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THE FLOW CHARACTERISTICS AROUND A CAR A-PILLAR.

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ABSTRACT

Experimental investigation of the flow structure in the A-Pillar region of a car was conducted using a full-scale wind-tunnel. Flow visualisation was carried out, and mean and transient flow properties were measured. The results show there were significant changes in local velocity with distance from the side window, and also affected by increased negative yaw angles. Turbulence intensity strongly depends on the yaw angle. The effects of Reynolds number were evident for all the flow characteristics measured. The effects of yaw angles were shown to have a significant influence on the A-Pillar vortex.

1. INTRODUCTION

High levels of driving comfort of today's passenger cars are considered essential in car markets throughout the world. One of the criteria pertains to the aerodynamic (interior) noise. Reduced structure-borne, engine, tyre and powertrain noise has meant wind-induced noise sources at driving speeds exceeding 100 Km/h are now significant. Additionally, vehicle manufacturers wish to reduce their time to market and thus need to incorporate evaluation of aerodynamic noise at an early stage in the vehicle manufacturing cycle. Currently vehicle manufacturers expend considerable time and money on the measurement and reduction of aerodynamic noise utilising full-size vehicles in wind tunnel or on-road tests.

Methods that permit the evaluation of aerodynamic noise sources to occur earlier in the development cycle include computational fluid dynamics and acoustics and small-scale model testing. None of the computational methods are presently able to predict aerodynamic noise sources, forces and moments for basic or more realistic vehicle configurations with a level of confidence and accuracy attained in wind-tunnel tests, Hucho, et al. (1998). It should be noted that one of the drawbacks of the model-scale testing (and computation methods) is that it is only practicable to evaluate the noise sources and not the acoustic transmission loss through the cabin structure.

Previous studies have revealed the passenger car's A-Pillar region (the corner post between the front side glass and the windshield) is the primary source of aerodynamic noise since the highest fluctuating pressure occurs here and it is the region closest to the driver's ears. A conical vortex and flow separation occurs at the A-Pillar region, the vortex travels downstream along the window and then upward to the roof line, where the flow expands and adds to the interior noise of the car.

Sadakata (1988), Popat (1991) and Dobrzynski (1994) studied the flow around the A-Pillar region. Their interest were about the relative angles between the side windows, the bonnet and the windshield, as well as details of the joints between them. The aim was to minimise flow separations and vortical flows, thus reducing the vehicle interior noise. Sadakata et al. (1988) found that by optimally combining inclination angle and curvature of the windshield and a smooth large radius at the A-Pillar, wind noise can be reduced considerably. However, the optimal angles of the windshield get so low that heating by solar radiation on the large flat glass surface becomes a problem. In addition, large, highly inclined windshields reduce the head and shoulder room inside the car cabin.

Popat et al. (1991) carried out an experimental investigation of the A-Pillar vortex region on idealised road vehicle models. His investigation was aimed at examining the effect of windshield angle on the A-Pillar vortex (flow structure) and flow-induced noise and was based on mean and transient static pressure measurements in the A-Pillar region. The study showed that the A-Pillar angles have significant influence on vortical flows but his work was restricted to a maximum Reynolds number that was approximately 40 % of a full-scale vehicle at 100 km/h. Popat did not consider the effects of yaw angle (defined as the angle between the vehicle centreline and the mean direction of the wind as seen by the moving vehicle), turbulence (which exists on the road), A-Pillar curvature and windscreen curvature. It is well known that noise is greatly increased as the side of the vehicle is yawed to the leeward direction, defined here as negative yaw angle. However, the effects of scale (i. e., Reynolds number) on noise variation are relatively unknown.

Haruna et al. (1990) studied the aerodynamic noise generated around the A-Pillar of a production car for the yaw angles of 0 and 10 degrees for a free stream velocity of 180 km/h in the wind tunnel. They again found that the sound pressure level varied with the yaw angle. The yawed conditions showed an increase of noise around the A-Pillar region. Dobrzynski et al. (1994) investigated the sensitivity of yawed conditions on the A-Pillar region flow. Surface pressure around the side window varied with the yaw angles. The investigation was based on model scale production type cars in the wind tunnel. Here again both Haruna and Dobrzynski did not consider the effect of turbulence, A-Pillar and windshield curvatures. They considered limited degree yaw angles (0, 5 and 10) in their studies, but did not consider Reynolds number effects.

2. OBJECTIVES

This investigation is a part of a larger program to study the car A-Pillar region with various windshield angles, curvatures, yaw angles and turbulence characteristics. The work presented here investigated the following areas using experimental investigations on full-scale passenger car in a wind-tunnel :

- The flow structure of the A-Pillar conical vortex, by flow visualisation and flow measurement including the influence of Reynolds number and yaw angles and ;
- The possibility in the A-Pillar region of predicting the full-scale flow characteristics using model-scale geometries

3. EXPERIMENTAL METHOD

It has been noted in the literature that in the A-Pillar region, there is an extremely complex three dimensional flow consisting of separated flow areas. Therefore , to understand the flow pattern and effects of yaw angles on it, the following steps were taken:

i. Flow visualisation with wool tufts near the A-Pillar on the side window of a full-scale car (Ford Falcon ER) and;

ii. Measurement of flow with a Cobra Pressure Probe near the A-Pillar on the driver's side window of full-scale car.

3.1 Monash and RMIT Universities' Joint Aero-Acoustic Wind-Tunnel

This is a closed circuit 3/4 open jet wind-tunnel with a maximum speed of 180 km/h. The test section has a turntable and is large enough to accommodate a full-scale car. The tunnel is driven by two independently controlled fans of 5 m diameter and is relatively quiet with a background noise 10 dBA less than the typical wind noise of a car, Saunders et al. (1997). The free stream turbulence intensity is approximately 3 %.

3.2 Flow Visualisation With Wool Tufts On Full-Scale Car

Wool tufts were used to see the flow pattern on the passenger side window near the car A-Pillar. Flow visualisation was performed with and without the external rear view mirror at 40, 80, 120 and 140 km/h under 0, -5, -10 and -15 degree yaw angles (negative yaw angles were with the window on the leeward side). Flow structures were documented with video and still cameras.

Figure 1 Typical Flow Pattern On The Front Side Window

3.3 Flow Measurements

With a view to investigating the turbulence intensities, the time-averaged local velocity, yaw and pitch angles and other turbulent flow characteristics, a high frequency Cobra Pressure Probe was used. The probe can take up to 20 blocks of data for each calculation. Each block of data has 4096 samples and was obtained in 0.8 second. Use and calibration of the Probe has been discussed by Hooper, et al. (1991).

The body of the Probe was mounted inside the full-scale Ford Falcon. A fibre-glass side window replaced the original glass and a hole was made through which the tip of the Cobra Pressure Probe could move freely. The position of the hole was approximately half way between the separation and re-attachment line of the A-Pillar conical vortex. This position was located by flow visualisation. Data were sampled at 3 different free stream speeds; 40, 60 and 120 km/h and at four different positions away from the side window (10, 30, 50 and 80 mm) under 0, -5, -10 and -15 yaw. All measurements were taken with the external rear view mirror removed.

4. RESULTS AND ANALYSIS

The tunnel speed U was measured from the tunnel data acquisition system. Software was used to calculate the local velocity components (u, v and w), local yaw angles, pitch angles, Reynolds stresses, and static pressure. From the velocity file, time-averaged velocities u, v, w and turbulence intensities (Iu, Iv, Iw) were calculated hence the turbulence intensities were non-dimensionalised by dividing by the averaged local velocity. The error in flow measurement by the Probe was within acceptance range. Time- averaged velocity and local yaw and pitch angles verses distance from the side window were plotted in Figures 2 to 9. The local velocities were non dimensionalised by dividing by the free stream velocities.

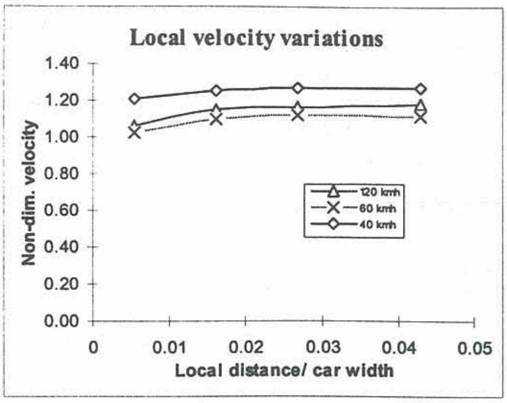

Figure 2 Velocity Variation, Yaw = 0°

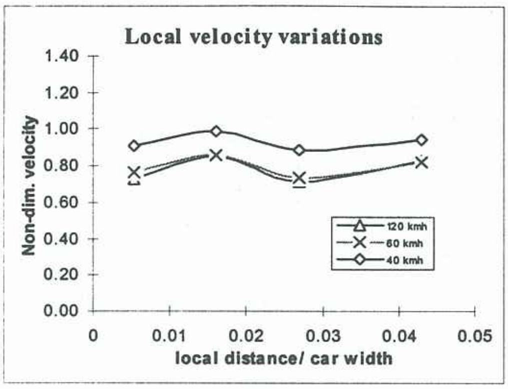

Figure 3 Velocity Variation, Yaw = -15°

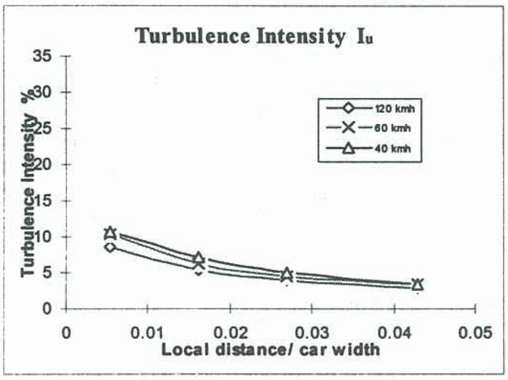

Figure 4 Turbulence Intensity, Yaw = 0°

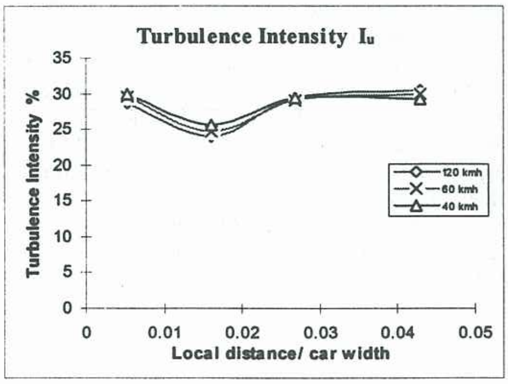

Figure 5 Turbulence Intensity, Yaw = -15°

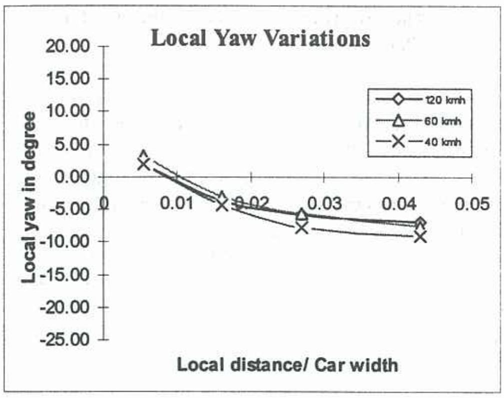

Figure 6 Local Yaw Variation, Yaw = 0°

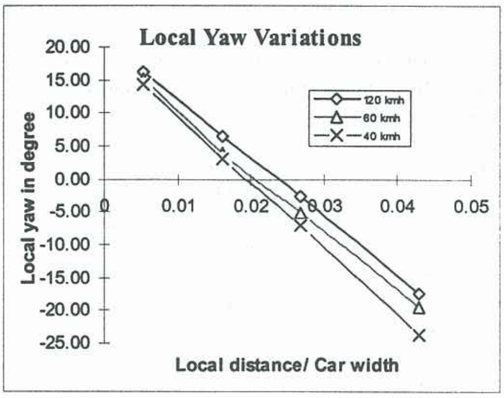

Figure 7 Local Yaw Angle Variation, Yaw = -15°

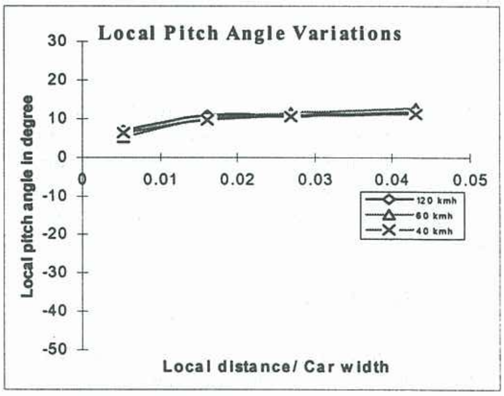

Figure 8 Local Pitch Angle Variation, Yaw = 0°

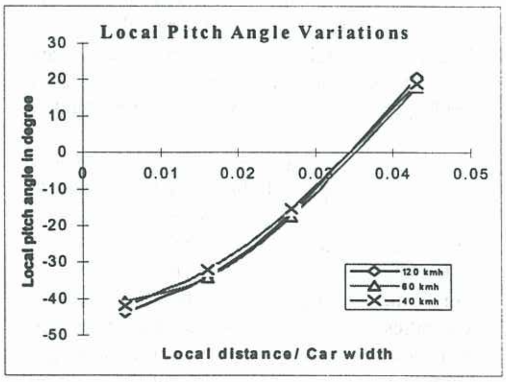

Figure 9 Local Pitch Angle Variation, Yaw = -15°

4.1 The Effects Of Reynolds Number On Flow Characteristics

Possible Reynolds number dependence could be assessed since the tests were conducted with the same full-scale vehicle but at speed ratio's of 1 : 2 : 3. Flow visualisation showed a significant difference between free stream velocities of 40 and 80 km/h. The separation and re-attachment lines on the side window near the A-Pillar were not at the same place. A small change was noted between 80 and 120 km/h. But changes were insignificant between the 120 and 140 km/h. The flow pattern can be seen for the case of -5° and 140 km/h in Figure 1.

4.2 The Effects Of Yaw Angle On Flow Characteristics

As expected, the effects of yaw angle on the A-Pillar vortices of the full-scale car are significant at all speeds tested.

Turbulence intensities for the full-scale car at speeds of 40, 60 and 120 km/h and 0 degree yaw angle had similar trends. As the probe was moved further into the free stream, the intensity can be seen to asymptote to the tunnel free stream value (approximately 3 %). The intensity at 120 km/h was slightly lower than either 60 km/h or 40 km/h. Intensities were significantly higher under -5, -10 and -15 degrees yaw (leeward side). Unsteadiness evident in the flow visualisation supported this. The intensity close to the side window was generally highest and reduced with increasing distance from the side window. This was particularly true for 0 and -5 degree yaw. The turbulence intensity for -10 degree yaw sharply reduced after 50 mm away from the side window (not presented here) but for -15 degree yaw, the intensity was almost constant up to 80 mm away from the side window. It is interesting that even with low free stream turbulence the unsteadiness in the vortex is high at moderate yaw angles.

5. CONCLUSIONS

- Significant changes in velocity with distance from the side window and yaw angle were observed and increased as a more negative yaw angle was encountered.
- Turbulence Intensities depended on the yaw angle and varied slightly with the velocity.
- Local yaw angle varied with distance and velocity and car yaw angle and local pitch angle had a similar trend though the variation with velocity was less.
- Reynolds number dependency was observed at lower speed, especially between 40 to 60 km/h. This has been noted by flow visualisation and quantitative data. Only slight changes were noted between 60 and 120 km/h.
- For 0 and -5 degree yaw, the time-averaged velocities have similar trends. But there were significant differences in time-averaged velocities between the yaw angles for more negative yaw angles.
- The results for velocity variation and yaw angle demonstrate that the effects of Reynolds number were evident and the flow pattern would be slightly different at a one third scale Reynolds number, as frequently occurs in model scale tests.

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