

A Computational Process for Early Stage Assessment of Automotive Buffeting and Wind Noise

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ABSTRACT

A computational process for early stage vehicle shape assessment for automotive front window buffeting and greenhouse wind noise is presented. It is a challenging problem in an experimental process as the vehicle geometry is not always finalized. For example, the buffeting behavior typically worsens during the vehicle development process as the vehicle gets tighter, leading to expensive late counter measures. We present a solution using previously validated CFD/CAA software based on the Lattice Boltzmann Method (LBM). A CAD model with realistic automotive geometry was chosen to simultaneously study the potential of different side mirror geometries to influence the front window buffeting and greenhouse wind noise phenomena. A glass mounted mirror and a door mounted mirror were used for this comparative study. Interior noise is investigated for the two phenomena studied. The unsteady flow is visualized and changes in the buffeting and wind noise behavior are explored.

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INTRODUCTION

In recent years, there has been an increasing trend towards adoption of digital simulation based design in industrial applications. In the automotive industry digital simulation technologies are used to solve an increasing number of customer problems. Automotive interior noise is one such challenging problem which requires multiple technologies to efficiently and accurately solve it. The interior noise is a result of loading from multiple external sources, ranging from the road, engine and wind, and buffeting resonances from any openings such as sunroof or windows. Currently, these sources are investigated separately in simulations as it is challenging to provide a fully integrated solution. The simulation of external wind loads propagating into the interior has been recently accomplished. Recent studies have reported successful simulation of wind noise from side glass panels on a sedan [1] and an SUV [2] using a combination of CFD for the exterior air flow and SEA for the structural acoustic propagation to the interior. A statistical analysis of the CFD/SEA simulation accuracy was summarized in [3]. Using a frequency spectrum of A-weighted sound pressure level in four octave bands centered from 500 Hz to 4000 Hz, the grand mean difference between simulation and

experiment over a set of 120 data points was -0.8 dB. The simulation of direct noise propagation of low frequency buffeting in the cabin interior due to open sunroof or windows is another challenging problem that has been recently overcome. The efficiency of sunroof buffeting suppression of a gap type deflector was studied in [4] on a sedan and an SUV. The deflector was not found to be universally effective and was shown in simulation as due to the different flow mechanisms present in the shear layer. The problem of open window buffeting was investigated for a small scale model of an automobile [5]. Deaton [6, 7] investigated the causes and addressed methods of reducing rear window buffeting.

During the development stages of the design, a car gets tighter [6] in order to reduce the exterior sound paths from reaching the interior. From a wind noise perspective, the car gets quieter as it approaches the later stages of the design. However, a tighter car is known to exhibit worse buffeting. Late stage counter measures like a sunroof deflector or a different mirror may be required to achieve the buffeting noise targets. A mirror design change in the later design stages also needs to satisfy the wind noise targets and this can lead to expensive fixes in the form of thicker glass panels.

A simulation process to simultaneously study the wind noise and open window buffeting performance of a CAD model representing a realistic early stage vehicle is detailed in the following sections. A comparative study of the performance of a door mirror and a glass mounted mirror is also detailed. Noise source identification is done using mean and transient flow.

COMPUTATIONAL PROCESS

Numerical Scheme

Numerical results were obtained using the commercial CFD/CAA software package PowerFLOW 4.4 from Exa Corporation. The simulation kernel of this software is based on the numerical scheme known as the Lattice-Boltzmann Method (LBM). A very large eddy simulation (VLES) turbulence model based on a dynamically coupled two-equation RNG formulation is included. This scheme accurately and robustly predicts time-dependent aerodynamic behavior of turbulent flow including effects of complex detailed geometry [8,9,10,11,12,13,14]. It has also been demonstrated to accurately capture aero-acoustic behavior including turbulent flow wall pressure fluctuations [15,16,17,18,19,20] and automotive sunroof buffeting [21,22,23,24]. Due to its inherent transient and compressible nature, the LBM based approach allows for bi-directional coupling between the aerodynamic excitation and the acoustic response. This contrasts with other CFD/CAA approaches that assume no feedback from acoustics to flow.

For wind noise simulations, interior noise is analytically calculated using a 2 step process detailed in [1]. The initial CFD step simulates the fluctuating pressure loads on the exterior panels of the vehicle at speed. In the second SEA step, these transient pressures are analyzed in the frequency domain using PowerACOUSTICS 2.0c to develop load cases for a structural acoustics model of the vehicle panel dynamics and interior acoustics. For this study, the cabin interior volume is sub-divided into 20 SEA acoustic subsystems [2] in order to simulate gradients of interior SPL. For both left and right sides, there is upper, middle and lower acoustic subsystems for front, middle and rear seating areas, plus a space above the instrument panel at the windshield. Acoustic absorption is applied by specifying a typical cabin reverberation time. Panel thickness, lamination layup, material properties and an effective damping loss factor spectrum are assigned to each active glass panel.

For buffeting simulations, the interior noise is obtained from direct sound propagation to the driver head space. Real world effects such as compliance, damping and leakage are modeled as in previous validated studies [4, 5, 21, 22, 23, 24].

Simulation Methodology

Numerical simulations were done in the aero-acoustic digital wind tunnel. A detailed CAD model of a realistic vehicle with a high quality triangular surface mesh was used

to specify the exterior and interior geometries. The geometry of the open window configuration is shown in [Figure 1](#). The glass mounted and door mirrors are shown in [Figures 2-3](#).



Figure 1. CAD model showing open front window

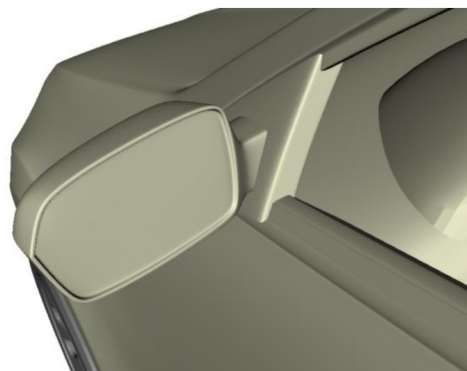


Figure 2. CAD model showing glass mounted mirror

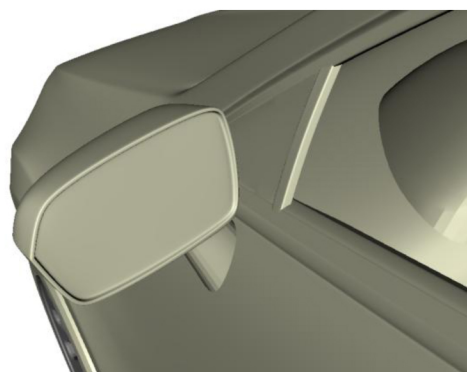


Figure 3. CAD model showing door mirror

Variable resolution fluid discretization regions were used with fine resolution in critical regions. Coarse resolution was used in regions away from the critical regions to keep the computational effort efficient. For the wind noise simulation, fine resolution was used to obtain accurate boundary layer development, flow separation and high frequency structures. For the front window buffeting simulation, additional high resolution region was used to accurately obtain the flow structures in the vicinity of the opening. The finest cell size

used in the wind noise and buffeting simulations was 1mm and 1.5mm respectively.

The aero-acoustic digital wind tunnel enables easy switching of geometries and/or applications (such as switching from wind noise to front window buffeting) enabling rapid turn-around of multi-vehicle or multi-application studies.

Measurements

Mean flow measurements and transient flow measurements are obtained in a region around the car to perform three dimensional visualization. In addition, high frequency plane measurements and microphone measurements are also obtained for frequency domain and frequency band filtered time domain analysis. For wind noise studies, transient measurements are obtained at high frequency on the vehicle front side glass, front quarter glass (present in door mirror configuration) and windshield glass panels which are the dominant wind noise sources at the driver's ear locations in a fully-taped vehicle. Sufficient over-sampling above the minimum Nyquist requirement ensures accurate spectral post-processing for the frequency range desired.

RESULTS AND DISCUSSION

Wind Noise

The simulations were run at a speed of 70 mile/hr for a simulation time of 1.0 second. The separated flow structures in the vicinity of the passenger side front window are shown time averaged in [Figures 4 and 5](#) for the glass mounted and door mirror configurations. The separated flow regions are defined using iso-surfaces of zero non-dimensional total pressure. These images show the vortex and separation regions that generate deficits in the flow momentum, as represented by the total pressure coefficient. The strongest turbulent pressure fluctuations on the side-glass are produced within these separated regions and the attached vortex, due to high-Reynolds-number instability of these flow structures. In addition to the A-pillar vortex and the mirror wake, the glass mounted mirror pedestal wake is shown in [Figure 4](#) to impinge on the side glass, thus contributing additionally to the pressure fluctuations on the side glass. The door mirror has an additional noise path from the A-pillar vortex impingement on the quarter glass which replaces the mirror sail in the glass mounted mirror configuration.

The interior noise resulting from the exterior glass panel convective and acoustic fluctuations are transmitted into the interior using the 2 step process explained earlier. The absolute sound pressure levels in 1/3 Octave bands are compared in [Figure 6](#) and the differences (glass mounted mirror - door mirror) are compared in [Figure 7](#). The door mirror is found to be 0.5 dB - 1.5 dB louder over all frequency bands above 200 Hz.

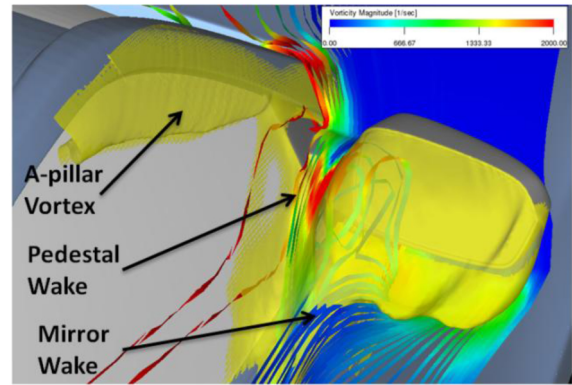


Figure 4. Mean flow, three-dimensional stream ribbons colored by vorticity magnitude: Glass mounted mirror

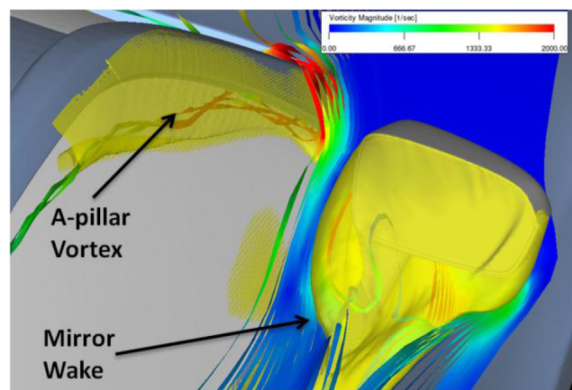


Figure 5. Mean flow, three-dimensional stream ribbons colored by vorticity magnitude: Door mirror

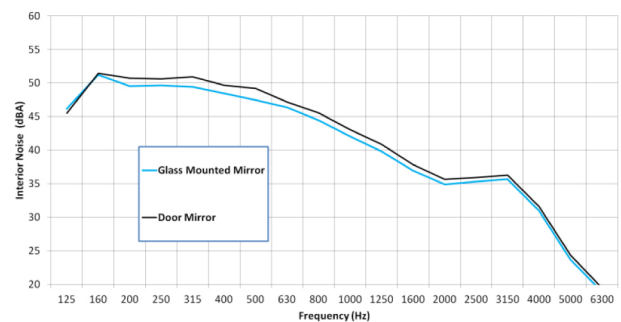


Figure 6. Interior noise: Driver head space

Next, we will present unsteady flow visualization to identify the size, location and strength of the noise sources for the glass mounted mirror and the door mirror configurations.

The dominant exterior noise sources on the glass panels are shown using dB (or SPL) maps in [Figures 8 and 9](#). These dB maps are very high fidelity representations of the sound pressure level (SPL) distribution for a fixed frequency band. The dark red regions correspond to the largest pressure fluctuations, and consequently, highest SPL values. For the