Jet noise — overview

Aircraft are amongst the loudest sources of human-created noise. At close range, the noise generated by jet engines presents an acute hazard to ground crews. In these situations, the sound levels are so great that even the most advanced hearing protection technologies are not completely effective. Also, at takeoff and landing, both the propulsion system and the airframe generate significant levels of noise, adversely affecting noise pollution levels in communities surrounding airports.

The desire to understand and eventually control the production of aviation noise at its source motivated five projects at the 2014 Summer Program of the Center for Turbulence Research. As outlined below, each of these projects utilized techniques of computational aeroacoustics to understand different aspects of sound created by complex turbulent flows. These techniques and their results were discussed at length in a series of lively group meetings during the summer program. Modern large-scale simulation and data analytics are indeed creating a second golden age of aeroacoustics, as predicted 22 years ago by Sir James Lighthill.

Two projects focused upon simulation techniques for the prediction of noise created by turbulent jets. The first project by Brès *et al.* simulated an isothermal Mach 0.9 single-stream jet using large-eddy simulation on unstructured meshes with an explicit dynamic subgrid-scale model. Again, the entire interior nozzle geometry was included in the simulation. In addition, a wall model was introduced and the interior boundary layer was tripped far upstream within the nozzle so that it emerged from the nozzle in a fully turbulent state. Far-field noise predictions extracted from this simulation agreed impressively well with experimental measurements. A second project by Casalino & Lele applied the lattice Boltzmann method to the simulation of a hot Mach 0.87/0.9 coaxial jet. Using a variable resolution nested mesh, the entire internal geometry of a dual-stream nozzle was simulated in addition to the downstream development of the exhaust jet.

The next two projects focused on analysis of the mechanisms responsible for the production of peak noise in high-speed jets. As discussed in a recent review by Jordan and Colonius, even though the turbulence generated by high-speed jets is chaotic, fluctuations that most efficiently generate acoustic radiation are highly organized, or coherent. However, these organized motions, or wavepackets, typically have much less energy than the turbulence in which they reside, so they are usually hidden from plain view, except perhaps in the near hydrodynamic pressure field sticking out of the rotational turbulent region. As discussed by Prof. Colonius during his CTR Summer Program tutorial on high-speed jet noise, while wavepackets computed from stability analysis about turbulent mean flows agree well with near-field measurements and simulation data, projection of these data using acoustic analogy does not yield sufficient far-field levels to explain experimental observations. To explain this missing sound, a project by Jordan *et al.*, considered that relative to the frequency of the peak noise-producing wavepackets, the underlying base flow actually contains much lower frequencies. Using the simulation data of Brès *et al.*, Jordan *et al.* found that performing stability analysis on time-varying base flows indeed yielded intermittent wavepackets that recover much of the missing sound. In addition, a project by Nichols and Jovanovic investigated whether there may be additional types of coherent motions relying upon the volumetric forcing received by the turbulence in which they live. Treating the jet as an input-output system, a resolventbased analysis recovers both the wavepacket predicted from stability analysis as well as a host of suboptimal modes. For subsonic jets in particular, these suboptimal modes are nearly as important as the leading stability wavepacket and so may also contribute significantly to farfield noise.

The final project by Papadogiannis *et al.* investigated the generation of indirect combustion noise generated by the propagation of entropy waves through a transonic high-pressure stage. This flow was highly complex in the sense that involved complicated, moving geometry, transitioning and turbulent boundary layers, and shocks. Although all of these effects tend to hide the mechanism of indirect noise, its coherence enabled sparsity-promoting dynamic mode decomposition (SPDMD) to extract the responsible physics and shed new light on its three-dimensional vs. two-dimensional nature.

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