

THE ESTIMATION OF NEAR-FIELD SOUND PRESSURE LEVELS DUE TO JET NOISE

1. NOTATION

c_p	specific heat at constant pressure of fully-expanded jet gases	J/kg K	ft lbf/slug K
D	jet nozzle diameter	m	ft
f	frequency	Hz	Hz
L	overall sound pressure level	dB	dB
L_v	correction to L due to change in jet velocity	dB	dB
L_ρ	correction to L due to change in jet density	dB	dB
L_0	datum overall sound pressure level	dB	dB
n	velocity index		
p	ambient pressure	N/m ²	lbf/ft ²
R	gas constant for air (287 J/kg K) (3090 ft lbf/slug K)	J/kg K	ft lbf/slug K
T_j	jet pipe static temperature	K	K
T_{Hj}	jet pipe total temperature	K	K
V	mean fully-expanded jet velocity	m/s	ft/s
V_0	datum fully-expanded jet velocity (610 m/s) (2000 ft/s)	m/s	ft/s
x	axial distance from jet pipe nozzle plane, measured in jet direction	m	ft
y	radial distance from jet axis	m	ft
ρ_j	density of jet gases	kg/m ³	slug/ft ³
ρ_0	datum density (0.49 kg/m ³) (0.000 95 slug/ft ³)	kg/m ³	slug/ft ³

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

2. INTRODUCTION

This Memorandum gives a method of estimating the near field sound pressure levels due to high velocity jet noise from a single stationary conical nozzle.

Detailed noise data from the engine manufacturer should be used for preference but, when this is not possible, a number of methods of estimation are available. These methods give widely differing results and after comparing them the following method has been found to give the closest agreement with experimental results. This method is intended to give a value of the overall sound pressure level that is somewhere near the mean. The accuracy of the estimated levels is expected to be within ± 5 dB, *i.e.* between approximately 60 per cent and 170 per cent of the actual r.m.s. pressure. Under reheat conditions or at jet velocities well above the datum velocity, however, the discrepancy could be wider. At jet velocities below about half the datum velocity, V_0 , other sources of noise than pure jet mixing can become significant. In such cases this method underestimates the apparent jet noise.

The noise levels predicted by the method described here are free field values but do not apply to the field within a conical surface emanating from the jet nozzle perimeter and expanding at a semi-angle of approximately 15 degrees relative to the jet axis, since this region contains the turbulent mixing region of the jet.

This Memorandum is not applicable to the case of "shock cell noise", a phenomenon which can occur when a jet nozzle is operating in an over-choked condition. A relatively discrete note is then produced, giving in a narrow band an intensity much greater than that of the basic jet noise.

3. CALCULATION PROCEDURE

The following information is required as a basis for the computation of the sound pressure level at some point in the field:

jet nozzle diameter	D ,
co-ordinates of the point	(x, y) ,
mean fully-expanded jet velocity	V ,
jet pipe total temperature	T_{Hj} .

- (i) Evaluate x/D and y/D .
- (ii) From Figure 1, which shows the free field datum noise level contours, read off the datum overall sound pressure level L_0 at the position $(x/D, y/D)$.
- (iii) From Figure 2, which shows velocity index contours, read off the velocity index n at the position $(x/D, y/D)$.
- (iv) Calculate the first part of the velocity correction term ΔL_{v1} , from

$$\Delta L_{v1} = 10 n \log_{10} \left(\frac{V}{V_0} \right).$$

- (v) Obtain the second part of the velocity correction term, ΔL_{v2} from Figure 3, which shows ΔL_{v2} plotted against $\log_{10}(V/V_0)$ for different values of n .

- (vi) Calculate the total jet velocity correction L_v from,

$$L_v = \Delta L_{v1} + \Delta L_{v2}.$$

- (vii) Calculate the density of the jet gases ρ_j ,

where
$$\rho_j = \frac{p}{RT_j}$$

and
$$T_j = T_{Hj} - \frac{V^2}{2c_p}$$
 for all jet velocities.

- (viii) Calculate the density correction L_ρ ,

where
$$L_\rho = 20 \log_{10} \left(\frac{\rho_j}{\rho_0} \right).$$

- (ix) Evaluate the overall sound pressure level (SPL) at the required point (x, y) as

$$L = L_0 + L_v + L_\rho.$$

This level can be converted to a pressure loading by the use of the relation

$$\text{r.m.s. fluctuating pressure in N/m}^2 = 10^{(0.05L - 4.699)}$$

or using Item No. 66018.

- (x) For a given frequency the spectrum level in decibels relative to an arbitrary overall SPL may be read from Figure 4, after evaluating fD/V and x/D . Alternatively, if the spectrum level is required in terms of pressure loading, this may be found using Figure 5. Taking values of fD/V and x/D the spectrum level in $(\text{N/m}^2)/\text{Hz}$ relative to 1 N/m^2 overall SPL is read from the ordinate of Figure 5 and is then multiplied by the value of L obtained as a pressure loading in (ix). This gives the pressure spectrum level for a specified frequency in $(\text{N/m}^2)/\text{Hz}$.

4. USE OF CALCULATED SOUND PRESSURE LEVELS

After the free field sound pressure levels have been estimated, corrections must be made for local effects, for example reflection. When the wave fronts of this noise field strike a structure they are partially reflected, and the reflection process locally increases the pressure loading on the surface. When the wave front strikes the surface at right angles (normal incidence) the pressure loading is doubled (a 6 dB increase on the calculated values). If the wave front moves parallel to the surface (grazing incidence) there is no increase in loading. To allow for this reflection process, it is fairly general engineering practice to add a mean correction of 3 dB to the calculated free air levels.

The effects of different nozzle arrangements, aircraft configurations, *etc.*, should be taken into consideration.

Further corrections must be made for the case of an aircraft in motion to allow for the effects of the aircraft velocity and the ambient speed of sound.

An alternative computer-based method that plots overall sound pressure levels for various engine operating conditions can be seen in Derivation 3.

5. DERIVATION

1. FRANKEN, P.A.
et al. Methods of flight vehicle noise prediction. Wright Air Development Center, Tech. Rep. WADC TR 58-343, 1958.
2. Unpublished work by Rolls-Royce Ltd and Bristol Siddeley Engines Ltd.
3. PLUMBLEE, H.E.
et al. Near field noise analyses of aircraft propulsion systems with emphasis on prediction techniques for jets. Air Force Flight Dynamics Lab., Tech. Rep. AFFDL-TR-67-43, 1967.
4. RILEY, M.P. Near field jet noise prediction techniques. British Aircraft Corporation Ltd, Acoustics Lab. Rep. A.R.324, 1971.
5. Acoustic fatigue design data. Part 1. AGARD-AG-162-72, 1972.

6. EXAMPLE

It is required to estimate the r.m.s. sound pressure level and the pressure spectrum level at 300 Hz at a specific point given the following conditions:

$$\begin{aligned}
 D &= 0.61 \text{ m}, & x &= 5.5 \text{ m}, & y &= 6.7 \text{ m}, \\
 V &= 670 \text{ m/s}, & T_{Hj} &= 900 \text{ K}, \\
 R &= 287 \text{ J/kg K}, & c_p &= 1160 \text{ J/kg K} \\
 p &= 101 \times 10^3 \text{ N/m}^2.
 \end{aligned}$$

Firstly $\frac{x}{D} = \frac{5.5}{0.61} = 9.02$

and $\frac{y}{D} = \frac{6.7}{0.61} = 11.0$

Hence, from Figure 1,

$$L_0 = 140 \text{ dB}$$

and, from Figure 2, by interpolation

$$n = 6.2.$$

Now $\Delta L_{v1} = 10 \times 6.2 \log_{10} \left(\frac{670}{610} \right) = 2.5 \text{ dB}$

and, from Figure 3, for $\log_{10}(V/V_0) = 0.0407$ and interpolating for $n = 6.2$,

$$\Delta L_{v2} = -0.9 \text{ dB}$$

so that $L_v = 2.5 - 0.9 = 1.6 \text{ dB}.$

As $T_j = 900 - \frac{670^2}{2 \times 1160} = 707 \text{ K}$