



AEROSPACE INFORMATION REPORT

AIR1826™**REV. A**

Issued 1989-07
Revised 2016-08
Reaffirmed 2024-10

Superseding AIR1826

Acoustical Considerations for Aircraft Environmental Control System Design

RATIONALE

The report required revision to reflect current technology of aircraft ECS noise sources and reduction methods.

AIR1826A has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

Noise levels in aircraft passenger cabins and flight stations have primarily been caused, in the past, by the engines and the external airflow. The introduction of high by-pass ratio engines of considerably lower noise level, plus improved treatments for aerodynamic noise have resulted in significantly quieter interiors. Against these lower background levels, however, the noise from the environmental control system (ECS) is likely to be more noticeable and may be the dominant contributor to the overall interior noise level. It is important, therefore, for the designer to appreciate the principles governing the generation of ECS noise and to understand the available means for controlling and reducing this noise.

TABLE OF CONTENTS

1.	SCOPE.....	4
1.1	Purpose	4
2.	REFERENCES.....	4
2.1	Applicable Documents	4
2.1.1	SAE Publications.....	4
2.1.2	ANSI Publications	4
2.1.3	ASTM Publications	4
2.1.4	Code of Federal Regulations (CFR)	5
2.1.5	European Aviation Regulations.....	5
2.1.6	U.S. Government Publications	5
2.1.7	Applicable References	5
2.2	Related Publications	5
3.	FUNDAMENTALS OF ACOUSTICS.....	5
3.1	Sound	5
3.2	Noise	6
3.3	Frequency Spectrum.....	6
3.4	Octave Bands.....	7
3.5	Levels and Decibels	8
3.6	Decibel Calculations.....	10
3.7	Comparative Levels of Common Sounds	12

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2024 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, or used for text and data mining, AI training, or similar technologies, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER:
Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE AIR1826A

For more information on this standard, visit
<https://www.sae.org/standards/content/AIR1826A/>

Documents

Standard, visit Sharing Hub

4.	DESIGN APPROACH	12
4.1	Design Verification	13
5.	NOISE SUPPRESSION METHODS	13
5.1	Location and Orientation	13
5.2	Absorptive Materials	14
5.2.1	Solid Foams	15
5.2.2	Fibers	15
5.2.3	Selection Criteria	15
5.3	Transmission Loss	17
5.4	Mufflers	18
5.4.1	Absorptive Muffler Design	20
5.5	Vibration Isolation	22
5.6	Damping	24
5.7	Wrappings	27
5.8	Enclosures	27
5.9	Active Noise Control	27
6.	APPLICATION OF NOISE SUPPRESSION METHODS	29
6.1	Cooling Units	29
6.1.1	Air Cycle Machine	29
6.1.2	Vapor Cycle Machines	30
6.1.3	Ram Air Inlets	30
6.2	Bleed Air High Pressure Pneumatic Equipment	30
6.2.1	Air Turbine Motor	30
6.2.2	Emergency Power Units	30
6.2.3	Control Valves	31
6.2.4	Bleed Air Discharges	31
6.2.5	Jet Pumps	31
6.3	Air Distribution Systems	33
6.3.1	Ducting	33
6.3.2	Plenums	35
6.3.3	Outlets	35
6.3.4	Grilles	36
6.3.5	Gaspers	38
6.4	Air Exhaust Systems	38
6.4.1	Flow Regulating Valves	38
6.5	Fans	42
6.5.1	General	42
6.5.2	Vapor Cycle System Fans	43
6.5.3	Ground Cooling Fans	44
7.	NOTES	44
7.1	Revision Indicator	44
FIGURE 1	WAVELENGTH IN AIR VERSUS FREQUENCY AT 68 °F (20 °C)	6
FIGURE 2	EXAMPLE SOUND SPECTRUM	7
FIGURE 3	SOUND PRESSURE AND PRESSURE LEVEL RATIOS	9
FIGURE 4	CHART FOR COMBINING LEVELS	11
FIGURE 5	TYPICAL FOUR-ENGINE COMMERCIAL JET TRANSPORT MEASURED NOISE LEVELS	14
FIGURE 6	UNFACED URETHANE FOAM 0.5 INCH (0.0127 M) THICK DENSITY 3.8 LB/FT ³ M ³ (60.7 KG/)	17
FIGURE 7	THEORETICAL TL OF MASS-CONTROLLED LIMP PANELS	19
FIGURE 8	TYPICAL DUCT LINING	21
FIGURE 9	EXAMPLES OF NOISE CONTROL METHODS	23
FIGURE 10	TYPICAL NOISE CONTROL RESULTS	23
FIGURE 12	VARIATION OF MODULUS WITH TEMPERATURE FOR A TYPICAL VISCOELASTIC MATERIAL	26
FIGURE 13	ANCS, FEEDFORWARD CONTROL APPROACH	28
FIGURE 14	ANCS, FEEDBACK CONTROL APPROACH	29
FIGURE 15	GENERALIZED SCHEMATIC OF JET PUMP AND NOISE ABSORPTIVE LINING	29

FIGURE 16	COMPARISON OF NOISE DOWNSTREAM OF A JET PUMP USED TO PULL AIR FROM LAVATORIES AND GALLEYS	33
FIGURE 17	OUTLET NOISE TEST	34
FIGURE 18	DUCT BRANCHING	34
FIGURE 19	DUCT ROUTING	35
FIGURE 20	DUCT NETWORKING	35
FIGURE 21	PLENUM CONFIGURATION	36
FIGURE 22	CREW AIR OUTLETS	37
FIGURE 23	GRILLE NOISE LEVEL - EFFECT OF VELOCITY	39
FIGURE 24	VARIATION OF GRILLE NOISE WITH AREA AT CONSTANT VOLUME FLOW	40
FIGURE 25	GASPER OPERATION AFFECTING CABIN NOISE	41
FIGURE 26	A TYPICAL BUTTERFLY OUTFLOW CONTROL VALVE, CROSS SECTION	42
TABLE 1	OCTAVE PASS BANDS	8
TABLE 2	COMPARATIVE LEVELS OF COMMON SOUNDS	12
TABLE 3	SOUND ABSORPTIVE MATERIAL PROPERTY COMPARISON	16
TABLE 4	MAXIMUM ACHIEVABLE ENCLOSURE NOISE REDUCTION	27
TABLE 5	SPECIFIC POWER LEVEL FOR VANE-AXIAL FANS	43

1. SCOPE

This Aerospace Information Report (AIR) is limited in scope to the general consideration of environmental control system noise and its effect on occupant comfort. Additional information on the control of environmental control system noise may be found in 2.3 and in the documents referenced throughout the text.

This document does not contain sufficient direction and detail to accomplish effective and complete acoustic designs.

1.1 Purpose

The purpose of this AIR is to provide aid for the reduction of environmental control system noise levels and to minimize their effect on passengers and crew members through engineering design. The reader should be aware that the material included in this document is for general guidance purposes only.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org

AIR1168/3	Aerothermodynamic Systems Engineering and Design
ARP1307	Measurement of Exterior Noise Produced by Aircraft Auxiliary Power Units (APUs) and Associated Aircraft Systems During Ground Operation
ARP1323	Type Measurements of Airplane Interior Sound Pressure Levels During Cruise
ARP4245	Quantities for Description of the Acoustical Environment of the Interior of Aircraft
ARP4721/1	Monitoring Aircraft Noise and Operations in the Vicinity of Airports: System Description, Acquisition, and Operation

2.1.2 ANSI Publications

Copies of these documents are available online at <http://webstore.ansi.org>.

ANSI S1.6-1984 (R 2006)	Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements
-------------------------	---

2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM C522-03	Standard Test Method for Airflow Resistance of Acoustical Materials
ASTM E90-09	Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements

2.1.4 Code of Federal Regulations (CFR)

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes

2.1.5 European Aviation Regulations

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Cologne, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

CS-25 Certification Specifications for Large Aeroplanes

2.1.6 U.S. Government Publications

Copies of these documents are available online at <http://quicksearch.dla.mil>.

MIL-STD-740-2 Structureborne Vibratory Acceleration Measurements and Acceptance Criteria of Shipboard Equipment

MIL-STD-1472 Human Engineering Design Criteria for Military Systems, Equipment and Facilities

MIL-STD-1474 Noise Limits

2.1.7 Applicable References

J. S. Lamancusa, Engineering Noise Control, Pennsylvania State University, 2000

2.2 Related Publications

This list of publications is provided for informational purposes only. These publications are not a required part of this SAE Aerospace Technical Report.

L. L. Beranek, Noise and Vibration Control, Institute of Noise Control Engineering, Arlington, NY, 1989.

C. M. Harris, Handbook of Noise Control, McGraw-Hill, New York, 1979.

C. H. Hansen, Understanding Active Noise Cancellation, Taylor & Francis, 2001

D. Middleton, The Noise of Ejectors, Aeronautical Research Council Reports, UK Ministry of Aviation, 1965

D. M. Howard, J. A. S. Angus, Acoustics and Psychoacoustics, Elsevier Ltd, 2009

ANSI S1.1-1994 (R2004) Acoustical Terminology

ANSI S1.2-1962 (R 2001) Method For The Physical Measurement Of Sound

ASHRAE 2007 HANDBOOK – HVAC Applications, Chapter 47 Sound and Vibration Control

3. FUNDAMENTALS OF ACOUSTICS

3.1 Sound

Pressure alterations or particle displacements propagated in an elastic medium produce sound. In air, sound consists of propagated changes in pressure that alternate above and below the ambient pressure. These changes occur when vibrating objects accelerate the air particles next to them.

The speed of sound in a particular medium is defined as the product of frequency and wavelength:

$$c = f \lambda \quad (\text{Eq. 1})$$

where: c is the speed of sound

f is the frequency

λ is the wavelength.

The speed of sound in air, which varies with temperature, is given by the formula:

$$c = 49.03 R^{1/2} \text{ ft/s} \quad (c = 20.05 T^{1/2} \text{ m/s}) \quad (\text{Eq. 2})$$

where T is the temperature expressed in Kelvin, and R the temperature expressed in Rankine.

At 68 °F (20 °C) $c = 1125 \text{ ft/s}$ (343 m/s). The wavelength of sound in air as a function of frequency at 68 °F can be read from Figure 1.

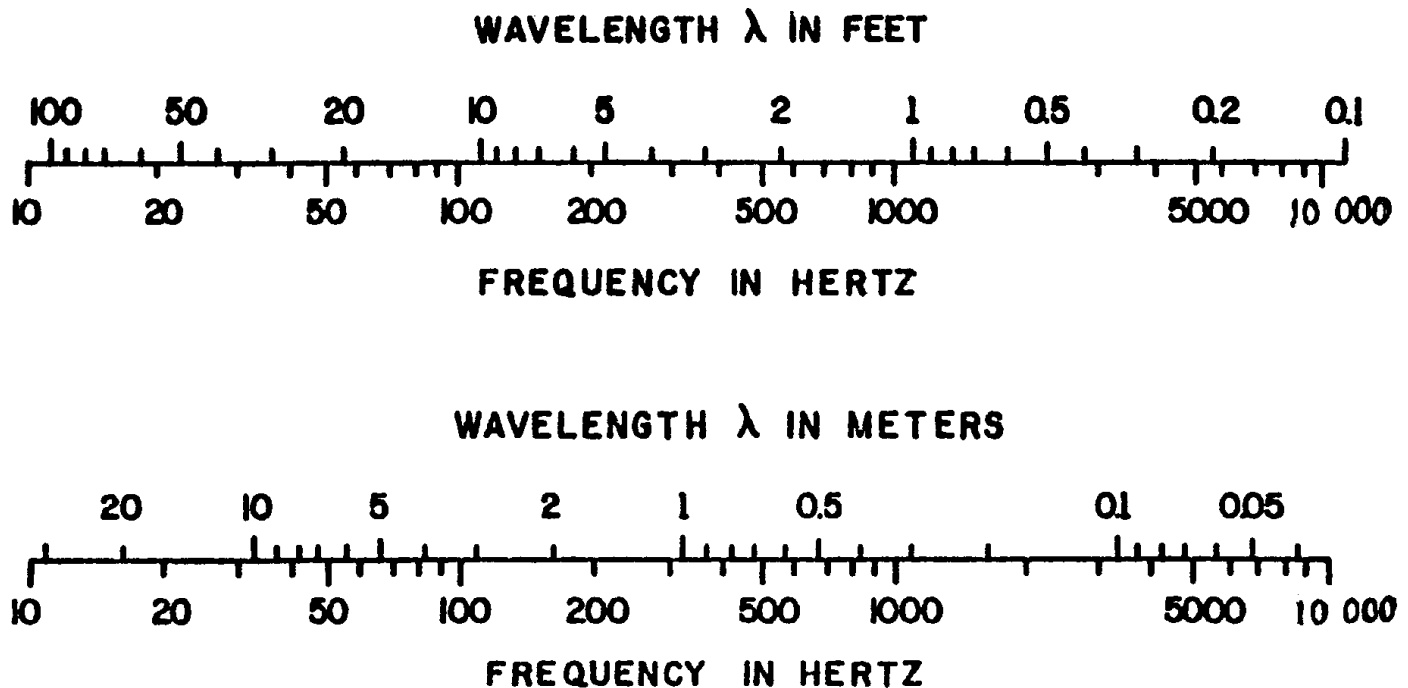


Figure 1 - Wavelength in air versus frequency at 68 °F (20 °C)

3.2 Noise

Noise is any undesired sound (If ambiguity exists as to the nature of the noise, a phrase such as "acoustic noise" or "electric noise" should be used).

3.3 Frequency Spectrum

The quality of sound is determined primarily by its frequency spectrum. A plot of sound pressure level or sound power level against frequency is called a frequency spectrum.

A "pure tone" is a sound whose level is concentrated in a single frequency (i.e., the frequency spectrum is a single point plot and the sound waveform is a pure sinusoidal curve). As an extension, a "tone" or "tonal noise" is one in which the sound levels spread around a narrow frequency band, while in a "broadband noise" the sound levels are evenly distributed on a large frequency range. "Harmonics" are tonal noises whose characterizing frequency is an integer multiple of a lower frequency known as "fundamental frequency".

The principle of superposition is applicable to waveforms, thus a generic sound can be decomposed in a number of linearly combined waveforms, and will show one or more of the features discussed above (see an example in Figure 2).

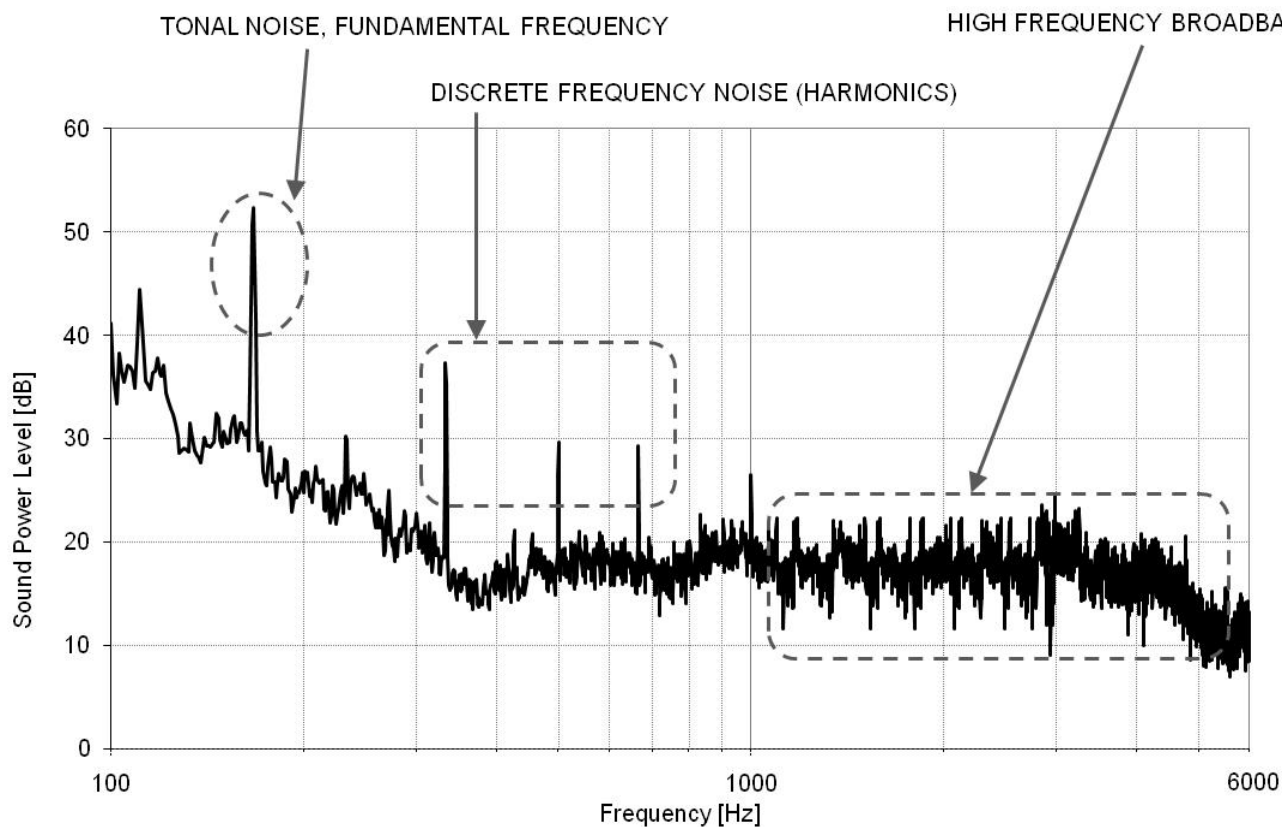


Figure 2 - Example sound spectrum

3.4 Octave Bands

Part of the audible frequency range, approximately 20 to 10000 Hz is divided into bands, usually one octave wide. The term octave means that the frequency of the upper limit of the pass band is twice that of the lower limit. An octave band sound pressure spectrum is obtained with an octave band analyzer containing electronic filters that pass only those components of the measured sound that have frequencies within the limits of the filter. The first set of octave band limits shown in Table 1 is specified by ANSI S1.6-1984. The second set has been in general use for some time and is given for comparison. Data from the second set can be converted to the first set by graphical interpolation with sufficient accuracy.

Table 1 - Octave pass bands

Frequency Bands	Frequency, Hertz							
Preferred								
Mid-frequency	63	125	250	500	1000	2000	4000	8000
Approximate frequency limits								
Lower	45	90	180	355	710	1400	2800	5600
Upper	90	180	355	710	1400	2800	5600	11200
Previously Used								
Approximate geometric mid-frequency	53	106	212	425	850	1700	3400	6900
Frequency limits								
Lower	37.5	75	150	300	600	1200	2400	4800
Upper	75	150	300	600	1200	2400	4800	9600

3.5 Levels and Decibels

The magnitude of sound is expressed as levels. The level is a measure of the ratio of sound power, or sound pressure to a reference value, and is expressed in decibels. The relationship between sound power and sound pressure corresponds to that between heat and temperature. The ear and instruments respond to sound pressure, but equipment sound ratings are best expressed in terms of sound power output. Sound power cannot be measured directly; it has to be computed from sound pressure measurements. Acoustical energy is proportional to the square of sound pressure.

Sound pressure level L_p (or SPL) in decibels, referenced to the approximate threshold of hearing, i.e., 2×10^{-5} Pascal (N/m²):

$$L_p = 10 \log_{10} \left(\frac{p}{2 \times 10^{-5}} \right)^2 = 20 \log_{10} \left(\frac{p}{2 \times 10^{-5}} \right) \quad (\text{Eq. 1})$$

where: p = sound pressure in Pa

Sound power level L_w (or PWL) in decibels, referenced to 10^{-12} watt, is defined as:

$$L_w = 10 \log_{10} \left(\frac{W}{10^{-12}} \right) \quad (\text{Eq. 4})$$

where: W = sound power in watt

Whenever the word level is used as a modifier for sound power or pressure, a reference power or pressure has to be given and the ratio between the measured quantity and the reference quantity is used to calculate the decibel level. The reference for sound power level must be noted since 10^{-13} watt is still often used. If the 10^{-13} watt reference is used, simply subtract 10 dB from the power level to obtain levels referenced to 10^{-12} watt.

Figure 3 is a graphical representation of the pressure and power level formulas. When the pressure or power level changes, its ratio to the referenced value changes accordingly. For a 3 dB increase, the power ratio is doubled while a 6 dB increase in pressure level doubles the pressure ratio. About the smallest change the ear can detect is 1 or 2 dB. While stationary, 3 to 5 dB changes are detected, however, they are not detected walking from one area to another. A 10 dB noise increase would be perceived as twice as loud.

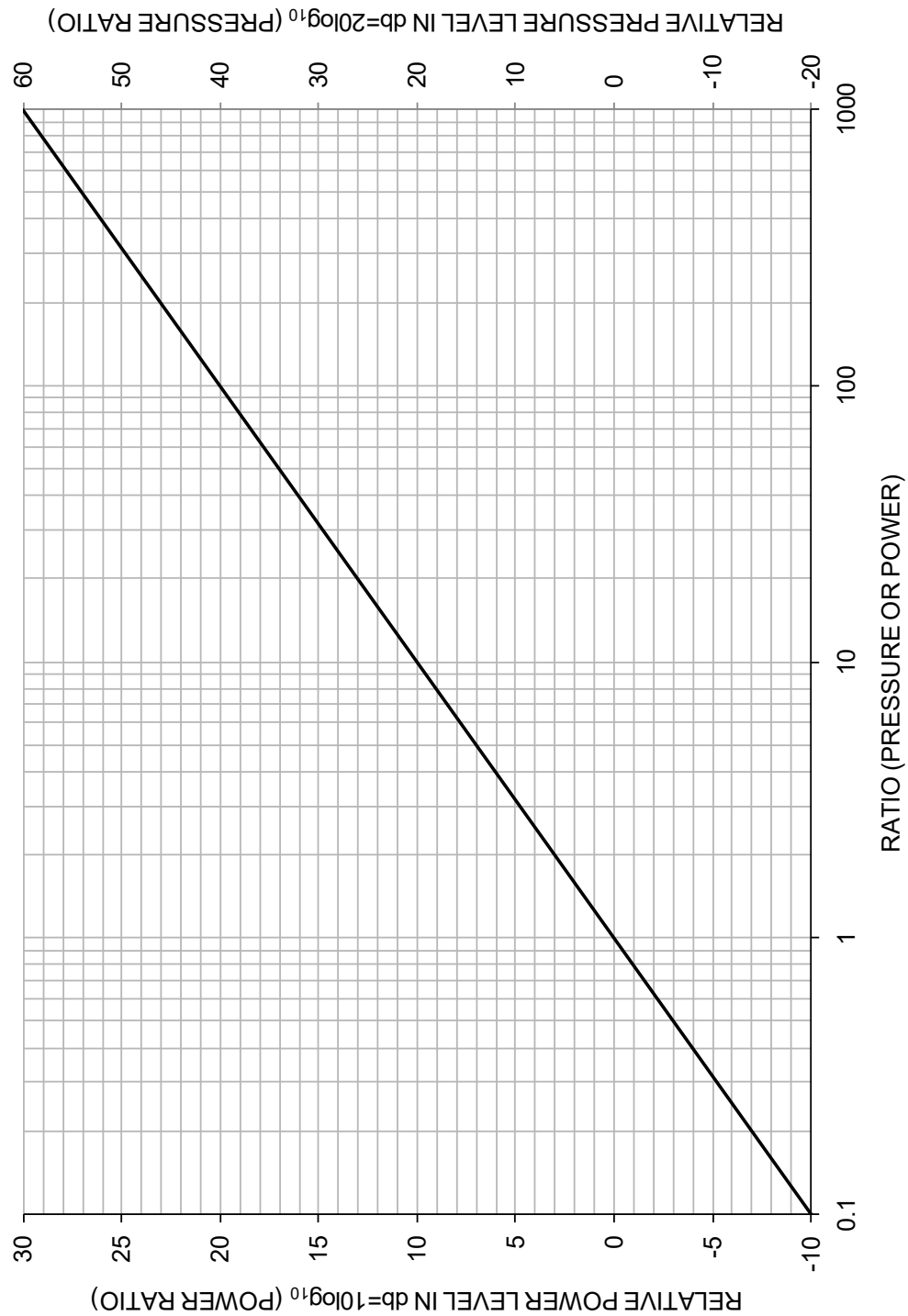


Figure 3 - Sound pressure and pressure level ratios

3.6 Decibel Calculations

The ratio of the sound power entering an element of a system to the sound power continuing beyond the element, expressed in decibels, is called the attenuation of that element:

$$\text{Attenuation (in db)} = 10 \log_{10} \left(\frac{W_e}{W_c} \right) \quad (\text{Eq. 5})$$

where: W_e = Sound power entering, watt

W_c = Sound power continuing, watt

Figure 3 may be used to convert the ratio of sound power to decibels and vice versa. If an attenuator absorbs 99.9% of the entering sound power, the power ratio is $100/0.1 = 1000$, and the attenuation is 30 dB. Since this is relative, no reference is necessary. If referenced decibel levels are used, the attenuator equation reduces to a simple arithmetic expression:

$$\text{Attenuation (in db)} = L_{We} - L_{Wc} \quad (\text{Eq. 6})$$

where: L_{We} = sound power level entering (dB)

L_{Wc} = sound power level continuing (dB)

The attenuation of a group of elements through which the sound passes in succession is the arithmetic sum of all individual attenuation values in decibels.

When the decibel system is used, the levels of two or more sounds cannot be added or subtracted arithmetically. The following equation can be used to combine levels:

$$L = 10 \log_{10} \left(\sum_i 10^{\left(\frac{L_i}{10} \right)} \right) \quad (\text{Eq. 7})$$

where:

L_i = i^{th} level to be combined

A graphical method can also be used to combine two sound levels at a time. If more than two levels are to be combined, the two highest levels should be combined, and then the resulting value combined with the next highest level.

Rearranging terms from Equation 7 for the case of only two levels, the following formula can be derived:

$$Y = 10 \log_{10} \left(1 + 10^{\left(-\frac{X}{10} \right)} \right) \quad (\text{Eq. 8})$$

where:

X (in dB) = arithmetic difference between the two sound levels to be combined (larger minus smaller).

Y (in dB) = amount to be arithmetically added to the larger sound level to be combined in order to obtain the sum of the two levels.

Equation 8 can then be plotted to get Figure 4 which correlates Y to X .

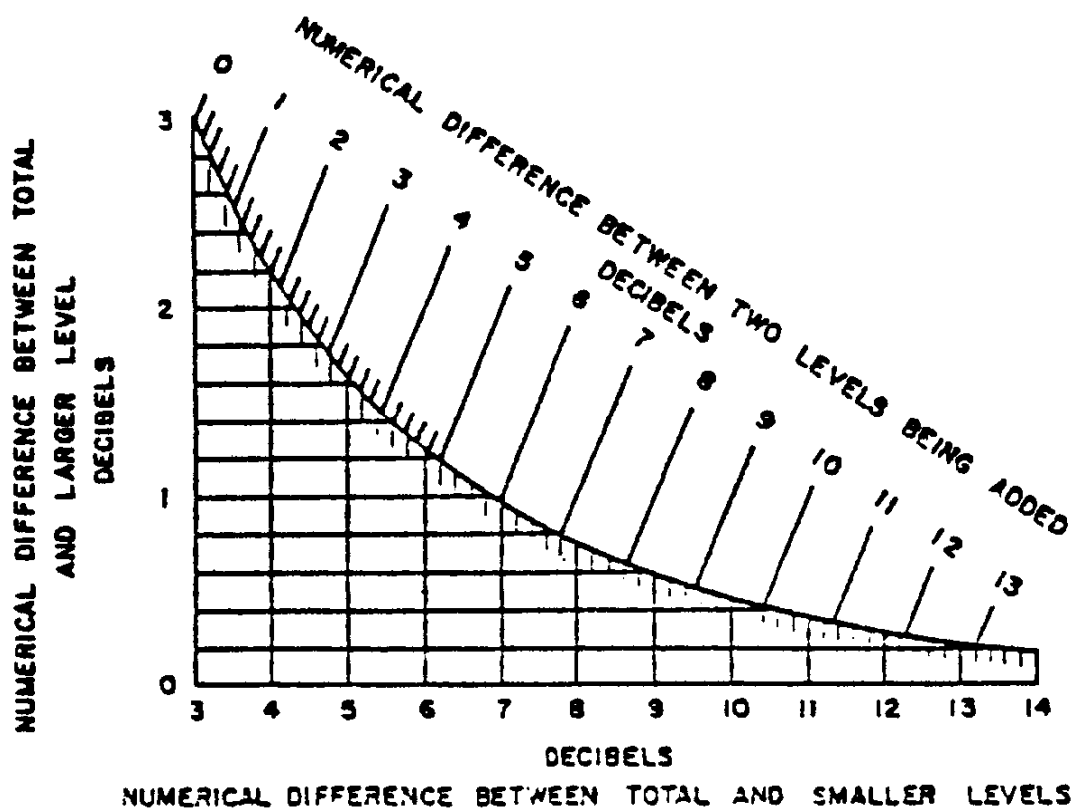


Figure 4 - Chart for combining levels

Example calculations:

Given $L_{W1} = 86$ dB and $L_{W2} = 80$ dB, their arithmetical difference is $X = 6$ dB. From either Equation 8 or Figure 4 it follows that $Y = 0.97$, so to obtain the sum of the two sound levels (L_{W1} amplified by L_{W2}) we add Y to L_{W1} , or $L_W = L_{W1} + Y = 86.97$ dB.

3.7 Comparative Levels of Common Sounds

Table 2 - Comparative levels of common sounds

Sound Pressure Level (dB)	Sound Pressure		Common Sounds and Qualitative Perception
	(Pa)	(psi)	
160	2×10^3	3×10^{-1}	Medium Jet Engine
140	2×10^2	3×10^{-2}	Large Propeller Aircraft-Air Raid Siren-Riveting
130	64	9.6×10^{-3}	<i>[Pain threshold]</i>
120	20	3×10^{-3}	Discotheque
100	2	3×10^{-4}	<i>[Very noisy]</i> Heavy City Traffic Subway
80	2×10^{-1}	3×10^{-5}	Busy Office
70	6.4×10^{-2}	9.6×10^{-6}	<i>[Noisy]</i>
60	2×10^{-2}	3×10^{-6}	Normal Speech at 1 m
40	2×10^{-3}	3×10^{-7}	<i>[Quiet]</i> Quiet Residential Neighborhood
20	2×10^{-4}	3×10^{-8}	Whisper
0	2×10^{-5}	3×10^{-9}	<i>[Barely Audible]</i> Threshold of Hearing for a child

For the definition of the Sound Pressure Level (L_p) see Equation 3.

4. DESIGN APPROACH

To reduce the ECS noise in the aircraft interior, two approaches are possible, source reductions and transmission path attenuations. In order to reduce noise at the source, it is necessary to identify the components or parts of the system generating the noise and to determine the mechanism of the sound generation process. Modifications may then be designed as appropriate. When all available steps have been taken to reduce noise at the source, any further improvement must come from the addition of insulation, absorption, or other treatments into the path between source and cabin. This requires that the dominant sound transmission path be determined, i.e., either structureborne or airborne.

Excessive noise can be generated by active components such as air cycle machines and by the flow of air through the system. Air noise is generated at valves, in the ducts at positions of rapid area or shape change, and at exits from the ducts. Noise radiated from the surface of ducts may be due to unsteadiness in the internal air flow. Vibration of ducts and/or equipment may be transmitted via the airframe structure and radiated as noise into the cabin.

Information on noise suppression methods is given in Section 5, while Section 6 provides information on their application.

Although the major problems arising from ECS noise concern the passenger cabin and flight station, efforts should also be made to protect ground crews working around the aircraft.

Noise generated by the aircraft while parked on the ground, typically during routine operations between two flights, is referred to as "ramp noise". Unlike noise generated during flight, ramp noise is not regulated by Airworthiness Authorities: the authorities of each airport set their own limitations and/or penalties for ramp noise levels based on a number of factors that may include the proximity of nearby housing or standards agreed upon with a labor union. The more stringent limitations require that all gas turbine auxiliary power units (APU), and consequently environmental control systems (ECS) be shut down 5 minutes after arrival at the gate and started no more than 5 minutes before the estimated time of departure.

Air exhausting from air cycle machine fans or other overboard bleed flows can generate unacceptably high noise levels. Potential noise problems can be minimized in the design stage of equipment (such as fans) by adopting minimum noise generation principles.

Further improvement can come from the treatment of exhaust ducting and by reducing the exhaust velocity of emergent jets to as low a value as possible. A general design rule to be borne in mind is that high frequency sound is more easily attenuated and absorbed than low frequency sound (see Figure 5 for typical four-engine jet interior noise level).

4.1 Design Verification

Verification methods for the ECS interior noise and for ramp noise are largely based on full scale measurements on the final aircraft configuration.

The following SAE documents have been specifically published to support the designer in the verification effort:

ARP1323 "Type Measurements of Airplane Interior Sound Pressure Levels During Cruise" provides guidance for the definition of measurement procedures, for the selection of instrumentation and for data reporting when showing compliance with aircraft interior noise level goals or contractual requirements.

ARP4245 "Quantities for Description of the Acoustical Environment of the Interior of Aircraft" defines quantities that may be used to describe various attributes of the sound field in the interior of aircraft.

ARP1307 "Measurement of Exterior Noise Produced by Aircraft Auxiliary Power Units (APUs) and Associated Equipment During Ground Operation" provides guidance for the definition of measurement procedures, for selection of instrumentation and for data reporting when showing compliance with airport regulations for ramp noise. The document covers not only APU, but also associated equipment like ECS.

ARP4721 "Monitoring Aircraft Noise and Operations in the Vicinity of Airports: System Description, Acquisition, and Operation" provides engineering methods that can be applied to monitor aircraft noise in the vicinity of airports, as well as validation methods for permanent monitoring installations.

5. NOISE SUPPRESSION METHODS

5.1 Location and Orientation

The overall acoustic design for occupied areas in a passenger aircraft should be such that the noise due to the ECS does not contribute to the ambient noise level, i.e., it is not greater than a level about 10 dB below the combined engine and aerodynamic noise in each octave band. If the ECS equipment noise contains discrete frequencies or tones, the restriction becomes more severe and is a special problem. The ECS and its components can produce noise in two ways: (1) direct radiation of airborne sound waves into a space and (2) transmission of vibration or structureborne noise through the mechanical mountings to large radiating surfaces.

Noisy ECS equipment should, whenever practical, be mounted in areas as far away acoustically from occupied compartments as possible, such that the structureborne noise has to travel through long and tortuous mechanical paths, and airborne noise is subject to the transmission loss of one or more walls and partitions.

Noise should be reduced at the source, whenever possible. ECS equipment such as fans, blowers, valves, solenoids and regulators should have maximum permissible noise levels included as a part of the procurement specifications.

The noise sources should be oriented so that maximum sound radiation patterns are directed away from points of possible complaint. Maximum sound radiation usually occurs in the direction that air enters and leaves the duct.

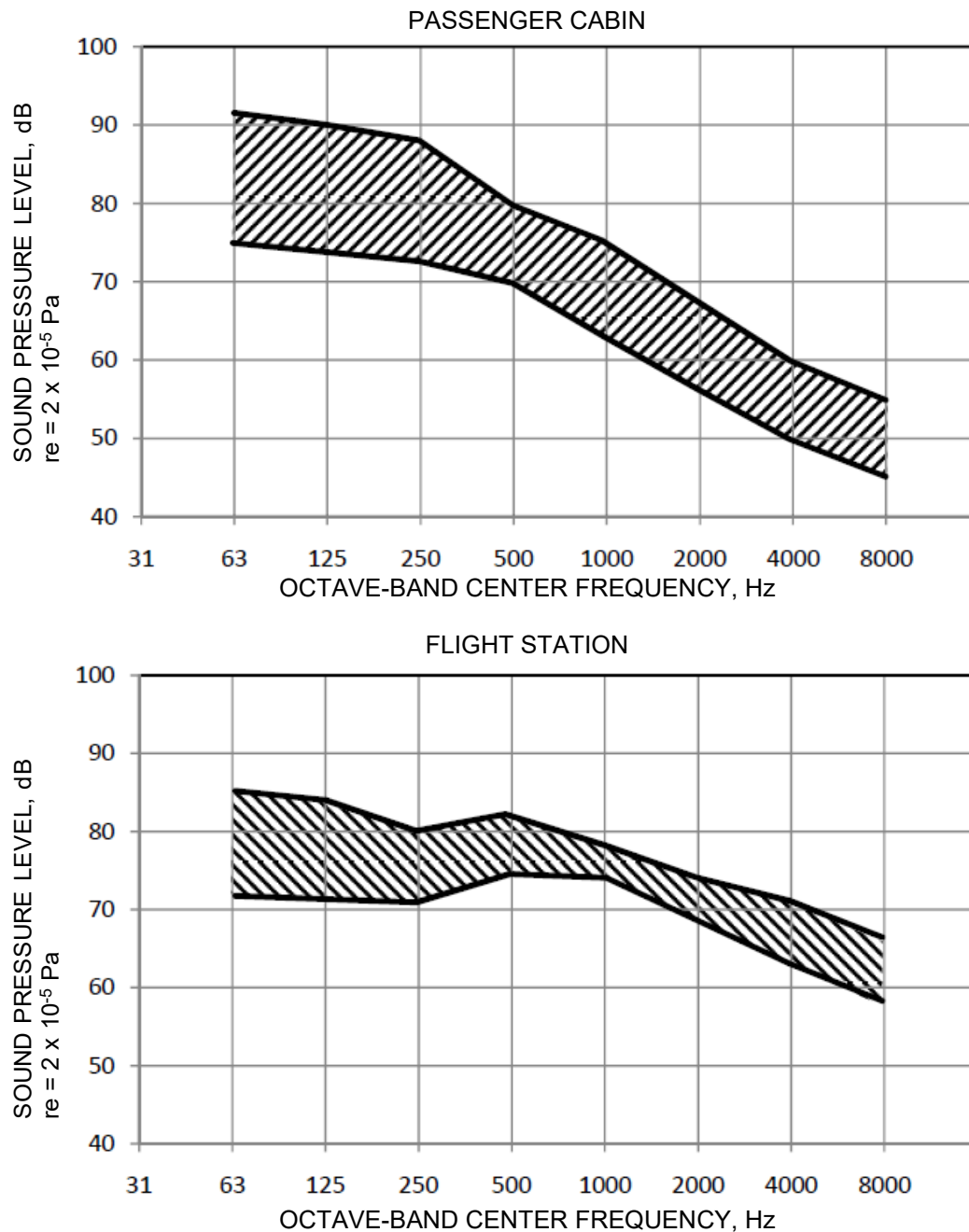


Figure 5 - Typical four-engine commercial jet transport measured noise levels

NOTE: Existing conditions include:

(1) low bypass ratio turbofan engines, (2) normal long range cruise conditions, (3) measured at head height at aisle and window seats, (4) cabin air conditioning in normal operation, (5) individual passenger “eyeball” ventilators closed, and (6) measured at head positions of pilot and copilot.

5.2 Absorptive Materials

The process of sound absorption involves the conversion of acoustical energy into heat as friction is encountered. This attenuation results in a reduction of reverberation.