Acoustics - overview

The acoustics group for this summer program was unique in two respects. First, approximately mid-way through the program the original three groups led by Casalino, Moreau, and Cohen were joined by M. Ihme & M. Kaltenbacher and by J. Eldredge. The former addition served to place combustion noise within the purview of 'acoustics,' while the latter addition resulted from a collaboration that grew out of a non-acoustics area and was not originally proposed. The second unique aspect of these five groups was their attention to acoustics in complex environments and geometries, being less oriented towards investigating 'simple' flows, and focusing more on approaches that can be applied to realistic engineering systems.

The paper by Ihme, Kaltenbacher, & Pitsch concerns the prediction of noise from reacting systems by considering an open diffusion non-premixed flame. Their topic is one currently receiving significant attention world-wide as being relevant to noise reduction from gas turbine systems, especially auxiliary power units. In contrast to isothermal jets where Lighthill's analogy has been thoroughly investigated, reacting jets are less understood due, in large part, to the challenges posed by accurate description of the chemistry from a computationally efficient perspective. Thus, Ihme *et al.* applied Lighthill's original analogy, suitably adapted to reacting systems, and Phillips' analogy to the space-time database created by a low-Mach number simulation of the open flame. The latter analogy rearranges the governing equations in such a manner as to permit a temporally and spatially dependent speed of sound, which is certainly present in the near field of the flame. Using a finite element method to propagate the sound using either analogy they report both analogies yield similar predictions over a range of frequencies, including the dominance of the acoustic sources associated with the chemical reactions.

The paper by Eldredge, Shoeybi, & Bodony provides a transition from the simpler geometry but highly complex environment of the previous paper to the more complex geometry by considering the acoustic response of a multi-perforated liner. These liners play dual roles in gas turbine engines in that they provide effusion cooling air within combustors (see the paper by Mendez *et al.* elsewhere in this Proceedings) and are capable of damping acoustic waves for noise reduction. The latter function is considered by Eldredge *et al.*. Using an incompressible LES solver for the flow near an isolated hole they focus on the pressure response on the downstream side of the hole due to mass flow fluctuations, associated with an incoming acoustic wave, on the upstream side of the hole. An incompressible investigation is valid due to the domain of interest in the calculation being very small relative to the acoustic wavelength implied by the fluctuating mass flow. From the simulations Eldredge *et al.* find that the existing analytical model for the liner's response provides a rough estimate for its real performance, but needs to be modified to account for the presence of a bias flow through the liner and effects due to the hole geometry.

The next two papers by Moreau and co-workers consider the noise produced by low-speed fans commonly found in cooling systems for automobiles and computers. The paper by Moreau, Henner, Casalino, Gullbrand, Iaccarino, & Wang aims to provide an estimate of the full noise spectrum of an automotive cooling fan using a hybrid of methods according to the noise source quality. The rotating fan/stator system has a series of periodic interactions that produce a correspondingly tonal acoustic signature, and for this source Moreau *et al.* use unsteady Reynolds-averaged Navier-Stokes solutions for the flow description and an unsteady Ffowcs Williams-Hawkings surface to determine the accompanying sound. The latter surface is 'attached' to the fan geometry and relates the surface fluctuations, mostly in the form of hydrodynamic pressure variations, to the acoustic pressure. The rotating fan has a suitably high chord-based Reynolds number to sustain active turbulence which also contributes to the far-field noise in the form of a broadband spectrum. By using an extended version of Amiet's theory applied to a incompressible LES simulation of the turbulent flow over a section of the rotating fan, they estimate the turbulence-generated noise from the fan, finding that the leading- and trailing-edges must be included for accuracy. When the tonal spectrum is 'added to' the broadband spectrum the overall estimate is a reasonable facsimile of the experimental spectrum.

The second low-speed fan paper by Moreau, Neal, Khalighi, Wang, & Iaccarino compares the flow and trailing edge noise predictions given by three unstructured LES solutions against a reference structured grid solution. The main idea here is to validate automatric grid generation capabilities unique to the unstructured LES solver against existing, validated data. Moreover, Moreau *et al.* assess the impact the different grids have on the predicted trailing edge noise through the acoustic analogy using both approximate and numerically-computed Green's functions. The work reported therein is accompanied by experimental data taken at two facilities with configurations that are reflected in the simulations.

In the paper by Casalino & Bodony a new numerical method is applied to acoustic wave propagation phenomena, in particular to those phenomena encountered by the exhaust gas streams of gas turbine engines. The Pridmore-Brown operator linearized about a three-dimensional, steady mean flow is discretized using a finite element Galerkin approach wherein the basis functions are taken to be the Green's functions from the convective Helmholtz equation, the latter being a local approximation to a general mean flow. The method is suitable for complex geometries discretized using arbitrary tesselations but is here validated against simple acoustic problems with well characterized solutions. After being tested in the case of duct acoustics, the scattering of sound by compressible vortices and the radiation of sound by a source in a Gaussian profile jet are considered, with the method showing promise against previously-validated solutions.

The final paper in the Acoustics section is by Cohen, Ooi, & Iaccarino and is concerned with a relatively new numerical technique dealing with an immersed boundary method for wave propagation. Developed by P. Morris and colleagues at Penn State the impedance mismatch method (IMM) represents solid bodies placed in an acoustic medium as localized 'jumps' in the acoustic impedance wherein a corresponding finite difference discretization can be constructed. Cohen *et al.* attempt to use the IMM to solve the acoustic propagation of sound determined by a theory developed by Hardin & Pope called the expansion about incompressible flow (EIF). The EIF description is based on a low Mach number expansion of the governing equations and results in a form that can be interpreted as sound propagation with an accompanying source term. Cohen *et al.* discretize the EIF using the IMM and consider a series of more complicated validation problems. Though the IMM-EIF approach performs well for static media, the method is problematic for problems with non-zero flow velocity. Cohen *et al.* develop an alternative formulation that is stable for convective problems which yields encouraging results for the limited problems thus far considered.

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