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An introduction to aircraft noise



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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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AN INTRODUCTION TO AIRCRAFT NOISE

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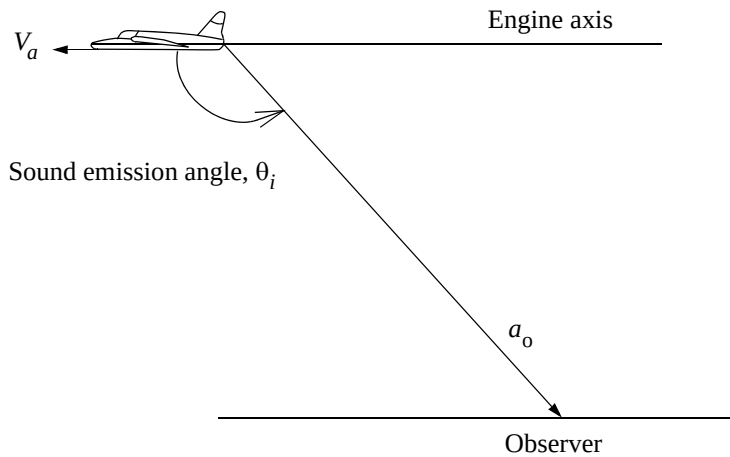
AN INTRODUCTION TO AIRCRAFT NOISE

1. NOTATION

a_0	ambient speed of sound	m/s	ft/s
B	number of rotor blades		
B_s	bending stiffness	N m	lbf ft
BPF	blade passing frequency (= BE)	Hz	Hz
D	jet nozzle diameter	m	ft
E	rotor shaft rotational speed	rev/s	rev/s
f_{flight}	flight frequency	Hz	Hz
f_{static}	static frequency	Hz	Hz
M	fully-expanded Mach number of jet flow based on the ambient speed of sound, V_j/a_0		
M_a	flight Mach number, V_a/a_0		
M_c	convection Mach number based on ambient speed of sound, $(V_a + V_j)/2a_0$		
M_n	local Mach number based on local speed of sound		
m	mass per unit area of surface	kg/m ²	slug/ft ²
n	harmonic number		
P	acoustic power	W	ft lbf/s
p	acoustic pressure	Pa	lbf/ft ²
R	resistance of liner		
S	spacing between shocks in jet flow	m	ft
V_a	flight velocity (see Sketch 1.1)	m/s	ft/s
V_j	fully-expanded jet velocity relative to nozzle	m/s	ft/s
v	particle velocity	m/s	ft/s
X	reactance of liner		

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x, x_1	distance upstream from rotor face (see Sketch 5.2)	m	ft
Z	normalized acoustic impedance		
β	Prandtl-Glauert number ($= \sqrt{M^2 - 1}$)		
θ_i	sound emission angle between engine axis and observer (see Sketch 1.1)	deg	deg
ρ_j	fully-expanded jet density	kg/m ³	slug/ft ³
ρ_0	ambient air density	kg/m ³	slug/ft ³



Sketch 1.1

2. INTRODUCTION

This Item provides an introduction to the main sources of aircraft noise. Aircraft noise is generated both by the power-plants and by the airframe as it passes through the air. Fluctuating pressure disturbances in the air associated in the first case, with flow through the power-plant and, in the second case, with flow over the airframe, are perceived by observers as noise.

Both power-plant and airframe are considered in turn. Noise sources such as air and hydraulic power systems or auxiliary power units (APUs) are not considered here.

A major source of aircraft noise is the aircraft propulsion system. Propulsion systems can take several forms but it is common to divide aircraft into those powered by jet engines and those driven by propellers. The gas turbine engine has, over the years, been developed for jet propulsion in the form of turbojets and turbofans. Transport category propeller-driven aircraft are generally powered by turboprops, *i.e.* gas turbines driving propellers through gearboxes. The use of turboprops instead of piston engine driven propellers is becoming increasingly common, even for “general-aviation” aircraft.

Throughout this Item, references to other ESDU Item numbers, where relevant, are given.

3. PROPULSION SYSTEM NOISE

3.1 The Gas Turbine Engine

The gas turbine engine has undergone major changes in design and operating cycle since it entered commercial service as a jet engine in the 1950s. Turbojets draw in air, compress it, mix fuel with the compressed air, ignite the mixture and after extracting energy to drive the compressor through a set of turbine blades release the gas into the atmosphere through a nozzle as a hot jet at high velocity. A high jet exhaust velocity leads to a high level of what is termed 'jet mixing noise' from the turbulence caused by the mixing of the exhaust gas with the surrounding air.

Improvements in material and turbine-cooling technology allowed engine designers to move larger masses of air at lower exhaust velocities using bypass engines. In bypass engines the airflow into the engine is divided into two streams, one of which bypasses the combustion process and exhausts into the atmosphere at a lower velocity and temperature than the stream through the core of the engine. However, at high-bypass ratios the energy extracted from the core stream can reduce that velocity to lower than the bypass stream velocity at some power conditions.

The high-bypass ratio turbofan takes the process further by having higher levels of bypass flow using a large fan at the front of the engine.

The main sources of noise from gas turbine engines are listed below. They are

- (i) jet noise,
- (ii) fan and compressor noise,
- (iii) turbine noise,
- (iv) core noise, which includes combustion noise.

The relative importance of these sources depends largely upon the type of gas turbine. As described above, there are at least three main types of gas turbine: the pure turbojet, the low-bypass ratio engine and the high-bypass ratio turbofan. The major differences between these types is that for a given thrust, the fully mixed jet velocity is progressively decreased as the bypass ratio is increased. Since jet mixing noise varies as a high power of jet velocity, usually near the eighth power, the use of high-bypass engines is an effective way of reducing jet-mixing noise. Another method of control is to mix the primary and secondary flows upstream of a single common nozzle. The primary and secondary flows are sometimes forcibly mixed by a mechanical device, a mixer, to give a more uniform pressure and temperature profile at the nozzle exit.

As jet velocity is decreased, fan noise becomes more prominent. This is more easily attenuated through the use of absorption treatment.

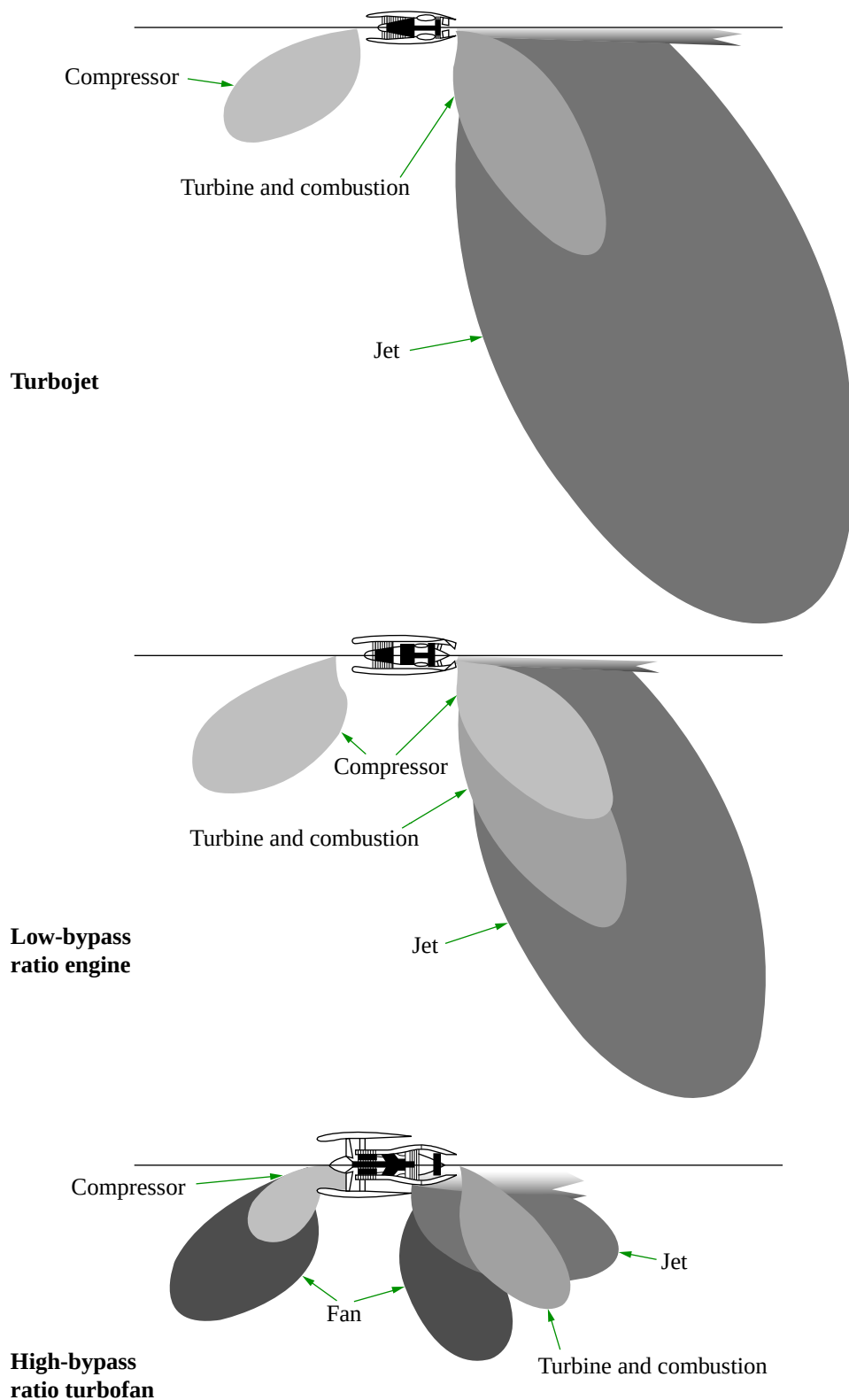
The noise levels from the various sources should be estimated separately and then combined to give the total noise level.

A diagrammatic representation of the noise radiation pattern in the far-field from the three main types of gas turbine engines is shown in Sketch 3.1.

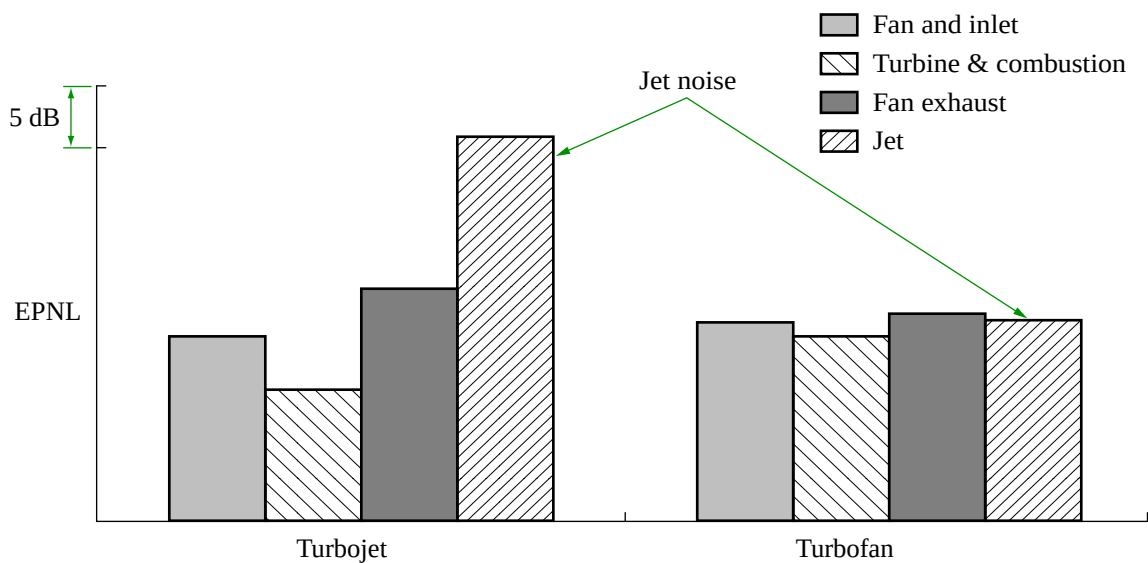
Sketch 3.2 shows how source strength distributions have changed over time from turbojets to current turbofans.

Sketch 3.3 illustrates typical noise distributions for takeoff and for landing for a high-bypass ratio turbofan. Each noise source is considered separately in subsequent sections. In both Sketches 3.2 and 3.3 source strength distributions are shown in EPNL (see Section 13).

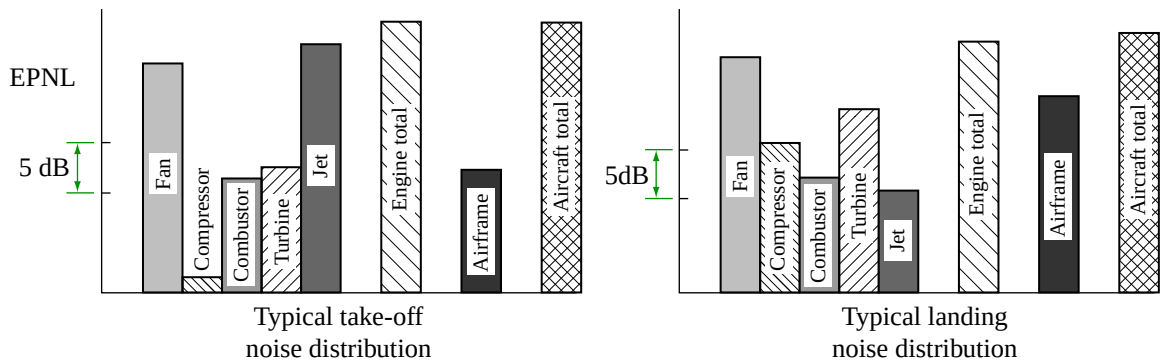
Sketch 3.4 is an illustration of the relationship between bypass ratio and fully-mixed jet velocity and therefore jet noise.



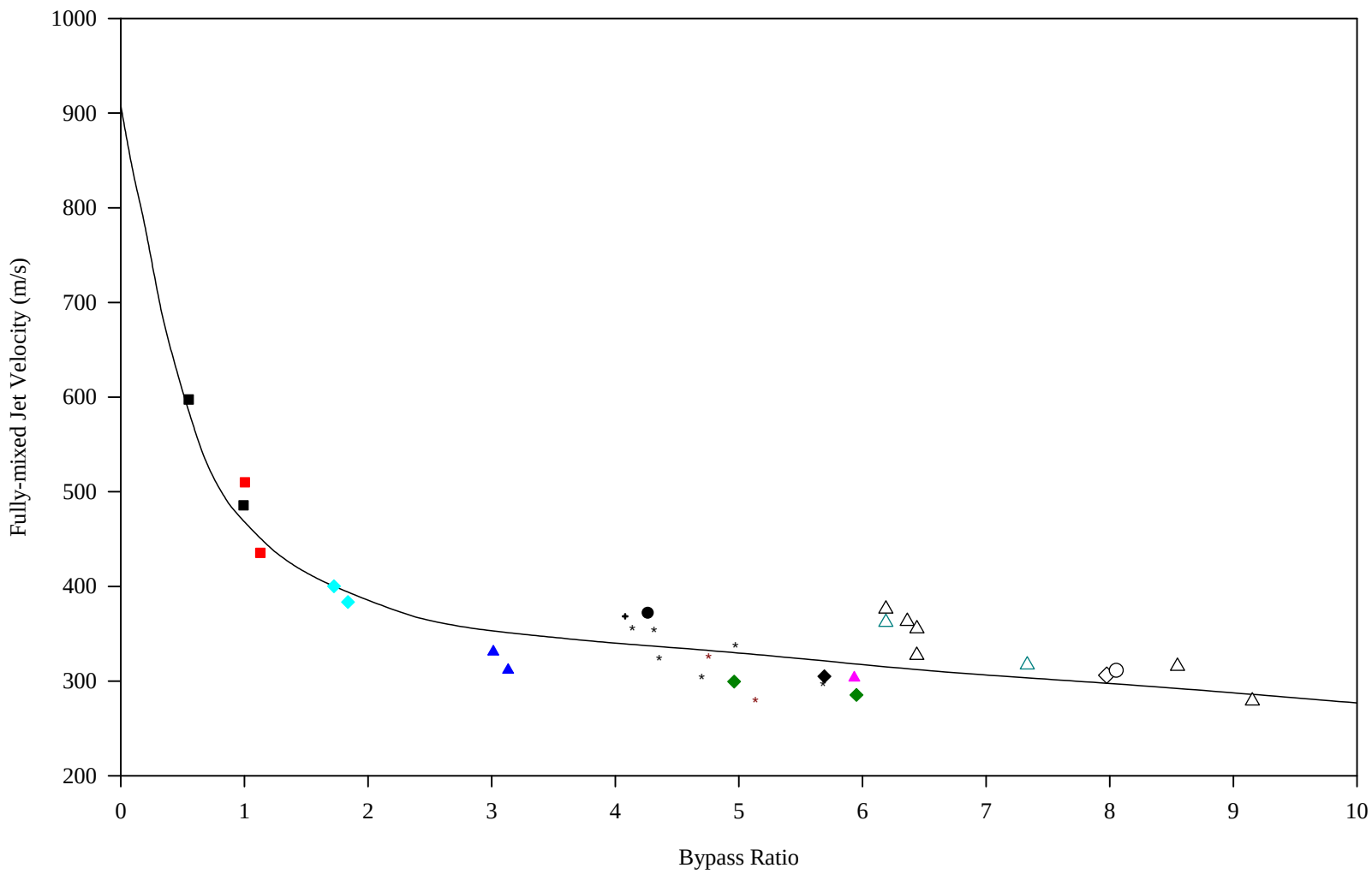
Sketch 3.1 Representation of aircraft gas turbine noise radiation patterns in the half-plane below the engine axis



Sketch 3.2 Noise source distributions



Sketch 3.3 Take-off and landing noise distributions for a high-bypass ratio turbofan



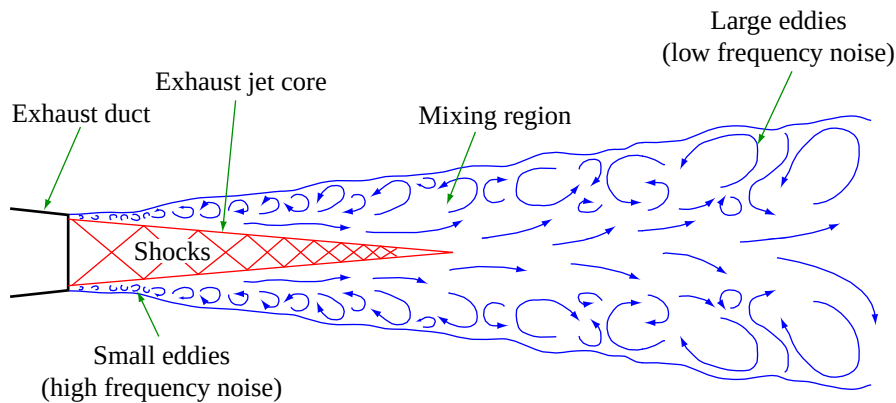
Sketch 3.4 Jet velocity vs bypass ratio for a range of engines

4. GAS TURBINE EXHAUST NOISE

4.1 Jet Noise

Jet noise is caused by the discharge of the high velocity jet from the engine exhaust (see Sketch 4.1) with potentially three distinct sources.

- The shearing and turbulent mixing of the exhaust flow with the ambient medium produces jet-mixing noise.
- Jet shock noise can only occur when the flow is not fully expanded to the local ambient pressure. Shock waves are formed in the flow, which generate noise consisting of both shock-cell screech and shock-associated noise.
- Finally there is jet entropy noise which only becomes apparent at low velocities and with hot jets.



Sketch 4.1 Jet exhaust mixing and shock structure.

4.1.1 Jet mixing noise

The turbulent mixing of the exhaust stream with the external air produces noise having acoustic power, P , which varies as shown below.

$$P \propto \frac{\rho_j V_j^8 D^2}{a_0^5}.$$

This relation applies to all jets with velocities below about 600 m/s. As the jet velocity increases above 600 m/s the acoustic power eventually becomes proportional to the jet kinetic energy flux, *i.e.*

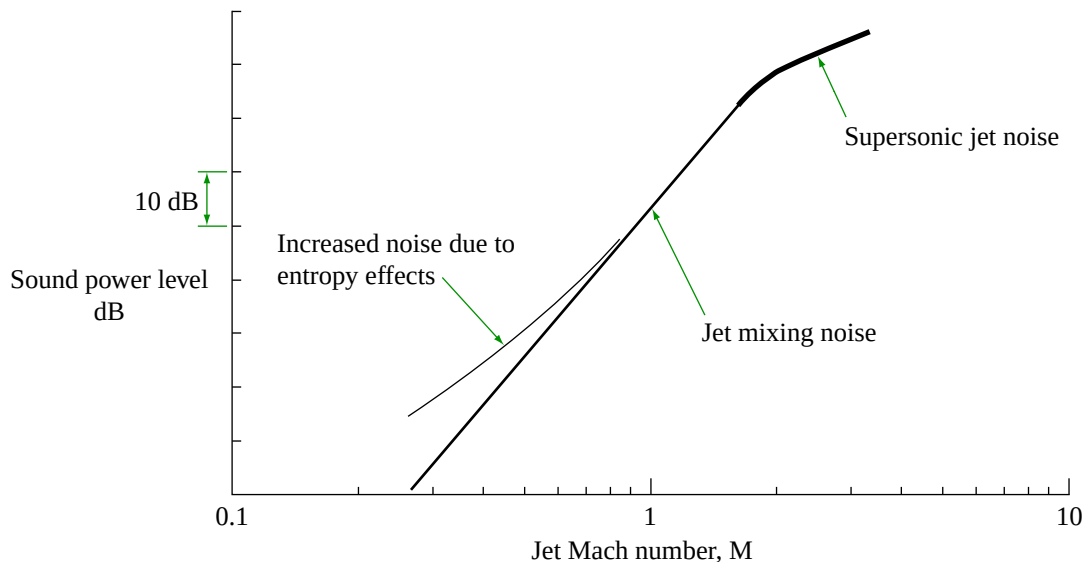
$$P \propto \rho_j V_j^3 D^2.$$

It is found that the sound field is very directional, with the maximum intensity occurring in the rear arc ($\theta_i \approx 150^\circ$).

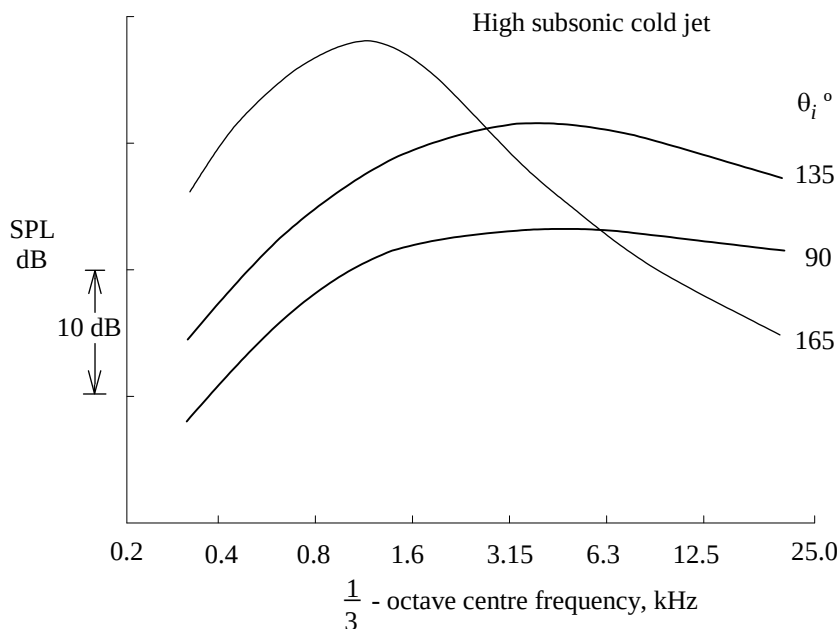
The intensities in the forward arc are considerably lower than in the rear arc. The spectrum also changes shape as the angle to the axis varies.

Examples of the dependence of turbulent mixing noise on jet velocity and angle, together with typical spectra, are shown in Sketches 4.2 and 4.3.

Heating the jet, which has the effect of reducing its density at the same jet velocity, produces a slight change in the spectrum shape and directivity. At low velocities, the noise from the jet can be increased by heating due to the presence of temperature fluctuations which produce an additional dipole* source.



Sketch 4.2 Jet mixing noise – jet Mach number dependence



Sketch 4.3 Jet mixing noise – typical spectra

* The radiation of noise can be described in terms of monopole, dipole and quadrupole noise sources, each of which has its own characteristic properties. A monopole source is a pulsating sphere that radiates sound due to a time varying volume displacement acting on the surrounding fluid. A dipole source is one generated by a fluctuating pressure distribution on a surface. Fluctuating velocity field interactions generate quadrupole type sources. These include sound generation by turbulent waves, the interaction of the potential flow fields of fixed and moving blades, and the interaction of turbulence with a potential flow field.