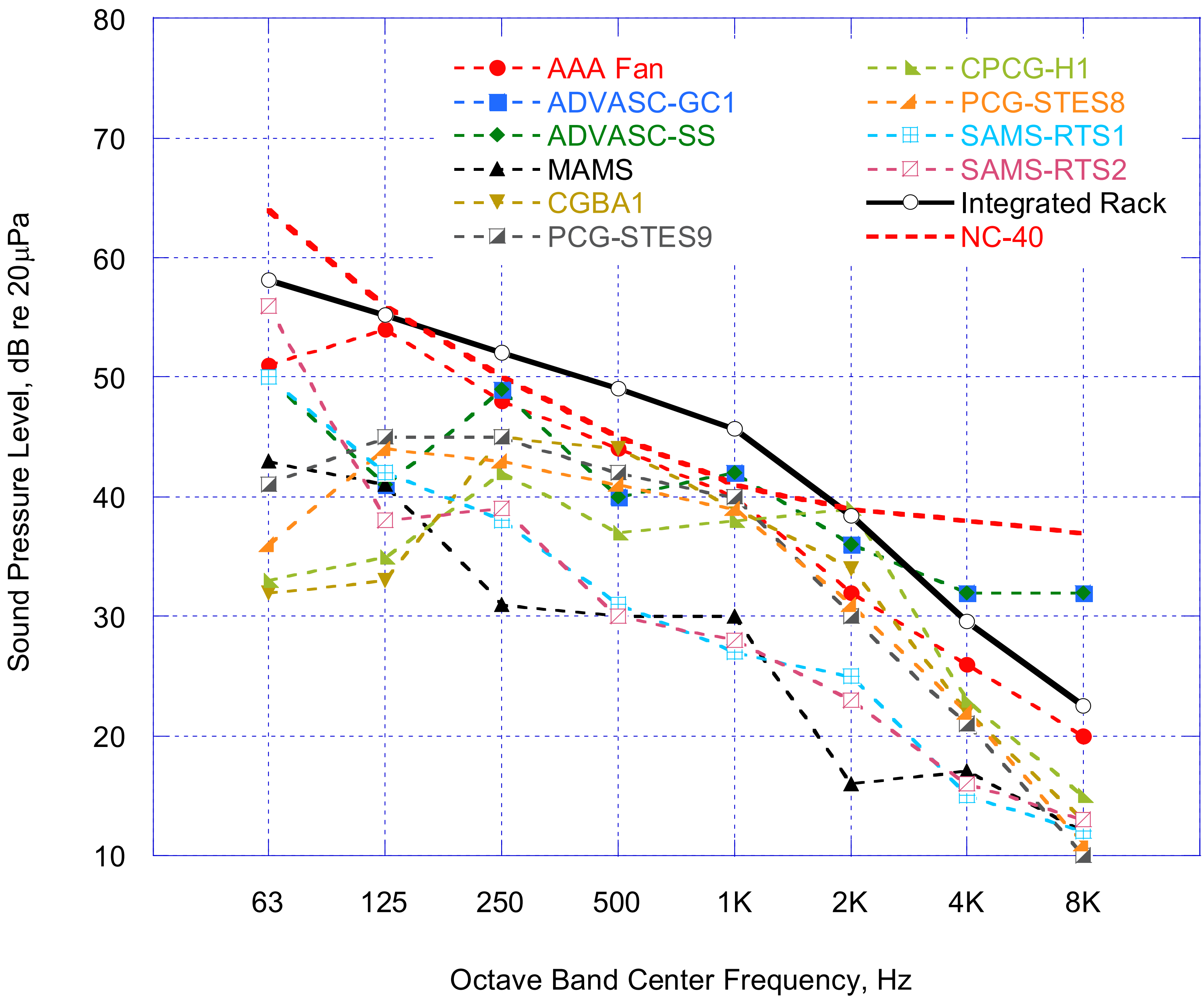
CPCG

MAMS

PCG-STES

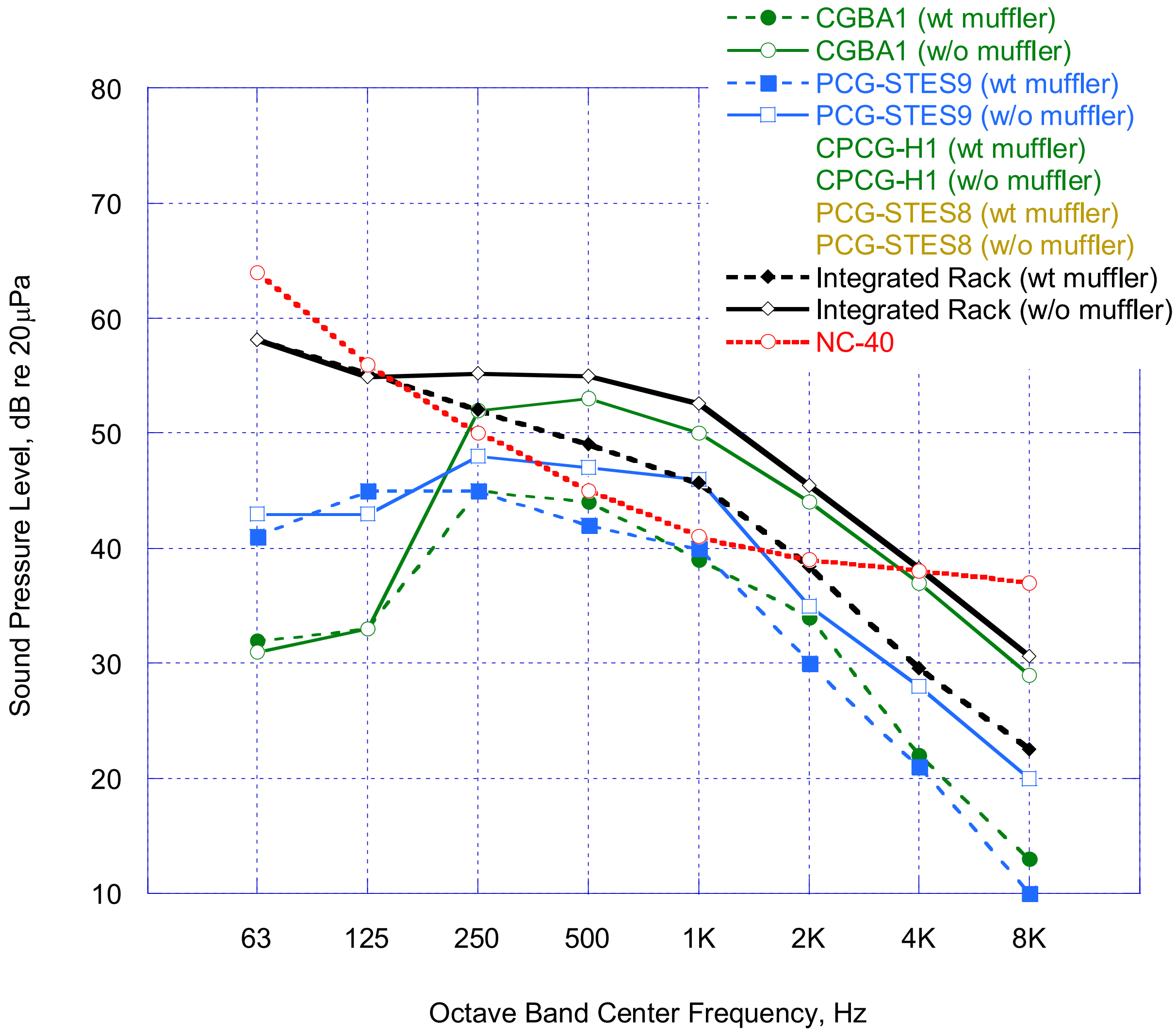
SAMS-I

SAMS-II



AAA Fan
ADVASC-GC1
ADVASC-SS
MAMS
CGBA1
PCG-STES9
CPCG-H1
PCG-STES8
SAMS-RTS1
SAMS-RTS2
Integrated Rack
NC-40
Sound Pressure Level, dB re 20μPa
80
70
60
50
40
30
20
10
63
125
250
500
1K
2K
4K
8K
Octave Band Center Frequency, Hz

Muffler Effects



CxP 70024, HUMAN-SYSTEMS INTEGRATION REQUIREMENTS

3.2.6.2.4 Sound Pressure Level (SPL) Limits for Continuous Noise during the Orbit Phase

The system shall limit the SPLs, created by the sum of all simultaneously operating equipment, averaged over any 20 second measurement period, throughout the crew habitable volume, to the values in Table 3.2-7 or less, within each of the specified octave bands, during all mission phases except launch and entry. [HS3076]

Rationale: This NC-52 requirement will limit noise levels within the crew-habitable volume to allow for adequate voice communications and habitability during the on-orbit mission operations. The octave band sound level limits from 63 Hz to 8 kHz are equivalent to NC-52 and the 16 kHz octave band has been added to extend the range throughout the audible frequency range. This requirement does not apply to alarms, communications, items listed in Table 3.2-8, or to any noise experienced during maintenance activities. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement. This limit does not apply to impulse noise.

Table 3.2-7 Octave Band Sound Pressure Level Limits

Band center frequency (Hz)	63	125	250	500	1 k	2 k	4 k	8 k	16 k
SPL (dB)	72	65	60	56	53	51	50	49	48

CxP 70024, HUMAN-SYSTEMS INTEGRATION REQUIREMENTS

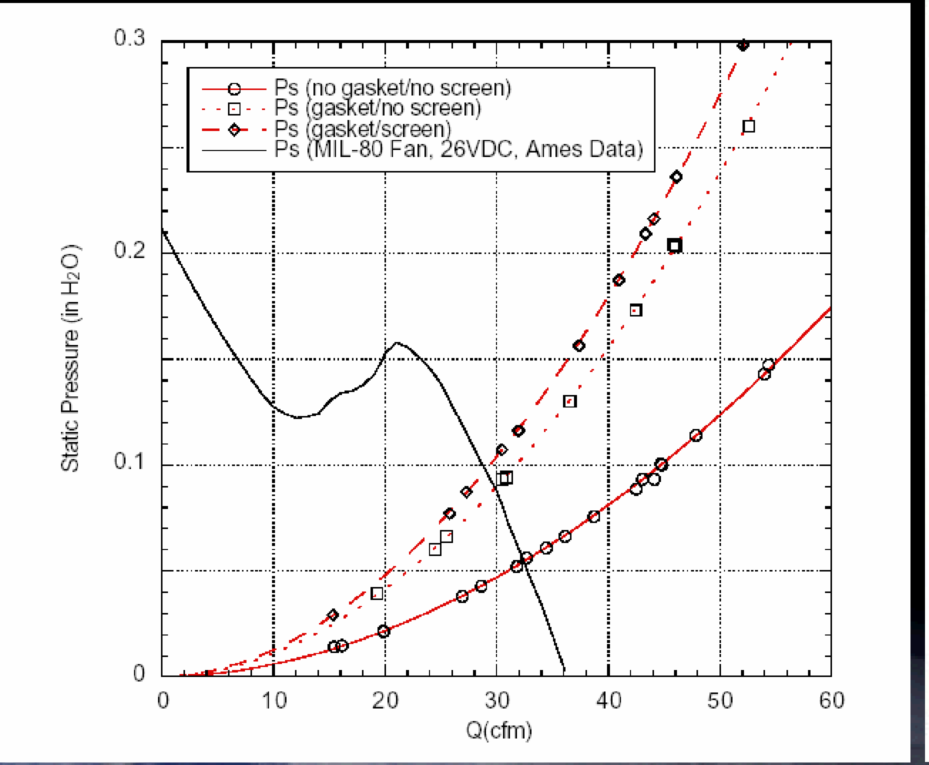
3.2.6.3.1 Tonal and Narrow-Band Noise Limits

The system shall limit the maximum SPL of narrow-band noise components and tones to at least 10 dB less than the broadband SPL of the octave band that contains the component or tone for the 1, 2, 4, and 8 kHz octave bands, and at least 5 dB less than the broadband SPL of the octave band that contains the component or tone for the 63, 125, 250 and 500 Hz octave bands. [HS3080]

Rationale: *Limiting narrow band noise component and tone levels to 10 dB below the broadband level will prevent irritating and distracting acoustic conditions. Ref.: NASA-STD-3000, Fig 5.4.3.2.3.2.*

Quiet Equipment Fan Database Data Acquisition

- Performed at ARC, Nate Burnside, Clif Horne



Quiet, Efficient Fans for Space Exploration

Fan Database development website:

http://jsc-sls-sisl8/devroot/fpd/hefo/efo/acoustics/quietfan/form.cfm