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# The Contribution of the A-Pillar Vortex to Passenger Car In-Cabin Noise

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### Abstract

The flow around the A-pillar of a passenger car is a source of aerodynamic noise as well as a source of surface pressure fluctuations on the side window glass. A car was fitted with flush mounted microphones to measure surface pressure fluctuations and an Aachen Head system to measure interior noise. Testing was carried out in two different wind tunnels, as well as on road. Testing was carried out with the vehicle in factory trim, and also with the addition of acoustic insulation to reduce mechanical, tyre, and aerodynamic noise other than from the A-pillar region. It was found that simple changes in geometry have significant effects on reducing flow separation in this area, however the difference in interior noise SPL in realistic on-road driving conditions is not readily discernable.

### Introduction

There are several sources of noise in passenger cars. Below approximately 80km/h mechanical and tyre/road noise sources dominate, whereas above about 100km/h noise from the interaction of the body structure can dominate (Hucho [6]). The shape of a passenger vehicle has to be a compromise between many factors, including aerodynamic efficiency and drivetrain/occupant space requirements. There will generally be flow separation in the A-pillar region and this has been shown to influence wind noise (Watanabe [8], Popat [7], Haruna [5], and Alam [1]). The position and scale of this separation will depend on speed, yaw angle, and specific vehicle types (Hucho [6]). In most situations the flow will reattach in the area of the side window, and there will be a region of fluctuating pressure between separation and reattachment lines. There are a number of mechanisms whereby this fluctuating surface pressure will manifest itself into noise heard by the vehicle occupant; these mechanisms are leakage past seals, rigid body motion or flexure of the side glass. Mechanisms of transmission were studied by Callister [3], and Callister and George [4].

The objectives of this research are to determine the effect of local A-pillar flow on interior noise, how simple geometry changes can affect flow and noise, and how significant A-pillar generated noise is in normal on-road driving conditions.

### Fluctuating Local Surface Pressures

The test vehicle was a General Motors Holden Commodore sedan. The general shape and aerodynamic characteristics of this vehicle are similar to many contemporary passenger cars. This vehicle is shown in Figure 1.

Figure 1: Test vehicle

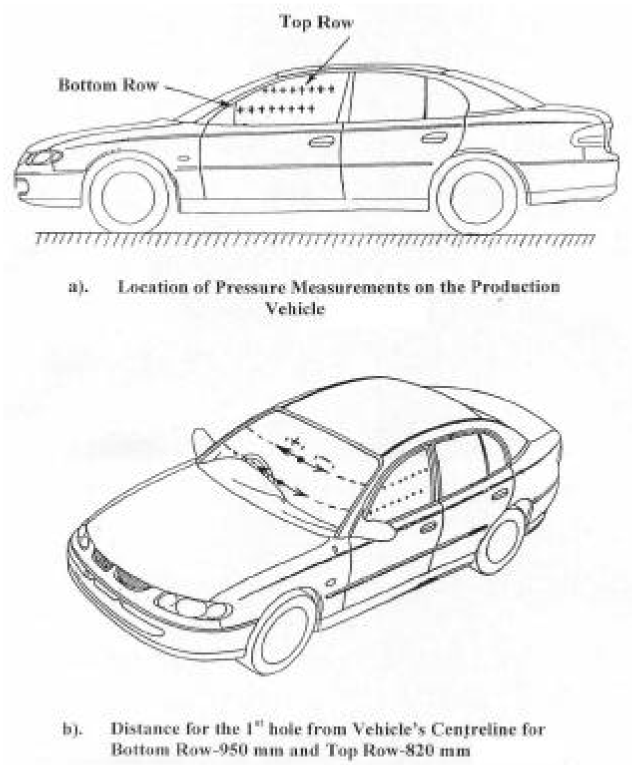


Figure 2: Microphone location points.

In order to measure the flow regime in the A-pillar / side window area, the passenger side door window was removed and replaced by a sheet of 4mm Perspex. This was cut to the shape of the original window and mounted in the original channels at the leading and trailing edges. A total of sixteen 11mm OD holes were drilled in two rows, at 1/3 and 2/3rds of the height of the normal window opening. Figures 2 and 3 show this arrangement.

Figure 3: Microphones in bottom row holes.

The holes were spaced 80mm apart horizontally. These are referred to as nos.1 to 8 (Bottom Row or BR) and 9 to 16 (Top Row or TR). Due to the A-pillar slant, No.9 was 280mm rear of no.1. Figure 3 shows 8 microphones in the bottom row of holes. For measurement of fluctuating surface pressures G.R.A.S. ¼" condenser microphones in cylindrical adapters were inserted in the window holes flush with the exterior surface. (The authors also experimented with slight protrusion or recession of the microphones, and found negligible effect on the signal obtained.)
The signal from each G.R.A.S. microphone was taken via amplifiers to a 16 channel Sony DAT recorder sampling at 24kHz. Signal processing was carried out using Matlab and fluctuating pressure is presented here as Cp(rms), this being defined as the standard deviation of the pressure fluctuations divided by free stream velocity head.

During testing, an attempt was made to reduce noise transmission through windows and panels by using acoustic insulation. This comprised of 60mm thick expanded polystyrene bats, and "Wavebar" brand 4mm thick high-density lead-based vinyl sheet. This was installed in the front and rear footwells, between the doors and B-pillars, above and below the rear parcel tray, lining the roof, behind the rear seat, rear window, and trunk floor and sides.

## Interior Noise Measurement

During wind-tunnel and on-road testing, passenger compartment noise was measured using an artificial head (Aachen Head) measurement system. The Aachen Head was secured in the front passenger seat. Signals from left and right channels were recorded on the DAT mentioned previously.

## Wind Tunnel Testing

Initial testing was undertaken at the RMIT University Industrial Wind Tunnel, Melbourne, Australia. This tunnel is 3m x 2m, and the vehicle produced a blockage of approximately 35% (Zimmer [9]). The primary aim in that case was systems checkout, and although good results were obtained they will not be presented here.

Principal testing was undertaken at Monash/RMIT Universities' wind tunnel, also in Melbourne, Australia. This tunnel is a vertical closed loop type, with an open jet test section. The jet nozzle is rectangular 4m x 3m, and exits into an 8m wide x 6m high plenum. The collector is approximately 12m behind the nozzle exit. Test speeds were 60, 80, 100, 120 and 140 km/h. As the Monash/RMIT wind tunnel is equipped with a turntable, the vehicle was yawed at angles of -15° to +15° in increments.

## Road Testing:

Road testing was carried out on a relatively smooth section of the Hume Highway, near Broadford, Victoria, Australia. The vehicle was driven at indicated speeds corresponding with those of previous wind-tunnel tests. Ambient wind conditions were checked using a hand-held anemometer. Many aspects of road testing on public highways are of course beyond the control of the experimenters, however great care was taken to avoid traffic and wakes of other vehicles, and sufficient test runs were conducted to provide reliable data.

## Presentation of Results:

Figure 4 shows the fluctuating pressure, Cp(rms), from a wind tunnel test of a car in standard configuration, at 0° and at speeds of 60km/h to 140km/h. The x axis scale represents the distance rearward of the A-pillar. The 80mm longitudinal spacing of the microphones is also represented to scale. Thus there are two plots, the first for the lower row of microphones, the second for the upper row of microphones.

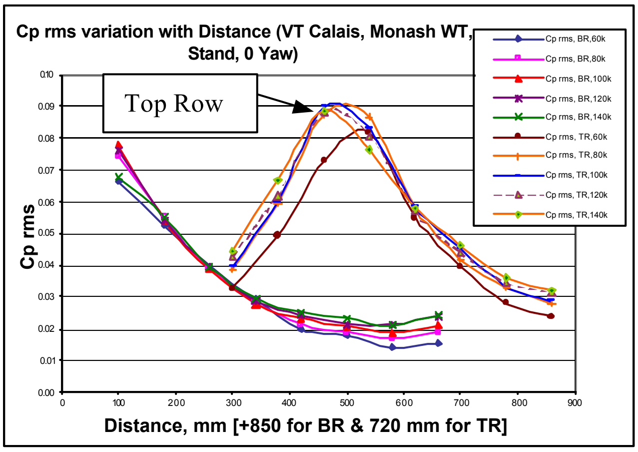


Figure 4. Cp(rms) standard

Figure 4 shows indicates a region of fluctuating pressure in the location of the top row microphones, rearward of a similar peak in the lower row microphones. It was not possible to mount any instruments further forward (i.e. further to the left on the x axis) of

Position 1 due to the car body structure. For all speeds the data collapse, the exception being top row positions 9 to 11, at 60km/h. At this speed signal strength was very low and source of deviation.

Fig. 5 shows Cp(rms) measured on the same vehicle, in the wind tunnel, also at 0° and at the same velocities. The only difference was that this vehicle was "modified", with the addition of polyethylene sheet and tape to streamline and increase the local radius of the A-pillar.

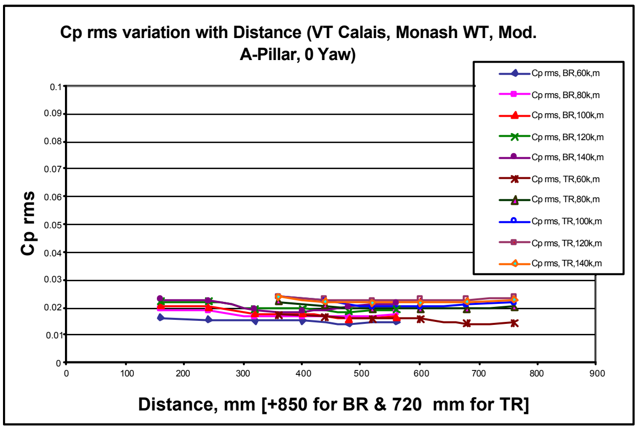


Figure 5: Cp(rms) mod-A-pillar

What can be seen in fig.5 is that the magnitude of the fluctuating pressure now reduces from a peak value of 0.09 in fig.4 to a reasonably uniform value of around 0.02, which is to be expected in a turbulent boundary layer (Blake [2]). Comparison between figs 4 and 5 show a simple modification in geometry has a dramatic effect on the strength of the A-pillar vortex and the pressure fluctuations on the window surface.

Figure 6 shows the spectra (PSD) of interior noise for the standard vehicle, as measured in the Monash/RMIT wind tunnel, at a speed of 140km/h. Yaw angles of -15°, 0°, and +15° were used, although experiencing a yaw angle of ±15° at this speed would be unusual in daily driving.

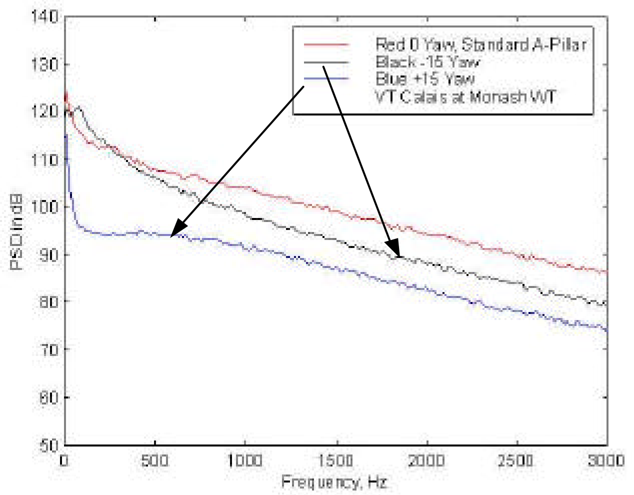


Figure 6: Interior Noise, standard car, wind tunnel, 140km/h.

A positive yaw angle is defined as the instrumented side of the vehicle angled to windward. This shows that interior noise is highly dependent upon yaw angle, and the highest level of noise occurs when flow is separated, i.e. at both 0° and negative yaw angles, which exhibit similar trends. When flow is attached, at positive yaw, noise levels are consistently lower.

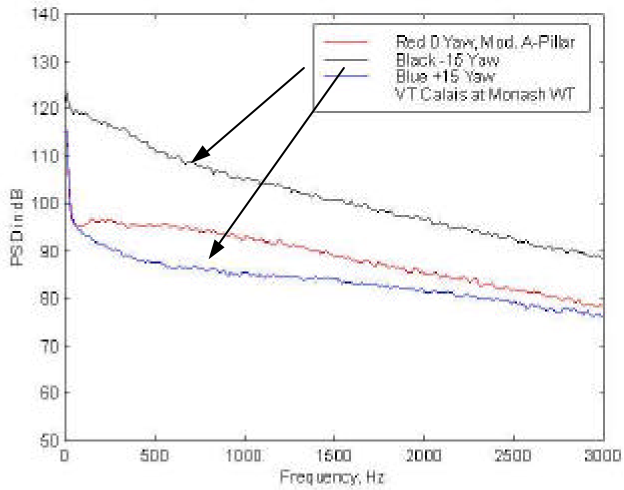


Figure 7: Interior noise, modified A-pillar, wind tunnel, 140km/h.

When fitted with the A-pillar modification, the PSD of the 0° yaw condition now conforms more closely to the PSD obtained with the vehicle at positive yaw (figure 7). Due to the A-pillar modification, the flow over the side window region now remains attached during the 0° yaw condition. The A-pillar vortex is now either eliminated or reduced, and the magnitude of fluctuating pressure on the window is considerably reduced.

During wind-tunnel testing, the only noise source was external aerodynamics, as the tunnel background noise was approximately 10dB below the signal recorded. The engine was not running, there was no noise generated by transmission, drivetrain, tyres, exhaust, etc. However when testing on-road, these sources are present. Fig. 8 shows the acoustic spectra from one road test, both with and without acoustic insulation.

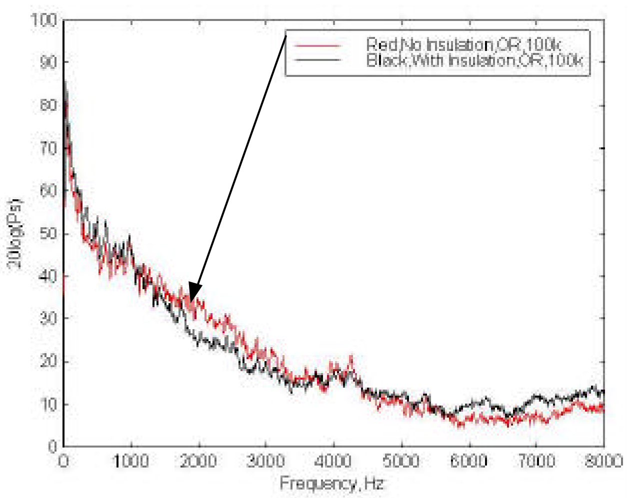


Figure 8: Interior noise spectra, with and without acoustic insulation, on-road, 100km/h.

The acoustic insulation was not designed to be effective over 5kHz. Fig. 8 shows that with the vehicle insulated to reduce the intrusion of aerodynamic and mechanical noise from most parts of the vehicle interior surface except the A-pillar regions, there is essentially no difference in interior noise SPL. The reason for this is that while the A-pillar vortex is a source of surface pressure fluctuations (in the standard configuration described previously), the overall contribution of this noise has to be compared with (a) noise from other aerodynamic sources such as the underbody, grille, wheel openings, etc; and (b) noise from mechanical components, tyre/road interaction, and the exhaust. The second factor is that for all these noise sources, there are many mechanisms of transmission into the vehicle interior. The structure and damping characteristics of vehicle components is of consideration. Tests were carried out using the Aachen Head to compare the Perspex replacement window with the original glass one, no significant difference was found. A far greater difference to interior SPL was found when driving on different road surfaces, and any window opening resulted in noise increasing by up to 10dB. The contribution to interior noise by the A-pillar vortex is far less significant. Additionally, the insulation in the vehicle was not installed uniformly, for example when driving on-road the windscreen was not covered in insulation for obvious reasons!

#### Conclusions

Simple alterations in passenger car vehicle geometry will result in a significant reduction of fluctuating surface pressures, as measured in the region of the A-pillar vortex. In the wind-tunnel environment, under non-driven conditions, reductions in interior noise level were noticed, however on-road at normal highway speeds the A-pillar vortex contribution is far less that the contribution of mechanical and other non-aerodynamic noise sources.

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