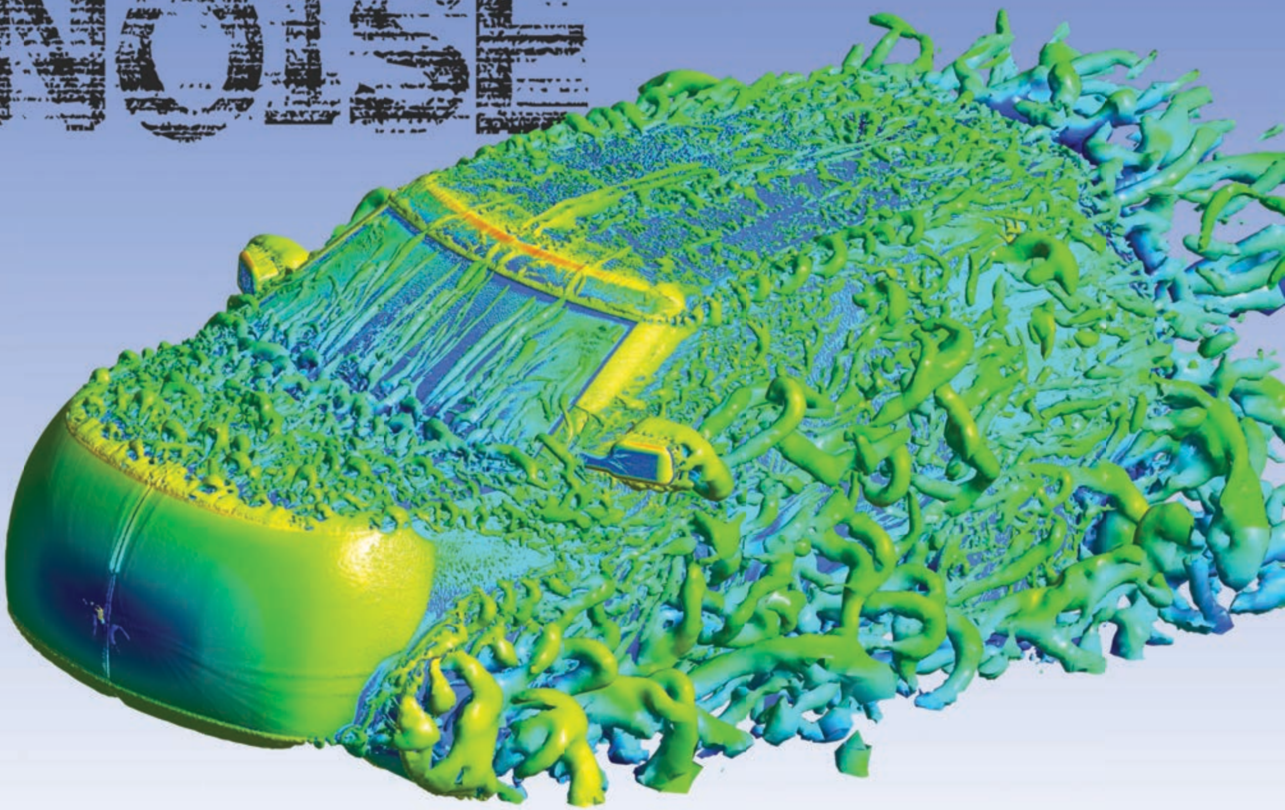
A WINDOW INTO AUTOMOTIVE NOISE

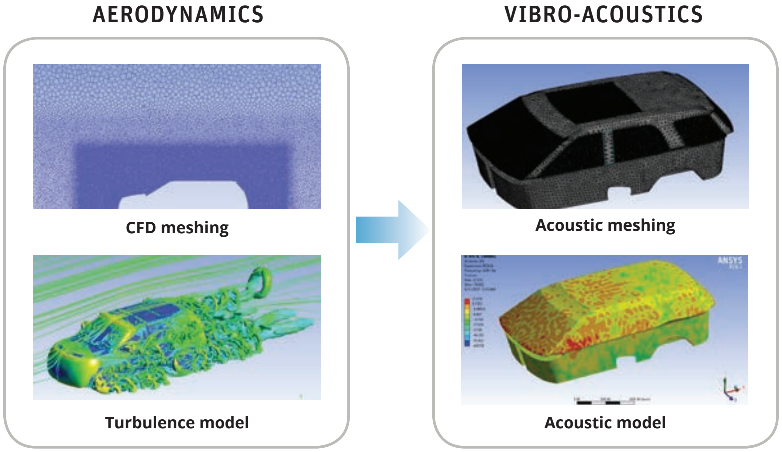


The interior of a vehicle can be distractingly loud due to wind turbulence, especially at highway speeds. At Corning, engineers combined aerodynamic and vibro-acoustic analysis in ANSYS Workbench to determine how glazing can help control interior noise.

By **Chao Yu**,
Senior Project Engineer,
Advanced Machine Systems,
Corning Incorporated,
Corning, USA

Most drivers understand that they have to turn up the radio on the highway if they want to hear their favorite station, or speak louder if they want to have a conversation with their passengers. This is the direct result of the turbulent air flowing around their vehicle when driving at high speed. Recent studies by J.D. Power on U.S. vehicle dependability [1] have reported that excessive wind noise was one of the top problems most commonly experienced by vehicle owners. Depending on where the exterior noise falls in the frequency spectrum, vehicle occupants may perceive that noise as falling anywhere between a quiet conversation (40 to 50 decibels, or dB) and a busy city street (70 to 80 dB).

To help mitigate this problem, engineers at Corning [2] have been studying the physical mechanism by which exterior wind translates into cabin noise. At highway speeds, the air surrounding a vehicle is disturbed by the vehicle's front end, the A-pillar (windshield support structure) and side mirrors. This results in turbulent flow that causes fluctuations in the air pressure field on the outer surface of the vehicle. These pressure variations cause the glazing (windshield and other window glass) to vibrate, which in turn excites the cabin air and generates some of the interior noise. Another major cause of interior noise is the wind on the rest of the automobile surfaces being transmitted through the automobile parts to the cabin (flanking noise). In addition, the sound generated by tires in contact with the road and by the operation of the automobile's mechanical systems contributes to cabin noise.



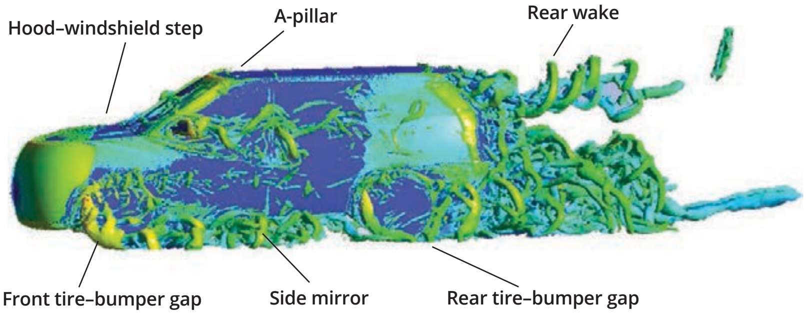
Full-vehicle wind noise model illustrates the combination of aerodynamic modeling with vibro-acoustic modeling used in the DAVA method.

Corning engineers wanted to determine which glass surfaces were the most important paths for glazing noise transmission, and also whether lighter-weight glass material would have an impact. The team employed a simulation method called deterministic aero-vibroacoustics (DAVA) using fluid and structural analysis tools in ANSYS Workbench. The DAVA process began with a simplified geometry of a common U.S. sport-utility vehicle to reduce the cost of meshing and overall computation. Because the study focused on sound transmission through glazing, detailed vehicle features in the regions surrounding the glass — such as mirrors and the A-pillar — were maintained, while areas around the bumpers and tires were modeled with less detail. Taking advantage of symmetry, the engineers used ANSYS CFD meshing capability to create a computational fluid dynamics (CFD) mesh of 55 million hexcore cells to model the fluid domain surrounding half of the vehicle geometry. The size of the domain was chosen so that vortex shedding, flow separation and reattachment phenomena could be captured.

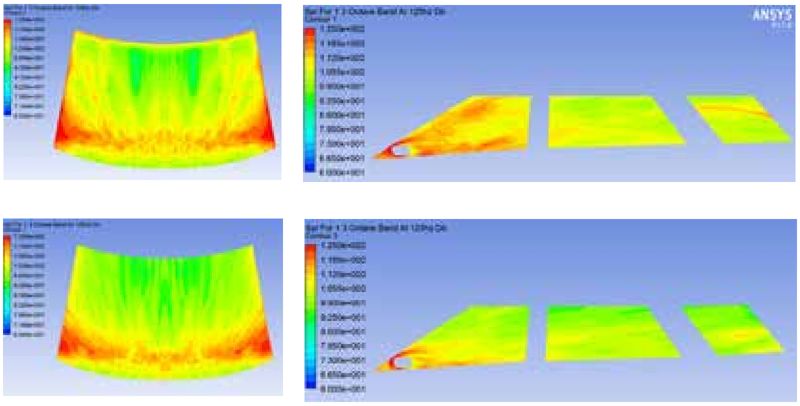
> “There was excellent agreement between the simulation results and experimental SPL data.”

Noise Generation

Once the mesh was complete, Corning's engineering team used the ANSYS Fluent CFD solver to simulate the transient turbulent flow in the domain. To predict the vortices generated by 80 mph air flow over the vehicle, the engineers chose to use the detached eddy simulation (DES) model. DES is a hybrid formulation that switches between the standard Reynolds-averaged Navier-Stokes (RANS) solution and large eddy simulation (LES) modeling based on the mesh resolution and distance from the wall. LES is computationally more expensive, and was used in the coarser domain away from the vehicle, while RANS was used to solve the more finely resolved areas at the wall boundaries. The team ran the DES model for 10,000 time steps to simulate



Main vortex shedding regions from the turbulent flow field using the Q-criterion, colored by velocity magnitude

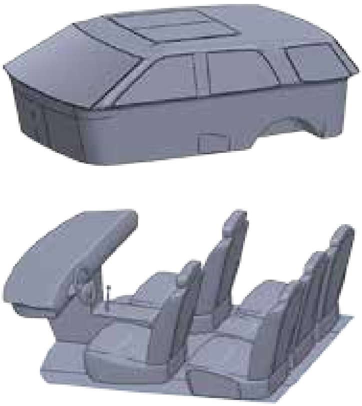


Contours of exterior SPL at 125 Hz on the windshield (left) and side windows (right) for standard transition (top) and smooth transition (bottom). The standard transition shows locally higher SPL values on the sides of the windshield and front side windows.

0.5 seconds of actual turbulent flow. Such a small time step was required because the team needed to resolve frequencies up to 5 kHz to cover the wide range of airborne noise. Corning converted the transient data from the time domain to the frequency domain using the fast Fourier transform (FFT) capability, which allowed them to evaluate the sound pressure levels (SPL) of glazing in the more commonly understood dB scale. This large case required use of ANSYS HPC on Corning's HPC cluster.

The initial CFD analysis showed greater exterior SPL values at the lower corners of the windshield and on the front side windows when compared to the rest of the glazing. In a standard windshield design, there is usually a small under-flushing discontinuity between the glass surface and the A-pillar where the edge of the glass extends under the pillar. The team's baseline vehicle model considered a design with 5 millimeters of under-flush, which they compared to a modified design with a smooth transition (no under-flush) between the windshield and A-pillar. The modified design predictions indicated an exterior noise reduction of up to 5 dB on the front side windows. In addition to the modified geometry, the team ran the simulation twice more at air flow speeds of 60 mph and 30 mph. As expected, the predicted exterior wind noise was reduced as vehicle speed decreased.

> "Corning engineers wanted to determine which glass surfaces were the most important paths for glazing noise transmission, and also whether lighter-weight glass material would have an impact."



Interior cabin geometry (top) and structures (bottom)

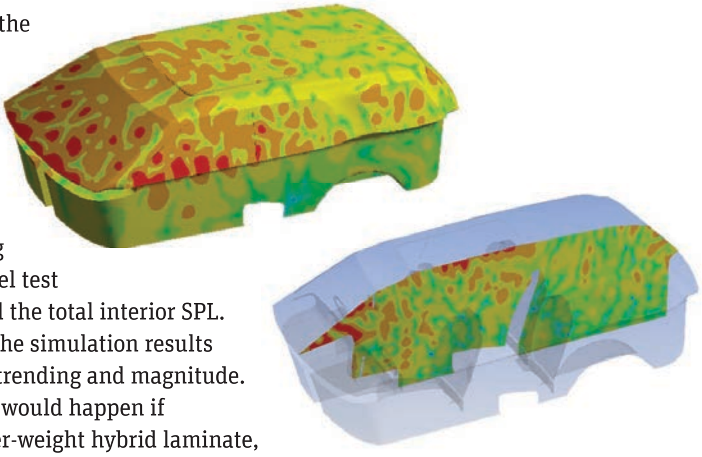
Noise Transmission and Propagation

With the exterior SPL predictions in hand, the Corning team used them as inputs in ANSYS Mechanical for the vibro-acoustics analysis. The engineers mapped the pressure onto surfaces of the vehicle body to act as external excitations. The team created a separate mesh for the cabin boundary and interior, with the glass surfaces being shared by the exterior and interior geometries. The interior geometry also included structural bodies for the seats, dashboard, gearbox and steering wheel to better represent sound wave absorption and reflection. Initially, the engineers considered windshield and front side windows composed of two layers of soda lime glass (SLG) laminated together with polyvinyl butyral resin, and monolithic SLG material for all other vehicle glazing. At a typical frequency of interest (1 kHz), the harmonic response simulation predicted that the SPL would be higher at the front end of the vehicle, with most of the noise coming from the windshield and front side windows. The combined simulation time for the ANSYS Mechanical analysis was 300 CPU hours over the range of 21 sampling frequencies.

ANSYS Aero Vibro-Acoustics
ansys.com/aero-vibro-acoustics

As validation for their results, the team collected SPL measurements from a wind tunnel using a microphone placed at the location of the driver's ear in a test vehicle. However, since the wind tunnel measurements were of the total interior SPL, the team also needed information about the flanking noise in addition to the glazing noise. They could ignore the tire and mechanical system contributions to the SPL in this study since the test vehicle was stationary and not in operation. To account for the flanking noise, the team performed a separate wind tunnel test with all glass surfaces shielded and then derived the total interior SPL. Overall there was excellent agreement between the simulation results and the experimental SPL data in terms of both trending and magnitude.

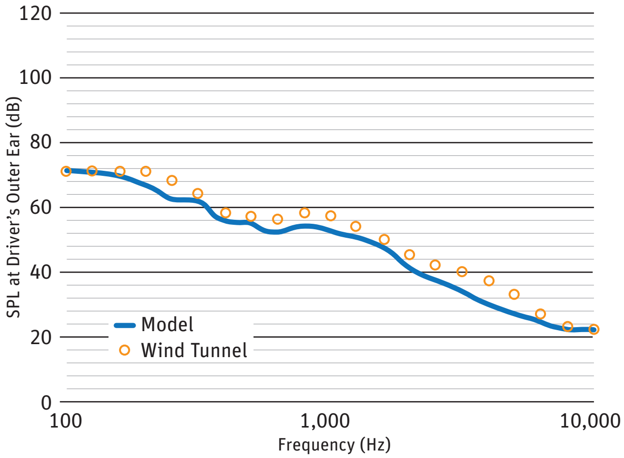
As an additional test, Corning analyzed what would happen if windshield and front side windows used a lighter-weight hybrid laminate, with the inner SLG layer replaced by a thinner layer of Gorilla® glass material. Though the simulations showed an acoustic penalty in terms of the glazing noise, the team judged the overall effect to be minimal since flanking noise is the dominant source at highway speeds. For both SLG–SLG and SLG–Gorilla glass laminate materials, using the smooth transition from the windshield to A-pillar compared to the standard under-flush transition reduced the perceived cabin SPL for lower frequency (under 500 Hz) exterior noise.



Cabin SPL at 1 kHz shown in overall 3D (top) and cross-section (bottom) views, with red and orange representing the highest values

> "The team estimated that it will reasonably be able to see a 30 to 50 percent improvement in the efficiency of its design and evaluation process, leading to a similar level of process cost savings."

At the end of the process, the Corning group had developed a model that provided powerful analysis for investigating full vehicle noise generation, transmission and propagation. With these initial results, the team estimated that it will reasonably be able to see a 30 to 50 percent improvement in the efficiency of its design and evaluation process, leading to a similar level of process cost savings. Although different vehicle designs may show different levels of importance for the noise transmission paths, this general DAVA evaluation approach enables the designer to focus on the most critical glazing and optimize the design.



Comparison of DAVA method predictions with wind tunnel data at different noise frequencies, showing excellent agreement in both trending and magnitude for cabin SPL

References:

[1] J.D. Power. jdpower.com/cars/articles/jd-power-studies/vehicle-dependability-study-top-10-problems-3-year-old-vehicles (01/11/2018)

[2] Yu, C., *Automotive Wind Noise Prediction using Deterministic Aero-Vibro-Acoustics Method*, 23rd AIAA/CEAS Aeroacoustics Conference, AIAA AVIATION Forum, (AIAA 2017-3206).