

# Jet-by-jet shielding of noise

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## JET-BY-JET SHIELDING OF NOISE

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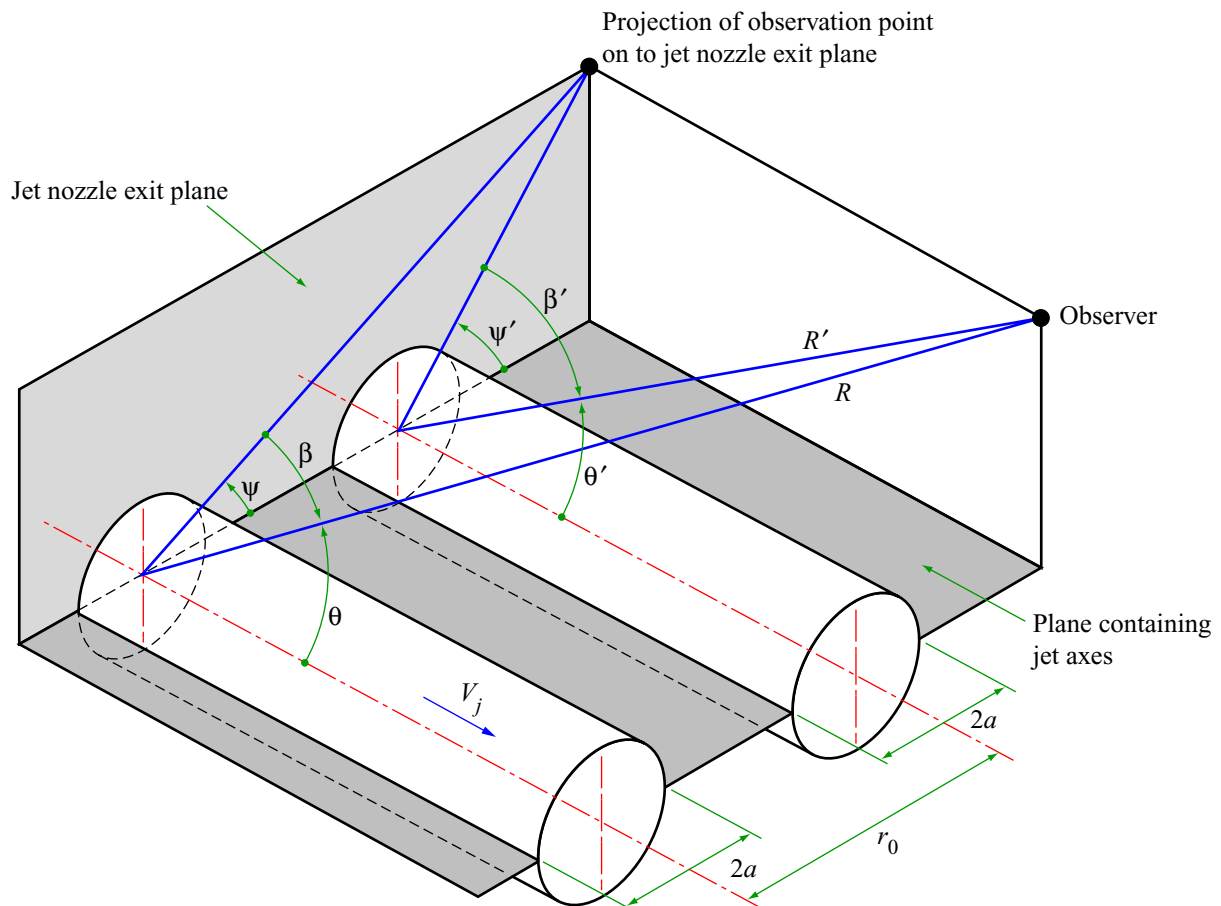
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## JET-BY-JET SHIELDING OF NOISE

### 1. NOTATION

|                  |                                                                                  | <i>Units</i>               |                            |
|------------------|----------------------------------------------------------------------------------|----------------------------|----------------------------|
|                  |                                                                                  | <i>SI</i>                  | <i>British</i>             |
| $a$              | radius of jet                                                                    | m                          | ft                         |
| $c_0$            | speed of sound outside jet                                                       | m/s                        | ft/s                       |
| $c_1$            | speed of sound inside jet                                                        | m/s                        | ft/s                       |
| $D$              | diameter of jet                                                                  | m                          | ft                         |
| $k_0$            | wave number ( $\omega/c_0$ )                                                     | $\text{m}^{-1}$            | $\text{ft}^{-1}$           |
| $M$              | local Mach number ( $V_j/c_1$ )                                                  |                            |                            |
| $P_S^2$          | total power spectral density with shielding operative                            | $\text{volts}^2/\text{Hz}$ | $\text{volts}^2/\text{Hz}$ |
| $P_T^2$          | total power spectral density for two independent jets                            | $\text{volts}^2/\text{Hz}$ | $\text{volts}^2/\text{Hz}$ |
| $p$              | acoustic perturbation pressure                                                   | Pa                         | $\text{lbf}/\text{ft}^2$   |
| $p_{in}$         | acoustic perturbation pressure in the absence of shielding                       | Pa                         | $\text{lbf}/\text{ft}^2$   |
| $Q_0$            | source strength                                                                  | $\text{m}^3/\text{s}$      | $\text{ft}^3/\text{s}$     |
| $R, R'$          | distance from jet nozzles to observer (see Sketch 1.1)                           | m                          | ft                         |
| $r_0$            | distance between the axes of the two jets (see Sketch 1.1)                       | m                          | ft                         |
| $T_{js}$         | jet static temperature                                                           | K                          | K                          |
| $T_0$            | ambient temperature                                                              | K                          | K                          |
| $V_j$            | fully expanded jet velocity                                                      | m/s                        | ft/s                       |
| $\beta, \beta'$  | polar angles of observer measured from plane normal to jet axes (see Sketch 1.1) | deg                        | deg                        |
| $\phi$           | velocity potential function                                                      |                            |                            |
| $\phi_{in}$      | velocity potential in the absence of the shielding jet                           |                            |                            |
| $\rho_0, \rho_1$ | densities outside and inside jet respectively                                    | $\text{kg}/\text{m}^3$     | $\text{slug}/\text{ft}^3$  |

|                   |                                                                    |       |       |
|-------------------|--------------------------------------------------------------------|-------|-------|
| $\psi, \psi'$     | azimuthal angles of observer (see Sketch 1.1)                      | deg   | deg   |
| $\theta, \theta'$ | polar angles of observer measured from jet axes ( $= 90 - \beta$ ) | deg   | deg   |
| $\omega$          | circular frequency                                                 | rad/s | rad/s |



Sketch 1.1

## 2. INTRODUCTION

The changes in the observed noise levels from a jet, caused by the presence of an adjacent jet are commonly referred to as jet-by-jet shielding effects. The mechanisms giving rise to these changes, which could be noise amplification or noise reduction depending on the precise location of the observer, are discussed in subsequent sections. This Item provides a computerized method for predicting the noise shielding effect at a far-field observation point for a dual jet system. Both jets are assumed to have identical geometries and be operating at similar conditions. The method is valid for all azimuthal angles, but is not applicable for downstream locations where the polar angle,  $\theta$ , is less than 20 degrees.

The computational procedure is based on an analytical model of jet shielding described in Derivation 1. This model of a discrete frequency point source shielded by a cylindrical jet has been extended to simulate a dual jet configuration. The geometry of this configuration is shown in Sketch 1.1.

The method requires geometric parameters and jet operating conditions as input data to estimate the shielding effect in decibels, in one-third octave bands, over a frequency range specified by the user.

### 3. QUANTITATIVE DEFINITION OF JET-BY-JET SHIELDING

The transmission of sound through a jet is controlled by the flow and temperature discontinuities that exist at the jet interface. Because the jet has a different impedance from the surrounding ambient atmosphere, it tends partially or totally to reflect sound impinging on it, to refract the sound wave that penetrates it, to diffract sound by the discontinuity at the jet interface, or to scatter sound by the turbulent flow regime of the jet. The difference between the sound pressure level at a reception point in the presence and in the absence of the shielding jet defines the noise change due to the phenomena of reflection, refraction, diffraction and scattering. Because acoustic energy is conserved through all these processes in the theoretical model described, a noise reduction at one location is compensated for by a noise increase at another. It should be noted, however, that in practice, if the jets are sufficiently close together other processes such as jet interaction can arise.

In the simulation of a dual jet system, each jet is considered separately to be an isolated independent acoustic source operating with an adjacent shielding jet. The two sound fields thus obtained are then superimposed to estimate the total shielding effect. A quantitative definition of the shielding effect can thus be formulated.

Assuming no shielding, the total power spectral density  $P_T^2$  at a reception point is given by  $P_1^2 + P_2^2$ , where  $P_1^2$  and  $P_2^2$  are the individual power spectral density contributions from each jet. With shielding present, if the total power spectral density at the reception point is denoted by  $P_S^2$ , the shielding effect,  $\Delta SPL$ , may be defined as follows.

$$\Delta SPL = 10 \log_{10} \frac{P_S^2}{P_T^2} = 10 \log_{10} \frac{P_S^2}{P_1^2 + P_2^2} \text{ dB.} \quad (3.1)$$

If no shielding is present,  $P_S^2 = P_T^2$  and  $\Delta SPL = 0$  dB. A positive value of  $\Delta SPL$  will thus indicate noise increase and a negative value will indicate noise reduction.

### 4. THEORETICAL BACKGROUND

The analytical model of jet shielding described in Derivation 1 forms the kernel of the prediction procedure. Although this model describes the sound field emitted from a stationary, discrete frequency point source which impinges on a cylinder of locally parallel flow, it incorporates the basic elements essential for its extension to a representation of a dual jet configuration by treating the source jet as a multiple frequency point source.

The derivation of the equations that quantify the shielding effect are based on those described in Derivations 1 and 2. The starting point is the wave equation for the velocity potential inside and outside the shielding jet. The temperature and velocity profiles are assumed to be uniform within the shielding jet. The solution of the wave equation for the region outside the shielding jet provides an equation for the source field.

The source field impinges on the shear layer leading to transmitted and reflected waves. The unknown amplitudes of the transmitted and reflected waves are determined by matching pressure and fluid displacement at the jet boundary, to provide an equation for the total acoustic velocity potential.