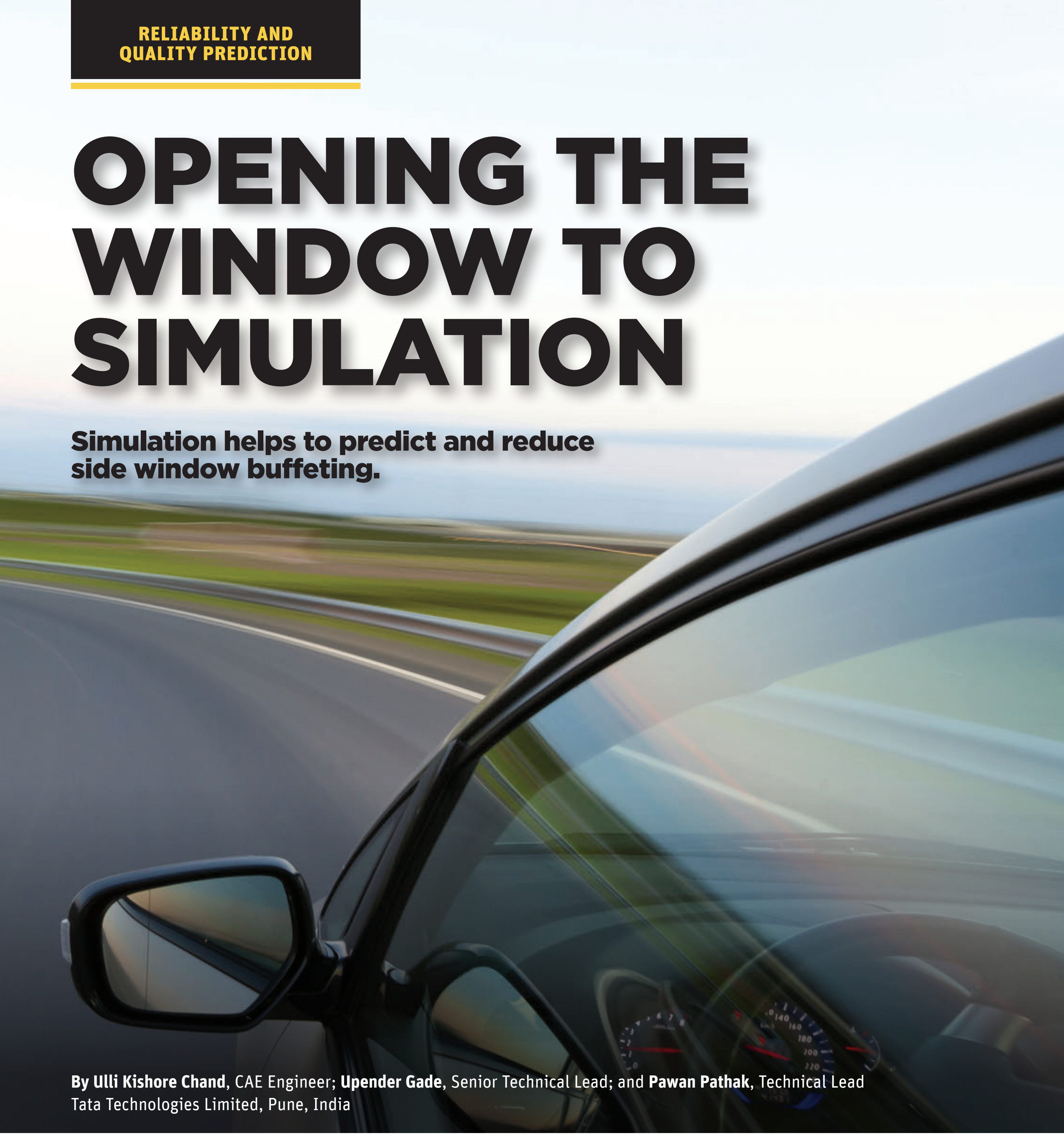

OPENING THE WINDOW TO SIMULATION

Simulation helps to predict and reduce side window buffeting.

By **Ulli Kishore Chand**, CAE Engineer; **Upender Gade**, Senior Technical Lead; and **Pawan Pathak**, Technical Lead
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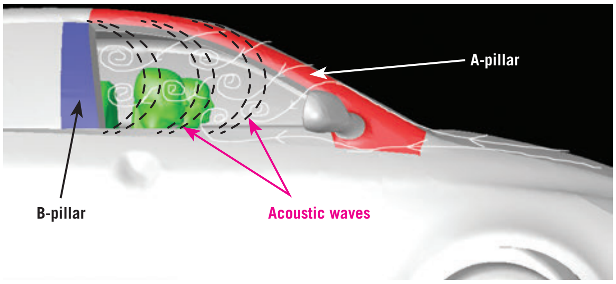

▲ Wind buffeting can intensify due to flow-acoustic feedback.

Imagine that while driving you open the window to let in cool, fresh air. But soon, you feel uncomfortable pulsations and hear noise, called wind buffeting or wind throbbing. Other sources of vehicle noise have been reduced, so automotive engineers are spending more time and effort addressing wind buffeting. Traditionally, engineers have built and tested each design to determine how it performs with regard to wind buffeting. However, Tata Technologies engineers are now accurately simulating wind buffeting with ANSYS Fluent computational fluid dynamics (CFD) software, making it possible to evaluate many different designs without the time and cost involved in building a prototype.

CFD makes it possible to quickly and inexpensively evaluate possible corrective measures and provide diagnostic information.

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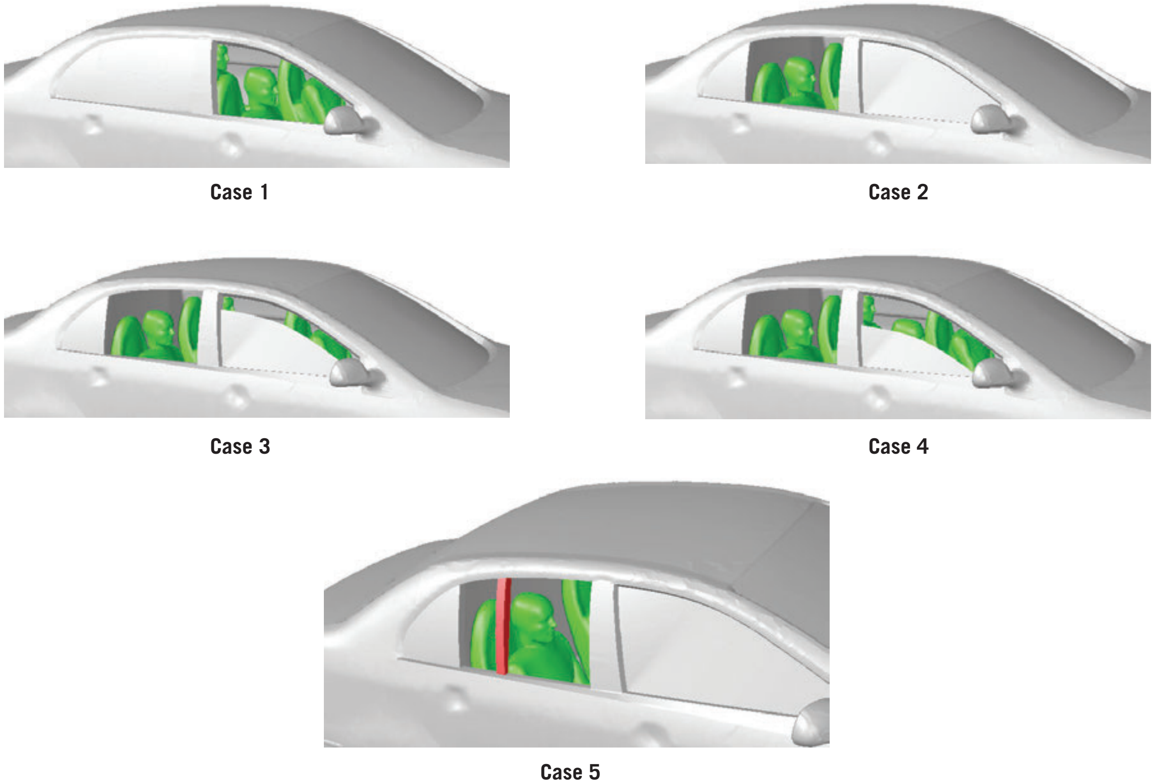
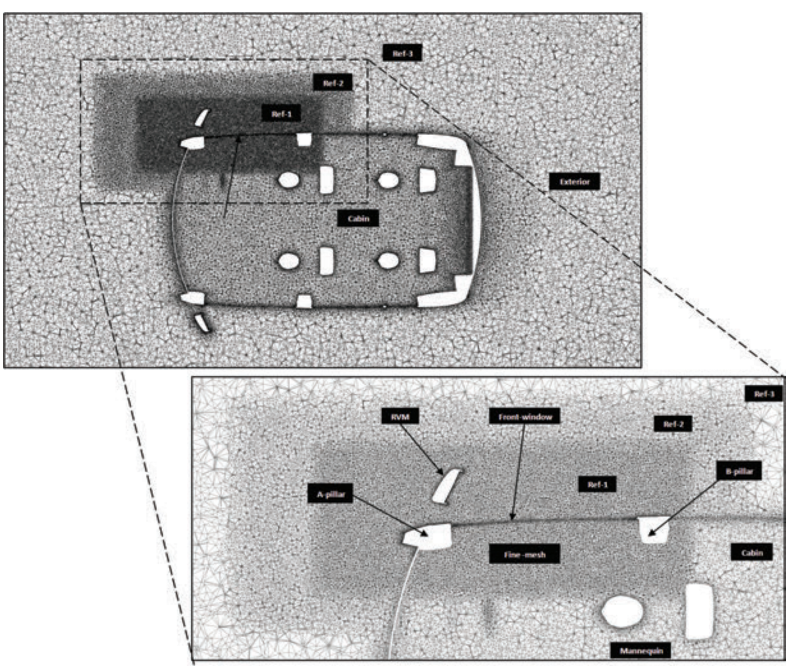


Five wind buffeting cases studied by Tata Technologies



Volume mesh

[redacted]

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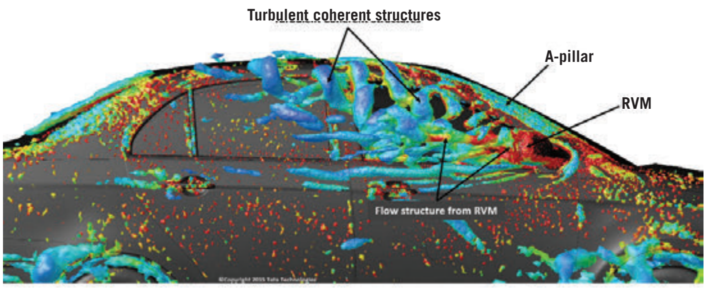
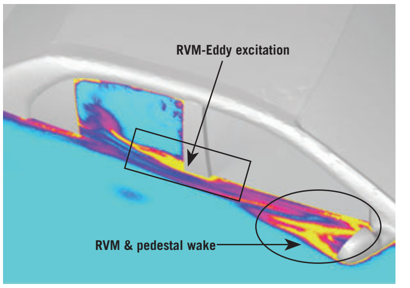
Wind buffeting typically occurs when an unstable shear layer is established at the upstream edge of the window opening, along the A-pillar in the case of front-side window buffeting. Vortices are shed from this location and travel downstream along the side of the vehicle to the structure. When these vortices reach the B-pillar, they interact with the B-pillar to generate acoustic waves that propagate inside and outside the passenger compartment. When the forward-moving waves reach the A-pillar, they trigger more vortices that move back to the B-pillar. At certain travel speeds and for certain window and cabin geometries,



▲ Turbulent structure visualization around A-pillar



▲ Flow visualization shows the importance of the rear-view mirror in exciting wind buffeting in case 2.

this process generates self-sustaining oscillations that can create large pressure variations in the cabin that are uncomfortable and annoying for vehicle passengers.

LIMITATIONS OF PHYSICAL TESTING

To increase passenger comfort, automotive manufacturers have been steadily reducing structure-borne and airborne noise. Vehicles now operate much more quietly, but this makes wind buffeting more noticeable than it had been in the past. The frequency of wind buffeting is often below the range that can be heard by human ears, yet passengers can still experience an unsettling fluctuating force. Engineers measure these pressure fluctuations generated by wind buffeting with microphones. They then typically perform Fourier transform analysis on the analog signal to convert it to an acoustic spectrum in which amplitude is plotted as a function of frequency to better understand the causes of buffeting and its effects on vehicle passengers. These measurements can be performed only relatively late in the design process when vehicle prototypes have been created. At this point, many design decisions have been made, so changes are expensive and run the risk of delaying product introduction. Physical testing and design validation are conducted in anechoic wind tunnel facilities, which are expensive and complex to build and maintain. Sometimes they provide only very rudimentary diagnostic information, so engineers must rely upon intuition and experience in developing alternative solutions.

APPLYING SIMULATION TO WIND BUFFETING

Working with leading automotive original equipment manufacturers, Tata Technologies engineers are using numerical methods to simulate wind buffeting in the early stages of the product development process, long before prototypes are available. In the example shown here, engineers used CATIA® computer-aided design (CAD) to create five models:

- **Case 1:** Front window completely open, rear window closed
- **Case 2:** Front window closed, rear window completely open
- **Case 3:** Front window slightly open, rear window completely open
- **Case 4:** Front window halfway open, rear window completely open
- **Case 5:** Front window closed, rear window completely open, split pillar divided rear window

The objective of the study was to understand the influence of partially or fully open combinations of windows while cruising. A split-bar was installed in one of the cases to study the effect of altering window geometry. All cases were simulated at ambient conditions for vehicle speeds between 80 and 100 kilometers per hour. Virtual mannequins represent vehicle occupants, and other cabin details — like dashboard, seats, interior trim, etc. — were used to accurately model the cabin volume.

Tata Technologies engineers performed boundary meshing of each CAD model and then used ANSYS software to generate a volume mesh. Four stages of grid refinement were used with the finest mesh in the area around the window and rear-view mirror to resolve the turbulent structures and boundary layer. Buffeting is an inherently transient and complex turbulent phenomenon that involves generation and interaction of nonlinear turbulent eddies at the window corners. This poses a challenge in terms of computational resources.

A steady-state compressible Reynolds-averaged Navier–Stokes (RANS)/k-ε solution was used to initialize an unsteady large-eddy simulation (LES) solution. LES models resolve large turbulent structures in both time and space as well as simulate the influence of large-scale eddies that are responsible for generating acoustic sources on the window posts. The flow simulation calculated unsteady static pressure signals at four locations near

Tata Technologies engineers accurately simulate automotive wind buffeting, making it possible to evaluate many different designs without the time and cost involved in building a prototype.

Integrating simulation from the early stages of the design process helps the company to reduce wind buffeting and increase customer satisfaction.

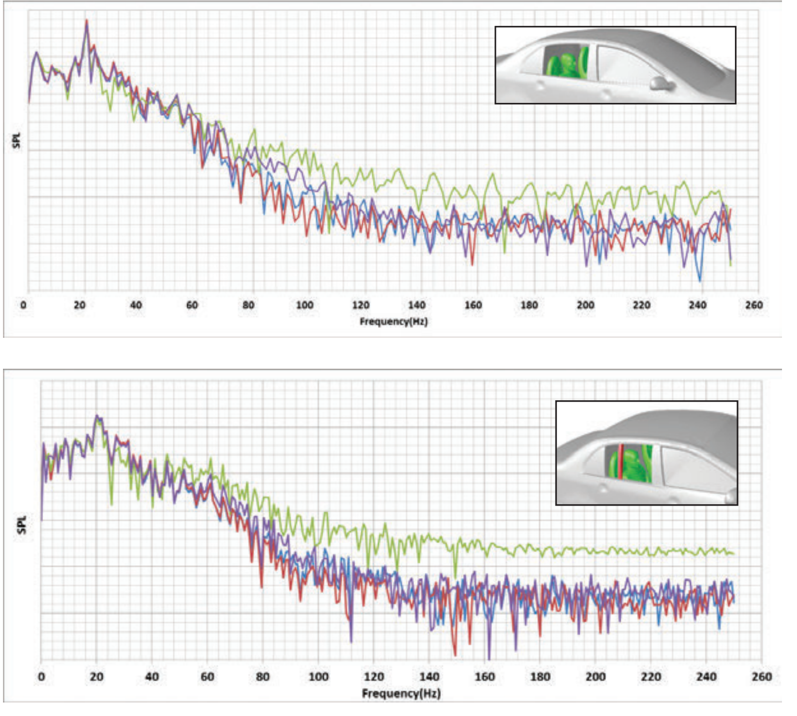
each mannequin's right ear. This method is analogous to pressure extraction using microphones placed on a test dummy in wind tunnels.

The Tata Technologies team post-processed each unsteady static pressure signal using the fast Fourier transform (FFT) tool. FFT converts the pressure signal from the time domain to the frequency domain. FFT enabled engineers to conduct spectral analysis that determined the peak sound pressure levels and frequencies at each virtual microphone location on the test dummy.

RESULTS USED TO IDENTIFY AND CORRECT WIND BUFFETING PROBLEMS

Buffeting studies on benchmark cases have shown that CFD results correlate well with wind-tunnel testing data. Similar modeling methodologies applied to the five case studies provided diagnostic information far beyond what could have been obtained with physical testing. For example, simulation results for case 2 showed that the side mirror and its pedestal wake excited the unstable shear layer at the B-pillar, reducing wind buffeting by about 6 dB with respect to a baseline case without a rear-view mirror. This demonstrates that protruding surfaces like the rear-view mirror and window visor offer opportunities to suppress buffeting. This information would have been difficult or impossible to determine with physical testing alone.

Power spectral density plots generated by the simulation showed that in case 2 much of the acoustic energy was concentrated at a frequency of about 20 Hz, which is close to the cabin's resonant frequency. Case 3 showed that this frequency slightly increased by 5 Hz when the front window was one-quarter open while the rear window was fully open, due to venting effects. Sound pressure level plots showed that the peak sound pressure level and the corresponding frequency was the same for all the four vehicle occupants although the overall sound pressure level varied from location to location.



Sound-pressure level comparison between case 2 (top) and case 5 (bottom) shows the beneficial effects of the split pillar.

The results also showed that case 2 generated the highest sound pressure levels, between 120 dB and 130 dB, for vehicle velocities between 80 kph and 100 kph. Cases 3 and 4 showed a drop in sound pressure level of between 5 dB and 10 dB with respect to case 2, and case 1 produced the lowest sound pressure level. Reductions in sound pressure levels ranging from 8 dB to 12 dB for the different passengers in the vehicle were predicted with the split pillar in case 5 relative to the same configuration without the split pillar (case 2).

CFD makes it possible to quickly and inexpensively evaluate possible corrective measures; it provides diagnostic information that helps determine why a potential solution does or does not work without investing the time and cost of building a prototype. The ability to model acoustic generation/propagation and visualize the turbulent flow structures responsible for generating acoustic sources helps engineers to understand exactly why wind buffeting occurs in a particular case and assists them in identifying promising solutions. Tata Technologies engineers use CFD to investigate a wide range of possible design solutions to wind buffeting problems and to determine general guidelines for reducing wind buffeting. Integrating simulation from the early stages of the design process helps the company to reduce wind buffeting and increase customer satisfaction.