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Estimation of the surface pressure fluctuations in the turbulent boundary layer of a flight vehicle

Associated software: ESDUpac A7521

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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 Aircraft Noise Committee. This Committee first met in 1971 and now has the following membership:

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Mr M.J.T. Smith — Rolls-Royce (1971) Ltd, Derby
Mr D.R.B. Webb — Royal Aircraft Establishment.

The work on this Item was carried out in the Environmental Projects Group of 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 the available information and the construction and subsequent development of the Item was

Mr A.R. Green — Acoustics Specialist.

Further development of the computer program was undertaken by

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

The person with overall responsibility for the work in this subject area is Dr C.B. Chinoy, Head of the Aircraft Noise and Structural Dynamics Group.

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ESTIMATION OF THE SURFACE PRESSURE FLUCTUATIONS IN THE TURBULENT BOUNDARY LAYER OF A FLIGHT VEHICLE

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ESTIMATION OF THE SURFACE PRESSURE FLUCTUATIONS IN THE TURBULENT BOUNDARY LAYER OF A FLIGHT VEHICLE

1. NOTATION AND UNITS

		Units	
		SI	*British*
a	speed of sound	m/s	ft/s
f	frequency	Hz	Hz
Δf	frequency bandwidth	Hz	Hz
L_S	spectrum level of fluctuating pressure†	dB/Hz	dB/Hz
L_T	overall fluctuating pressure level†	dB	dB
L_1	component of L_T depending on Re_x and M	dB	dB
L_2	component of L_T depending on altitude	dB	dB
L_3	component of L_T depending on $f\delta^*/U$ (Strouhal number)	dB	dB
M	freestream Mach number		
Re^*	Reynolds number at $M = 1$, $\rho a x/\mu$		
Re_x	Reynolds number at freestream velocity, MRe^*		
U	freestream velocity	m/s	ft/s
x	distance along surface from virtual origin of turbulent boundary layer	m	ft
δ^*	boundary layer displacement thickness	m	ft
ρ	freestream density	kg/m^3	slug/ft^3
μ	dynamic viscosity	kg/m s	slug/ft s

† The reference pressure for fluctuating pressure levels is 20 μN/m^2 (0.0002 dyn/cm^2 or 0.42×10^{-6} lbf/ft^2).

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2. INTRODUCTION

This Data Item provides a method of estimating the wall pressure fluctuations in the turbulent boundary layer on a flight vehicle.

It is based on an analysis of flight test results which are considered to be more appropriate for project estimation than the data from the more idealised environment of wind tunnels. Details of the analysis method and results are presented in Derivation 1.

Both the overall level of fluctuating pressure in dB and its spectrum level in dB/Hz can be determined.

Hence by application of the appropriate bandwidth corrections to spectrum level the distribution of fluctuating pressure can be found in, for example, octaves or third octaves of frequency (Reference 4).

The data presented are applicable to cases of relatively smooth attached flow on cylindrical or conical type bodies and should not be used for highly perturbed flows, *e.g.* shocks and separated flows.

The ranges of data applicability are as follows:

Mach number	0.1 to 4.0
Reynolds number	10^6 to 10^9.

Within these limitations the rms error between calculated and measured fluctuating pressure levels is approximately 3.0 dB. However, this figure should be taken only as an upper boundary, as the mean of the data was taken, having due regard for what were considered to be the most reliable experimental results in terms of instrumentation used, location of measurements and amount of information reported.

If the fluctuating pressure levels estimated from this Item are used to evaluate stresses induced in skin panels, using procedures presented in Items in the Acoustic Fatigue Series, information on the spatial correlation of the boundary layer pressures is required. The correlation length for boundary layer noise is shorter than for jet noise so that the pressure may not be exactly in phase over the whole of the panel considered. Consequently, the excitation efficiency of boundary-layer noise is not as high as for jet noise. Some guidance on the correlation lengths for boundary layer noise is given in Reference 2. An additional factor to be considered for the structural response to boundary layer noise is that higher modes of vibration may be excited than in the case of jet noise loading.

A computer program known as ESDUpac A7521 is provided with this Item. It permits the user to evaluate the overall level of fluctuating pressure and its spectral distribution. Implementation of the computer program is described in Appendix A.

3. CALCULATION PROCEDURE

3.1 Overall Fluctuating Pressure Level

The overall fluctuating pressure level is calculated from the expression

$$L_T = L_1 - L_2 \text{ (dB)}$$

where L_1 is obtained from Figure 1 for a given Mach number and calculated Re_x, and L_2 is obtained from Figure 2 for a given pressure altitude.

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3.2 Frequency Distribution

The spectrum level of fluctuating pressure is calculated from the expression

$$L_S = L_3 + L_T - 10 \log_{10} U/\delta^* \text{ (dB/Hz).}$$

The value of δ^* is obtained from Figure 3, for a given value of x and calculated value of Re_x, and L_3 is obtained from Figure 4 for each calculated value of $f\delta^*/U$.

The band spectrum level of fluctuating pressure for any frequency bandwidth, Δf, is then

$$L_S + 10 \log_{10} \Delta f .$$

4. DERIVATION AND REFERENCES

4.1 Derivation

1. GREEN, A.R. — Comparison of surface pressure fluctuations in a turbulent boundary layer as measured on various flight vehicles. Memorandum No. 58, ESDU, London, June 1974.

4.2 References

2. WHITE, R.W. — Theoretical study of acoustic simulation of in-flight environment. *The Shock and Vibration Bulletin*, No. 39, Part 3, pp. 55-75, January 1969.

3. – — Atmospheric data for performance calculations. ESDU 68046, ESDU, London, U.K., 1968 (Amendment C, October 1977).

4. – — Bandwidth correction. ESDU 66016, ESDU, London, U.K., 1966 (Amendment A, February 1978).

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