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Simulation of Air Flow-induced Interior Noise with Hybrid Modeling Method

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1. Introduction

Air flow has played more and more important role in a number of vehicle performances such as wind noise, ventilation, air condition (HVAC), intake and exhaust. These ones have a significant influence on today's customer satisfaction index because the customers want not only proper capability but also higher-grade comport in terms of NVH(Vibration, Noise and Harshness).

The interior noise of a vehicle is generated by two types of sources: the aero-acoustic noise resulted from turbulence on the structure and the noise radiated from the structural vibration which undergoes excitation due to the air flow.

To predict the interior sound pressure level caused by air flow on the exterior of a vehicle, a hybrid modeling method is proposed by combining CFD(Computational Fluid Dynamics) and measured noise or acoustic transfer functions in the manner of a linearized interface between CFD and CSD(Computational Structural Dynamics).

2. Hybrid Modeling of Fluid Structure Interface

The numerical simulations to find transient pressure fluctuation on the exterior of a vehicle are performed by using a commercial CFD program based on Lattice Boltzmann Method (LBM). Because LBM finds a solution by a simple algebraic computation unlike solving discretized partial differential equations like a general Navier-Stokes equation solver, it is an inherently transient solver which gives a stable solution with very high parallel efficiency.

To create a hybrid model for FSI(Fluid Structure Interface), the global system has to be divided into a master system and a slave system. The master one contains the source DOFs and the slave one includes response DOFs where the responses are measured. Loads are defined at the interface between the master and slave system. The so-called transfer functions also referred to as Frequency Response Function (FRF) characterize the relationship between a load and a response. The paths are represented by those transfer functions. The individual contribution of each transfer path to the response can be calculated by multiplying the load by the corresponding transfer function. Using this model, an interior sound pressure level response can be expressed as follows:

$$p_k = \sum_{i=1}^{N} \frac{p_k}{F_i} \cdot f_i + \sum_{j=1}^{M} \frac{p_k}{Q_j} \cdot q_j \qquad (1)$$

Here in is

p_k : Total sound pressure level at response DOF *k*

f_i and q_j : Aerodynamic structural load at path *i* and aero-dynamic acoustic load at path *j*, respectively.

N and M: The number of structural paths and acoustics paths, repectively.

$\frac{p_k}{F_i}$: Noise transfer function at response DOF *k* due to a force input at transfer path *i*

$\frac{p_k}{Q_j}$: Acoustic transfer function at response DOF *k* due to a force input at transfer path j

1^{st} and 2^{nd} terms of the rightside in Equation 2 consists of the contribution of structural paths i and acoustic paths j, respectively. Above equation can be solved if two kind of quantities are measured: the transfer functions and the operational forces. According to the hybrid modeling scheme, both quantities can be achieved with one way, FEM (Finite Element Method) based calculations such as CFD and CSD or the other way, direct measurements.

Considering that fluid-structure interface is naturally expressed as non-linear. So, Equation 1, of which format is linearized, has been obtained with an assumption of one-way coupling. This means that only aerodynamic forces effectively excite the structure. This assumption is useful and efficient to address to an engineering problem as depicted in Section 3.

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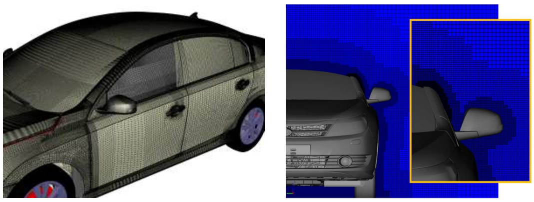
3. Numerical Example

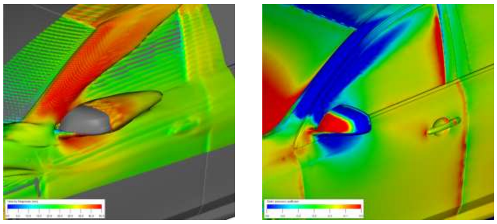
Aerodynamic interior noise in lower frequency range caused by A-pillar air flow has been investigated as a numerical example. A D-segment notchback sedan on the mass production is used for the simulations.

To check the effect of vehicle driving velocity to the pressure fluctuation, three different velocities were simulated (120, 140, and 160 km/h) at the yaw angle of zero degree. Unsteady time step for the flow simulation was set to 2×10^{-6} second for all cases and total 600,000 iterations were performed. Pressure sampling frequency was 2000Hz for the sampling points at the front side glasses.

Figure 1(a) shows surface and volume mesh distributions. For the accurate geometric modeling, less than 0.05mm chordal deviation is allowed for A-pillar and rear view mirror. For the efficient and accurate prediction of unsteady pressure fluctuation, mesh adaptation is used around A-pillar and rear view mirror wake area, which gives about 60 millions of volume meshes with the symmetric boundary condition along with vehicle longitudinal direction. 50 hours are required for one simulation using 120 CPUs parallel machine composed of 2.4GHz Zeon CPU.



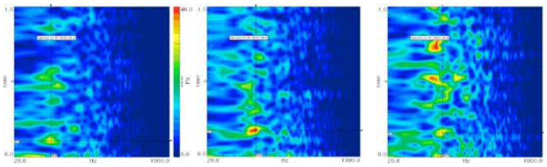
(a) Surface (left) and volume mesh in the active side of symmetric plane (right)



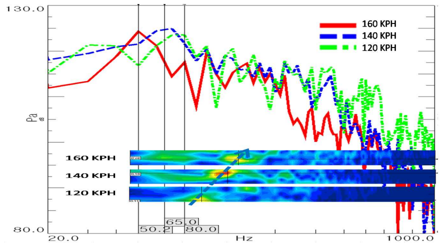
(b) Iso-surface of zero total pressure coefficient (left) and surface pressure coefficient distribution (right)

Figure 1. Computational model for Computational Fluid Dynamic Analysis

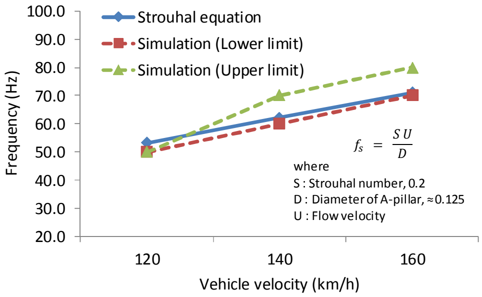
Secondly, each pressure time history was processed with FFT(Fast Furier Transform) to interpolate the CFD result to CSD input in the form of frequency spectrum. Figure 2(a) ~ (c) says the color maps of the spectrums corresponding to the vehicle velocities (120, 140, and 160 km/h). The 1st largest peaks in the color maps could be traced by the frequency spectrum corresponding to the time band from 0.1 sec to 0.2 sec. The frequency spectrum in Figure 2(d) tells that the main peak is approximately travling from 50Hz to 65±5Hz and 75±5Hz. Strouhal frequency is well matched with the frequency values as described in Figure 2(e). After the interfacing step, the hybrid modeling synthesis has been done to forecast interior noises.



(a) 120 km/h (b) 140 km/h (c) 160 km/h



(d) Frequency spectrum of time band



(e) Comparison of vortex shedding frequency: Theory vs. simulation

Figure 2. (a) ~ (c) Color-maps of the aerodynamic pressure corresponding to the interfacing point at the center of driver's side window glass, X-axis in log scale, Y-axis & Z-axis in linear scale, (d) Frequency spectrum of the time band, 0.1sec ~ 0.2 sec corresponding to 1st largest peak, X-axis in log scale, Y-axis in dB scale, (e) Validation of vortex shedding frequency

4. Conclusions

This multiphysics study has been addressed. Analyzing the frequency spectrums of aerodynamic pressure time histories, it has been found that the frequencies of the largest peak below 100Hz are related to the vortex shedding frequency.