Acoustics

Substantial reductions in jet noise have been made since the dawn of the jet age over 50 years ago, following for the most part the same simple approach: higher and higher bypass ratios. This reduces noise by reducing jet exit velocity, taking advantage of Lighthill's result that jet noise scales as a high power ("near the eighth") of the flow velocity. This was the first aeroacoustic theory and remains after 50 years the most effective theory for jet noise reduction. However, the gains it affords have been exploited to the utmost, and is unclear how to make further reductions. Trial-and-error experiments have shown that nozzle modifications can further reduce noise, but there is currently no predictive tool or modeling framework that can provide an engineer even the basic noise trends to expect for specific nozzle modifications. In light of this, our projects focused on key issues in jet noise physics, modeling, and prediction.

Large-eddy simulation is an attractive candidate for making jet noise predictions because it is the energetic scales, those that are resolved in a large-eddy simulation, that make most of the noise in a jet. However, early attempts suggest that the noise may be significantly more sensitive to the approximations made in large-eddy simulation than the standard flow quantities for which the large-eddy simulation was initially designed. Even in cases where the mean flow and basic turbulence statistics are well predicted, the predicted noise can be erroneous because it depends on subtle (quadrupole-like) cancellations. In this case, small errors made in the energetic flow field overwhelm the low energy sound field. Rembold, Freund, and Wang explored this directly by evaluating the far-field sound from a large-eddy simulation of a 5:1 aspect ratio rectangular jet, making a direct comparison to a corresponding direct numerical simulation. Results showed substantial errors especially in sideline and upstream directions, which has motivated an ongoing effort to identify their precise cause.

In the second project, Freund, Bodony, and Lele developed and implemented tools to quantify the turbulence interaction leading to jet noise. In a subsonic jet, most of the turbulence does not have a frequency-wavenumber makeup that allows it to radiate to the far acoustic field. In order to radiate, turbulence components must have supersonic phase velocity, which result from the growth, decay, and interactions of substantially convecting eddies. To quantify these dynamics, this group developed linearized equations for the very large turbulence scales, which are defined by a filter with a width greater than the integral scale of the turbulence but smaller than the wavelength of the dominant acoustic radiation. Using this formulation and tools they developed for analyzing the jet directly in wavenumber-frequency coordinates, they have initiated a study into the dynamics of these very large, radiation capable scales.

The third project examined flow-acoustic interactions in jets, which are important for statistical models of jet noise as well as for experimental identification of noise source location and spectral characterization. While it is widely accepted that the mean flow of a jet refracts some of the noise, the specific effect of the turbulence in scattering the noise, both in direction and frequency, is not understood. Cerviños, Bewley, Freund and Lele used a numerical solution of the adjoint flow equations to quantify the scattering of sound by the turbulence. The scattering of plane waves in the adjoint solution provides an adjoint Green's function for the unsteady jet flow. That is, this procedure gives the forward Green's function for the selected far field direction for all source points in the jet. A substantial broadening of the frequency spectrum was observed. Directivity will be compared with a corresponding Green's function that accounts only for mean-flow refraction, to develop corrections for scattering by the turbulence.

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