Center for Turbulence Research
Proceedings of the Summer Program 2008

Acoustics - overview

The acoustics group members were primarily European, from France (Moreau, Roger, Nicoud, Poinsot, Leyko), Germany (Winkler), and Belgium (Christophe), with one member from the United States (Bodony). The international group was focused on two primary areas: trailing-edge noise from airfoils and indirect combustion noise, each with a practical application in mind. The main objective of all participants was to improve the predictive capability of existing acoustic source and propagation models using fairly well established numerics. The trailing-edge noise studies were led by Moreau and examined the noise radiated by three different airfoils, each in its own report, at high-lift conditions using large-eddy simulation (LES). Two of studies were for airfoils at high angles of attack, at or near stall, and the remaining study was of a highly cambered airfoil at low angle of attack. The indirect combustion noise studies examined two complementary aspects of noise generation in gas turbine engines. Leyko *et al.* considered a modern investigation of the classical problem of noise generated by an accelerating entropy disturbance through a nozzle. Bodony, on the other hand, considered the noise radiated by an accelerating entropy disturbance in the vicinity of an idealized turbine blade.

The study by Christophe and Moreau examined in detail both the main flow features, steady and unsteady, of a Valeo controlled-diffusion (CD) airfoil often used in low-speed automotive fans. This airfoil has been studied previously at lower angles of attack, but the conditions considered here are more representative of the fan operating at design conditions. The simulation results, using Fluent's LES capability and CDP, Stanford's LES code, were compared with experimental data taken at Ecole Centrale de Lyon (ECL) by Moreau, Rogers, and colleagues. The first objective was a quantitative comparison of the flow predictions, including on-blade pressure spectra and wake velocity data, with ECL data. They observe *qualitatively* different flow predictions depending on the flow solver used (Fluent LES or CDP). Neither flow solution was found to be in very good agreement in wake and spectral comparisons. The CDP solution exhibited an unsteady shear layer separation phenomenon that strongly affected the flow, but was not observed in experiment nor found in the Fluent LES simulation. As a result only the Fluent LES solution was used to calculate the far-field sound using both Amiet's theory (which uses wall pressure fluctuation) and the Ffowcs Williams-Hall approach (which uses near-wall velocity statistics). In general both far-field sound prediction methods over-estimated the radiated sound, with the Ffowcs Williams-Hall method being slightly closer to the experimental data.

The study by Moreau, Christophe, and Roger of a NACA 0012 near stall also used the Fluent LES capability and compared flow predictions to those obtained with CDP, and with experimental data taken at ECL. The objectives for this study were to develop a pressure coherence model specific to the stall condition where additional tonal noise sources are present, and to develop a far-field prediction methodology based on this model. Interestingly, the Fluent LES and CDP predictions were again qualitatively different, but with CDP being more faithful to the experimental data this time. In fact, the Fluent LES simulation predicts a reattachment of the leading-edge shear layer, whereas the CDP solution does not.

The third trailing-edge noise study was conducted by Winkler and Moreau for a highly cambered NACA 6512-13 airfoil and zero degrees angle of attack with and without a boundary layer trip. Again two flow solvers are used, but with CFX replacing CDP as in the two other studies. Here they find that LES predictions are better than those based on Reynolds-averaged Navier-Stokes solutions and that the geometry of trip influences the downstream boundary layer response. The predicted flowfield is in better agreement than in the stalled cases, but the far-field predicted sound agreement depends on the particular trip-sound model combination. Without a trip, Curle's theory exhibits a frequency-dependent prediction accuracy that is a function of the source coherence, and the Ffowcs Williams-Hall predictions are consistent with experiment for the tripped airfoil.

When taken as a whole, the three airfoil studies suggest there is much work to do regarding airfoil trailing-edge noise predictions, including robust near-field predictions and the form of the acoustic model.

In the study of a nozzle-accelerated entropy spot by Leyko, Nicoud, Moreau, and Poinsot, the situation is somewhat reversed: the simulations provided useful feedback to the experiment. Here the authors computationally model an experimental facility at DLR using the CERFACS code AVBP. A plug of gas is electrically heated in a spatially uniform manner with a controlled temporal variation and then accelerated through a converging-diverging nozzle. Initial comparisons between simulation results and experimental data were unfavorable, with a strong qualitative difference between the two. Comparisons to the low-frequency theory, in which the authors generalize the Marble & Candle (1977) theory, agree with the simulation results. An investigation into the differences leads the authors to the downstream boundary conditions, which were modeled as non-reflecting based on the DLR data. When this condition was replaced with a reflecting boundary, with an appropriate impedance relationship determined by trial-and-error, the comparisons between all three data sets dramatically improved, in essence demonstrating that the experimental system has significant internal reflections.

The study by Bodony on the generation of sound by a convected entropy spot in the vicinity attempts to determine the relevant scalings between properties of the disturbance and the resulting sound. A dual computational-analytical study is conducted using the author's compressible Navier-Stokes solver in conjunction with Goldstein's rapid distortion theory formulation. In the simulation portion of the study, a NACA 0012 at zero degrees angle of attack is placed in a Mach 0.2 freestream. After steady state is achieved, a series of entropy disturbances are allowed to interact with the airfoil and its localized strain field. It is found that the acoustic response is linear for temperature disturbances less than 10% of the ambient temperature and that the maximum pressure amplitude scales strongly with the vertical separation of the pulse with the chord line. Interactions at the leading and trailing edges appear to produce the most acoustic radiation, but this was not definitely proven. An asymptotic analysis of the source term suggests that the radiation amplitude will scale with L_x^{-2}, where L_x is the axial length-scale of the disturbance.

Daniel J. Bodony