Engineering Notes

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Thrust Reverser Noise Estimation

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Nomenclature

a = speed of sound
D = nozzle exit diameter
f = one-third octave center frequency
K = nondimensional constant
$\overline{p^2}$ = mean square acoustic pressure
r = radial distance to field point
U = nozzle exit velocity
θ = angle from jet upstream direction to field point
ρ = density

Discussion

THRUST reverser noise estimates are needed for STOL aircraft because sideline noise from reversers at approach power settings after touchdown might exceed the takeoff sideline noise limit. There are no rigorous analytical methods for predicting such noise. A partial correlation of data for small cold jets with semicylindrical and V-gutter target-type thrust reversers had been developed[1,2] at NASA Lewis Research Center. Because separate correlation curves must be utilized for each direction angle, that correlation is less useful than an approximate analytic expression would be.

Over-all sound power level (OAPWL) was found to vary with jet velocity to the sixth power as expected for dipole noise. At first glance, measured directivity patterns resembled the $\cos^2(\theta/2)$ variation predicted[3] for noise caused by turbulence flowing past one side of a sharp trailing edge. It was found empirically that $\cos^2(\theta/3)$ gave a close approximation to directivity measured with semicylindrical reversers. No analytical justification exists for use of this trigonometric function. Also, from dimensional analysis one would expect the mean square acoustic pressure to be given by

$$\overline{p^2} = K(\rho^2 U^6/a^2)(D/r)^2 \cos^2(\theta/3)$$

which, except for the directivity function, had been given elsewhere.[1,2] Numerical values for the constant would depend on jet temperature; data for cold jets should be applicable to reversers for high bypass ratio fans.

Over-all sound pressure levels (OASPL) measured for the smaller semicylindrical thrust reverser[1] at three velocities and two reverser orientations are shown in Fig. 1. Maximum OASPL for the nozzle without a thrust reverser was less than the minimum value measured with a reverser. Effects of velocity and direction angle on reverser noise are closely estimated by the above equation with $K = 3 \times 10^{-5}$. There was no consistent effect of reverser orientation (horizontal or vertical). The V-gutter reverser was about 6 dB louder and had a less smoothly varying directivity pattern that was dependent on orientation. Measured OASPL and values calculated with $K = 1.2 \times 10^{-4}$ are compared in Fig. 2. For both horizontal and vertical orientation, magnitudes at most direction angles are estimated with ±3 dB.

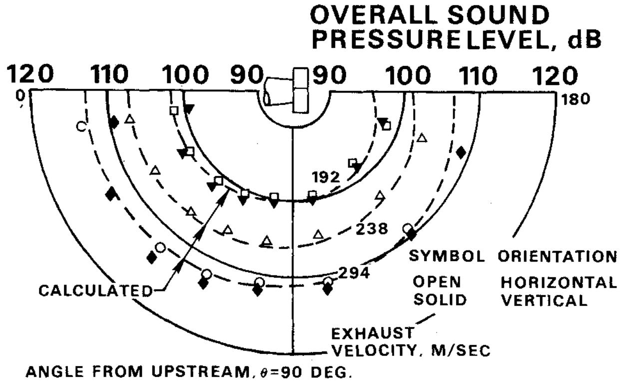

Fig. 1 Calculated and measured OASPL directivity for semicylinder reverser.

One-third-octave acoustic spectra measured at each direction angle and different velocities, normalized with respect to OAPWL, had been found[2] to correlate with Strouhal number fD/U. If spectra for each angle had been normalized with respect to OASPL measured at the same angle, they would also correlate for different direction angles. Variations of these correlated spectra with reverser size and orientation are within the spread of data. To illustrate this additional result, normalized ⅓-octave spectra are plotted in Fig. 3 for the two different sizes of semicylinder reversers at 10°, 80°, and 160° direction angles and one exit velocity. Nozzle exit velocity and diameter are constant for these data, so normalized SPL can be plotted against frequency rather than Strouhal number. Except for frequencies strongly affected by ground reflection, the normalized spectra coalesce about a smooth curve with a total spread generally less than 3 dB. Power spectral density seemed to vary directly with frequency for Strouhal numbers less than 0.5 and inversely with frequency cubed for Strouhal numbers greater than 2. Somewhat worse correlation was obtained for spectra of V-gutter reversers. These had relatively more acoustic energy at low frequencies where the spectra were strongly affected by ground reflection.

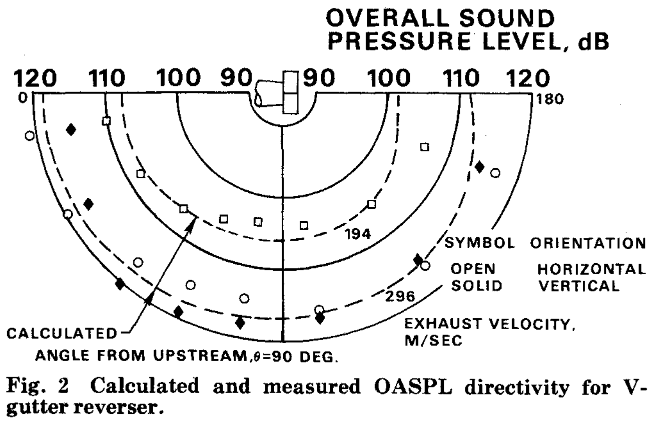

Fig. 2 Calculated and measured OASPL directivity for V-gutter reverser.

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Index categories: Aircraft Deceleration Systems; Aircraft Noise, Aerodynamics (Including Sonic Boom); Aircraft Noise Powerplant.

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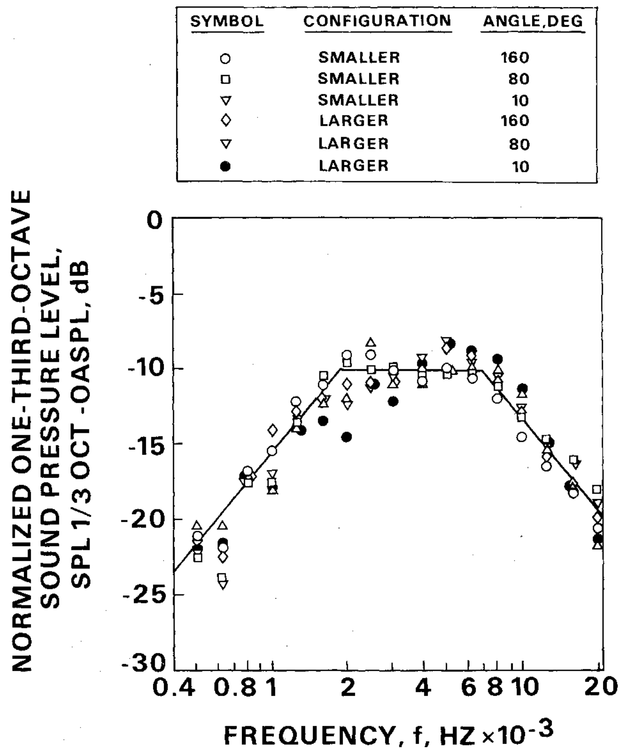

Fig. 3 Normalized spectra for semicylinder reversers.

References

[1]Gutierrez, O. A. and Stone, J. R., "Preliminary Experiments on the Noise Generated by Target-Type Thrust Reverser Models," TM X-2553, May 1972, NASA.

[2]Stone, J. R. and Gutierrez, O. A., "Target-Type Thrust Reverser Noise," *Journal of Aircraft*, Vol. 10, No. 5, May 1973, pp. 283–288; also TM X-68082, Aug. 1972, NASA.

[3]Ffowcs Williams, J. and Hall, L. H., "Aerodynamic Sound Generation of Turbulent Flow in the Vicinity of a Scattering Half Plane," *Journal of Fluid Mechanics*, Vol. 40, Pt. 4, March 1970, pp. 657–670.

Unique Characteristics of Exhaust-Plume Interference

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Nomenclature

A = cross-sectional area
C_D = drag coefficient, $D/(q_0 A_m)$
C_{Dp} = pressure drag coefficient, $(1/A_m)\int_{Am}^{Ab} C_p dA$
C_p = pressure coefficient, $(p - p_0)/q_0$
D = nozzle external drag
M = Mach number
NPR = nozzle pressure ratio, P_j/p_0
P_j = nozzle-exhaust total pressure
p = static pressure
q = dynamic pressure

Subscripts

b = nozzle end
m = nozzle maximum
o = freestream

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Introduction

AERODYNAMIC interference is a term often used to describe the interactions between closely spaced solid bodies. But interference between solid bodies and plumes also occurs. For example, jet-engine exhaust plumes can significantly affect aerodynamic forces on nearby airplane structure. In fact, this frequently happens. Studies have shown that airplane drag, lift, and moments can vary if plume conditions change.[1-8]

What complicates the prediction of plume interference is that plumes, unlike solid bodies, create entrainment effects as a result of viscous shear, or mixing, with the surrounding flow. Yet plumes are also obstacles to the surrounding flow, as are solid bodies. Therefore, plume interference can be depicted as being a composite of two constituents, plume entrainment and plume shape, which iteracts with airplane flowfields.

Objectives and Methodology

Researchers using various techniques have examined the fundamental case of jet interference on isolated exhaust nozzles.[9-12] Changes in plume conditions, such as different pressure ratios, can significantly change nozzle external drag. These interference effects are more noticeable during subsonic and transonic flight than during supersonic flight. At supersonic speeds, disturbances can transmit upstream, toward the nozzle, only through the relatively small subsonic portion of the nozzle boundary layer.

Exhaust plumes are represented in some analyses as being solid bodies, often cylinders.[13-16] This is obviously a simplification of the true situation; nevertheless, it is an approach sometimes used for pragmatic reasons. So that such approaches may be evaluated, an objective of this study was to compare, experimentally, flowing jets with

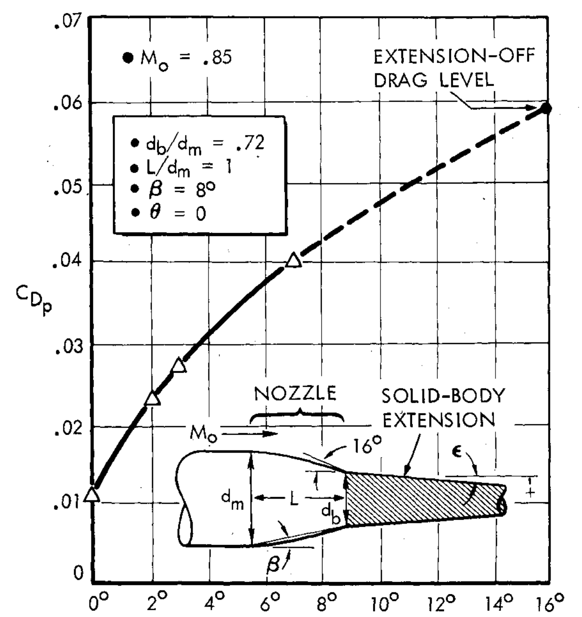

Fig. 1 Effects of solid-body plume simulators on nozzle pressure drag.