NASA Quiet, Efficient Fans for Space Flight Workshop

Fan Acoustic Issues in the NASA Space Flight Experience

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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 significant 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

Cabin Fan Filters
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 interaction
- Inlet turbulent flow
- Blade pressure fluctuations
- Blade-vortex interaction
- Exhaust

Structureborne Noise
- Motor
- Rotor unbalance
- Bearings
Noise spectra in FGB

- Panel 206
- Panel 202/204 (Dust filters with mufflers)
- Panel 202/204 (Dust filters)
- FGB/SM hatch
- Panel 219
- Node, Pressurized Adapter
- Panel 215
- Maximum Allowable Level_WORK
- Maximum Allowable Level_SLEEP
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
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

![Image of fans with labels: MO-2-5008, 17KC.53IO5009-0, 17KC.53IO5014-0]

Graph showing levels of noise in 1/3-octave bands, dB:
- MO-2-5008
- 17KC.53IO5009-0
- 17KC.53IO5014-0
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

IMV Case radiated noise, SN1–10, 13–16, 19

Sound Pressure Level @ 2ft [dB re 20μPa]

1/1-Octave Band Center Frequency [Hz]

- NODE1 fans (2,4,6)
- USLAB fans (5,7,8)
- SN 8,9,10
- Qual Unit pre & post vib
- SN3 8/97
- SN3(10/99), SN13,14,15,16 (Node 3)
- SN19 (Node 3)

Sam Denham
August 7, 2002
OGS

- Problem with manifold causing the fan to stall
- Show levels before and after choke
Effect of Reducing Backpressure

AAA only
(2’ from AAA inlet)

Sound Pressure Level (dB)

AAA only (26,000 rpm)
AAA with scar duct off & knub off (26,000 rpm)
NC-40

Octave Band Center Frequency (Hz)

20 25 30 35 40 45 50 55 60 65
63 125 250 500 1000 2000 4000 8000
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
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

Increase of passage area:
- 75% on common zenith perforated plate
- 100% on common midbay perforated plate

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.
• Test Performed on May, the 17\textsuperscript{th} 2007 (ACOUSTICS)
ISS Noise Requirements

- EXPRESS sub-rack alloc. (approx NC-32)
- New Non-Integrated Payload Spec. (NC-34)
- Payload Rack and Non-Int GFE Spec. (NC-40)
- Payload Compliment Spec. (NC-48)
- Vehicle/Module Spec. (NC-50)
- Resultant Vehicle + Payload Req. (NC48 + NC-50, approx NC-52)
- Russian Spec.
Sound Pressure Level, dB re 20μPa vs Octave Band Center Frequency, Hz
Muffler Effects

Sound Pressure Level, dB re 20μPa

Octave Band Center Frequency, Hz

- - CGBA1 (wt muffler)
- - CGBA1 (w/o muffler)
- - PCG-STES9 (wt muffler)
- - PCG-STES9 (w/o muffler)
- - CPCG-H1 (wt muffler)
- - CPCG-H1 (w/o muffler)
- - PCG-STES8 (wt muffler)
- - PCG-STES8 (w/o muffler)
- - Integrated Rack (wt muffler)
- - Integrated Rack (w/o muffler)
- - NC-40
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>
<thead>
<tr>
<th>Band center frequency (Hz)</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1 k</th>
<th>2 k</th>
<th>4 k</th>
<th>8 k</th>
<th>16 k</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPL (dB)</td>
<td>72</td>
<td>65</td>
<td>60</td>
<td>56</td>
<td>53</td>
<td>51</td>
<td>50</td>
<td>49</td>
<td>48</td>
</tr>
</tbody>
</table>

Table 3.2-7 Octave Band Sound Pressure Level Limits
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: