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THE RELEVANCE OF THE EXTERNAL REAR VIEW MIRROR FOR WIND-TUNNEL TESTING

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ABSTRACT

It is considered that when performing aerodynamic experiments on passenger cars, particularly those involving noise, A-pillar flow, or surface pressure measurement, the presence of the external rear vision mirror is necessary. This experiment was designed to test this conjecture. Wind tunnel testing was done with a full-size passenger sedan, with and without external mirror. Three methods were employed: flow visualization (smoke), fluctuating pressure on the side window surface, and measurement of velocity variation near the window surface using a dynamic pressure probe. Tests were performed at 0 and 15 degrees (leeward) yaw, and 100km/h except for flow visualization. Surface pressures and off-surface velocities were measured both in and out of the mirror wake. It was found that the separated flow from the mirror does not impinge on the window surface, but is deflected downward. Off-surface velocity measurements show that the mirror wake is very localized. At large negative yaw angles the larger separation from the A-pillar overshadows the separated flow from the mirror. It can be inferred that a range of surface pressure and related testing can give reasonably accurate results without an external mirror present.

Keywords: Wind Noise, A-Pillar, Wind Tunnel, Flow Visualization, Surface Pressure, Mirror.

1. INTRODUCTION

Many researchers such as [1],[2],[3] [4] and [5] have carried out experimental work connected with A-pillar vortex effects on a such as noise, surface pressure and external flow. It has been assumed that the presence of the external rear view mirror as fitted to passenger cars is necessary in order to produce accurate results. The purpose of this study is to determine whether the absence of the mirror has any influence on certain A-pillar vortex phenomena, and ultimately whether testing can be done without external mirrors.

In order to test this conjecture, a series of wind tunnel experiments using a full-size passenger sedan were carried out both with and without the external mirror fitted for direct comparison. Wind tunnel tests used flow visualization, measurement of fluctuating surface pressures, and 3-axis orthogonal off-surface velocity measurement in the A-pillar vortex region.

2. TEST PROCEDURES

Experimental work was conducted at the Monash Wind Tunnel located at Monash University, Clayton, Victoria, Australia. This facility is described in [6], it is used for postgraduate research work as well as commercial automotive and industrial testing. The tunnel is a vertical closed loop type, with a rectangular 4m x 3m nozzle exiting into an 8m x 6m plenum. The collector is approximately 12m behind the nozzle exit. Its maximum wind speed is 160 km/h. As this wind tunnel is equipped with a turntable, testing parameters included yaw angles of -15° to +15° in 5° increments.

The test vehicle used for this study was a Instrumentation for this study was a 2001 model Holden Commodore sedan. To the left front door was fitted a replacement front side window made from Perspex fitted to a. This allowed holes to be drilled. The instrument arrangement used was two horizontal rows at one third, and two thirds times the height of the window opening. A horizontal spacing of 80mm was selected. This arrangement is shown in Figure 2. Positions 2 and 3 (lower row) were used for Cp(rms) measurement. This method is described in [7].

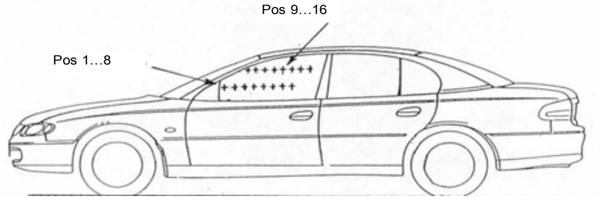

Fig 1. Schematic of instrument locations in side window

For off-surface velocity measurements using a four hole pressure probe [8], additional instrument locations we employed, both 40 and 80mm above and below relative to positions 2 and 3. Thus positions 2 and 3 on the original 1/3 window height line are called 2c and 3c, while 2a is 80mm below 2c, and 3e is 80mm above 3c.

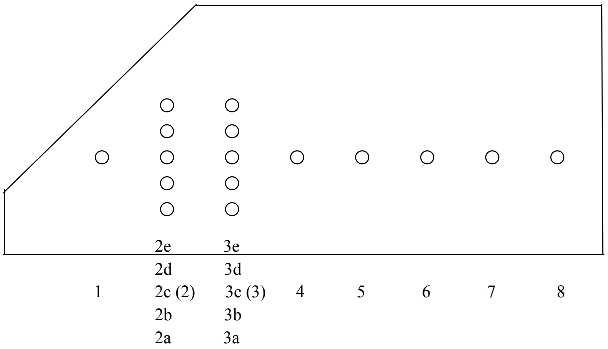

Fig 2. Schematic view of additional mounting locations above and below positions 2 and 3 used for 4-hole pressure probe, horizontal spacing 80mm, vertical spacing 30mm (not to scale).

3. EXPERIMENTAL RESULTS

Table 1: Summary of Experiments

Method	Parameters	Locations
Flow Vis. (Smoke)	U ˜ 20km/h Ψ=0°, -15°	Side window
Off-Surface Velocity	U = 100km/h Ψ=0°, -15°	Positions 2a -3e
Cp(rms)	U = 100km/h Ψ=0°, -15°	Positions 2, 3

3.1 Flow Visualization Using Smoke

Flow visualization tests were undertaken at 0° and -15° yaw, with and without external mirror. The tests with the external mirror fitted show that air flowing around the A-pillar at approximately 1/8 pillar height or below goes under the mirror and from there continues below the beltline. This can be seen in Figures 3 and 4.

At approximately 1/6 pillar height the flow meets the front face of the mirror. There is flow reversal at the mirror trailing face, as expected with an abrupt trailing edge, and there is an approximately conical vortex behind the mirror. This continues back on a downward angle. Past the midpoint of the door length this mirror vortex continues below the beltline, At no stage was this mirror vortex seen to impinge on the window surface, or interact with the A-pillar vortex.

Above 1/4 pillar height the flow around the A-pillar forms the familiar vortex pattern. In the upper 1/4 section of the pillar, the flow turns over the roof. Above 1/3 pillar height the vortex forming and the flow reattaching on the side widow surface. This flow pattern is not influenced by the presence of the external mirror.

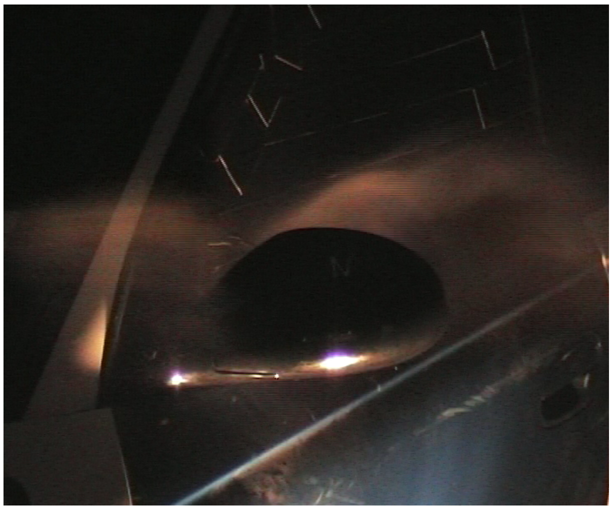

Fig 3. Flow visualization (smoke) 0° yaw angle, with mirror, 1/4 pillar height

Fig 4. Flow visualization (smoke) 0° yaw angle, No mirror, 1/4 pillar height

3.2 Fluctuating Surface Pressures

Fluctuating pressures are expressed as Cp(rms) [coefficient of pressure root mean squared], which is the standard deviation of the pressures divided by the dynamic pressure based on the mean velocity, thus:

$$Cp_{rms} = \frac{\sigma^2\{P\}}{\frac{1}{2}\rho\overline{U}^2} \quad or \quad \frac{P_{rms}}{\frac{1}{2}\rho\overline{U}^2} \qquad (1)$$

G.R.A.S. Type 40BP ¼” condenser microphones were used as pressure transducers. The G.R.A.S. microphones are cylindrical in shape, approximately ¼” in diameter. The G.R.A.S. microphones were flush mounted with the window surface by being installed in 11mm OD, ¼” ID cylindrical collars. The adapters were retained in the window by a slight interference fit.

Cp(rms) was measured at two locations, Positions 2 and 3 Bottom Row; with and without the external mirror.

This test was done in the Monash Wind Tunnel, one speed of 100km/h and two yaw angles of 0° and -15° were used. Table 2 shows that Cp(rms) is unchanged (within measurement error) with or without mirror fitted.

Table 2: Cp(rms) values, comparing mirror and no mirror.

	Mirror	**No Mirror**
Position 2 BR, 0° yaw	0.044	0.050
Position 2 BR, -15° yaw	0.107	0.111
Position 3 BR, 0° yaw	0.031	0.023
Position 3 BR, -15° yaw	0.099	0.103

3.3 Off-Surface Velocities

A four hole pressure probe (Figure 5) was used to measure orthogonal velocity components. This device is described in [8]. The probe was mounted in turn in each of 10 locations and traversed in a horizontal plane from Z=10mm to Z=50mm from the window surface in 10mm increments, thus covering a 3D grid of 50 points per test. Wind tunnel speed was 100km/h only, two yaw angles were employed: 0 and -15 degrees. Tests were done with and without the door-mounted rear view mirror. X is longitudinal distance along vehicle side, Y is vertical distance up the window height, and Z is distance from the window surface. The z-axis on Figures 6 to 13 shows the magnitude of velocity.

Fig 5. Mirror fitted, probe shown at position 3b, 50mm from window surface (Z=50 mm)

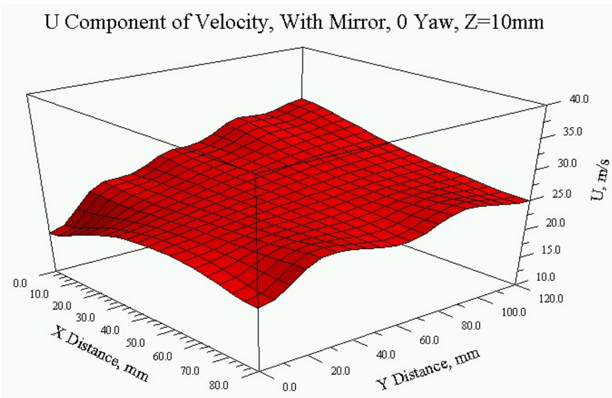

Fig 6. Mesh Plot, U(m/s) at 0° yaw, Z=10mm, mirror

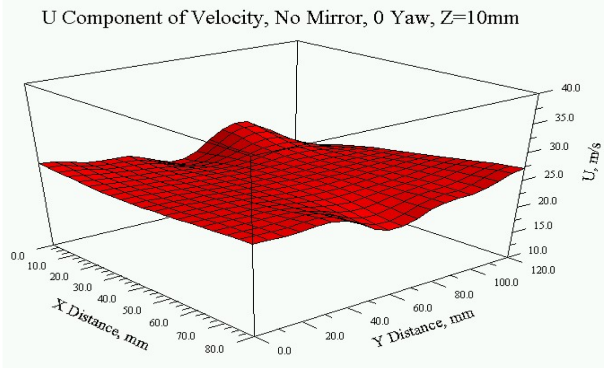

Fig 7. Mesh Plot, U(m/s) at 0° yaw, Z=10mm, No mirror

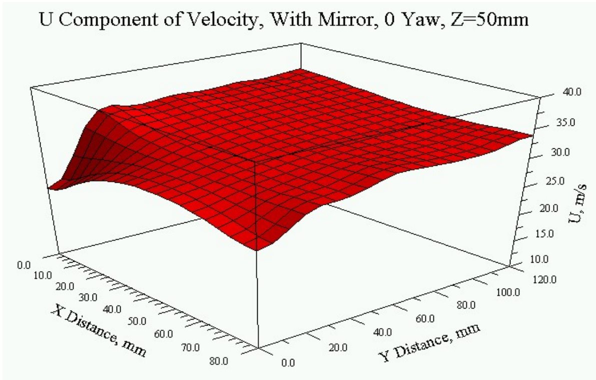

Fig 8. Mesh Plot, U(m/s) at 0° yaw, Z=50mm, With mirror

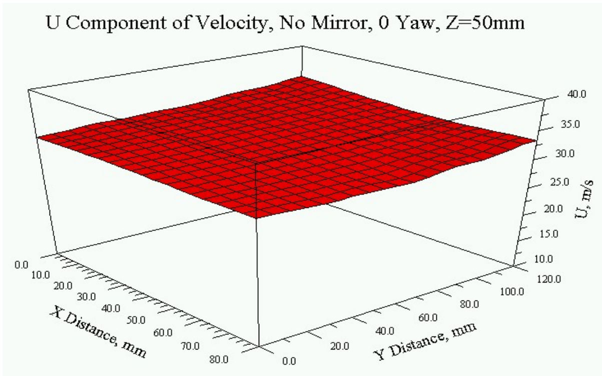

Fig 9. Mesh Plot, U(m/s) at 0° yaw, Z=50mm, No mirror,

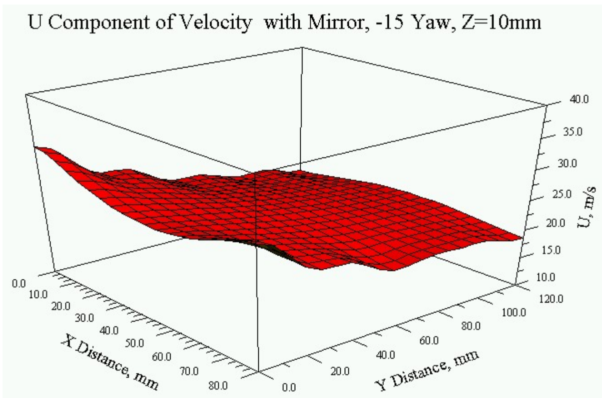

Fig 10. Mesh Plot, U(m/s) at -15° yaw, Z=10mm, With mirror

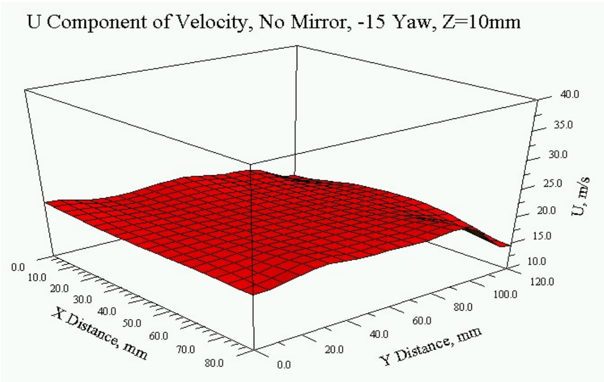

Fig 11. Mesh Plot, U(m/s) at -15° yaw, Z=10mm, No mirror

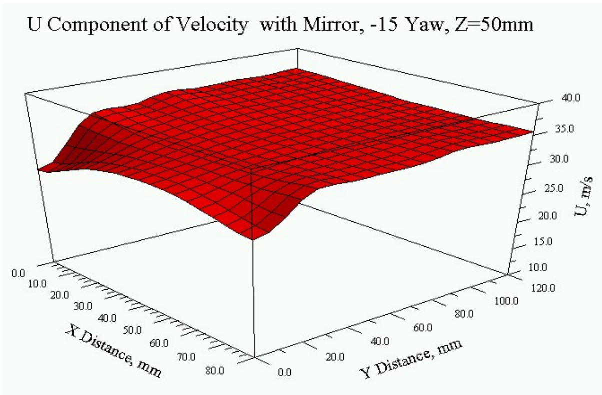

Fig 12. Mesh Plot, U(m/s) at -15° yaw, Z=50mm, With mirror

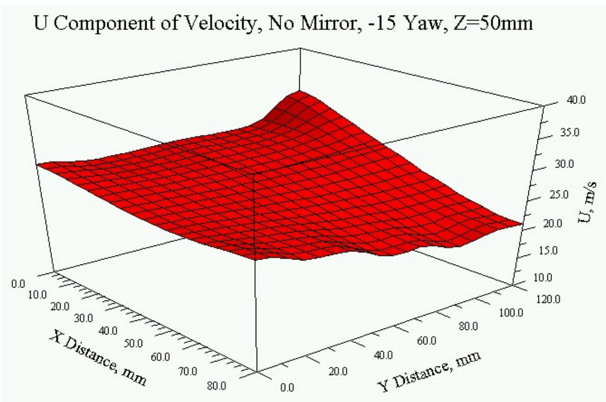

Fig 13. Mesh Plot, U(m/s) at -15° yaw, Z=50mm, No mirror

4. DISCUSSION

Figures 6 and 7, and Figures 10 and 11 show that at Z=10mm, closest to the window surface, there is minimal velocity change due to the presence or absence of the mirror along the Y=60 line, i.e. the line used for time-averaged and fluctuating surface pressure measurement. Any velocity changes caused by the presence of the mirror are confined to a small region around positions 2a, 2b and 3a. This region is below the original Bottom Row as detailed in Figures 1 and 2. Figures 8 and 9 illustrate the velocity profile at Z=50mm. These show velocity around Position 2a is below the mean local velocity, indicating that the mirror wake forms at least 10mm away from the window surface, and not on the surface itself. At Z=10mm (Figures 6 and 7) velocities on the Y=60mm line are practically unchanged due to the presence or absence of the mirror. There is a change due to yaw angle, and below the Y=60 line and any velocity change caused by the mirror wake occurs further out Z=50mm (Figures 12 and 13), not in close to the surface e.g. Z=10mm. The effect of yaw angle is far greater than the presence or absence or the external mirror.

The above is in agreement with the flow visualization images that for this particular combination of car body and mirror at least, the mirror wake at Position 3 does not impinge on the window surface or affect the A-pillar vortex.

In all both cases of yaw and both cases of vehicle configuration tested, the following was found:

- The effect of the mirror wake can be seen as the velocity reduction in the lower front corner (Positions 2a, 2b, 3a) of the window.
- The velocity patterns attributable to the mirror wake begin to appear at around 30mm from the window surface and further out.
- At or near the surface (Z=10mm) On the Y=60mm line (where surface pressure instruments were located in P2 and P3), the velocity change due to the presence of the mirror is minimal, acting below 1/3 pillar height, and not combining with the velocity increase due to vortex flow noticeable around Position 2e.
- Leeward yaw has a far greater effect on velocities in the region than the presence of the mirror.

Smoke images (Figures 3 and 4, as well as those from video), show two separate flow separation effects, from the A-pillar and from the mirror. Where an external mirror is fitted, its wake does not interfere with the A-pillar vortex. Smoke flow visualization would suggest that at least for this combination of body style and mirror fitting, (a) the A-pillar vortex and the mirror wake are largely separate entities, and (b) the mirror wake does not have any influence on the A-pillar flow in the upper 2/3rds of the window surface.

5. CONCLUSIONS

It can be safely concluded that any part of the window surface above and behind Position 2 Bottom Row, will not be affected by the mirror wake. Of course these findings apply to the particular body style and mirror combination used, but there is no reason to think that cars of a similar shape with similar mirror mountings would not behave in a like manner.

6. ACKNOWLEDGEMENT

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8. NOMENCLATURE

Symbol	**Meaning**	**Unit**
U	Velocity	(m/s)
Ψ	Yaw angle	(°)
P	Pressure	(Pa)
Cp(rms)	Fluctuating pressure coefficient	(-)
ρ	Air density	(kg/m^3)
σ	Variance	(-)
X, Y, Z	Orthogonal distances	(mm)