LARGE EDDY SIMULATION IN THE COMPUTATION OF JET NOISE

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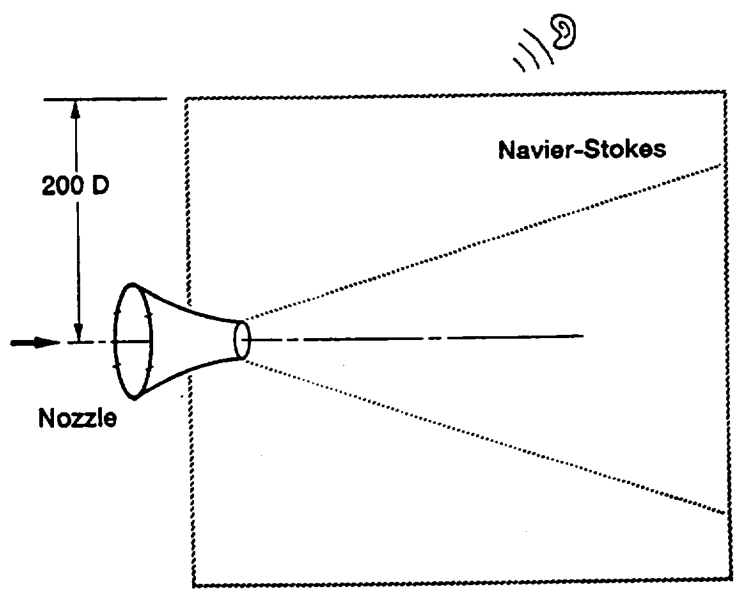
Navier-Stokes Equations in Aeroacoustics

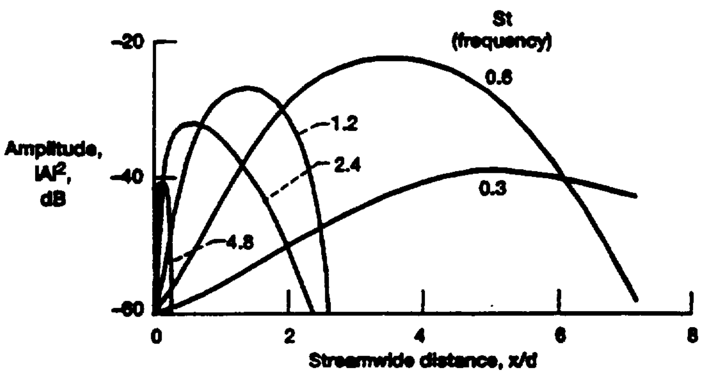
- Noise can be predicted by solving Full (time-dependent) Compressible Navier-Stokes Equation (FCNSE) with computational domain extended to far field -- but this is not feasible.



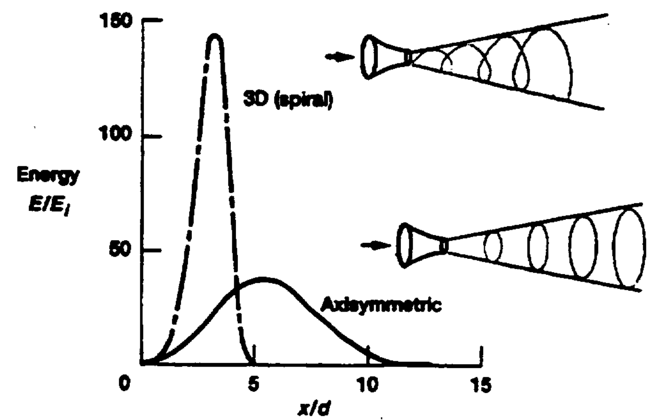
The fluctuating near field of the jet produces propagating pressure waves that produce far-field sound. The fluctuating flow field as a function of time is needed in order to calculate sound from first principles. Noise can be predicted by solving the full, time-dependent, compressible Navier-Stokes equations with the computational domain extended to far field --- but this is not feasible as indicated above. At high Reynolds number of technological interest turbulence has large range of scales. Direct numerical simulations (DNS) can not capture the small scales of turbulence. The large scales are more efficient than the small scales in radiating sound. The emphasize is thus on calculating sound radiated by large scales.

SUBSONIC JETS

- **Development of the coherent structure is largely controlled by the Strouhal number**



- **The structure is both axisymmetric and three-dimensional**

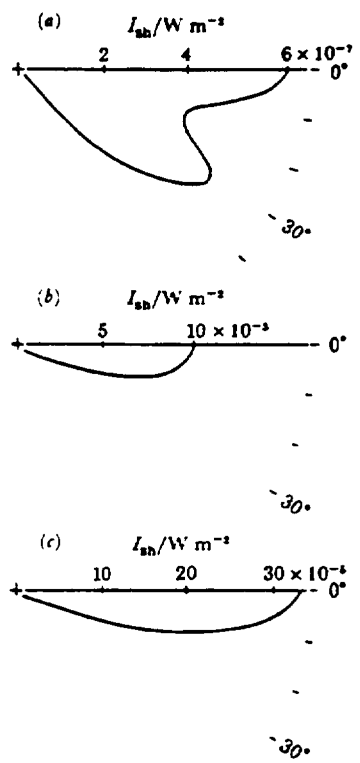


The large-scale structure in the initial region of the jet, where most of the noise is produced is modelled by extending ideas from the nonlinear stability theory. The large-scale component is modelled as

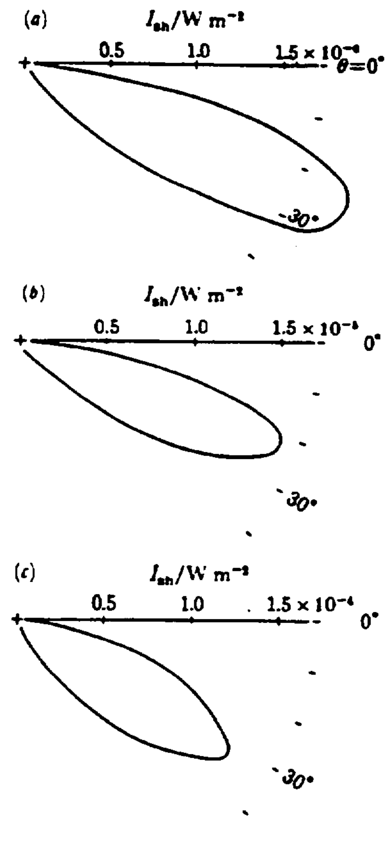
$$\tilde{u}_i = \Sigma_{m,n}|A_{mn}(x)|\ \hat{u}_{i,mn}(r,x)\quad \exp[i\psi_{mn}(x)\ - u\omega_m t\ + iN\phi]\ + CC \qquad (1)$$

The transversal profile is taken as the eigen function given by the locally-parallel linear stability theory. For a review on this approach see Mankbadi (1992, Applied Mechanics Reviews). The amplitude and phase are determined from nonlinear theory. Results of this theory as seen above indicates that the development of the large structure is largely controlled by the Strouhal number. At large-enough amplitudes the process is nonlinear in the sense that one mode can generate/cancel other modes, which represents a possible technique for noise control. The results also indicates that the three-dimensional mode of the structure could dominate the axisymmetric one, depending on the Strouhal number, initial conditions, and axial location.

● PREDICTION OF SUBSONIC JET NOISE USING LIGHTHILL'S THEORY



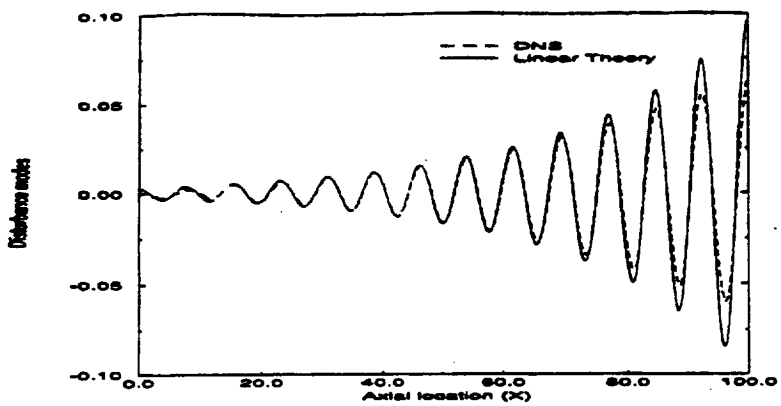
Polar distribution of the shear noise intensity I_{sh} for $n = 0$. (*a*) $St = 0.18$; (*b*) $St = 0.30$; (*c*) $St = 0.80$.



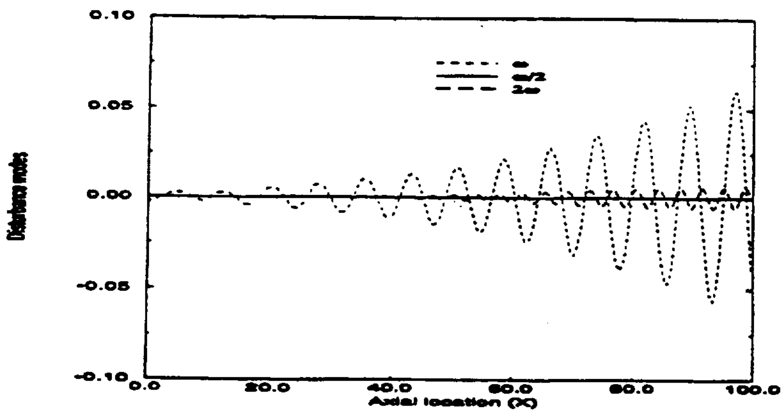
Polar distribution of the shear noise intensity I_{sh}(W m^{-2}) for $n = 1$. (*a*) $St = 0.18$; (*b*) $St = 0.30$; (*c*) $St = 0.80$.

The above shows the directivity of the axisymmetric modes and that of the first helical modes. These results are from Mankbaldi and Liu (1984) in which Lighthill's (1952) theory is used to calculate the shear noise produced by the large-scale structure in the initial region of the jet.

SUPERSONIC JET NOISE

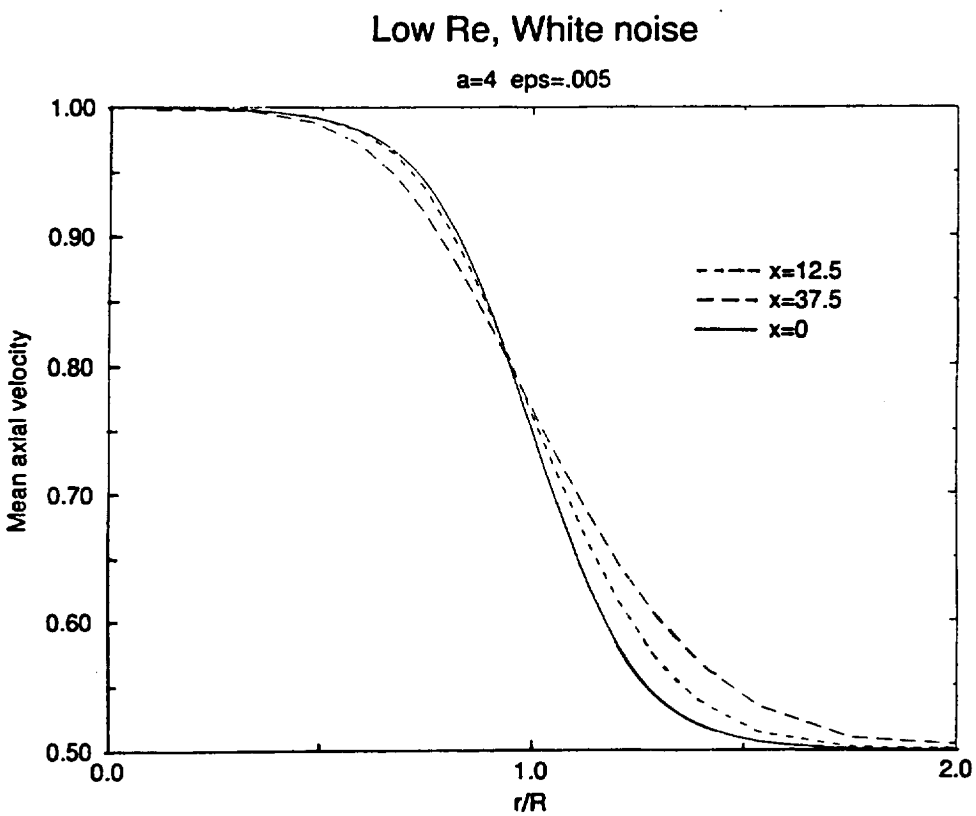


GROWTH OF DISTRUBANCE IN UNSTEADY AXISYMMETRIC JET



EXCITATION OF DISTURBANCE MODES IN AXISYMMETRIC JET AT r = 1

The large scale structure is calculated using the full Navier-Stokes equations. Gottlieb & Turkel scheme is applied to shear flows. The numerical scheme is fourth-order accurate in space and second-order accurate in time. The results are validated by comparing the predicted growth of input disturbance against the results of the linear stability theory. As the amplitude of disturbance becomes large nonlinearity come into effect and the linear stability theory is no longer valid.



The small scale turbulence is modelled following Smagorinski's (1963):

$$\tau_{ij} = q_R^2 \delta_{ij}/3 - 2\nu_R S_{ij} \tag{2}$$

where q_R^2 is the energy of the residual turbulence,

$$S_{ij} = \frac{1}{2}\left(\frac{\partial \langle u_i \rangle}{\partial x_j} + \frac{\partial \langle u_j \rangle}{\partial x_i}\right) \tag{3}$$

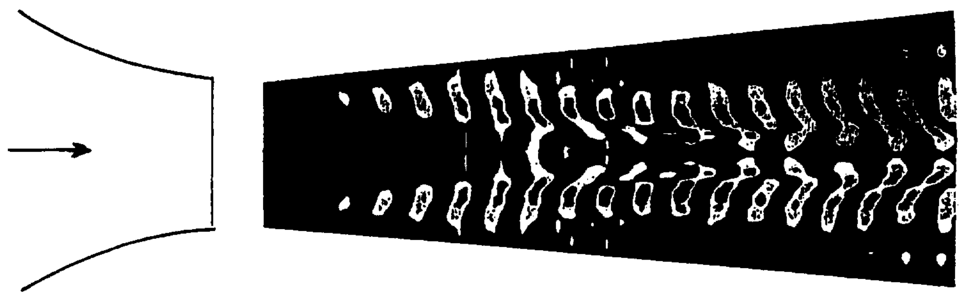
is the strain rate of the resolved scale, and ν_R is the effective viscosity of the residual field. Here we take

$$\nu_R = (C_S \Delta_f)^2 \sqrt{2 S_{mn} S_{nm}}, \qquad C_S = 0.23 \tag{4}$$

and Δ is the filter width.

The above figure shows the radial distribution of the mean flow axial velocity at several streamwise locations.

FOURIER COMPONENT OF NEAR-FIELD SOUND SOURCE



This figure shows the Fourier component of the near-field sound source (Strouhals number = 0.5) of a supersonic jet at Mach number 1.5 as seen by an observer in the far-field at 30° to the jet axis.

FUTURE PLANS

- Subgrid-Scale Models:

  Compressibility Effects -- Erelbacher (1990)
  Dynamical -- Moin et al. (1992)
  One-Equation Model -- Hortituti (1985)

- Validation of the near field against experimental results

- Far-Field Sound:

  Lilley (1974)
  Linearized Euler Equation

- Validation of the far-field sound against experimental data