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VIBRATION OF AUTOMOBILE SIDE VIEW MIRROR DUE TO AERODYNAMIC INPUTS

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ABSTRACT

The primary function of vehicle side rear view mirrors is to provide visual information to the driver regarding his immediate surrounds outside the vehicle, such that the driver does not need to divert his attention away from the vehicle's direction of motion. Due to the location of these side rear view mirrors, aerodynamically induced noise from the wake of the mirrors can lead to severe vibration. The vibration of automotive side rear view mirror is a concern for vehicles safety. Although the primary causes of mirror vibration are due to mechanical (power train, road/tyre interaction) and aerodynamic pressure fluctuations. The primary objective of this paper is to study the aerodynamic pressures on mirror surface at various speeds to determine the effects of aerodynamic inputs to mirror vibration. Additionally, the mirror was modified by shrouding around the external periphery to determine the possibility of minimisation of aerodynamic pressure fluctuations and thereby vibration. The mean and fluctuating pressures were measured using a production rear side view mirror fitted with a ¼ quarter production passenger car.

Keywords: Automotive side rear view mirror, Vibration, Aerodynamic pressure, Pressure sensor, Passenger car, Wind Tunnel

1. INTRODUCTION

A significant effort has been made by the automobile and component manufacturers to reduce aerodynamic drag, noise and vibration. However, relatively less attention has been drawn to the refinement of performance of automobile side rear view mirrors, especially mirror vibration. The primary function of a side rear view mirror is to provide the driver a clear vision of all objects to the rear and side of the vehicle. However, there are several problems associated with it such as image distortion due to aerodynamically induced and structural vibration, aerodynamically induced noise (due to cavities and gaps) and water and soil accommodation on mirror surface due to complex mirror shapes and airflow around it. An automotive mirror is a bluff body and causes significant periodic flow separation at the housing, which produces oscillating aerodynamic forces (due to hydrodynamic pressure fluctuations) on mirror surface. These pressure fluctuations not only cause the mirror surface to vibrate but also generate aerodynamic noise. Due to excessive vibration, the rear view mirror may not provide a clear image. Thus, vibrations of the side rear view mirrors can severely impair the driver's vision and safety of the vehicle and its occupants. The rear view mirrors are generally located close to the A- pillar region on the side window. An intense conical vortex forms on the side window close to A-pillar due to complex A-pillar geometry and the presence of side rear view mirror and flow separation from it makes the airflow even more complex. Although some studies ([2], [4], [5], [6] and [7]) have been undertaken to investigate the structural input (engine, road/tyre interaction etc) as well as aerodynamic input to mirror vibration, very little or no study was undertaken to quantify the aerodynamic input to mirror vibration. Therefore, the primary objective of this work as a part of a larger study is to measure the aerodynamic pressures (mean and fluctuating) on mirror surface to understand the aerodynamic effects on mirror vibration. Additionally, the mirror was modified by shrouding around the external periphery with the help of thin plywood of 44mm, 34mm, and 24mm to determine the possibility of minimisation (if not elimination) of aerodynamic pressure fluctuations and thereby vibration. The mean and fluctuating pressures were measured using a production rear side view mirror fitted with a ¼ quarter production passenger car in the RMIT Industrial Wind Tunnel. A frequency based analysis was also conducted. Airflow around the mirror was visualised with smoke and documented with video and still photographs (not shown here).

2. EXPERIMENTAL PROCEDURE AND EQUIPMENT

The testing on mirror was carried out in the RMIT

Industrial Wind Tunnel using a quarter model 1998 Ford Falcon AU family size sedan passenger car. The RMIT Industrial Wind Tunnel is closed return circuit with a turn table to yaw a suitable model to simulate the crosswind effects. The dimension of the test section is 9 m long, 3 m wide and 2 m high with a maximum air speed of 150 km/h. A plan view of the RMIT Industrial Wind Tunnel is shown in Figure 1.
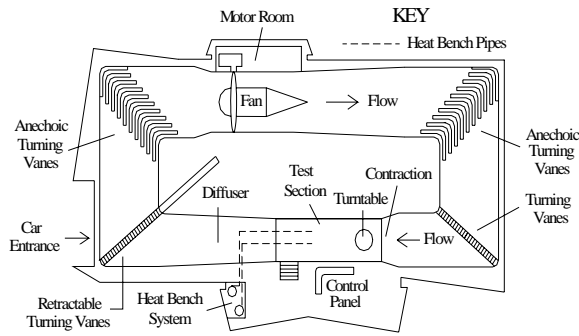

Fig 1. A Plan View of RMIT Industrial Wind Tunnel

In order to replicate the airflow around the mirror location, the quarter model Ford Falcon car was used for mirror attachment. The quarter model was secured against the tunnel wall and was located in the middle of the tunnel test section (see Figure 2). As mentioned earlier, the primary objectives of this work was to measure the aerodynamic inputs on mirror vibration by determining the pressures (mean and fluctuating) on mirror glass surface. As it is virtually impossible to drill holes to the toughened glass surface of the mirror for pressure taps, the mirror glass was replaced with a rigid aluminium plate (2.4 mm thick) and the mirror case was slightly modified with the help of wooden blocks in order to hold the aluminium plate. A series of holes (around 51) were drilled on the aluminium plate in a grid pattern (see Figure 3). The diameter of the hole was 2 mm. The space between the two holes was 25 mm horizontally and 13 mm vertically. The mirror face was pressure tapped with rubber tubing that was connected to four pressure sensor modules of Dynamic Pressure Measurement System (DPMS) and later to Interference box which was connected to a data acquisition system (a dedicated computer). A schematic layout of experimental pressure measurement setup along with DPMS modules are shown in Figures 3 and 4.

The DPMS data acquisition software provides mean (time averaged), rms (time dependent fluctuating), minimum and maximum pressure values of each pressure port on mirror surface. For the given tubing dimensions (length and diameter), the data can be linearised to correct for the tubing response in order to obtain accurate dynamic pressure measurements. The sampling frequency of each channel was 1250 Hz. It may be noted that the peak energy of fluctuating pressure on mirror surface is well below 500 Hz (for more details, refer to [5], [6], and [7]). The dynamic response of the tubing was calibrated in order to minimise the attenuation of frequency. The mean and fluctuating pressures were measured at a range of speeds (60 to 120 km/h with an increment of 20 km/h) at zero yaw angles. Prior conducting the experiments each individual pressure taps was subjected to pressure leak test with the help of an Inclined Precision Manometer. Pressure measurements were carried out for the standard configuration first (see Figure 5) and then modified configuration (see Figure 6). The mirror was modified by shrouding around the external periphery using thin plywood of 24 mm, 34 mm and 44 mm edge to determine effects of shrouding on aerodynamic pressures.

The measured mean and fluctuating pressures were converted into non-dimensional mean pressure coefficient (C_P) and fluctuating pressure coefficient (C_{Prms}) dividing by the velocity head (q). The RMIT Industrial Wind Tunnel was calibrated before conducting the experiments and tunnel air speeds were measured via a modified NPL (National Physical Laboratory) ellipsoidal head Pitot-static tube (located at the entry of the test section) connected to a MKS Baratron Pressure sensor.

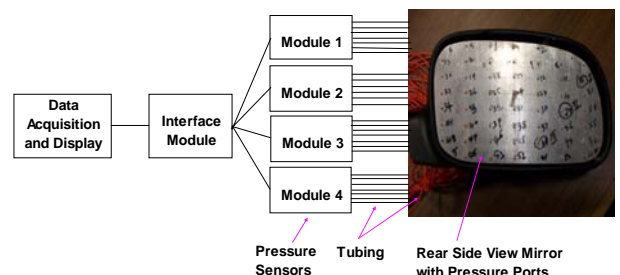Fig 2. Experimental Set Up of the Quarter Model in Wind Tunnel

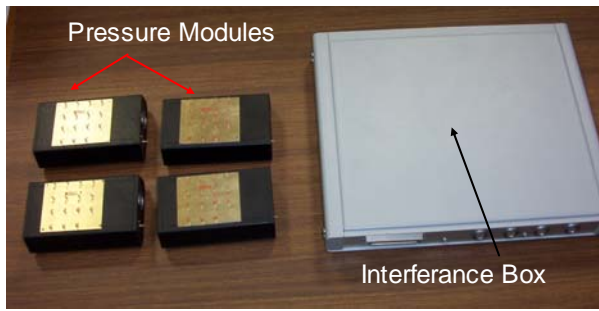Fig 3. A Schematic of Pressure Measurement Set Up
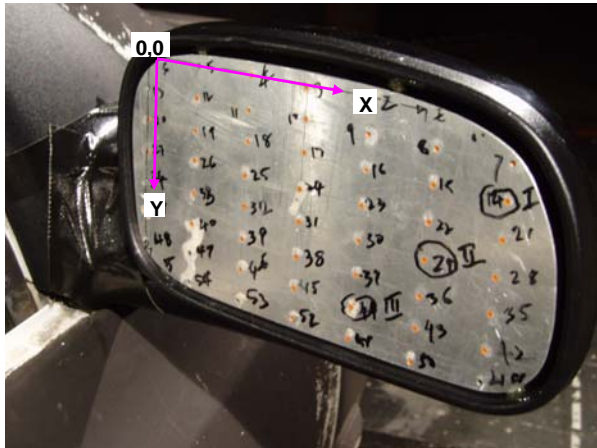
Fig 4. Components of DPMS

Fig 5. Schematic of Data Representation in Relation to Mirror Geometry and Coordinates of the Standard Mirror

Fig 6. Modified Mirror with 44 mm Shrouding

3. RESULTS AND DISCUSSION

3.1 Standard Mirror

As the fluctuating pressure plays a vital role for the aerodynamic inputs to mirror vibration, only the fluctuating pressure coefficient (Cp rms) is plotted in 3-D and in contour. The 3-D fluctuating Cp rms for the standard mirror configuration at different speeds is shown in Figures 7 to 10. The contour plots for the same

configuration and speeds are shown in Figures 11 to 14. It may be mentioned that in contour plots, the extreme top left and right, and bottom left data points need to be ignored as these points are beyond the mirror geometry. These points are shown here for the sake of grid formation only due to the complex shape of mirror surface. The origin of the plot is located at the top left hand corner position (e.g., Position 1). The x-distance is horizontal and y-distance is vertically down (see Figure 5).

The maximum fluctuating pressure was measured at the bottom right part of the mirror surface at all speeds tested. However, with the increase of speed, the magnitude of fluctuating pressures shifts towards the bottom central part of the mirror surface. 3-D and contour plots clearly show that the fluctuating pressure is not uniformly distributed on mirror surface rather concentrated at lower central part of the mirror surface. It is believed to be due to the strong flow separation from the edge. Generally the higher the magnitude of fluctuating pressure, the greater possibility of generating intermittent force and aerodynamic noise. With the increase of speed, the affected area and magnitude of fluctuating pressures increase.
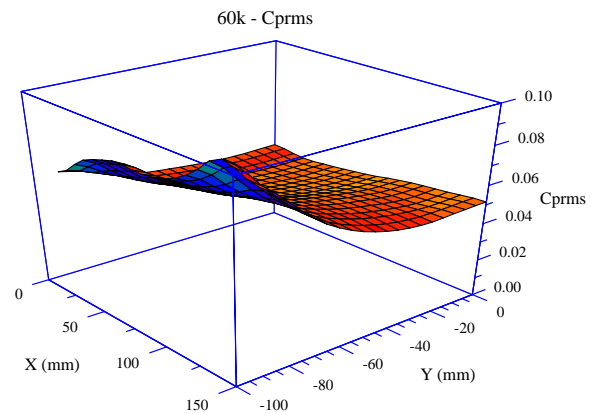

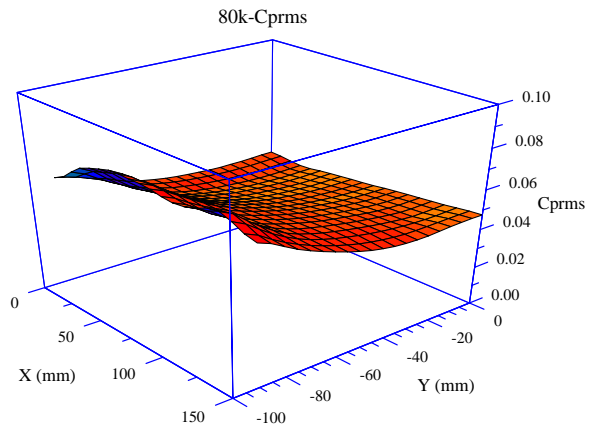Fig 7. Fluctuating Pressure coefficient in 3D, 60 km/h

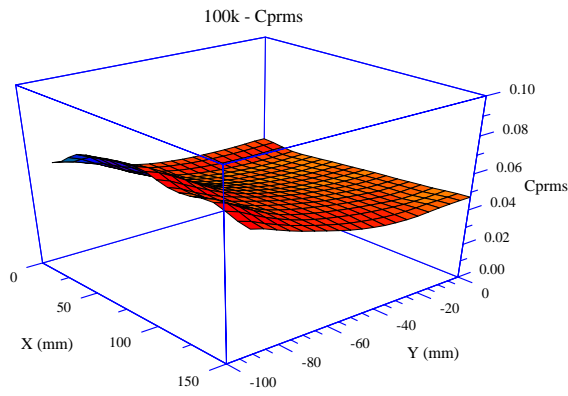Fig 8. Fluctuating Pressure coefficient in 3D, 80 km/h

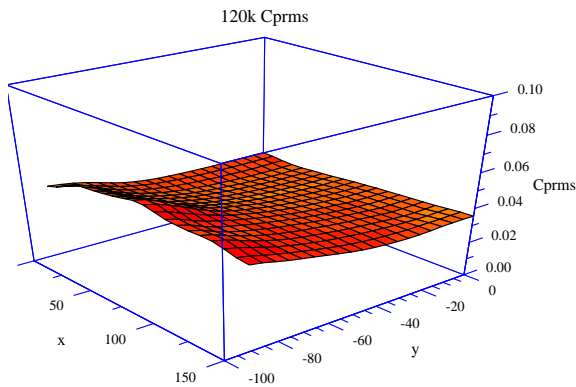Fig 9. Fluctuating Pressure coefficient in 3D, 100 km/h

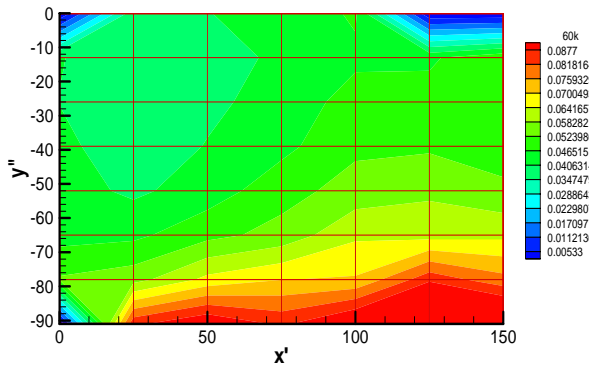Fig 10. Fluctuating Pressure coefficient in 3D, 120 km/h

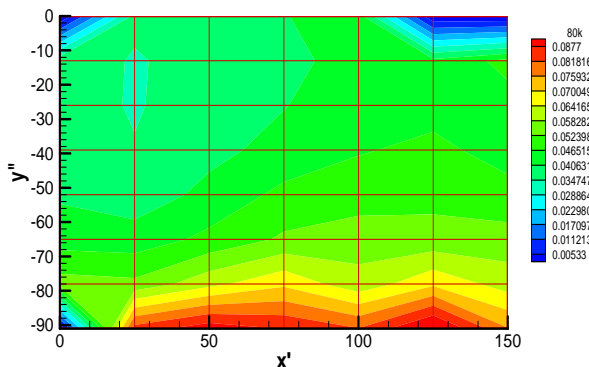Fig 11. Fluctuating Pressure coefficient contour
60 km/h

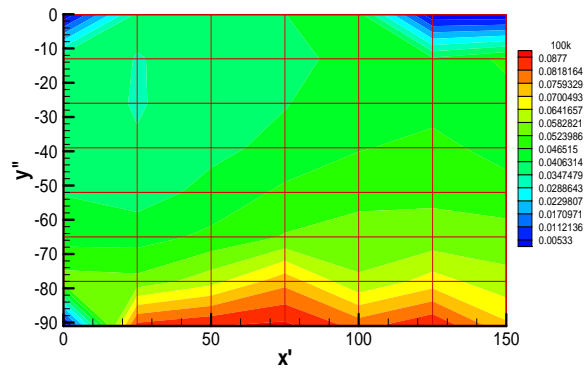Fig 12. Fluctuating Pressure coefficient contour
80 km/h

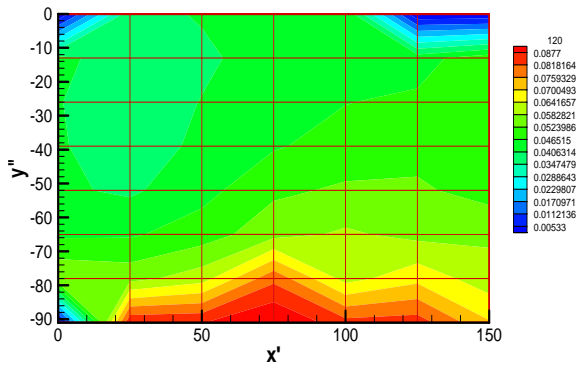Fig 13. Fluctuating Pressure Coefficient contour
100 km/h

Fig 14. Fluctuating Pressure coefficient contour
120 km/h

3.2 Modified Mirror

As mentioned earlier, the mirror was modified to see the edge effects on mirror surface pressure fluctuations. The fluctuating pressure coefficient (Cprms) for the modified configurations is plotted in 3-D and in contours. These plots are shown in Figures 15 to 20. The plots are shown here for 120 km/h only. The general trend of maximum fluctuating pressures is noted at the top central part of the mirror surface. It may be noted that the maximum pressure for the standard configuration was at the bottom central part of the mirror. The modifications have reversed the location of the maximum fluctuating pressure. The effects of shrouding length have maximum impact on pressure fluctuations, which can be seen in Figures 15 to 20. With the increase of shrouding length, the magnitude of the fluctuating pressure decreases. The maximum effect was achieved with the 44 mm shrouding length.
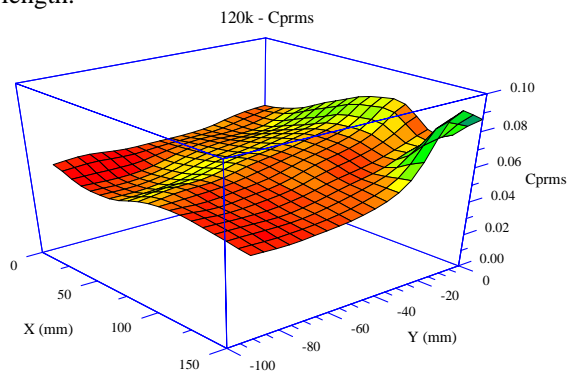

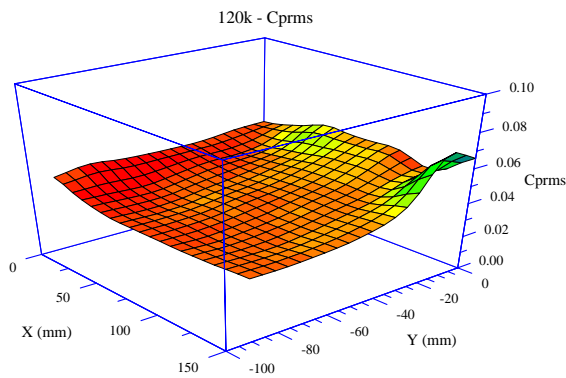Fig 15. Fluctuating Pressure Coefficient in 3D, 120 km/h, 24 mm Shrouding

Fig 16. Fluctuating Pressure Coefficient in 3D, 120 km/h, 34 mm Shrouding
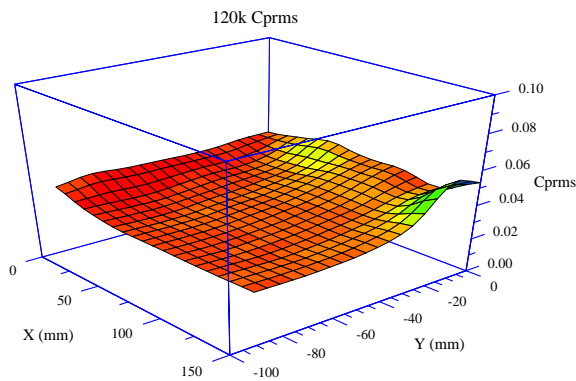

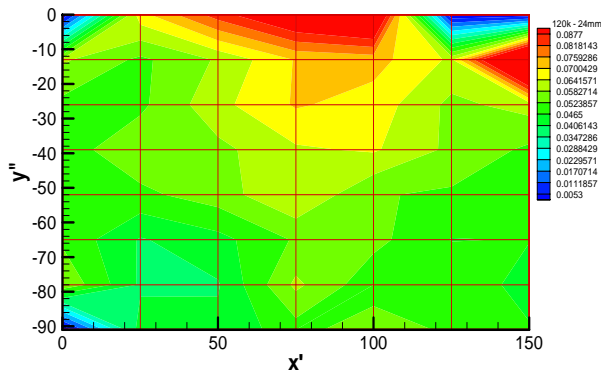Fig 17. Fluctuating Pressure Coefficient in 3D, 120 km/h, 44 mm Shrouding

Fig 18. Fluctuating Pressure Coefficient contour 120 km/h, 24 mm Shrouding
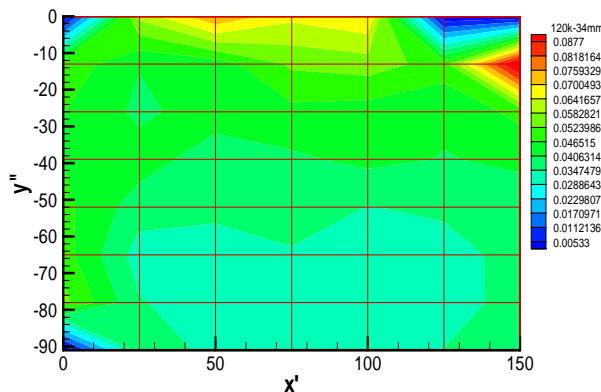

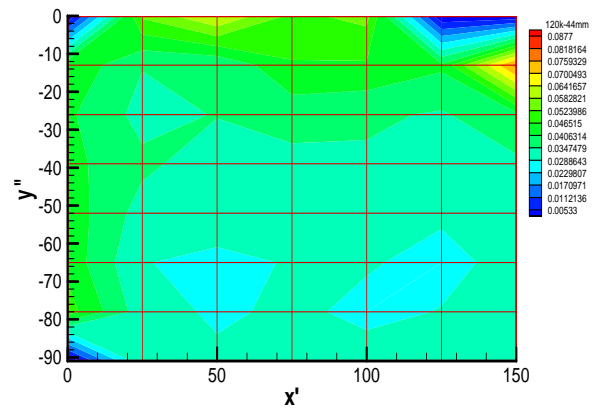Fig 19. Fluctuating Pressure Coefficient contour 120 km/h, 34 mm Shrouding

Fig 20. Fluctuating Pressure Coefficient contour 120 km/h, 44 mm Shrouding

4. CONCLUSIONS

The following conclusions have been made from the work presented here:

- Fluctuating aerodynamic pressures are not uniformly distributed over an automobile mirror surface.
- The highest magnitude of fluctuating pressure for the standard mirror was found at the central bottom part of the mirror surface
- The highest magnitude of fluctuating pressure for the modified mirror was found at the central top part of the mirror surface
- The modification has significant effects on the magnitude of fluctuating pressures

5. RECOMMENDATIONS FOR FURTHER WORK

- A frequency based analysis is required to understand the energy characteristics of the flow paying particular attention to phase since it is the out of phase components that usually cause mirror vibration.
- The effects of yaw angles also need to be considered.
- On-road testing will provide a realistic replication however it may make the testing more complex.

6. ACKNOWLEDGEMENT

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