



ESDU 12001

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Prediction of turbine noise from aero-engines

**Associated software: ESDUpac A1201
ESDUpac B1201
VIEWpac M1201**



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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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PREDICTION OF TURBINE NOISE FROM AERO-ENGINES

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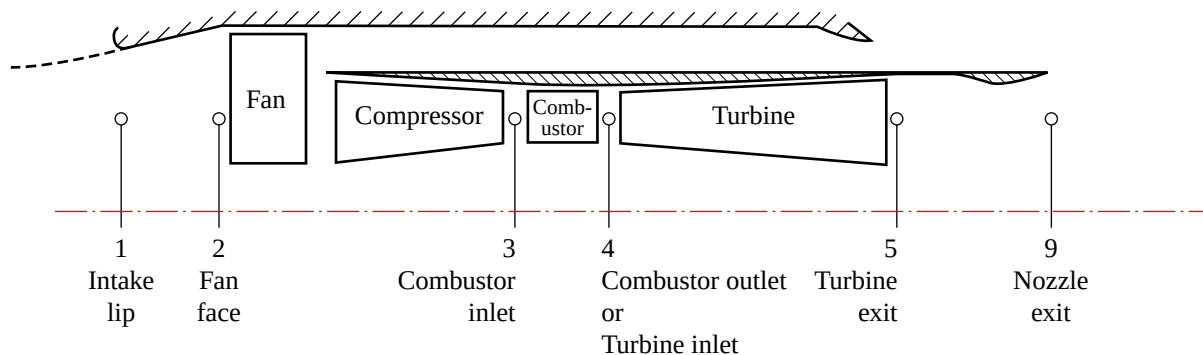
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PREDICTION OF TURBINE NOISE FROM AERO-ENGINES

1. NOTATION

B	number of blades in last rotor stage of turbine	
c_L	speed of sound at turbine exit	m/s
c_0	ambient speed of sound	m/s
$D_B(\theta_i)$	broadband directivity function	dB
$D_D(\theta_i)$	discrete tone directivity function	dB
$F(f/f_0)$	spectrum shape function	dB
f	frequency	Hz
f_0	fundamental blade passage frequency of last rotor stage of turbine, defined in Equation (3.4)	Hz
K	correction factor for nozzle exits (see Page 3)	dB
L_B	peak SPL for broadband noise	dB
L_D	SPL of fundamental turbine tone	dB
M_a	flight Mach number	
N	turbine shaft rotational speed	rev/min
p_{ref}	reference sound pressure ($= 2 \times 10^{-5}$ Pa)	Pa
p_0	ambient air pressure	Pa
r, θ, ϕ	spherical coordinates (see Appendix A)	
S/C	stator-rotor gap-chord ratio (see Sketch 3.1)	
SPL	one-third octave band sound pressure level, re p_{ref}	dB
T_0	ambient air temperature	K
T_5	total temperature at turbine exit (Sketch 1.1, station 5)	K
V_{TR}	relative tip velocity of last stage of turbine	m/s
W	turbine mass flow	kg/s

θ	angle between direction of aircraft motion and sound propagation path	degrees
θ_i	nominal engine angle (see Sketch 5.1)	degrees
θ_j	angle between engine exhaust axis and direction of sound propagation	degrees
ψ	angle between aeroplane flight path and engine axis	degrees



Sketch 1.1 Idealized engine station designation[†]

2. INTRODUCTION

This Item allows the user to estimate the noise levels in one-third octave bands emanating from the turbine within a gas turbine engine. The engine may be either static or in flight.

The prediction program accompanying this Item is based on a modified version (Derivation 2) of the Smith and Bushell method (Derivation 1). The method is an empirical one in that the prediction of noise is based on the correlation of engine measurements of turbine noise which have been deemed to emanate from the last stages of an aero-engine. As a consequence, it does not consider explicitly such factors as, for example, detailed blade geometry, hub-to-tip ratio and tone cut-off effects.

The paucity of available measured turbine noise data in the open literature has meant that this Item has not been validated by ESDU in the usual way. ESDU, however, has been made aware of a need for an Item that allows turbine noise to be estimated and therefore this Item is being issued.

Feedback from our users would be appreciated.

[†] The station numbers shown here are consistent with those in Reference 4.

3. EMPIRICAL MODELLING

The current prediction procedure considers the noise emanating from the turbine as the sum of two components: broadband noise and tonal noise. Both components are considered to vary with the relative tip velocity of the turbine's last stage, the local speed of sound at the turbine exit and the turbine mass flow. In addition, the tonal components have been seen to be dependent on the stator-rotor spacing.

Flight has an effect on sound pressure levels. Sound pressure levels are considered to change in flight by a fourth power 'Doppler' amplification factor.

The Doppler frequency shift for relative motion between source and observer is also included in the program.

3.1 Broadband Component

The peak one-third octave band SPL at a distance of 1m is given by

$$L_B = 10 \log_{10} \left[\left(\frac{V_{TR}}{0.305} \cdot \frac{c_0}{c_L} \right)^3 \cdot \left(\frac{W}{0.4536} \right) \cdot \left(1 - M_a \cos \theta \right)^{-4} \right] + D_B(\theta_i) + 23 \text{ dB}, \quad (3.1)$$

where c_L , the speed of sound at the turbine exit is calculated from

$$c_L = 19.8 \sqrt{T_5} \text{ m/s}. \quad (3.2)$$

and $D_B(\theta_i)$ is a directivity function shown in Figure 1[†]. The third-octave sound pressure level spectrum is then obtained by applying a spectrum shape function, F , shown in Figure 3, as follows:

$$SPL(f) = L_B + F(f/f_0), \quad (3.3)$$

where f_0 , the fundamental blade passage frequency of the last rotor stage of the turbine is given by

$$f_0 = \frac{B \cdot N}{60(1 - M_a \cos \theta)}. \quad (3.4)$$

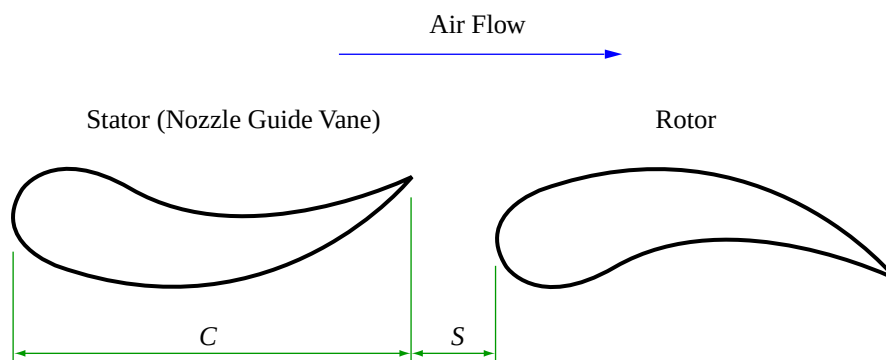
3.2 Discrete Tonal Components

The SPL of the fundamental turbine tone at a frequency of f_0 at a distance of 1m is given by

$$L_D = 10 \log_{10} \left[\left(\frac{V_{TR}}{0.305} \right)^{0.6} \cdot \left(\frac{c_0}{c_L} \right)^3 \cdot \left(\frac{W}{0.4536} \right) \cdot \left(\frac{S}{C} \right)^{-1} \cdot \left(1 - M_a \cos(\theta) \right)^{-4} \right] + D_D(\theta_i) + 89 \text{ dB} + K, \quad (3.5)$$

where $D_D(\theta_i)$ is a directivity function shown in Figure 2[†], S/C is the stator-rotor spacing as shown in Sketch 3.1. For internally mixed turbofan exhausts where the primary nozzle exit is upstream from the secondary nozzle exit, Derivation 2 suggests that a factor K be applied, where $K = -10 \text{ dB}$. K is otherwise zero.

[†] In the computer program, multi-ordered polynomials are used.



Stator-rotor gap-chord ratio = S/C

Sketch 3.1

The frequency of the fundamental or first discrete tone is f_0 given by Equation (3.4).

Test data indicate that the second harmonic ranges from 8 to 20 dB below the first harmonic *i.e.* the fundamental. The current prediction procedure assumes that harmonics fall off at a rate of -10 dB per harmonic. In practice, the higher harmonics are of little importance because of their very high frequencies

In the program, the first five tones are added to the broadband spectrum given in Equation (3.3) to provide the total turbine noise.

4. ACCURACY

The paucity of available turbine noise measured data has not allowed ESDU to validate this Item. However, some turbine noise data available to the NASA-Lewis Research Centre for several turbofan engines have been compared in Reference 5 with predictions using the method described in Derivation 2, which is very close to the method in this Item. The prediction errors range from -6 dB to 8 dB.

5. APPLICATION

The one-third octave band spectrum is calculated by adding the discrete tones to the broadband spectrum. The resulting spectrum at the reference 1m reception point is then adjusted to the source-receiver distance specified by the user.

In circumstances where the relative tip speed of the rotor is not known, a rough approximation can be made using 0.7 of the rotor tip speed.

The basic method as described in Section 3 provides sound pressure levels as a function of θ_i , the angle to the engine axis. Unless the engine axis is parallel to the flight path, this angle is different from θ , the angle used to specify the location of the aeroplane (see Sketch 5.1) by the user. The program requires the user to enter the value of the angle ψ , the angle between the flight path and the engine axis.

The equivalent θ_i for the specified θ is calculated automatically using the relationship

$$\theta_i = \theta + \psi, \quad (5.1)$$

which means that the correction is only valid in the flyover plane and not in the sideline direction.

The prediction can be carried out for θ_i in the nominal range of 40 to 160 degrees. For a static engine, $\psi = 0$.