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Aircraft noise prediction



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AIRCRAFT NOISE PREDICTION

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AIRCRAFT NOISE PREDICTION

1. NOTATION

a_0	ambient speed of sound	m/s	ft/s
f_{obs}	observed frequency	Hz	Hz
f_{source}	source frequency	Hz	Hz
M_a	flight Mach number, V_a/a_0		
T_{js}	jet static temperature	K	K
T_{ps}	primary jet static temperature in a coaxial jet	K	K
T_0	ambient temperature	K	K
V_a	flight velocity	m/s	ft/s
V_j	fully-expanded jet velocity relative to nozzle	m/s	ft/s
V_p	fully-expanded primary jet velocity	m/s	ft/s
V_s	fully-expanded secondary jet velocity	m/s	ft/s
θ	angle between aeroplane flight path and direction of sound propagation to observer (see Sketch 4.1)	degrees	degrees
θ_i	angle between engine inlet axis and direction of sound propagation to observer (see Sketch 4.1)	degrees	degrees
θ_j	angle between engine exhaust axis and direction of sound propagation to observer (see Sketch 4.1)	degrees	degrees
ψ	angle between aeroplane flight path and engine axis (see Sketch 4.1)	degrees	degrees

2. INTRODUCTION

ESDU 02020 provides an introduction to the main sources of aircraft noise, aircraft noise transmission, modifying effects and to subjective response. And the ESDU Aircraft Noise Series provides a range of methods for predicting the aircraft noise levels. The subjects covered include powerplant noise, airframe noise, propagation effects and cabin noise. Regarding powerplant noise, gas-turbine engines are treated in considerably more detail than piston engines. Propellers are considered separately and helicopter rotors are included in that methodology.

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Aircraft noise sources and propagation effects are complex insofar as they can depend on many variables. It is often not straightforward to be certain of the applicability of a particular method to the circumstances for which a user may want to perform a prediction. It is the purpose of this Item to assist in this process, particularly for those new to the subject.

It should be made clear from the outset, for example, that all currently known methods only apply to an aircraft or an engine operating in steady-state conditions. That is, the conditions are either stationary or at a constant flight speed along a linear path and there is thus no variation in the sound pressure levels with time. This applies to the noise source strengths, their radiation patterns and to propagation effects through the atmosphere arising from, say, wind and/or temperature gradients. Of course, for an aircraft in flight, an observer on the ground will experience varying noise levels.

Thus, transient aircraft manoeuvres can only be predicted assuming a succession of steady-state conditions. Prediction methods generally are not structured so as to be able to deal readily with other than straight, constant-speed flight paths.

None of the prediction methods predict the noise in the region within a few wavelengths of the noise source, the so-called 'acoustic near-field', except insofar as the prediction of the noise levels close to jets may include such effects in the database used. What are referred to as 'near-field' effects in propeller noise, for example, are not acoustic near-field effects but geometric effects related to the propeller diameter as described in Section 11.1.

This Item provides an overview of the extent to which currently-available prediction methods can meet the particular circumstances for which a user may desire to perform a prediction. All of the methods incorporated into the ESDU Aircraft Noise Series are included in this survey. At the end of each section, there is a list of references which are not references in the conventional sense but point the reader to other methods, recent work or sources of information in the public domain which may be of help. These references are not necessarily referred to explicitly in the text. Each reference list is intended to cover the foregoing subject completely, the same reference being repeated in different sections if required.

The Item treats the various mechanisms arising in the context of aircraft noise prediction, firstly by considering the several possible sources of noise

- (i) Gas turbine engine noise,
- (ii) Piston engine noise,
- (iii) Propeller noise and
- (iv) Airframe noise

and then going on to consider the transmission effects along the path from the noise component to the observer, whether through the atmosphere, over the ground, or into the aircraft cabin, viz.

- (v) Propagation effects and
- (vi) Cabin noise.

Engine noise from both gas turbine and piston engines is considered to be basically axisymmetric although the intake or nozzle geometry may alter this, and, apart from non-axial inflow effects, propeller noise is also considered to be axisymmetric whereas airframe noise, from any of its component sources, is fundamentally non-axisymmetric.

The noise of an aircraft is predicted by calculating separately the main source constituents which are applicable. As a consequence, the noise from many particular aircraft configurations can be predicted by summing, on a spectral basis, the individual levels estimated for the particular sources. This summation process may be carried out using ESDU 08018.

3. GAS TURBINE ENGINE NOISE

As described previously for the aircraft, the noise from gas-turbine engines is predicted by calculating its main constituents separately, thus enabling the noise from many particular engine configurations to be predicted. The noise prediction methods currently available are considered under the general headings of

- (i) Fan noise,
- (ii) Compressor noise,
- (iii) Combustor/core noise,
- (iv) Turbine noise and
- (v) Jet noise.

Fan or compressor noise is only considered here in the context of axial-flow engine designs. ESDU has not addressed the issue of the noise from centrifugal compressors and neither has it reviewed yet the available literature on this subject.

For a turboprop engine, the noise of the various engine components would be estimated and then added spectrally to the noise of the propeller. Experience may indicate that some sources are negligible and need not be predicted. It may be, however, that the source noise cannot be predicted because the operating conditions of the engine are not known in sufficient detail. There is no acceptably accurate means for predicting the engine noise in such circumstances.

The above noise components are often complex and hence many of the following paragraphs have several sub-divisions. Furthermore, the transmission of the component source noise to the observer can be altered by additional engine or aircraft features. The principal modifying effects arise from the installation of sound-absorbing liners inside the engine and, secondly, from the proximity of the engine to aircraft structure, giving rise to what are termed 'installation effects'. These latter effects can arise from acoustic effects (such as reflection and shielding) or from aerodynamic processes (such as wakes or turbulence shed into engine airflow). These processes are not well understood or quantified. These modifying effects are addressed briefly here in the subsequent sections headed:

- (vi) Duct liners and
- (vii) Installation Effects.

4. FAN AND COMPRESSOR NOISE

Although the fan and compressor stages of an axial-flow turbojet or turbofan engine are physically quite distinct from each other, the basic noise generating mechanisms are similar and a single prediction method can be applied to estimate noise generated by either component.

The estimation method contained in ESDU 98008 is based on the Heidman method developed at NASA Lewis, which was developed further by the Boeing Company under contract with the NASA Ames Research Center. ESDU 98008 offers the user the choice of using the Heidman method, the Heidman method using the modifications for small engines suggested by Allied Signal or a third ESDU method which includes further modifications at high frequencies based on data made available privately to ESDU by Rolls-Royce.

The prediction method in ESDU 98008 predicts axisymmetric free-field SPL values in one-third-octave bands from 50 Hz to 10 kHz for a still, lossless atmosphere, and these vary with the polar angle but not the azimuthal angle.

The method considers the noise radiated from the inlet duct and the exhaust duct separately. In both cases, there is a broad-band noise component and a discrete tone component. However, in the noise emitted from the inlet duct, there is an additional combination tone or “buzz-saw” component when the blade tip speed relative to the local airflow is supersonic. At each radiation angle, the individual component spectra are summed on an energy basis*. For multi-stage fans, a workable approximation to the final spectrum is obtained by summing the sound energy from the first and second stages. The program does not correct noise levels automatically for blade row attenuation. However, estimated values for the attenuation in the forward and rearward arcs may be input by the user, and these values will be subtracted from the noise levels. Some simple guidelines on estimating blade row attenuation in the forward arc are provided.

The prediction procedure in this Item is applicable to multi-stage turbofans with and without inlet guide vanes. Since the Item has only been validated for up to two stages, results for more than two fan or compressor stages are less reliable. It is assumed that the operating point is near the steady-state operating line and again the results will be less reliable if the operating point is off the design point. The method does not include an allowance for any duct effects such as those arising from non-circular intakes or sound-absorbing liners.

It should be noted that non-circular intakes, or circular intakes at incidence, will cause inlet flow distortion leading to asymmetry in the radiated noise. This may often be the case with military aircraft with, for example, bifurcated intakes. For these unusual intake conditions, the acoustic effects are complex and not covered currently in the ESDU Aircraft Noise Series.

In general, the ESDU method predicts adequately the general properties of far-field noise spectra. The trends exhibited by experimental data are predicted in a satisfactory manner, but, as Heidman states in his original paper, although the method predicts sound power and perceived noise levels within a couple of decibels, it does not always predict the detailed variations in the spectra from angle to angle. This is especially so for non-typical fan operating conditions.

The program in its current form predicts SPLs in one-third-octave bands summing the broad-band noise component, the discrete tone component and, for the inlet duct, the combination tone component† on an energy basis. The program will be modified in the future to give the user the option to print out the contributions of the different components.

4.1 “Buzz-saw” Tones (Combination Tones)

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 air stream exceeds unity anywhere along the blade span.

ESDU 75020 provides a method of estimating the sound pressure levels of buzz-saw tones in the far field. The method is based on a theory employing statistical analysis of the number, spacing and amplitude of the shocks generated from a fan of conventional design. No allowance is made for the effect of any sound-absorbing lining in the duct.

4.2 Flight Effects

Motion can affect noise source strengths, frequencies and radiation characteristics.

In fan or compressor testing on the ground, atmospheric turbulence ingested into the engine intake will increase the fan noise unless the fan intake is fitted with a control screen to reduce the scale of the ingested

* The term ‘energy basis’ is used here to describe the addition of noise levels in an incoherent manner *i.e.* without regard to relative phase.

† The buzz-saw or combination tone component prediction is also dealt with separately in ESDU 75020. This topic is discussed in the next section.

turbulence. For engines with a clean inflow, the turbulent intake flow distortions are reduced in flight and the associated fan noise will be reduced correspondingly. The opposite is also true. A complex inlet path can introduce additional flow distortions in flight and thereby increase the fan noise. The fan and compressor noise prediction method in ESDU 98008 addresses both conditions, that is, full or reduced atmospheric turbulence, simply by inquiring whether the aircraft is in flight.

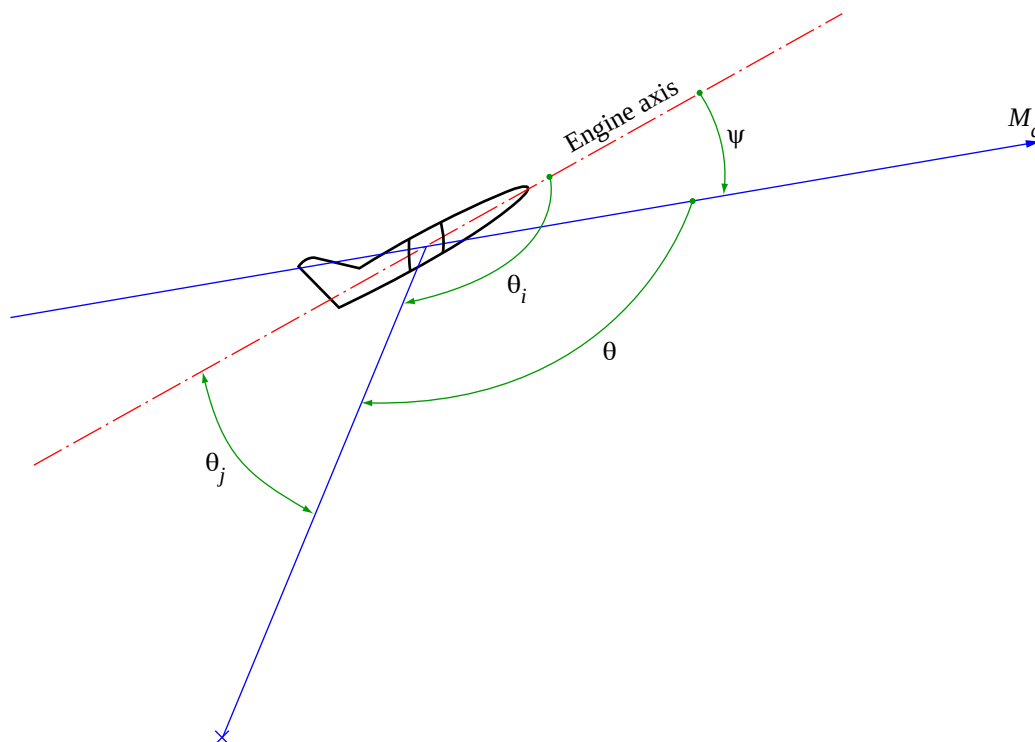
Fan and compressor noise arises from sources 'fixed' to the aircraft. Thus, having taken into account the change in the source noise from the changed inflow conditions, the noise radiation to the ground is subject to a Doppler shift in frequency and a Doppler amplification factor depending on the dipole nature of the noise source as detailed in Section 5.1. Static sound pressure levels are affected by a fourth power 'Doppler' amplification factor and the sound pressure level at an observation point from a source moving at a Mach number of M_a may be obtained from the static source sound pressure level using the equation

$$SPL_{obs} = SPL_{source} - 40 \log_{10}(1 - M_a \cos \theta), \quad (4.1)$$

In addition, corrections need to be made for the Doppler frequency shift for relative motion between source and observer. The relationship between observed (*flight*) frequency and emitted (*static*) frequency is given by

$$f_{obs} = f_{source} / (1 - M_a \cos \theta) \quad (4.2)$$

where $\theta = \theta_i - \psi$, and ψ is the angle between the flight path and the engine axis as depicted in Sketch 4.1.



Sketch 4.1 Source-receiver geometry in flight

At this time, these effects have not been included in ESDU 98008.

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5. COMBUSTOR/CORE NOISE

Core noise is considered to comprise all the noise emanating from the core of the engine exhaust system but excluding turbine noise. Uncertainties regarding the nature of this noise source are outlined in Section 7 of ESDU 02020. Only combustor noise has been correlated in a formalized manner while some observations of other core or so-called ‘excess’ noise are described in Reference 5.1.

Combustor noise is a somewhat vague term used to describe the noise resulting from the combustion process. Its existence has been recognised as a ‘hump’ appearing in engine noise spectra at low engine powers at around 400 Hz. It is believed to comprise two components: direct and indirect noise. The direct noise component is the noise of combustion propagating out of the engine through the exhaust nozzle. An indirect component is believed to be generated when the hot turbulent products of combustion pass through pressure gradients downstream of the combustor.

Existing knowledge is incapable of distinguishing any detailed features of the combustor design so that whether, for example, the fuel injection is by pressure sprayer or vaporizer is not considered to be a relevant factor. The ESDU method for predicting combustor noise, ESDU 05001, is based on the semi-empirical SAE method described in ARP876D (Reference 5.2). The method has been based on a broad-brush correlation of what have been deemed to be factors governing the noise from the combustor of several engines at low powers. These factors include the combustor temperature rise, mass flow, pressure and the subsequent temperature drop across the turbine system. The noise directivity and spectral shape have been determined empirically.

The ESDU method allows for some spectral adjustment if the user has engine data indicating combustor noise peaking at a different frequency.

5.1 Flight Effects

Lacking any published evidence on the effect of flight on combustor noise, ESDU 05001 corrects static noise spectra for flight effects according to the theoretical expectations for a dipole source fixed relative to the aircraft using the procedure described earlier in Section 4.2.

5.2 References

- | | | |
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6. TURBINE NOISE

Turbine noise does not usually have the importance of fan noise in being a major component. It is commonly only heard in the rear arc at low (*e.g.* approach) engine powers. Like fan or compressor noise, it consists of both broad-band and tonal components but it radiates from the engine core out through the exhaust nozzle.

ESDU 12001 offers the user a means of estimating noise levels in one-third octave bands from the turbine within a gas turbine engine, either static or in flight. The prediction program is based on a modified version (Reference 6.5) of the Smith and Bushell method (Reference 6.3). It does not consider explicitly such factors as detailed blade geometry, hub-to-tip ratio and tone cut-off effects.

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