Leading Edge Aeroacoustics

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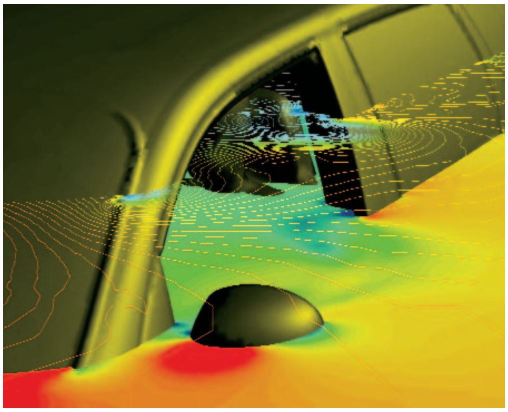
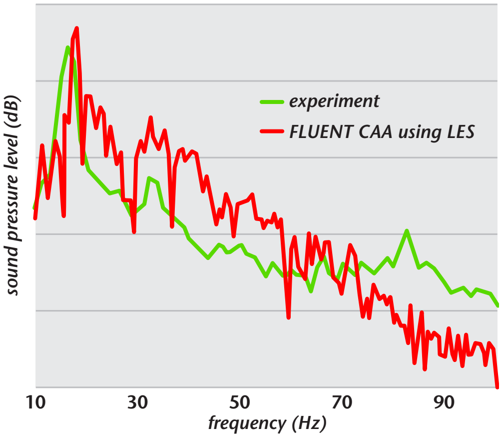
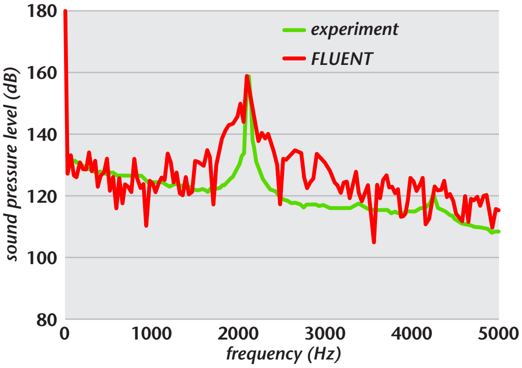


Pressure contours in a side window buffeting simulation of a passenger car, using CAA Courtesy of DaimlerChrysler



Spectrum of the side window buffeting sound heard by a car driver Courtesy of DaimlerChrysler



Computationally predicted (using CAA) and experimentally measured sound spectrum showing a loud whistle (tone) generated by an automotive air intake system

In recent years, as engineering design of components and systems has become increasingly sophisticated, a significant amount of effort has been directed toward the reduction of aerodynamically generated noise. With the ongoing advances in computational resources and algorithms, CFD is being used more and more to study acoustic phenomena. Through detailed simulations of fluid flow, CFD has become a viable means of gaining insight into noise sources and basic sound production mechanisms.

FLUENT offers four approaches for simulating aeroacoustics. In order of decreasing computational effort, these are computational aeroacoustics (CAA), the coupling of CFD and a wave-equation-solver, integral acoustic models, and broadband noise source models.

computational aeroacoustics

Computational aeroacoustics is the most comprehensive way to simulate aeroacoustics. It does not rely on any model, so is analogous to direct numerical simulation (DNS) for turbulent flow. CAA is a transient simulation of the entire fluid region, encompassing the sources, receivers, and entire sound transmission path in between. By rigorously calculating time-varying flow structures, pressure disturbances in the source regions can be followed. Sound transmission is simulated by resolving the pressure waves travelling through the fluid. While CAA is the most general and accurate theoretical approach for simulating aeroacoustics, it is unrealistic for most engineering problems because of a number of practical limitations, including widely varying length and time scales characteristic of the sound generation and transmission phenomena, and widely varying flow and acoustic pressures.

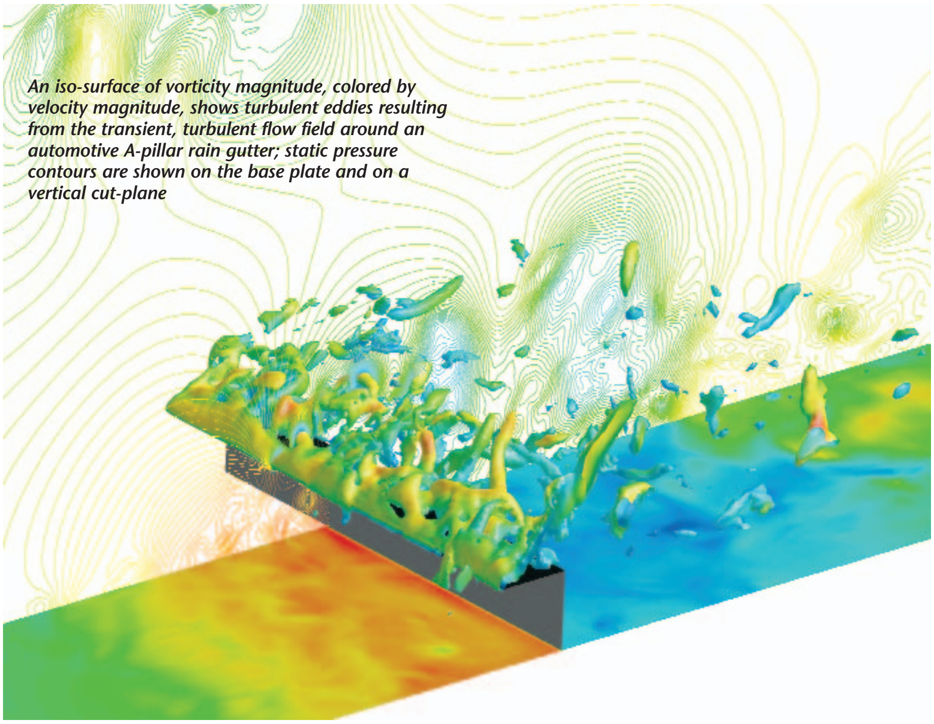
While these constraints render CAA unsuitable for most practical situations, there is a small class of engineering problems to which it can be successfully applied. This includes cases where the frequency range of interest is fairly narrow, the sources and receivers are located close to each other, and the sound to be captured is fairly loud. A classic example that is appropriate for CAA analysis is aerodynamic buffeting. Buffeting is a wind noise of high intensity (> 100 dB) and low frequency (15 to 25 Hz) heard in a moving vehicle when a window or sunroof is open. CAA has been used to simulate a passenger car with the driver's side and/or rear passenger's window open, to predict the buffeting frequency spectrum heard by the driver or passenger [1, 2]. The simulated spectrum was found to be in excellent agreement with corresponding experimental measurements. The flow around a generic automotive side view mirror and the sound radiated by it have also been calculated using CAA, and found to be in good agreement with experiment [3, 4].

Recently, CAA has been used successfully to predict whistles (loud tones) produced by automotive air intake systems. The whistling sound is caused by an air jet passing underneath the throttle plate. As it passes over a sump cavity, a shear layer is established. If resonance occurs between the flapping shear layer and sound waves bouncing off the sump bottom, a loud whistle develops. The sound spectrum predicted by a CAA simulation was found to be in excellent agreement with the corresponding experimental measurement [5, 6]. The CAA simulation predicted almost the exact same whistle frequency and sound pressure level (SPL) as measured in the experiments.

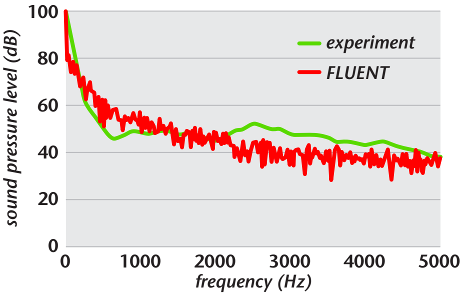
CFD-wave equation solver coupling

The computational aeroacoustics approach is prohibitively expensive for most practical problems due to the large difference in time, length, and pressure scales involved in sound generation and transmission. Computational expense can be greatly reduced by splitting the problem into two parts: (1) sound generation and (2) sound transmission. With this approach, sound generation is modelled by a comprehensive transient CFD analysis, while a wave equation solver is used for analyzing sound transmission. In one recent example, FLUENT 6.1 was used to simulate the transient flow field around the same generic side view mirror discussed in the previous section. Time-varying static pressure was recorded on the mirror surfaces and the base plate and exported to the commercial code Sysnoise from LMS International, which solves the wave equation using the boundary element

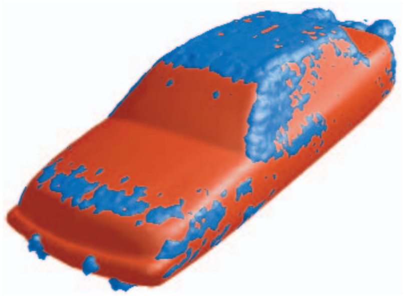
Simulation



An iso-surface of vorticity magnitude, colored by velocity magnitude, shows turbulent eddies resulting from the transient, turbulent flow field around an automotive A-pillar rain gutter; static pressure contours are shown on the base plate and on a vertical cut-plane



Sound spectrum at a point above the rain gutter shows good agreement between FLUENT's FW-H model predictions and experiment



An iso-surface of Lilley's acoustic source strength shows prominent wind noise sources on a generic sedan

method (BEM). The Sysnoise results include a spatial distribution of the sound level as a function of sound frequency.

integral acoustics methods

The approach of splitting the flow and sound fields from each other and solving for them separately can be simplified further if the receiver has a straight, unobstructed view of each individual point that is a source of noise. Sound transmission from a point source to a receiver can be computed by a simple analytical formulation. The Lighthill acoustic analogy [7] provides the mathematical foundation for such an integral approach. The Ffowcs-Williams and Hawkings (FW-H) method [8] extends the analogy to cases where solid, permeable, or rotating surfaces are sound sources, and is the most complete formulation of the acoustic analogy to date. Both methods are implemented in FLUENT. As an example, the FW-H method has been applied to the prediction of sound radiating from a backward facing elbow (a simplified representation of an automotive A-pillar rain gutter). Using the LES turbulence model, predictions of the sound pressure level for this case were found to be in very good agreement with experimental data taken from the literature [9].

broadband noise source models

The three methods described so far require well-resolved transient CFD simulations, since they aim to determine the actual time-varying sound-pressure signal at the receiver, and from that, the sound spectrum. In several practical engineering situations, only the locations and relative strengths of sound sources, rather than the sound spectra at the receivers, need to be determined. If the sound is broadband (without any prominent tones characterized by sharp peaks in the spectrum), the source strengths can be evaluated with reasonable accuracy from the time-averaged structure of the turbulent flow in the source regions.

Turbulence is the primary cause of sound in aeroacoustics, so in a broad sense, regions of the flow field where turbulence is strong produce louder sources of sound. FLUENT 6.2 includes a number of analytical models referred to as broadband noise source models which synthesize sound at points in the flow field from local flow and turbulence quantities to estimate local sound source strengths. The key advantage of these models is that they require very modest computational resources compared to the methods described in the previous sections. Broadband noise models only need a steady state flow solution, whereas the other methods require well-resolved transient flow solutions. One example recently studied involves the prediction of prominent sound sources around a simplified sedan, using Lilley's acoustic source strength broadband noise model.

In summary, FLUENT offers four ways for simulating aeroacoustics. These range from highly accurate, but expensive methods to quick and approximate approaches. All of these methods are included in the standard FLUENT software; no add-on modules are necessary. ■

references:

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