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An introduction and guide to noise in ventilation, air-conditioning and other ducting systems.

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The Internal Flow Panel, which took over the work on Internal Flow previously monitored by the Fluid Mechanics Steering Group, first met in September 1979 and had the co-operation of many engineers and scientists in industry, research establishments and universities from whom much assistance and information is being received.

AN INTRODUCTION AND GUIDE TO NOISE IN VENTILATION, AIR-CONDITIONING AND OTHER DUCTING SYSTEMS

CONTENTS

1.	NOTATION	1
2.	INTRODUCTION	2
3.	NOISE UNITS AND BASIC RELATIONSHIPS	3
3.1	Summation of Levels in dB Units	5
4.	ROOM ACOUSTIC CHARACTERISTICS	6
4.1	Reverberation Absorption Coefficient	6
4.2	Reverberation Time	6
5.	CRITERIA FOR NOISE CONTROL	8
5.1	Weighting Scales	8
5.2	Noise Limiting Curves	8
6.	ACOUSTIC CONSIDERATIONS IN THE DESIGN OF VENTILATION AND AIR-CONDITIONING SYSTEMS	10
6.1	Noise Sources and Transmission Paths	10
6.2	Design Considerations	11
6.2.1	Selection of noise limiting criteria	11
6.3	Noise Control	12
6.3.1	Duct noise control	12
6.3.2	Room noise control	12
7.	DERIVATION AND REFERENCES	13
7.1	Derivation	13
7.2	References	13
8.	EXAMPLE	14
8.1	The effect of audience on the room absorption and reverberation time. For the example above estimate and for 500 seats occupied.	15
9.	TABLES	16

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1. NOTATION

		<i>SI unit</i>
c	speed of sound	m/s
f	frequency	Hz
L_p	sound pressure level	dB
L_{pj}	sound pressure level in j^{th} octave band	dB
L_w	sound power level	dB
L_{wj}	sound power level of j^{th} source	dB
p	root mean square sound pressure	Pa
p_0	root mean square reference pressure	Pa
s_r	room surface area	m ²
T	reverberation time	s
v	room volume	m ³
W	sound power	W
W_0	reference sound power	W
α	reverberation sound absorption coefficient	—
$\bar{\alpha}$	mean room reverberation sound absorption coefficient	—

2. INTRODUCTION

Noise and its control are essential considerations both for health and safety and for the general comfort of the occupants of any enclosure. It is, therefore, not only the acoustic specialists but designers of ventilation and air-conditioning systems who need a knowledge of noise and its generation within these systems. The purpose of this Item is to provide an introduction to acoustic terminology and relationships and further to provide general guidance on the principles of noise control in ventilation and air-conditioning systems, and similar types of ducting systems. The Item is intended for use by engineers who are not acoustic specialists.

Ventilation is the process of changing the air in an enclosed space, and air-conditioning is the provision of filtered air to control the temperature and humidity in the conditioned space. These processes involve the movement of air through ducts that then provide a path for the sound generated by the fan driving the air and themselves generate noise due to the airflow over duct fittings (bends, dampers, *etc*). This Item should be used in conjunction with ESDU 81043 and 82002. ESDU 81043 provides essential data for estimating the changes in acoustic energy as sound propagates through the duct system. That Item also provides a means of estimating the sound pressure levels in a room due to the sound energy from the ventilation system. ESDU 82002 gives information on the reduction of sound in ventilation and air-conditioning systems and provides data for use in the selection of suitable silencers for air distribution systems. In addition, ESDU 82003 gives a number of examples of noise calculations using the data provided in this Item and in the Items mentioned earlier.

In this Item, following the information on noise units and their relationships (Section 3), data are provided on room acoustic characteristics which are required for the estimation of sound pressure levels within the room. Section 5 provides a guide to the currently used noise criteria by which the sound levels are assessed in terms of the acceptable background noise levels for a particular room usage. In Section 6 information is provided on the acoustic factors that should be taken into consideration in the design of ventilation and air-conditioning systems. The example in Section 8 illustrates the data provided on absorption coefficients by the calculation of the reverberation time for an enclosure.

3. NOISE UNITS AND BASIC RELATIONSHIPS*

Sound powers radiated in air have a practical range of about 10^{-12} W to 10^8 W. Sound powers for some familiar noise sources are tabulated in this Section. Because this range of powers is so large it is convenient to express sound powers in decibel units (dB). This unit may be used to compare the relative magnitudes of any quantity related to power. The number of bels (1 bel = 10 decibels) is the logarithm to the base 10 of the ratio of the powers. The two quantities most commonly used by heating and ventilation engineers that are measured in dB are sound power level, L_w , and sound pressure level, L_p . These quantities are defined as follows:

$$L_w = 10 \log_{10} \left(\frac{W}{W_0} \right) \quad (3.1)$$

$$\text{and } L_p = 20 \log_{10} \left(\frac{p}{p_0} \right), \quad (3.2)$$

where W_0 and p_0 are reference sound power and root mean square sound pressure respectively. The preferred[†] reference power W_0 is 10^{-12} W and the preferred reference sound pressure in gaseous media is $20 \mu\text{Pa}$ [‡]; these values are used in Items relating to noise in air-conditioning systems.

The quality of noise is dependent both on its volume and frequency content (*i.e.* its spectral composition). For a full description of a noise source it is, therefore, necessary to quote sound power (or pressure) levels within specific frequency bands. The frequency bands used for noise description in ventilation and air-conditioning systems are octave bands (*i.e.* bands of frequency having an upper frequency twice that of the lower frequency). The preferred frequency limits for each octave band, and their nominal centre frequencies, are tabulated for the eight octave bands of interest.

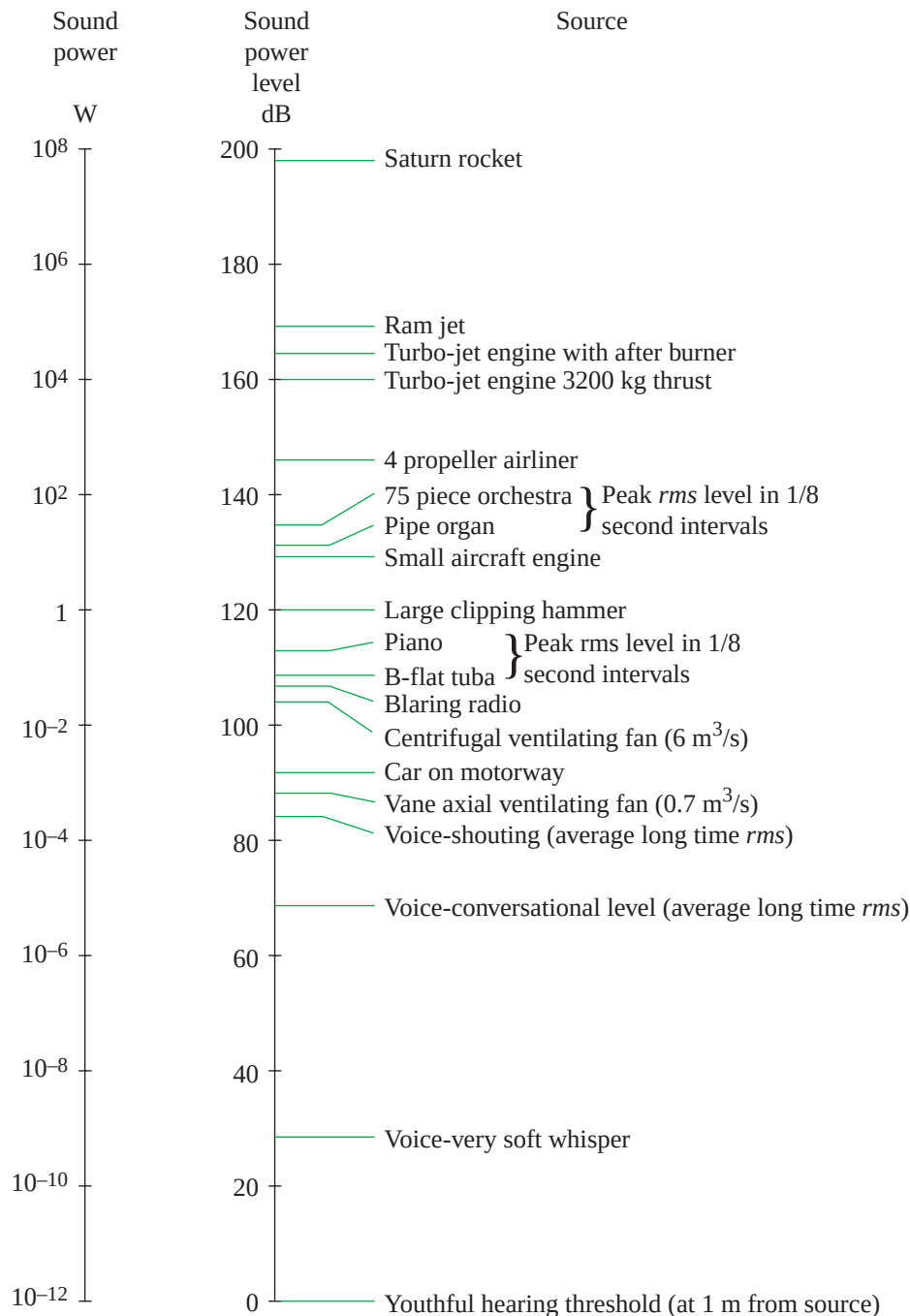
Lower band limit, Hz	44	88	177	355	710	1420	2840	5680
Centre frequency, Hz	63	125	250	500	1000	2000	4000	8000
Upper band limit, Hz	88	177	355	710	1420	2840	5680	11360

It should be noted that the band centre frequencies, by which the bands are usually referred to, are the nominal geometric mean of the upper and lower frequency limits, *i.e.* $f_{\text{centre}} = (f_{\text{upper}} \times f_{\text{lower}})^{1/2}$.

* The information in this Section is also provided in ESDU 79037. It is repeated here for the convenience of the user.

† The preferred reference values correspond to the youthful hearing threshold and are expressed in SI units in all Items in the "Noise in air-conditioning systems" volume. It should be stressed that for quantities expressed in dB the reference value should be stated when absolute values are given.

‡ 1 Pa is 1 pascal = 1 N/m^2 ; therefore $20 \mu\text{Pa} = 2 \times 10^{-5} \text{ N/m}^2$. The equivalent value of p_0 may be quoted in other units such as $2 \times 10^{-4} \text{ dyn/cm}^2$ or $4.18 \times 10^{-7} \text{ lbf/ft}^2$.



Sketch 3.1 Sound powers for some familiar noise sources

Sound pressure levels are dependent on both the source and its surroundings. Measured values of sound pressure levels, at some fixed position relative to the source, will vary depending on the size and acoustic characteristics of the room in which measurements are made. It is, therefore, most convenient to consider noise in ventilation systems in terms of sound power levels which may be considered to be independent of the source surroundings. However, to assess the response to noise it is necessary to use sound pressure levels since the ear responds to pressure fluctuations. The relationships between sound power levels and sound pressure levels are dependent on both temperature and barometric pressure but for the practical range of these parameters, found in ventilation systems, this dependence may be ignored. The required

relationships for the conversion of sound power levels entering a room and the sound pressure levels at a specific location within the room are given in ESDU 81043. In using relationships between sound power levels and the sound pressure it is essential to use linear dimensions in the appropriate units for the particular relationships. In ESDU 81043 it is necessary to use linear dimensions expressed in metres.

3.1 Summation of Levels in dB Units

Sound levels from more than one source, or over a number of octave bands, that are given in dB units may be summed by first converting the individual sound levels to their equivalent power related units. These values are then added and finally reconverted to a total sound level. To illustrate this summation consider the calculation of the total sound power level from J individual sources having sound power levels $L_{w1}, L_{w2}, \dots, L_{wJ}$. Each individual source is converted to a sound power in watts and the total sound power from all sources is converted to the required sound power level in dB. This procedure is expressed mathematically as

$$\text{total sound power level} = 10 \log_{10} \left[\text{antilog}_{10} \frac{L_{w1}}{10} + \text{antilog}_{10} \frac{L_{w2}}{10} + \dots + \text{antilog}_{10} \frac{L_{wJ}}{10} \right], \quad (3.3)$$

$$\text{i.e. total sound power level} = 10 \log_{10} \left[\sum_{j=1}^J 10^{L_{wj}/10} \right], \quad (3.4)$$

where L_{wj} is the sound power level of the j^{th} source. It should be noted that each of the individual levels summed in this way must be referenced to the same reference value. A graphical procedure for the summation of levels in dB is given in Appendix A of ESDU 81043.

4. ROOM ACOUSTIC CHARACTERISTICS

The sound pressure level at any point within a room has both a direct and reverberant component. The reverberant sound pressure level is dependent on the ability of the room to absorb sound. Parameters used to describe the acoustic characteristics of a room are its reverberation absorption coefficient and the reverberation time.

A method of estimating sound pressure levels in a room due to a ventilation system noise source is given in Section 7 of ESDU 81043.

4.1 Reverberation Absorption Coefficient

The reverberant absorption coefficient, α , is the ratio of the sound energy absorbed by a surface to that incident upon it at a given frequency. Typical values of α for materials commonly used for internal finishes and noise control are given in Table 9.1. A more extensive list of materials and their reverberation absorption coefficients may be found in Derivation 2. The tabulated values of α should be treated as approximate measures due to variations across the same type of material and because the method of measurement may influence the derived values. Typically α is measured in a reverberation room as described in Reference 8.

4.2 Reverberation Time

For sound of a given frequency, the reverberation time, T , is the time required for the sound pressure level to decrease by 60 dB from its initially steady level after the source is stopped. Enclosures with long reverberation times are normally rated as "live" and those having short reverberation times are rated "dead". Short reverberation times are encountered when conditions approximate to free-field (i.e. no sound is reflected). The reverberation time for a space varies with frequency and typical values for various types of room and their ratings are tabulated.

Typical room usage	T (s)	Rating
Radio studios, audiometric rooms	0.2 to 0.25	dead
TV studios, restaurants, department stores, boardrooms	0.4 to 0.5	medium dead
Offices, libraries, homes, conference rooms, lecture theatres, hospital wards	0.9 to 1.1	average
School rooms, art galleries, small churches	1.8 to 2.2	medium live
Large churches, factories, large canteens, gymnasiums	2.5 to 4.5	live

Values of T for a specific space may be calculated using the approximate* relationship

* The expression for T given in Equation (4.1) is applicable provided the sound field is truly diffuse and the room does not have a mid-frequency value of T less than about 0.5 s. If this latter condition is not met a more accurate value of T is given by

$$T = \frac{24.04 v}{c s_r [-\log_{10} (1 - \bar{\alpha})]} \quad (4.2)$$