

A Computational Approach to Evaluate the Automotive Windscreen Wiper Placement Options Early in the Design Process

Sivapalan Senthoooran, L.A.Raghu Mutnuri, Joe Amodeo and Robert Powell
Exa Corporation

Claire Freeman
Jaguar Land Rover

ABSTRACT

For most car manufacturers, wind noise from the greenhouse region has become the dominant high frequency noise contributor at highway speeds. Addressing this wind noise issue using experimental procedures involves high cost prototypes, expensive wind tunnel sessions, and potentially late design changes. To reduce the associated costs as well as development times, there is strong motivation for the use of a reliable numerical prediction capability early in the vehicle design process.

Previously, a computational approach that couples an unsteady computational fluid dynamics solver (based on a Lattice Boltzmann method) to a Statistical Energy Analysis (SEA) solver had been validated for predicting the noise contribution from the side mirrors. This paper presents the use of this computational approach to predict the vehicle interior noise from the windshield wipers, so that different wiper placement options can be evaluated early in the design process before the surface is frozen. In this study, this approach is applied on a production vehicle to predict the interior noise contribution for wipers on and off configurations and validated against wind tunnel test measurements. Prediction of noise sources on the windshield has been validated by comparing the wall pressure fluctuations on the windshield between the computational approach and the test measurements. Accurate prediction of both the exterior noise sources and the interior noise indicates that this approach can be used to make design decisions about wiper placement during the vehicle development process.

CITATION: Senthoooran, S., Mutnuri, L., Amodeo, J., Powell, R. et al., "A Computational Approach to Evaluate the Automotive Windscreen Wiper Placement Options Early in the Design Process," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(2):2013, doi:10.4271/2013-01-1933.

INTRODUCTION

The interior noise in an automobile due to wind noise is the result of external surface pressure fluctuations. When an automobile travels down the road, fluctuating pressures are generated everywhere on the surface due to the existence of turbulent flow, with the strongest pressure fluctuations generated in the separated and vortical flow regions. These separated flow regions are shown in [figure 1](#). Interaction of these unsteady separated flow regions with the surface of a car creates strong fluctuating pressure excitation loads on the vehicle panels that get transmitted to the interior of the cabin. Typically the largest noise sources originate from flow separations at the a-pillars, side mirrors, cowl, wipers and wheel openings. The ultimate goal in the simulation of automotive interior noise is to predict the noise that will be

experienced by the customer while driving on the road. But with so many sources and paths for noise and different simulation technologies required to predict each one, the development of a fully integrated noise model is still in its early stages. In the mean time, it remains practical to develop substitute characteristics that predict overall interior noise based on component behavior.

Previously an unsteady computational fluids solver based on a Lattice Boltzmann method had been validated for prediction of noise sources in the side glass region on multiple vehicles [1,2,4,8, 9, 10]. Also a computational approach that couples this fluids solver to a Statistical Energy Analysis (SEA) solver had been validated for predicting the noise contribution from the side mirrors [3,5, 6, 7]. This paper extends the use of this computational approach to predict the vehicle interior noise from the windshield wipers

so that different wiper placement options can be evaluated early in the design process before the surface is frozen.

3-4 dB [1] and to avoid the self-noise problems reported by Senthoooran et al [8].

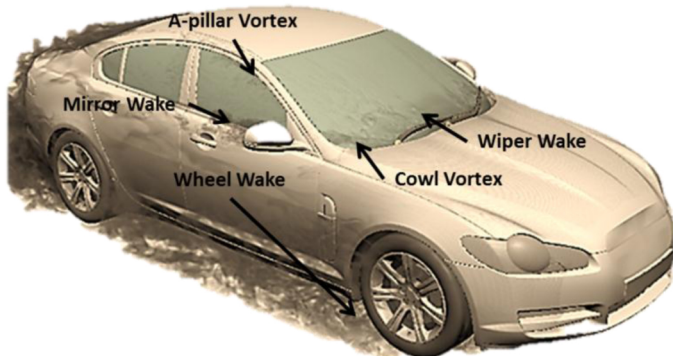


Figure 1. Separated flow field around an automobile



Figure 2. One set of exterior surface microphone locations

DESCRIPTION OF THE COMPUTATIONAL MODEL

A completely analytical simulation of interior wind noise is performed in two steps. The initial step simulates the flow field around the vehicle at speed using a Lattice Boltzmann method and predicts the fluctuating pressure loads on the exterior panels of the vehicle. These transient pressures are analyzed in the frequency domain to develop load cases for the noise transmission module based on a Statistical Energy Analysis approach and predict the interior noise in the cabin. The details of the computational fluid dynamics model and the noise transmission model are described in detail in Lepley et al [5] and thus are not repeated here.

EXPERIMENTAL DETAILS

Experimental results were obtained in the aeroacoustic wind tunnel facility in Cologne, Germany. Interior noise results were measured with binaural acoustic heads. During interior noise measurements for form, or shape, all closure margins and seals are taped to reduce sealing contributions. One-third octave band A-weighted sound pressure levels were calculated with the facility analysis system. Several speed and yaw configurations were taken for each vehicle configuration. In this paper, 130 km/h zero yaw results were selected and analyzed as representative of the wind noise performance.

Wall pressure fluctuations on the exterior were measured using surface microphones. Tracking the exterior wall pressure fluctuations is an integral part of the JLR aeroacoustics process, described previously by Freeman and Gaylard [1]. In these experiments, Bruel & Kjaer type 4949 surface microphones with conical fairings of 50 mm diameter were taped to the vehicle glass. Cables were routed carefully to minimize their effect on flow to downstream microphones. [Figure 2](#) is a photo of a typical such arrangement. This surface mounted microphone arrangement was shown to reproduce levels measured with true flush mounting within

COMPUTATIONAL DETAILS



Figure 3. Geometry used in the simulation

The CAD model used in the current computational studies is a complete geometrical replica of the experimental set up as shown in [figure 3](#). Geometries of the surface mounted microphones and cables on the windshield were excluded in the simulation since the effect of them on the wall pressure fluctuations is minimal. The CFD simulations for this study were done by matching experimental wind tunnel conditions, in the aeroacoustic digital wind tunnel of the commercial software PowerFLOW 4.4b and the interior noise predictions were performed using PowerACOUSTICS 2.0b. The Inlet velocity was set at a value corresponding to the test (130 kph). A variable resolution scheme with the finest cell size of 1mm was used in the simulations. Fine resolution was used around the wipers, cowl, windshield, mirrors, side glass, edge of the hood and A-pillar to capture the flow critical to acoustic evaluation accurately. The resolution was progressively coarsened away from the critical regions for computational efficiency. Simulations were executed for a physical time of 0.8 seconds with initial conditions seeded

form a coarse run. Measurements from the simulation were taken at a rate of 25 kHz for a duration of 0.5 sec starting from 0.3 sec (to allow for the flow to settle).

COMPUTATIONAL RESULTS

Greenhouse Wind Noise

For most of the automobiles, at high speeds, the highest contribution to the mid to high frequency interior cabin noise comes from the side glass and windshield panels. [Figures 4 and 5](#) show the anatomies of side glass and windshield noise sources. In these images the glass panels are colored with wall pressure fluctuations for the 500 Hz octave band and the separated flow structures in the fluid domain are shown with vorticity magnitude. Red regions on the glass panel indicate high intensity noise sources and these are generated when the separated flow structures impinge on the glass panels. In the side glass region the side mirror wake and a-pillar vortex generate the noise sources that get transmitted to the interior through the glass panel. Similarly in the windshield region the separated flow structures due to cowl vortex & wiper wake generate the noise sources that get transmitted to the interior.

Noise transmitted through the side glass & windshield panels is predicted using the described computational approach, for the vehicle configuration without the wipers and compared to the test results in [Figure 6](#). Experimental data used for this comparison was obtained from a separate wind tunnel session. Experimental data was taken on a fully taped vehicle configuration without the wipers. During the experiment the underbody was covered with a skirt, to remove its contribution to the interior noise and measure the greenhouse contribution only. This vehicle configuration has laminated windshield and tempered side glass. The prediction from the computational approach agrees very well with the test results up to 4 kHz. The roll-off of the computational results above 4 kHz could be due to the effect of resolution in the simulation results and the contribution of noise sources in the test that are not considered in the simulation.

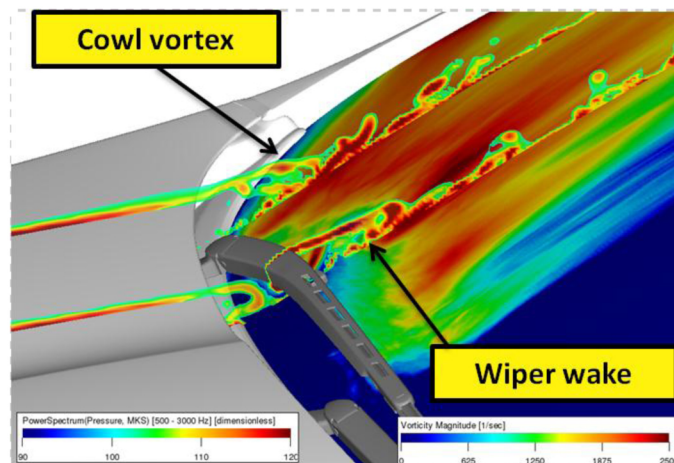


Figure 5. Noise sources in the windshield region

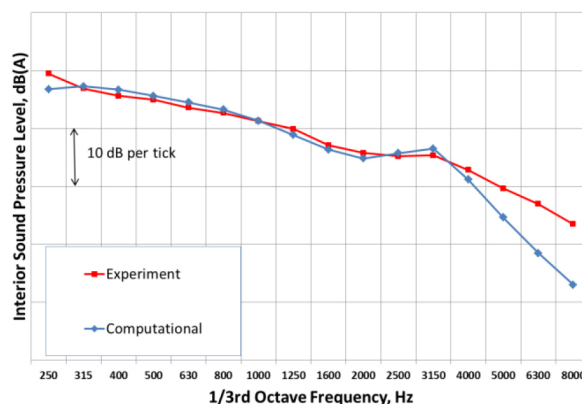


Figure 6. Interior 1/3rd octave band pressure spectra at driver head location

Effect of Wipers

Noise sources measured by the microphones

In the experiments, pressure fluctuations on the windshield for both wipers-on and wipers-off configurations were measured using 30 surface mounted microphones. The locations of these microphones are shown in [figure 7](#).

Simulations were performed with virtual microphones at the same locations to validate the accuracy of the noise source predictions. Spatially averaged spectrum for the 30 microphones that cover the entire windshield was calculated from the computational results and compared to experimental spectrum in [figures 8 and 9](#). For both configurations simulation results correlate well with the experimental results. This ensures that the computational approach is capable of predicting the overall noise sources on windshield with good accuracy.

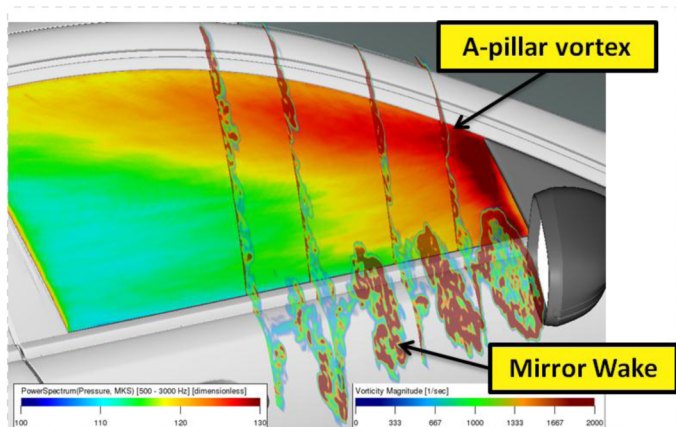


Figure 4. Noise sources in the side glass region