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Prediction of combustor noise from gas turbine engines

**Associated software: ESDUpac A0501
ESDUpac B0501
VIEWpac M0501**



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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 COMBUSTOR NOISE FROM GAS TURBINE ENGINES

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PREDICTION OF COMBUSTOR NOISE FROM GAS TURBINE ENGINES

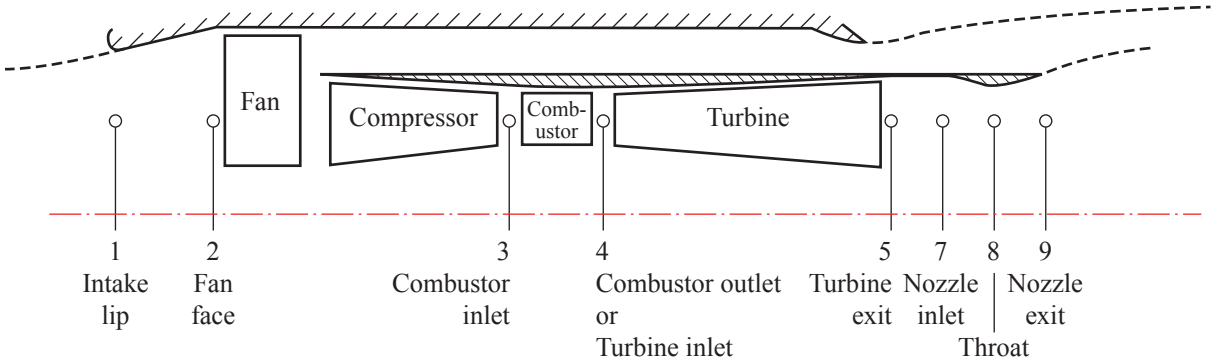
1. NOTATION

c_0	ambient speed of sound	m/s
$D(\theta_i)$	directivity function	dB
f	frequency	Hz
M_a	flight Mach number	
$OAPWL$	overall sound power level, re W_{ref}	dB
PWL	one-third octave band sound power level, re W_{ref}	dB
P_3	total pressure at combustor inlet (Sketch 1.1, station 3)	Pa*
p_{ref}	reference sound pressure ($= 20 \times 10^{-6}$ Pa)	Pa
p_0	ambient air pressure	Pa*
r, θ, ϕ	spherical coordinates (see Appendix A)	
$S(f)$	one-third octave spectral function	dB
SPL	one-third octave band sound pressure level, re p_{ref}	dB
T_0	ambient air temperature	K
T_3	total temperature at combustor inlet (Sketch 1.1, station 3)	K
T_4	total temperature at combustor exit or turbine inlet (Sketch 1.1, station 4)	K
T_5	total temperature at turbine exit (Sketch 1.1, station 5)	K
W	mass flow through engine core	kg/s
W_{ref}	reference power ($= 10^{-12}$ W)	W
ΔT_{ref}	$T_4 - T_5$, the total temperature drop across the complete turbine system, at maximum take-off condition	K
θ_i	nominal engine angle ($= 180 - \theta_j$) (see Sketch 3.3)	degrees

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θ_j	angle between engine exhaust axis and direction of sound propagation	degrees
ρ_0	ambient air density	kg/m ³
ψ	angle between aeroplane flight path and engine axis	degrees

* It should be noted that P_3 and p_0 are entered into the computer program in kPa for convenience.



Sketch 1.1 Idealized engine station designation

2. INTRODUCTION

This Item allows the user to estimate the noise levels in one-third octave bands resulting from the combustion process within a gas turbine engine. The engine may be either static or flying. This noise, referred to as combustor noise, generally comprises two components: direct and indirect noise. The direct noise is the noise of combustion itself propagating out of the engine through the exhaust nozzle. The indirect component, also referred to as entropy noise, is believed to be generated when the hot turbulent products of combustion pass through pressure gradients downstream of the combustor *e.g.* in the turbine stages.

The prediction program accompanying this Item is based on the semi-empirical SAE method described in Derivation 1.

3. THEORETICAL BACKGROUND

The overall sound power level, $OAPWL$, is first determined from the combustor operating conditions and the total temperature drop across the complete turbine system at the maximum take-off condition using Equation (3.1).

$$OAPWL = 10 \log_{10} \left[\frac{W c_0^2}{W_{ref}} \right] + 10 \log_{10} \left\{ \left(\frac{T_4 - T_3}{T_3} \right)^2 \left(\frac{P_3}{P_0} \right)^2 \left(\frac{\Delta T_{ref}}{T_0} \right)^{-4} \right\} - 60.5 \quad (3.1)$$

Tests have shown that combustor noise has a specific spectrum shape that peaks around 400 Hz irrespective of gas turbine type, size or power setting. This shape, shown in Sketch 3.1, is imposed on the overall power level to obtain a power spectrum. The power level spectrum, $PWL(f)$, is given by

$$PWL(f) = OAPWL + S(f) \quad (3.2)$$

The power level spectrum is converted into a sound pressure level spectrum at an angle θ_i and distance r using Equation (3.3).

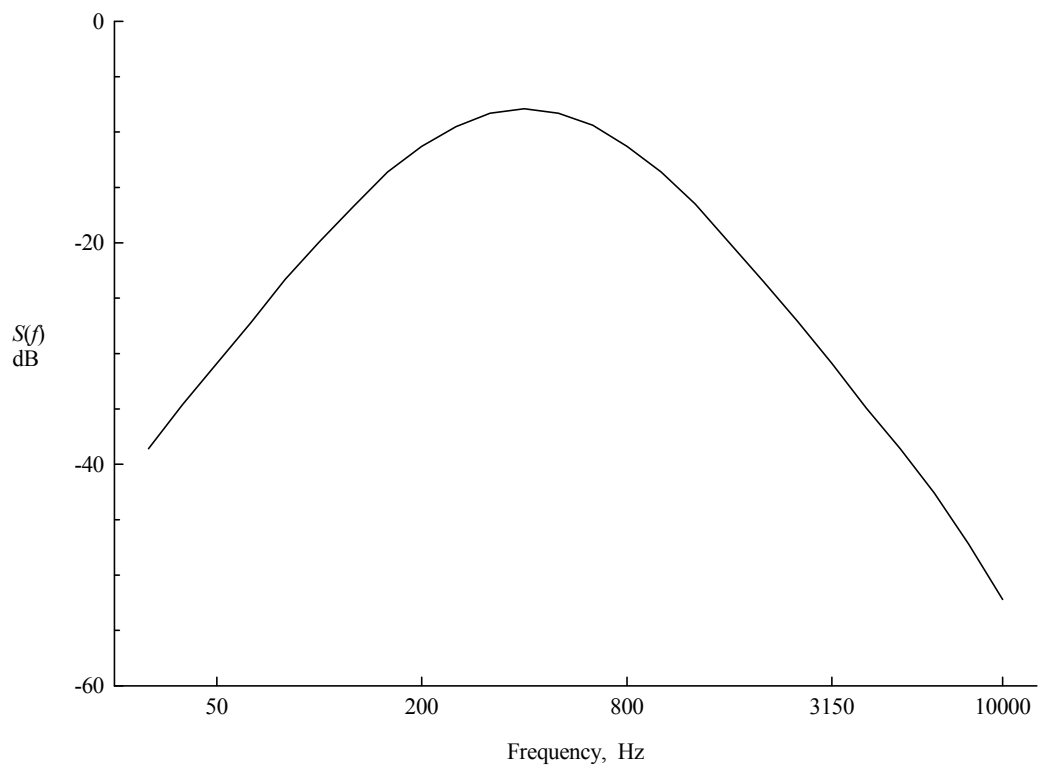
$$SPL(f, \theta_i) = PWL(f) + D(\theta_i) - 20 \log r + 10 \log_{10} \left(\frac{\rho_0 c_0 W_{ref}}{4 \pi p_{ref}^2} \right) \quad (3.3)$$

where the directivity function, $D(\theta_i)$ is shown in Sketch 3.2.

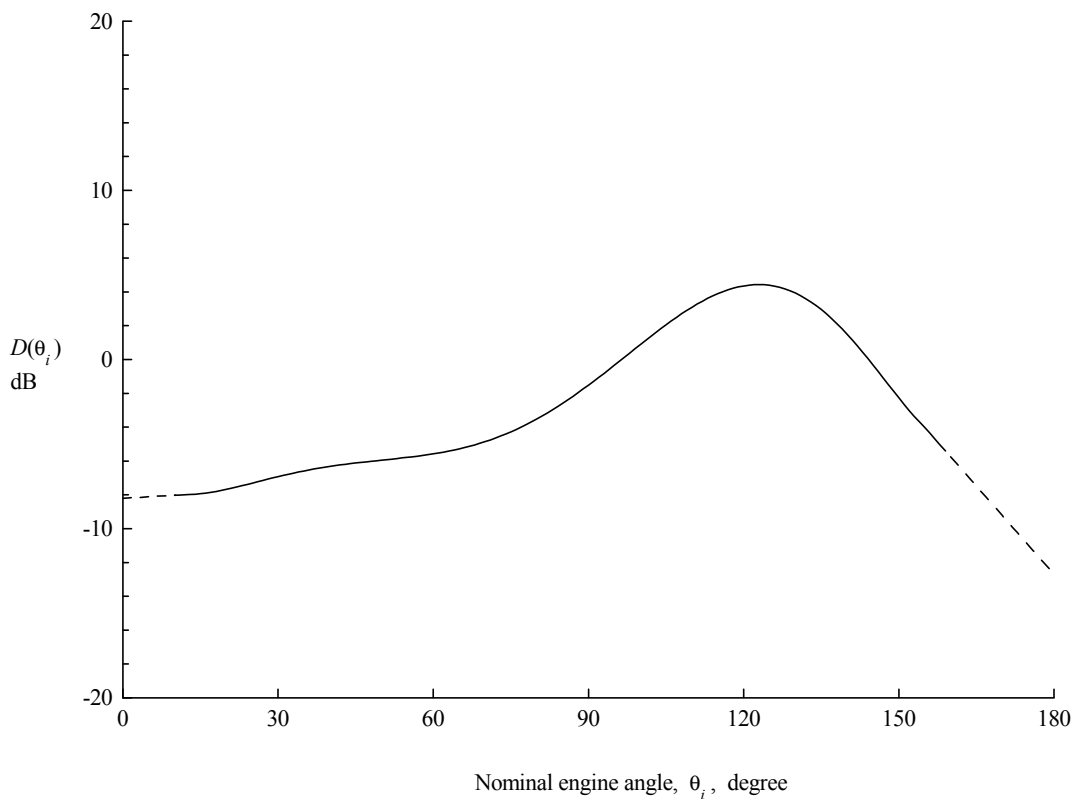
In the computer program, multi-ordered polynomials are used to replicate the curves in Derivation 1. These replicated curves are shown in Sketches 3.1 and 3.2. Any differences are negligible.

At Standard sea level conditions, *i.e.* $\rho_0 = 1.225 \text{ kg/m}^3$ and $c_0 = 340.294 \text{ m/s}$, the last term in Equation (3.3) is -10.8 dB .

In Sketch 3.2 the dashed lines indicate that linear extrapolation is applied outside the range of 10 to 160 degrees.



Sketch 3.1 Spectral function



Sketch 3.2 Directivity function

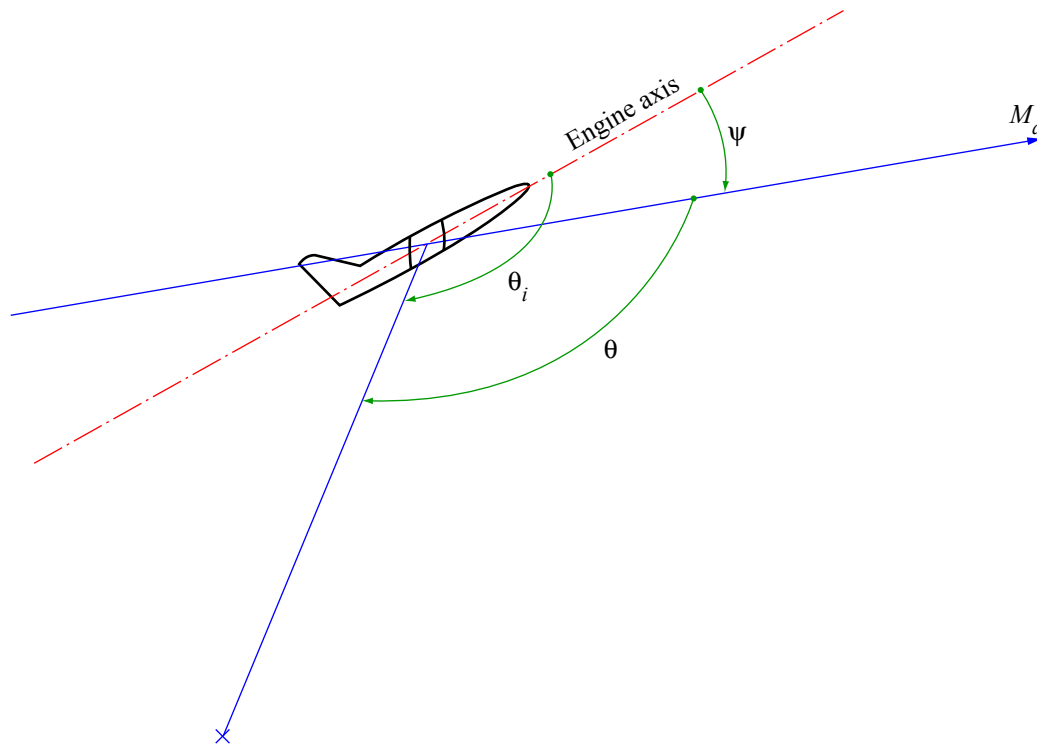
3.1 Flight Effects

Flight has an effect on source sound pressure levels. Static sound pressure levels are affected by a fourth power 'Doppler' amplification factor. The sound pressure level from a source moving at a Mach number of M_a may be obtained from the static sound pressure level using the equation below.

$$SPL_{flight} = SPL_{static} - 40 \log_{10}(1 - M_a \cos \theta), \quad (3.4)$$

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

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



Sketch 3.3 Source-receiver geometry