EX236

Cavity Acoustics

In this example, the detached eddy simulation (DES) turbulence model in FLUENT is used to simulate the transient flow inside an open cavity. An acoustics calculation is then used to predict several modes of pressure oscillation on the cavity ceiling, and the associated sound spectrum. The CFD results are in very good agreement with experimental data.

Cavity flows have been the subject of research since the 1950s. Although geometrically simple, the fluid dynamics in such flows is complicated, involving shear layer instability, flow induced resonance, and turbulence. The flow generated by transonic flow across the opening combines several clearly identifiable flow phenomena, such as a mixing layer with its train of large structures, recirculating flow in the cavity, pressure waves generated by the crossing of the structures, and strong acoustic coupling between all of these phenomena. Such flows occur in many different areas of engineering. Landing gear wells and bomb bays on aircraft are common examples of cavities where sonic fatigue and the reduction in pressure fluctuations and noise are of prime concern. The pressure vents on the space shuttle cargo bay have also been observed to cause high internal noise levels during ascent.

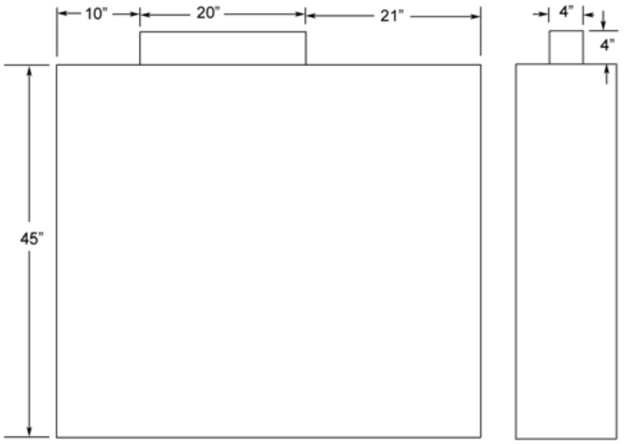

Figure 1:The cavity geometry

Computational aeroacoustics (CAA) is the most comprehensive way to simulate aeroacoustics, the sonic pressure fluctuations such as those generated inside an open cavity. CAA is a transient simulation of the entire fluid region encompassing the sources, receivers and the entire sound transmission path in between. The simulation computes pressure disturbances created in the source regions by rigorously calculating the time-varying flow structures. It also simulates sound transmission by resolving the pressure waves traveling through the fluid. At the receiver location, the time-varying static pressure, or sound signal, is recorded. To meet these varying needs, the simulation methodology needs to capture turbulence in the source region for the accurate prediction of source pressure fluctuations. In addition, fluid compressibility needs to be incorporated in the simulation to properly capture the transmission of sound (pressure) waves.

Cavities are good candidates for the CAA approach. The noise is generated in the shear layer and off the leading edge of the cavity, and these are close to receiver positions if they are located on the ceiling or just downstream of the cavity. The fact that the noise sources are high (loud) also

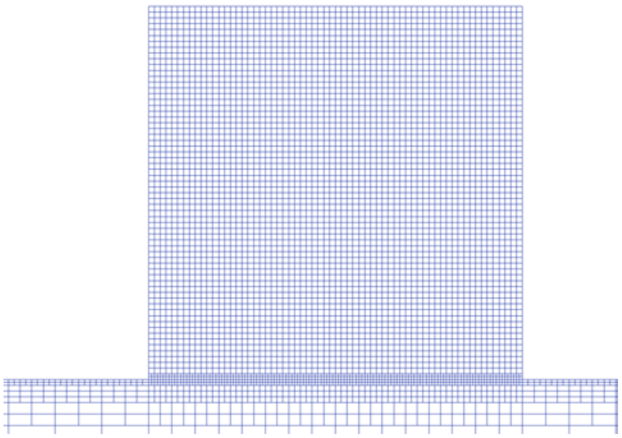

Figure 2:The computational mesh

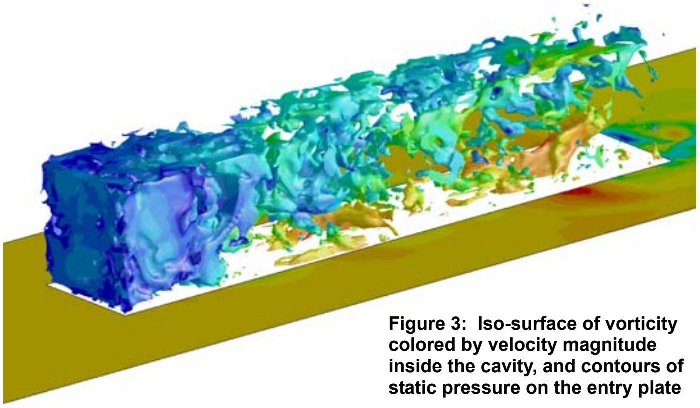

Figure 3: Iso-surface of vorticity colored by velocity magnitude inside the cavity, and contours of static pressure on the entry plate

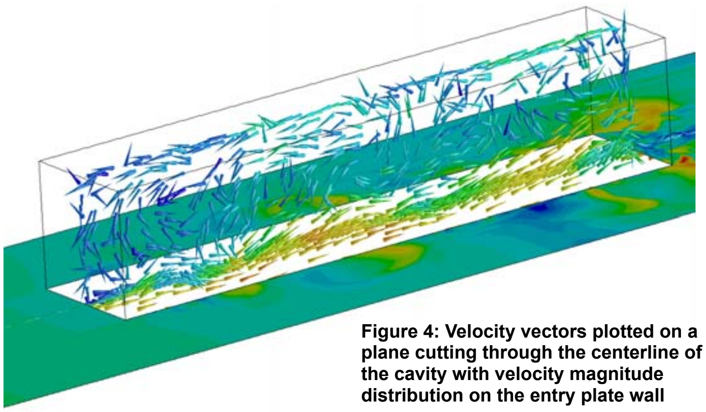

Figure 4: Velocity vectors plotted on a plane cutting through the centerline of the cavity with velocity magnitude distribution on the entry plate wall

makes this application suitable to a CAA analysis.

Plan and side views of the cavity and surroundings are shown in Figure 1. The overall computational domain is 51 inches by 12 inches by 49 inches. The domain extends 10 inches upstream and 21 inches downstream of the cavity edges. Boundaries on either side are placed 4 inches from the cavity sides. It was estimated that by positioning the boundary edges at these locations, the flow inside the cavity would not be affected by boundary interference.

Adaptive meshing technology was used to create a mesh containing approximately 1,400,000 Cartesian cells. The mesh is coarser in the free-stream and refined in the boundary layer and separated shear layer regions, as well as in the cavity region itself. Figure 2 illustrates the mesh in the vicinity of the cavity. The near wall spacing results in y+ values of between 10 and 200. By starting with a uniformly spaced coarse mesh and then employing an adaptive meshing approach, all the cells are orthogonal and have aspect ratios of no more than 3.

Transient calculations were carried out using FLUENT. The detached eddy simulation (DES) turbulence model was used with the Spalart-Allmaras RANS model and the dynamic Smagorinsky subgrid-scale model. The transient DES calculation was initiated from a steady state Spalart-Allmaras simulation. A bulk Mach number of 0.85 with a gauge static pressure of 63,200 Pa and temperature of 300K were specified at the outflow and upper boundaries. The side boundaries were defined using symmetry conditions. The inflow boundary conditions were taken from separate channel flow simulations at similar conditions. The non-iterative time advancement (NITA) solution scheme was used. The total duration of the run was 0.6 seconds and the statistical results were averaged over the final 0.2-second period (from 0.4 to 0.6 seconds).

In Figure 3, vortical structures inside the cavity are shown after 0.6 seconds have elapsed, and in Figure 4, velocity vectors are shown on the mid-plane at this time. These figures illustrate the complexity and transient nature of the cavity flowfield. Vorticity is generated principally in the free shear layer. Following the separation of the boundary layer from the leading edge of the cavity, Kelvin-Helmholtz instabilities quickly develop.

This cavity, with an aspect ratio of 5:1 (length:depth) is by definition a shallow cavity. For shallow cavities there may be several different mechanisms for generating noise. The fluctuating impact pressure at the trailing edge of the cavity is believed to

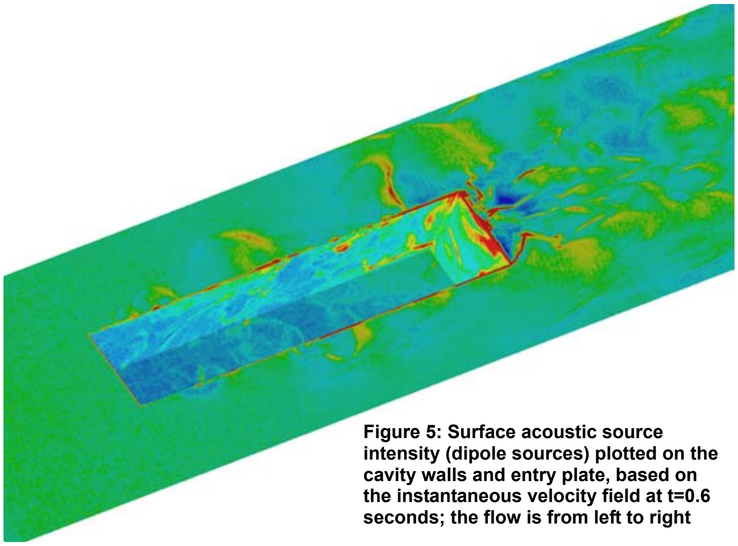

Figure 5: Surface acoustic source intensity (dipole sources) plotted on the cavity walls and entry plate, based on the instantaneous velocity field at t=0.6 seconds; the flow is from left to right

generate propagating waves. The shedding of vortices at the leading edge maybe another source, as is the flapping of the shear layer. It has been observed that the broadband buffeting noise has the highest energy at the lowest frequency, and increases with Mach number. The noise is highest near the trailing edge of the cavity, as is suggested in Figure 5, where the surface acoustic source intensity is shown.

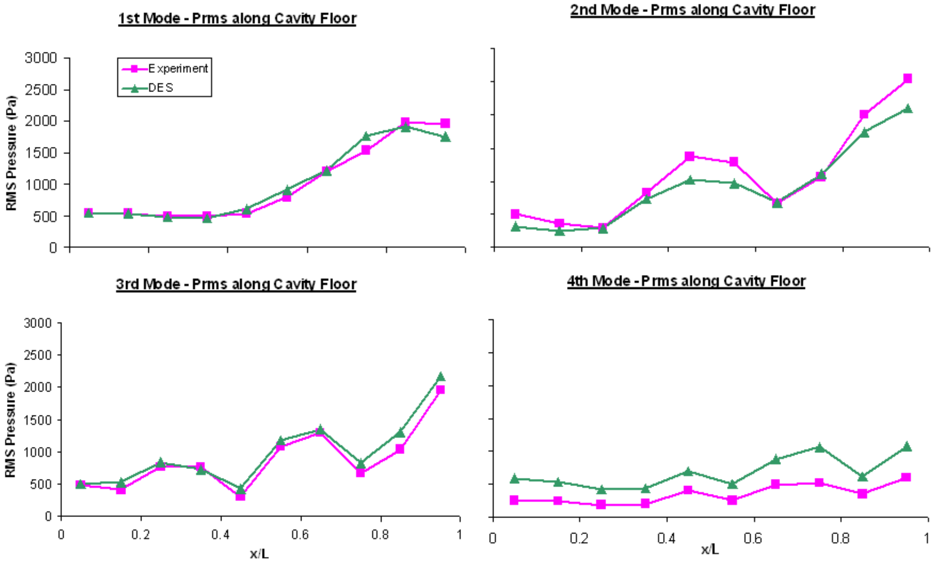

Figure 6: Band limited P_{RMS} along the cavity ceiling - 1st through 4th modes (Data: Ref. 1)

Rossiter first developed an empirical formula for predicting cavity flow resonant frequencies, today referred to as Rossiter modes. For this configuration, the first three Rossiter modes (peaking at 145Hz, 350Hz and 590Hz respectively) are of a similar strength across the ceiling of the cavity. The fourth mode has lower amplitude, and peaks at a higher frequency (810Hz). Each modal band is calculated using frequencies that bracket the peak, and each shows the strength of the pressure fluctuations in the cavity. These modes are straightforward to process, so provide a good measure of computational model performance. The RMS pressure along the cavity ceiling, P_{RMS}, is shown in Figure 6 for all four modes. The overall comparison with experiment (1) is very good, although the fourth mode is overpredicted.

The sound pressure level (SPL) at one of ten microphone locations is compared to experimental data (1) in Figure 7. The DES approach provides a frequency spectrum, computed using the last 0.2 seconds of simulation, that is in very good agreement with the data. For comparison, an unsteady RANS (URANS) simulation was also performed, and the results were used to predict the SPL and power spectral density (not shown). The URANS simulation compared poorly with the data, especially at the higher frequencies. These results were consistent at every monitor point considered in the study.

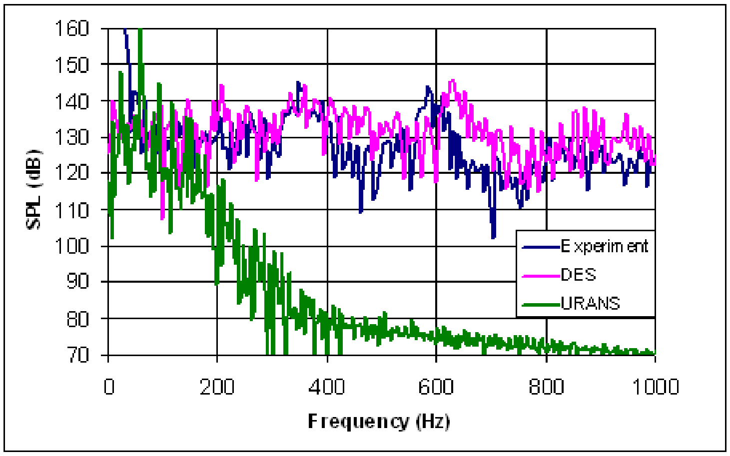

Figure 7: Sound pressure level (SPL) 7 inches downstream of the cavity, computed using DES, URANS, and compared to data (1)

In summary, a rectangular open cavity with a free stream Mach number of 0.85 has been investigated to assess an advanced turbulence modeling technique and solver scheme for predicting narrow- and broadband noise. Detailed experimental data for the open cavity configuration provided a valuable opportunity for comparing predictions of sound pressure levels and noise spectra at a number of points. The DES results were in very good agreement with the data.

Reference:

1. Experimental data provided by QinetiQ, funded by the UK MOD Applied Research Program.