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Estimation of the maximum discrete frequency noise from isolated rotors and propellers

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THE PREPARATION OF THIS DATA ITEM

This Data Item has been compiled by ESDU under a contract with Ministry of Defence (Procurement Executive); it forms part of the Aeronautical Series of ESDU, is numbered in that Series, and is in the same format.

The work of the permanent professional staff of ESDU on this particular Item was monitored and guided by the following Work Party:

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ESTIMATION OF THE MAXIMUM DISCRETE FREQUENCY NOISE FROM ISOLATED ROTORS AND PROPELLERS

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ESTIMATION OF THE MAXIMUM DISCRETE FREQUENCY NOISE FROM ISOLATED ROTORS AND PROPELLERS

1. NOTATION

		<i>SI Units</i>	<i>British Units</i>
a_0	ambient speed of sound	m/s	ft/s
B	number of blades in propeller or rotor		
C_T	thrust coefficient, K/σ		
D	diameter of propeller or rotor disc	m	ft
I_1 to I_7	component sound pressure levels	dB	dB
K	non-dimensional thrust coefficient, $4T/(\pi D^2 \rho V_t^2)$		
L_1	first harmonic sound pressure level, $I_1 + I_2 + I_3 + I_4 + I_5$	dB	dB
L_m	m^{th} harmonic sound pressure level, ($m > 1$), $L_1 + I_6 + I_7$	dB	dB
M_t	propeller or rotor blade tip Mach number, $\pi n D / a_0$		
m	harmonic number		
n^*	propeller or rotor rotational speed	rev/s	rev/s
$P^\dagger$	power supplied to propeller or rotor	W	ft lbf/s
p_{ref}	reference pressure for sound pressure level	(see Table 1.1)	
T	thrust generated by propeller or rotor	N	lbf
V_t	propeller or rotor blade tip speed	m/s	ft/s
x	distance from centre of propeller or rotor disc to observer	m	ft
β	angle between line joining centre of propeller or rotor disc to observer and upstream axis of rotation	deg	deg
ρ	density of air	kg/m ³	slug/ft ³
σ	(blade area)/(disc area), where blade area is total untwisted planform blade area of B blades of rotor or propeller		

* The rotational speed, entered as computer program input, must be described in rpm.

† For the computer program input, power must be entered in kW if SI Units are used or in horsepower if British Units are used.

TABLE 1.1

p_{ref}	Units
0.0002	dyn/cm ²
20	μ N/m ²
4.177×10^{-7}	lbf/ft ²

Both SI and British units are quoted but any coherent system of units may be used.

2. NOTES

2.1 General

Aerodynamically induced noise from rotors and propellers is conveniently separated into two parts, a discrete frequency component, occurring at a fixed frequency interval, called rotational noise and a broad-band component called vortex noise. Rotational noise is usually the dominant noise component in the low frequency region of the noise spectrum of rotors and propellers; however, for helicopter rotors the vortex noise may make a significant contribution to the noise spectrum at relatively low frequencies (above 250 Hz) and is likely to exceed the contribution of rotational noise in the perceived noise level.

Rotational noise is usually regarded as that noise which is directly attributable to the steady and fluctuating lift and drag forces on the propeller or rotor. The noise is radiated at low frequencies and shows up on narrow-band analysis as a series of “peaks”, or discrete frequencies, which are harmonically related to the blade passage frequency.

The rotational noise predicted in this Item does not include the component of noise called blade slap. This noise source is exclusive to rotors and results from the interaction between a blade and a concentrated vortex generated by the preceding blade. When it occurs blade slap is usually the dominant source of aerodynamic noise and in these cases this Data Item should not be used to predict peak values of discrete frequency noise.

The method of prediction provided in this Data Item is a tentative one based on the best available data. Because of the lack of test data it is not possible to account for all the discrepancies between measured data and predictions from the simple theory which is adopted as the basis of the Item. Section 2.6 indicates the accuracy to be expected and the limitations listed in that Section should be noted.

A computer program to perform the estimation, described in Appendix A, is included.

2.2 Rotational (Discrete Frequency) Noise Prediction

It is well known that using present complex theoretical methods (References 13, 14 and 15) it is possible to predict accurately only the lower harmonics of rotational noise (m less than about 4) because of difficulties in estimating higher harmonic blade loads. The simple prediction method provided in this Item is expected to be no less accurate than the more complicated procedures at the first harmonic level and provides higher harmonic rotational noise levels within a predictable tolerance over a greater range of harmonics than the more complicated methods. Generally the air induced by a propeller or rotor is of a turbulent nature due to such effects as cross-winds, atmospheric turbulence and upstream rotor disturbances. The blades then experience fluctuating forces which in turn produce fluctuating levels of discrete frequency and broad-band noise. This fluctuation in noise level is demonstrated by experimental data which show a high degree of scatter when generated by nominally similar rotor or propeller operating conditions.

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2.3 Presentation of Data

This Data Item gives a method of estimating the peak harmonic sound pressure levels from isolated rotors and propellers. The data are based on static measurements, mostly from rigs, from which the effect of ground reflection has been removed. Figures 1 to 5 provide components of the first harmonic sound pressure level in terms of non-dimensional parameters. Arithmetic summation of these components gives an estimate of the first harmonic sound pressure level. Figures 6 and 7 provide corrections which should be added to the first harmonic sound pressure level to obtain estimates of higher harmonic sound pressure levels.

2.4 Assumptions Made in Derivation of Figures

The base for the prediction method (Derivation 2) is provided by the Gutin first harmonic sound pressure level. The Gutin theory assumes that the blade loads are concentrated at a single point on the blade; for this Item the load point is assumed to be 0.8 times the blade radius from the centre of the propeller or rotor disc.

To reduce the measured values of first harmonic sound pressure level to free air values, 6 dB was subtracted from the measurements to account for the effect of ground reflection. Tests have shown that at the relatively low frequency of the first blade passing frequency the ground acts as an almost perfect reflector.

No allowance was made for atmospheric attenuation in the measured data. Since none of the measured data was recorded at distances greater than 150 m (500 ft), and the harmonic frequencies considered are low, atmospheric attenuation would be negligible.

2.5 Directionality

Both the first harmonic of rotational noise and the total rotational noise are generally at a maximum in the range $90^\circ < \beta < 120^\circ$. Within this range of β the variation of rotational sound pressure level is small. In using the Gutin theory to derive the basic uncorrected first harmonic rotational noise level the value of β was taken to be 105° .

2.6 Range of Applicability

The data presented may be used for helicopters and propeller driven aircraft in static or low forward speed (below 40 knots) conditions but the contributions from engines, or from wing, fuselage or ground reflection are not included. Helicopters in ground effect may produce higher noise levels than those predicted. For conventional propeller driven aircraft, where the propeller induced flow is in the flight direction, there is likely to be a reduction in the discrete frequency noise levels in flight.

The data are confirmed by available test data for the range of the parameter $P/a_0 T$ from 0.02 to 0.3, and for D/x from 0.015 to 0.33 (maximum $x = 150$ m). Within these ranges, the difference between calculated and measured first harmonic sound pressure levels is within ± 3 dB for 75 per cent of available data, and for higher harmonics ($m \geq 10$) the difference between calculated and measured sound pressure levels is within ± 10 dB for 93 per cent of available data.

Outside these ranges the Data Item should be used with some caution. In particular at values of x greater than about 150 m, consideration should be given to the reduction of estimated sound pressure levels due to atmospheric effects.

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