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Airframe noise prediction

**Associated software: ESDUpac A9023
ESDUpac B9023
VIEWpac M9023**



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THE PREPARATION OF THIS DATA ITEM

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

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AIRFRAME NOISE PREDICTION

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AIRFRAME NOISE PREDICTION

1. NOTATION

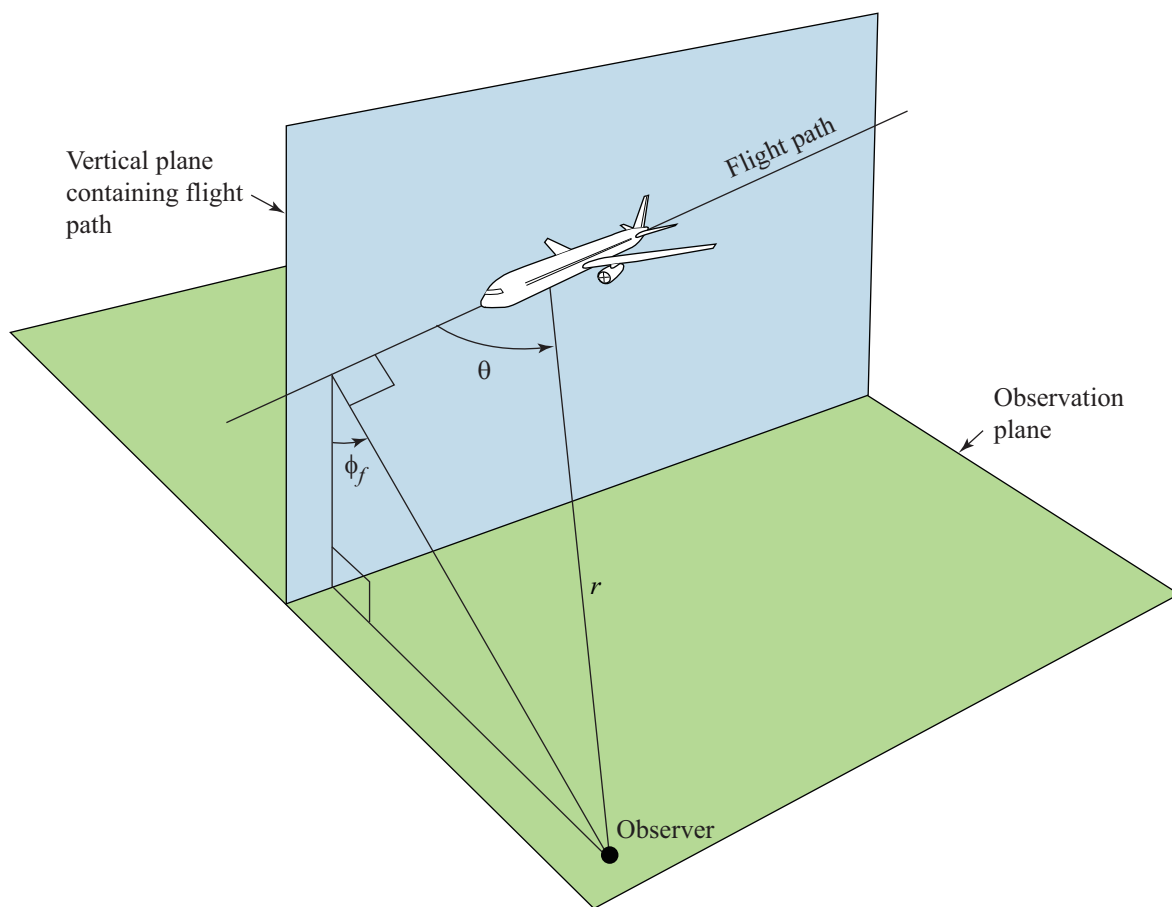
		<i>Units</i>	
		<i>SI</i>	<i>British</i>
b_w	wing span	m	ft
c	ambient speed of sound at aeroplane location at minimum range	m/s	ft/s
$D(\phi_f, \theta)$	directivity function		
$F(Sr)$	spectrum function		
f	frequency	Hz	Hz
k_1, k_2	constants in Equation (4.3)		
k_3	geometry function in Equation (4.3)		
l	length scale characteristic	m	ft
M	Mach number of aeroplane		
$OASPL$	overall sound pressure level	dB*	dB*
P	non-dimensional acoustic power		
p^2	non-dimensional mean-square acoustic pressure		
p_l	ambient pressure at aeroplane location	kPa	lbf/ft ²
p_0	ambient pressure at reception point	kPa	lbf/ft ²
p_{ref}	reference acoustic pressure	kPa*	lbf/ft ² *
r	distance from source to observer (see Sketch 1.1)	m	ft
SPL	sound pressure level	dB*	dB*
Sr	Strouhal number		
T_l	ambient temperature at aeroplane location	K	K

For footnotes refer to end of Notation Section

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θ	polar emission angle (see Sketch 1.1)	deg	deg
ν	kinematic viscosity at aeroplane location	m^2/s	ft^2/s
ρ	ambient density at aeroplane location	kg/m^3	slug/ft^3
ϕ	azimuthal angle in spherical coordinates (see Appendix C)	deg	deg
ϕ_f	azimuthal angle (see Sketch 1.1)	deg	deg

* The reference pressure is $20 \mu\text{Pa}$ (*i.e.* $2 \times 10^{-5} \text{N}/\text{m}^2$) or $0.42 \times 10^{-6} \text{lbf}/\text{ft}^2$.



Sketch 1.1

2. INTRODUCTION

Airframe noise is caused by airflow over aeroplane surfaces. It does not include powerplant noise and therefore sets a lower limit below which reductions in engine noise emission have no significant effect on the total noise level from the aeroplane. The level of airframe noise is dependent upon the aeroplane configuration. In basic terms, an aerodynamically 'clean' aeroplane produces less noise in the airflow than a 'dirty' one. The landing configuration with slats extended, flaps down and undercarriage lowered is therefore considerably more noisy than the clean configuration. An illustration of the magnitude of this increase in noise level for the aeroplane described in the example in Section 8 is shown in Sketch 2.1. The solid curve in Sketch 2.1 represents the predicted noise spectrum for the aeroplane overhead, in the landing

configuration, and the dashed curve is for the aeroplane in the clean configuration at the same location and flying at the same airspeed. The breakdown of the airframe noise spectrum for the landing configuration into its constituent component spectra is shown in Sketch 2.2.

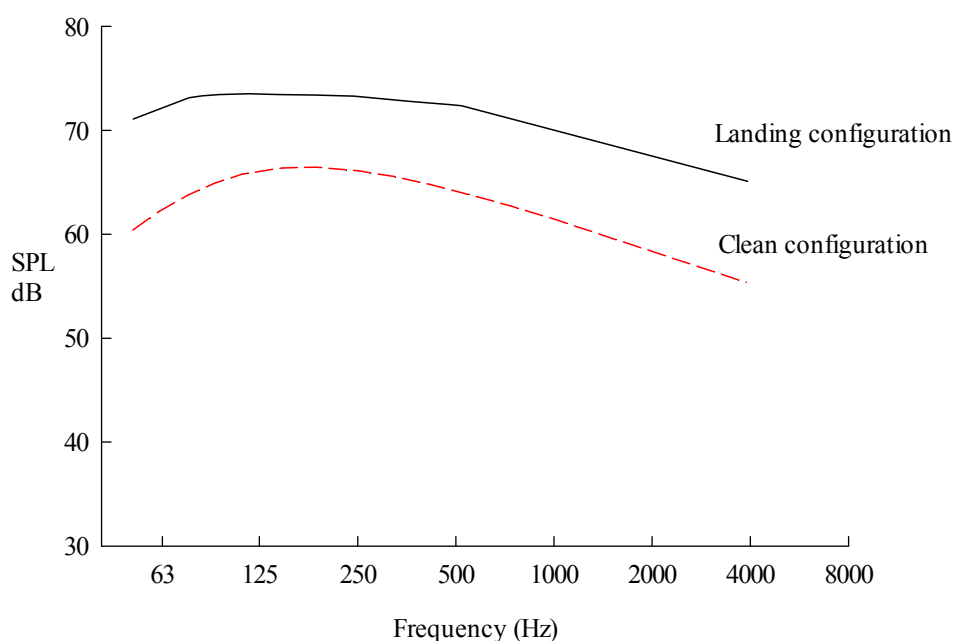
This Item provides a computerised method for estimating airframe noise in the far-field. The prediction method, which is a semi-empirical one, has been developed from that proposed by Fink (Derivations 2 and 5) with changes to directivity and spectral functions based on recently available data. The aeroplane geometry and operating conditions are required input data. The program permits the estimation of the *OASPL* and of one-third octave band sound pressure levels within a frequency range and over polar and azimuthal angular ranges set by the user. The output values are for free-field and still, lossless atmospheric conditions. Procedures to correct for atmospheric attenuation, ground reflection and lateral attenuation in still atmospheric conditions may be found in References 8, 9, 10 and 12. To account for wind and temperature gradients the method described in Reference 11 may be used.

This Item may be used to predict airframe noise for discrete airframe elements and by summation for any selected combination of the following aeroplane components:

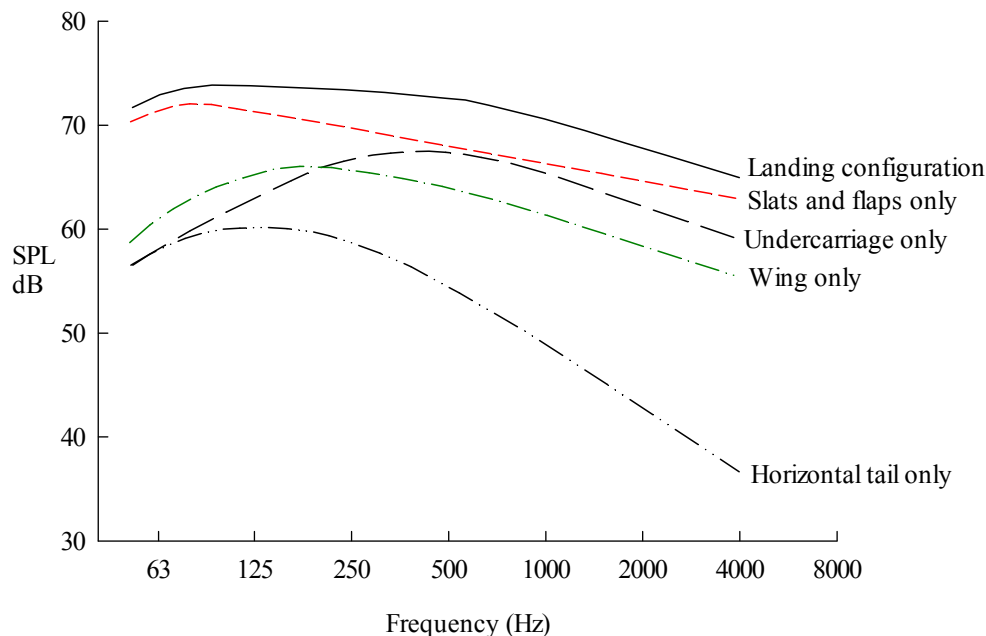
- i) wing (conventional or delta),
 - ii) slats,
 - iii) horizontal tail,
 - iv) vertical tail,
 - v) flaps (single-, double- or triple-slotted),
 - vi) main landing gear
- and
- vii) nose landing gear.

Although the fuselage does produce some lift, most of the fluctuating lift and drag forces which generate the noise are associated with the components listed above. The contribution of noise from the fuselage may be considered negligible at a reception point in the far-field.

In addition to the prediction of airframe noise from turbo-fan and turbo-jet powered aircraft, the method may be used for aerodynamically clean aeroplanes like sailplanes.



Sketch 2.1 Example airframe noise spectra for clean and landing configurations



Sketch 2.2 Breakdown of airframe landing noise spectrum

3. BACKGROUND TO METHOD

The prediction method works by modelling individual components of the airframe as elementary sources or source distributions. The spectral and directivity characteristics of these sources have been derived analytically or empirically, or have been assumed to be similar to sources of known characteristics.

The individual components of the airframe that are considered here are the wing, flaps, slats, tail and landing gear; no interaction between components is assumed. The computer program allows the discrete computation and output of the noise emanating from any of these components before summing the contributions for the selected combination. For example, in the clean configuration, the contributing components are the wing and the horizontal and vertical tail components. For the landing configuration, contributions from the landing gear, the leading-edge slats and the trailing-edge flaps must be added to the noise from the clean configuration.

4. METHOD OF CALCULATION

The method of calculating the broad-band noise contribution from each of the various airframe components is general and is similar to those given in Derivations 2 and 5. The same basic sequence of steps is followed for each component but with appropriately different values of constants and functions.

The general method of calculation is described in this section. Specific constants and functions for each component are contained in Appendix A.

The sound pressure level at the reception point, adjusted for the difference in ambient pressures at aeroplane and reception point locations is given by the equation

$$SPL = 10 \log p^2 + 10 \log \frac{\rho^2 c^4}{p_{ref}^2} - 20 \log \frac{p_l}{p_0}, \quad (4.1)$$

where p^2 is the mean-square acoustic pressure non-dimensionalised by $\rho^2 c^4$. In this form, it is given by

$$p^2 = \frac{P b_w^2 D(\phi_f, \theta) F(Sr)}{4\pi r^2 (1 - M \cos \theta)^4} \quad (4.2)$$

The term, $P b_w^2$, in Equation (4.2) is a function of Mach number, and has the form

$$P b_w^2 = k_1 M^{k_2} k_3, \quad (4.3)$$

where k_1 , k_2 are constants and k_3 is a geometry function depending on the airframe component under consideration. The acoustic power, P , has been non-dimensionalised by $\rho c^3 b_w^2$.

The Strouhal number Sr has the form

$$Sr = \frac{fl}{Mc} (1 - M \cos \theta), \quad (4.4)$$

where l is a length scale characteristic of the airframe component, details of which are provided in Appendix A.

Each airframe component also has its own directivity function, $D(\phi_f, \theta)$, and spectrum function, $F(Sr)$. Motion of the source is accounted for by the Doppler frequency factor $(1 - M \cos \theta)$, and a source amplification factor $(1 - M \cos \theta)^4$.

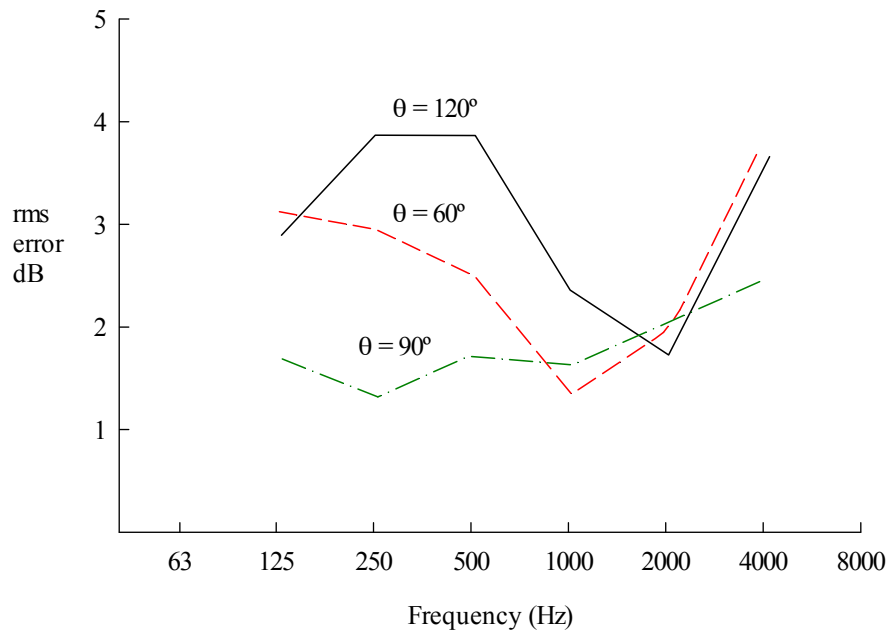
Values of ambient density and kinematic viscosity required by the calculation method are computed from input values of pressure and temperature using the relationships given in Derivation 3.

5. ACCURACY AND LIMITATIONS

The airframe noise prediction procedure contained in this Item is not suitable for use on propeller-driven aeroplanes. The principal reason for this unsuitability is that installation effects associated with propellers are likely to be very different from those associated with the turbofan aeroplanes used to develop the prediction method. The prediction method is not designed to account for either tonal components or to consider interaction between different airframe elements. The prediction method does not address airbrake or winglet noise, or the effect of podded undercarriages. Wing incidence effects have been neglected in the derivation of the method.

Although there are no explicit limits on take-off weights or airspeed, this prediction method has been validated for multi-engined turbofan aeroplanes with maximum take-off weights ranging from 42 000 kg to 390 000 kg and flying at airspeeds ranging from 70 m/s to 145 m/s. Wherever possible, data for runs in which engines had been set to flight idle were used for the validation process.

The airframe noise component is at its maximum fraction of the total aeroplane noise during the final approach, because all the high lift devices are usually deployed, the undercarriage is lowered, and the engines are set at the minimum thrust setting required for maintaining the desired glide slope. In this configuration the rms error between estimated and measured one-third octave band sound pressure levels has been estimated for the range of aeroplane flyovers in the available ESDU database. The corresponding values of rms error for the overall sound pressure level were of the order of 2 dB at $\theta = 60$ degrees, 1 dB at $\theta = 90$ degrees and 3 dB at $\theta = 120$ degrees. The rms error is shown as a function of frequency for three different values of polar angle, θ , in Sketch 5.1.



Sketch 5.1 rms error from eight recent flyover data sets

6. COMPUTER PROGRAM

There are three computer programs associated with this Item, A9023, B9023 and M9023.

Programs A9023 and M9023 provide a means of estimating the airframe noise generated by an aeroplane. The various components of the airframe addressed by the method are

- i) wing (conventional or delta),
 - ii) slats,
 - iii) horizontal tail,
 - iv) vertical tail,
 - v) flaps (single-, double- or triple-slotted),
 - vi) main landing gear
- and vii) nose landing gear.

The method is also suitable for gliders.

The program when run requires the user to enter the name of the input file. The structure of this input file is shown in Table 6.1.

Program B9023 can be run to create input files easily.

Typically, the program to estimate shock noise can be run by either typing in the program name or by clicking on the icon associated with the executable version of the program. The user is then prompted to enter the name of the input file.

The two programs described above follow the standard and familiar ESDU Aircraft Noise Series means of providing software. However, for users with MATLAB[†] installed on their systems an additional program,

[†] MATLAB is a registered trademark of The Math Works, Inc.

M9023, is included. When this program is run, a graphical user interface is launched through which input data may be entered. The data are stored in a file named by the user. The option to load the interface with data from an existing file is also available. Clicking on the 'RUN' push button starts program execution, with results output in the standard way to a text file named by the user. In addition, spectral plots of the total of all aircraft components are generated, displayed and written to Tagged Image File Format (TIFF or TIF) files. Files containing spectral plots for the case in the Example of Section 8 are displayed in that Section.

The frequency range for the calculations is set by the user. The program is designed to perform calculations at a set of locations at coordinates which must be specified by the user. These coordinates are r , θ and ϕ_f , defined in Sketch 1.1. This system of coordinates, which is commonly used in airframe noise calculations, differs from the standard system used for the ESDU Data File (see Appendix C) only in the definition of azimuthal angle. The relationship between the two angles is given by

$$\phi = \phi_f + 90 \quad (6.1)$$

Guidance on the estimation of aeroplane geometric parameters required as input data is provided in Appendix B. It is not necessary to enter geometric data for airframe elements when their noise contribution is not of interest, and zeros may be substituted in the input file. For example, the only geometric data required for a flyover in the clean configuration are wing and horizontal tail areas and spans.

Data may be entered either in SI or British Units provided a consistent system is used.

The airframe noise levels are calculated in one-third octave bands for free-field, lossless atmospheric conditions, and may be output for each airframe component selected as well as for the summation of components selected. The *OASPL* is also printed out for individual components and for the summation over all components. The output, in the same units as the input case data, is written to a file named by the user in the input file.

The facility to output three lines of descriptive text, which are entered as input, is provided.

TABLE 6.1

Enter first line of run title
Enter second line of run title
Enter third line of run title
Enter output filename
Enter common data input filename (enter 'NONE' if none present)
Enter common data output filename (enter 'NONE' if none is to be output)
Units: SI = 1; British = 2
Flight velocity
Lower frequency limit
Upper frequency limit
Control parameters: if not required set to zero
Wing: Conventional = 1 Delta = 2
Transport aircraft = 0 Glider = 1
Slats: Extended = 1
Horizontal tail: Transport aircraft = 1 Glider = 2
Vertical tail: Transport aircraft = 1 Glider = 2