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Estimation of sound pressure levels due to buzz-saw noise within the intake duct of a supersonic fan or compressor

Associated software: ESDUpac A7433

Endorsed by
The Royal Aeronautical Society

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Acoustic Fatigue Panel. This Panel first met in 1966 and now has the following membership:

Chairman
Prof. B.L. Clarkson — Institute of Sound and Vibration Research, University of Southampton

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Mr W.T.Kirkby — Royal Aircraft Establishment

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Mr J.A. Hay — British Aircraft Corporation (Weybridge) Ltd
Mr M.J.T. Smith — Rolls-Royce (1971) Ltd
Mr N.A. Townsend — Hawker Siddeley Aviation Ltd, Hatfield.

The work on this Item was carried out at ESDU under the supervision of Mr A.G.R. Thomson. The member of staff who undertook the technical work involved in the initial assessment of available information and the original construction of the Item was

Mr A.R. Green — Acoustics Specialist.

The subsequent development of the Item was undertaken by

Mr A.G.R. Thomson — Executive, Environmental Projects.

Since 1970, Governments of NATO Nations have provided financial assistance through the Advisory Group for Aerospace Research and Development (AGARD) for revising and extending the data provided in Data Items on acoustic fatigue that were first issued by ESDU in 1966 and 1967. The Acoustic Fatigue Working Group (under the Chairmanship of Mr A.H. Hall, National Aeronautical Establishment, Canada) of the AGARD Structures and Materials Panel initiated and directed this additional work and appointed National Coordinators (see below) for each of the sponsoring Nations to provide basic data and to review AGARDographs as prepared by ESDU staff, monitored and guided by the Acoustic Fatigue Panel.

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ESTIMATION OF SOUND PRESSURE LEVELS DUE TO BUZZ-SAW NOISE WITHIN THE INTAKE DUCT OF A SUPERSONIC FAN OR COMPRESSOR

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ESTIMATION OF SOUND PRESSURE LEVELS DUE TO BUZZ-SAW NOISE WITHIN THE INTAKE DUCT OF A SUPERSONIC FAN OR COMPRESSOR

1. INTRODUCTION

Buzz-saw tones (also known as combination tones) are generated by a fan or compressor when the rotor blade Mach number relative to the incident airstream exceeds unity. In a practical rotor the resulting shock waves propagate from the rotor face with differing intensities, spacing and angles because of geometric and aeroelastic differences between individual blades (see Figure 1). These variations can give rise to tones, at low frequencies that are integral multiples of shaft frequency as well as at blade-passage frequency, which can be sufficiently intense to cause acoustic fatigue damage within the intake duct. This Item gives a method of estimating the sound pressure levels of buzz-saw tones within the intake duct.

A computer program is provided with this Item. Implementation of the program is described in Appendix A of this Item.

2. NOTATION

		Units	
		SI	*British*
B	number of fan or compressor blades		
E	shaft rotational frequency	Hz	Hz
f	frequency of buzz-saw tone	Hz	Hz
K	shaft-order number, f/E		
K_{co}	shaft-order number at cut-off		
L_B	component of L_K dependent upon the number of blades and surviving shocks	dB	dB
L_K	average sound pressure level of tone of shaft-order K in intake duct at distance x from compressor face, $L_x + L_M + L_B + L_{K\sigma}$	dB	dB
$L_{K\sigma}$	component of L_K dependent on shaft-order number and standard deviations of shock spacing and amplitude	dB	dB
L_M	component of L_K dependent upon Mach number of incident flow on blades	dB	dB
L_x	component of L_K dependent upon x/R	dB	dB
M_A	intake axial-flow Mach number		
M_T	tangential Mach number at blade tip		

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N	number of shock waves per shaft revolution surviving at duct plane under consideration		
p_0	static pressure in intake duct	N/m^2	lbf/ft^2
p_{ref}	reference pressure for decibel scale, taken as 20 $\mu N/m^2$ ($0.42 \times 10^{-6} lbf/ft^2$)	N/m^2	lbf/ft^2
R	tip radius of fan or compressor	m	ft
x	axial distance upstream of compressor face	m	ft
γ	ratio of specific heat capacities for air (taken as 1.4)		
σ_A	standard deviation of normalised shock-wave amplitude		
σ_E	standard deviation of normalised shock-wave spacing		

3. NOTES

3.1 Summary of Method

The sound pressure level at the duct wall at distance x from the compressor face for any buzz-saw tone is estimated from the sum $L_K = L_x + L_M + L_B + L_{K\sigma}$.

The components L_x, L_M and L_B are plotted in Figures 2, 3 and 4 against the appropriate engine parameters. These components are constant at a given station in the duct for a given fan and given running conditions. The component $L_{K\sigma}$ is plotted in Figures 5 and 6. This component defines the shape of the envelope of the peaks of the buzz-saw tone spectrum and must be evaluated from each tone required. Figure 5 relates to tones at integer multiples, K, of shaft frequency and Figure 6 to tones at integer multiples of blade-passage frequency.

Tones below a critical cut-off frequency do not propagate efficiently along the duct. Figure 7 gives the value of the shaft order, K_{co}, at this cut-off. Except very close to the compressor face, the sound pressure levels at frequencies less than K_{co} may be expected to be much lower than calculated.

It is assumed that values of B, K, M_A, M_T, p_0, R and x are known or have been chosen. The remaining parameters required to estimate L_K are the standard deviations of shock-wave amplitude and spacing, σ_A and σ_E, and the number of surviving shock-waves, N. The values of these parameters for a given fan are not always available. Guidance on their estimation is given in Section 3.3.

3.2 Assumptions and Limitations

No allowance is made for the effect of any acoustic lining of the duct. It is assumed that the inlet flow is axial and uniform across the intake duct, which has parallel walls and no intake guide vanes. The data apply at values of x greater than about one blade spacing. Closer to the rotor face the sound energy is concentrated at blade-passage frequency and tends to a value dependent on the initial shock strength at the rotor face.

The estimation method shows good agreement with experimental results measured inside the duct within a few blade spacings of the compressor face. For fans with short ducts (duct length less than fan diameter) measurements in the far field, outside the duct, are also consistent with estimates. There are indications

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that for certain fans with intake ducts longer than the fan diameter the attenuation in the duct may be greater than predicted by this method.

In Figure 6, a value of $\sigma_A = 0.1$ has been assumed. Departures from this value have a negligible effect on the value of $L_{K\sigma}$ for integral values of K/N. It is assumed that the distributions of shock spacing and amplitude are statistically normal.

Because the noise at shaft-order frequencies is caused by small differences between individual rotor blades, each rotor has its own unique spectrum of buzz-saw levels. The method therefore can give only typical levels and should not be expected to produce precise agreement with any one set of measured results.

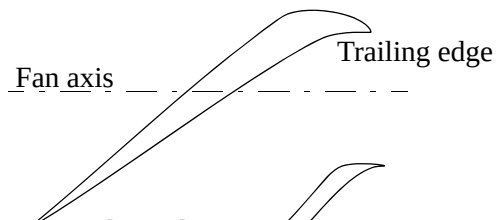
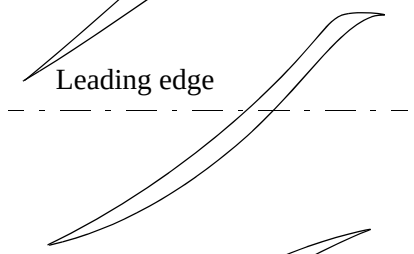
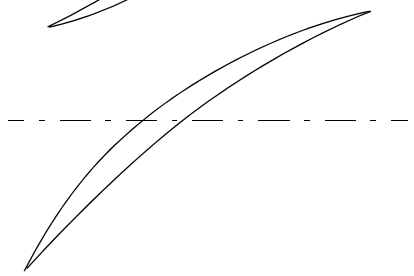
3.3 Statistical Parameters of Shock Waves

As buzz-saw tones are dependent on geometric and aeroelastic differences between individual blades, this Item is based on a statistical, theoretical treatment incorporating the statistical characteristics σ_A, σ_E and N of the shock waves of a particular fan.

It is recommended that, if possible, values of these parameters should be estimated from test data. The following guidance can be given. The exact value of σ_A has relatively little effect on the sound pressure level of the buzz-saw tones except at low shaft orders, or when σ_E is small (see Figure 5). The value of σ_A increases from a very small value close to the rotor face up to a value typically of 0.15 to 0.2 at large values of x. In the absence of test data it is recommended that σ_A should be assumed to be 0.1, unless tones at low multiples of shaft frequency are likely to be particularly critical as a source of acoustic-fatigue damage, when it is safer to allow for a value of σ_A up to 0.2.

The value of σ_E increases from a small value close to the rotor face up to a value typically between 0.2 and 0.3 at the duct exit.

For purposes of estimating N, the values given in the following sketch are recommended (Derivation 3).

Sketch of blade profile	*Type of blade*	*Type value of N*
	Straight entrance region	$B/2$
	Concave entrance region	$B/2$
	Convex entrance region	B

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4. DERIVATION

The Figures are based on the following expressions.

Figure 2

$$L_x = 20\log\left[\frac{\gamma}{\gamma+1}\cdot\frac{p_0}{p_{ref}}\cdot\frac{\pi R}{x}\right] + 10\log\frac{\pi}{6}.$$

Figure 3

$$L_M = 10\ \log\frac{4(M_A^2+M_T^2-1)[M_A(M_A^2+M_T^2-1)^{1/2}-M_T]^4}{(M_A^2+M_T^2)^4}.$$

Figure 4

$$L_B = 30\log\left[\frac{1}{B}\cdot\frac{B}{N}\right].$$

Figure 5

$$L_{K\sigma} = 10\log\frac{4}{\eta^4}\{\eta^2+2(1-\cos\eta)-2\eta\sin\eta\}(1+6\sigma_E^2)\{1+\sigma_A^2-\exp(-\sigma_E^2\eta^2)\}$$

where

$$\eta = 2\pi(K/N).$$

Figure 6

$$L_{K\sigma} = 10\log\frac{4}{\eta^2}(1+6\sigma_E^2)\{1+\sigma_A^2+(B-1)\exp(-\sigma_E^2\eta^2)\}$$

where

$$\eta = 2\pi K/N.$$

Figure 7

$$K_{co} = 0.77\left\{\frac{M_T}{(1-M_A^2)^{1/2}\left[1-0.1\exp 23.03\{1-(M_A^2+M_T^2)^{1/2}\}\right]}-1\right\}^{-3/2}.$$

1. MORFEY, C.L. FISHER, M.J. — Shock-wave radiation from a supersonic ducted rotor. *Aeronaut. J.*, Vol. 74, No. 715, pp. 579-585, July 1970.

2. PHILPOT, M.G. — The buzz-saw noise generated by a high duty transonic compressor. *J. Engng Pwr*, pp. 63-69, January 1971.

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