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ANALYTICAL SIMULATION OF THE FAR-FIELD JET NOISE AND THE UNSTEADY JET FLOW-FIELD BY A MODEL OF PERIODIC SHEDDING OF VORTEX RING FROM THE JET EXIT

By

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Summary of Research

In recent studies of turbulent flow fields, successful results have been obtained by the introduction of appropriate physical model and the simulation of the turbulent flow is reduced to the determination of few parameters. In several experimental investigations on turbulent free jets, flow field resembling that of vortex rings have been reported. It is therefore of interest to construct the theoretical flow field due to shedding of vortex rings, to identify the controlling parameters and to find out whether the theoretical model can successfully simulate the unsteady pressure field near jet and consequently the far field noise.

The basic parameters contained in the analytic solutions are the epoch at which a vortex ring is shed near the jet exit and the eddy viscosity coefficient. These parameters can be identified from the experimental data for the real-time pressure and from the spread of the mixing layer of jet. Also the function controlling the rolling up of the vortex sheet to a ring will be adjusted to fit the steep unsteady pressure variation in the experimental data as the vortex ring passing over each station. The essential details of the theoretical investigation are presented in reference 1. The results of the theoretical analysis show good qualitative agreement with the experimental data.

In paper 1, the near field pressure fluctuation induced by a turbulent shear layer around a jet has been simulated by shedding of circular vortex rings immersed in a uniform stream. In order to enforce the enlargement of the vortex ring as the shear layer spreads, one can replace the uniform stream by a steady flow of a point source with its mass flux inside the angle of the spreading shear layer matched with the mass flux of the jet. Thus a steady radial flow component from the axis of the jet is created. Unfortunately, the steady flow velocity of a point source decreases as the inverse square power of the distance and the decrease is too fast as compared with the experimental data. To create a steady flow field which will expand the radii of the vortex rings and with a steady velocity which will not decrease so fast as a point source, a linear source distribution along a circle of radius R, say the radius of the jet, located near the jet exit will be introduced. The velocity potential due to this ring source can be written as

$$\phi(r,x) = -\frac{mR}{\pi}\,[x^2+(r+R)^2]^{-1/2}\,F(\Lambda)$$

with $\Lambda = \{4rR/[x^2+(r+R)^2]\}^{1/2}$. The linear intensity m can be related to the mass flux of the jet by the equation

$$m = 2Q/(\pi R) .$$

The corresponding steady velocity components are

$$\phi_x = \frac{mRx}{2\pi}\,[x^2+(r-R)^2]^{-1}\,[x^2+(r+R)^2]^{-1/2}\,E(\Lambda)$$

and

$$\phi_r = -\phi/(2r) - \frac{x^2+R^2-r^2}{2r}\,[\phi_x/x] .$$

In the analysis of the noise propagation from the real time pressure variation in the near field to far field, it was confirmed that there exists a layer where the Laplace equation holds. The purpose of this intermediate potential layer is to filter out the components of short wave lengths in the near field data. However, this objective can be realized by examining directly the solution of the simple wave equation and discarding components which decay exponentially with respect to the radial distance from the axis of the jet.

For a periodic solution of the wave equation

$$\frac{1}{C^2}\phi_{tt} - \Delta\phi = 0$$

With axial wave length ℓ and circumferential wave number n, it can be written as

$$e^{i(\omega t - 2\pi x/\ell + n\theta)}\ R(r)$$

where R(r) obeys the Bessel equation

$$r^2 R'' + rR' + (\mu r^2 - n^2)R = 0$$

with $\mu^2 = (\omega/C)^2 - (2\pi/\ell)^2$.

The solution decays exponentially with respect to r when $\mu < 0$. That is for a given ω, the Fourier components of the near field data with short wave length ℓ such that

$$\ell < \frac{2\pi C}{\omega}$$

can be discarded in the study of the propagation to far field.

Publications and Papers Resulting from Research

1. "Simulation by Vortex Rings of the Unsteady Pressure Field Near a Jet," with L. Maestrello and M. D. Gunzburger. AIAA Paper No. 75-438, AIAA Second Aeroacoustics Specialists Conference, March 24-26, 1975, Hampton, VA. To appear in the Proceedings of the 2nd AIAA Aeroacoustics Conference, Vol I - Jet, Combustion and Engine Core Noise.

2. "Scattering of Coherent Sound Waves by Atmospheric Turbulence," with P. L. Chow and L. Maestrello. AIAA Paper No. 75-545, AIAA Second Aeroacoustics Specialists Conference, March 24-26, 1975, Hampton, VA.

3. "Numerical Study of Sound Progation in a Jet Flow," with S. L. Padula. To appear as NASA TN D-8012.