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Prediction of Interior Noise in a Box Structure due to Exterior Flows

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1.Introduction

Exterior flow causes surface excitation on a structure resulting source of sound. Transmitted sound through the structure sensed as interior noise is a challenge to the passenger comfort. The qualitative prediction of flow induced noise (A-Pillar Vortex & Side Window glass Interaction) is pivotal to the accurate prediction of Vibro-Acoustic transmission of sound through structural components. A simple box structured vehicle (HSM: Hyundai Simple Model) is considered for the analysis. Experiments have been carried out in HAWT at 110 KPH, 130 KPH with 0°,-10° yaw angles. Finite Volume Method (FVM) based high fidelity CFD code commercially renowned STAR-CCM+ is used for aero-acoustic computations.

2. Aero - Acoustic Modeling

2.1 Geometry

HSM has been released by HMC for public benchmark among CAE vendors. HSM being simplified model of car has vehicular features such as wind-shield inclination, sharp A-Pillar, upfront curvature of roof.

2.2 Mesh Model

Geometry is meshed with trimmer (unstructured) model in STAR-CCM+ with layered mesh with 15 cells adjacent and normal to the walls to capture the pressure-gradient induced separation on smoothly curved surfaces. The entire computational domain contains over 50 million cells with finest cell of size 4 mm around the structure as shown in figure 1.

2.3 Solver Settings

Non reflective boundary conditions have been applied at both inflow and outflow boundaries. Fully compressible treatment with ideal gas formulation for density is best suitable for acoustic calculation in STAR-CCM+ environment. SST K-Omega based DES is used for turbulent treatment. Fine temporal resolution of $2e^{-5}$ sec is chosen for acoustic analysis.

2.3 Results

A-pillar interaction with structural surfaces causes excitations. Figure 2 shows the A-pillar vortex in lambda-2 criterion value of $-8e^{5}$ for 130KPH at 0° yaw.

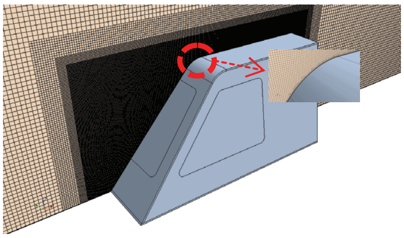

Figure 1: CAD geometry with mesh

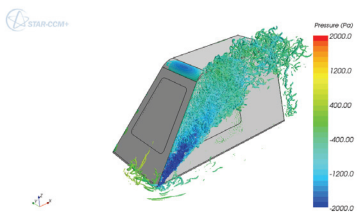

Figure 2: A-pillar vortex in lambda2 colored by pressure

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3. Vibro - Acoustic Modeling

In the CFD phase of the analysis, the HSM box structure is considered rigid (assuming flow induced vibrations do not impact the flow).The time-domain CFD data is then used in vibro-acoustic analysis as a pressure loading applied to the glass windows. The coupled-fluid-structural model is solved in the frequency domain to predict the interior SPL inside the box from 100 Hz to 5 KHz.

3.1 Structure

The box structure as shown in figure 3 consists of three 4-mm thick tempered glass panels mounted onto a 12-mm thick aluminum box structure. The aluminum structure is lined inside with a multi-layer noise control treatment (NCT) consisting of a foam-septum-foam designed to provide sound absorption within the box and to increase the Sound Transmission Loss (STL) of the aluminum structure. The effect of this NCT is to ensure that the principal source of interior noise is transmission through the side glass windows. Figure 4 compares the STL of a 4-mm thick glass sheet compared to 12-mm aluminum panel with the NCT. Below 200 Hz, the STL of the aluminum and glass are within 4-5 dB, so based on the STL predictions, airborne noise transmission through the glass windows is expected to be the dominant path above 200 Hz. The vibro-acoustic model only includes the glass windows as transmission path to the interior cavity is not expected to be accurate below 200 Hz of the measured data.

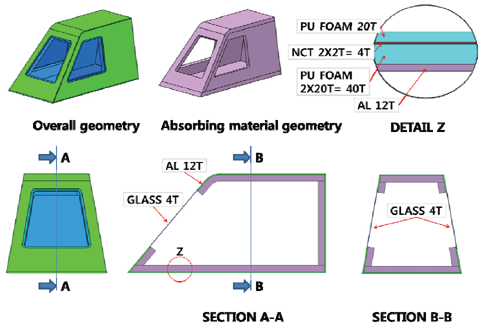

Figure 3: Detailed schematic of structure

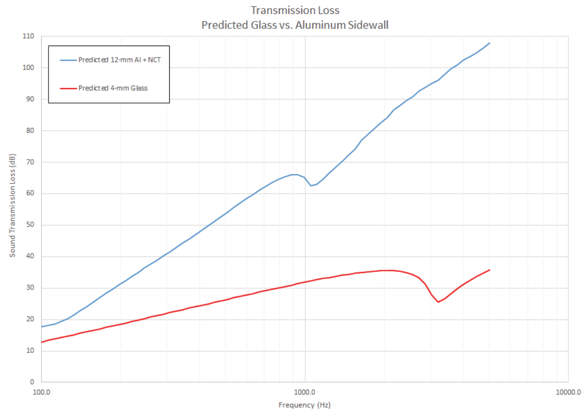

Figure 4: STL comparison 4-mm side glass vs. 12-mm wall structure+ NCT

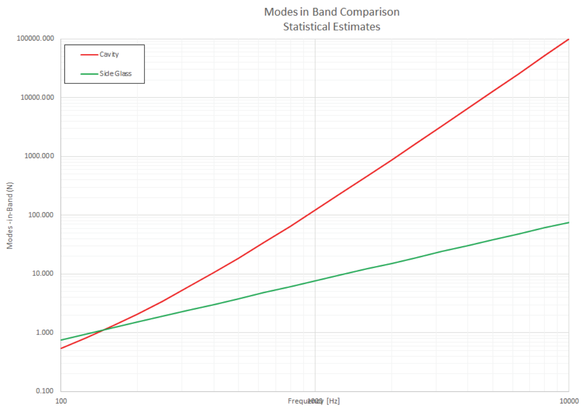

Figure 5: Statistical estimate of modes-in-band: 4-mm glass vs. interior cavity

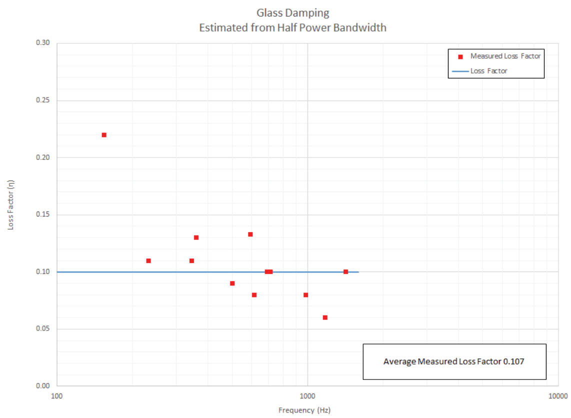

Figure 6: Glass Damping Loss Factor

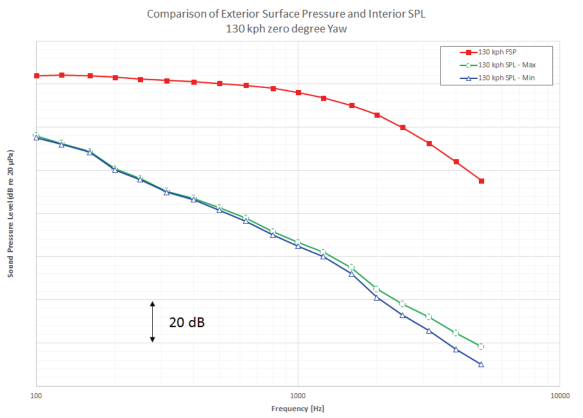

Figure 7: 130 KPH 0° yaw: exterior surface pressure vs. interior sound pressure.

Figure 5 shows a statistical estimate of the modes in 1/3rd octave bands in the side glass and interior acoustic cavity. The first acoustic mode and side glass mode are predicted to occur in the 160 Hz frequency band. Correlation with measured results below 200 Hz will therefore be sensitive to the exact spatial location where the data is recovered.

3.2 Damping loss factor

The damping used in the vibro-acoustic model was extracted from the measured data. For the glass, accelerance data (a/F) was measured at four points on the glass. The half power bandwidth from selected resonant peaks was used to estimate the glass damping loss factor is shown Figure 6.

For the acoustic cavity, the T_{60} time was measured inside the cavity. The sound absorption of the NCT could be predicted using transfer matrix methods to estimate the damping loss factor. This typically assumes a diffuse sound field, which might not be the case in the box until 1 kHz. Therefore the measured T_{60} time was used in the model after conversion to a damping loss factor.

3.3 Results

To predict the interior noise, the CFD time domain pressure results are recovered from the surface of the glass windows. The time domain pressure results are converted via fast Fourier transform and Welch’ s method to the frequency domain to provide a pressure loading that can be applied to the vibro-acoustic model. Figure 7 shows the exterior space-average surface pressure on the side glass for exterior flow at 130 kph, zero degree yaw. Also shown is the maximum and minimum interior predicted SPL across a series of data points within the cavity and illustrates the spatial variation. Note the predicted interior SPL is lower than would be expected in a full vehicle cabin, due to the high level of damping within the cavity of the HSM box.

Acknowledgements

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