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THE FLUCTUATING PRESSURES ON THE REAR OF A PASSENGER VEHICLE.

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ABSTRACT

Experimental, full-scale, time-accurate surface pressure testing of a passenger sedan vehicle was conducted. The structure of pressure fluctuations over the rear of a sedan is discussed; in particular, the large-scale unsteadiness observed from surface pressure measurements. Surface pressure periodicity has been investigated utilising spectral analysis techniques. Association of periodic pressure fluctuations with flow phenomena is also discussed.

INTRODUCTION

Sedan type passenger vehicles are essentially bluff bodies, which have inherently complex fluid flows due to regions of large separation. The region behind the rear window and above the boot lid of sedan passenger vehicles has received little attention from researchers.

The effect of the time dependent flow around sedan vehicles has been assumed to be a small perturbation about a dominant mean. However, recent papers by Bearman(1997) and Sims-Williams and Dominy(1998) have suggested that there is large scale, low frequency unsteadiness behind the rear of sedan vehicles. Nouzawa et al.(1992) investigated the unsteady flow regime both experimentally and numerically. Vortex shedding behind the rear window was considered to be an arch vortex on the boot lid intensifying alternately in similar fashion to a Von Karman vortex. Bearman(1997) suggests that that wake consists of apparently random distribution of strongly coherent vortex structures.

Flows around sedan (notchback) vehicles exhibit large-scale unsteadiness. To obtain an accurate understanding of the flow structures time accurate techniques are required. This paper takes the first step in time-dependent analysis through an investigation of pressure fluctuations over the rear of a full-scale vehicle.

Surface pressure fluctuations yield useful information about the scale, periodicity, coherency, and energy of the unsteadiness in the near wake region. The surface pressure structures also give a direct indication of the effect, of the instability on the primary aerodynamic coefficients of a notchback vehicle.

EXPERIMENTAL CONFIGURATION

Monash/R.M.I.T. joint automotive wind tunnel facility is an open jet wind tunnel with a main jet cross section of 4.05m wide by 2.6m high. The flow characteristics of the open throat test section is summarised in ***Table 1.***

Flow Quantity	Units	Average
Angularity in Pitch	deg.	± 4
Angularity in Yaw	deg.	± 1
Uniformity of Flow Velocity	%	± 4.6
Turbulence Intensity	%	2.33
Pressure Level Variation	-	< 0.01
Length of Pressure Level	-	1
Displacement Thickness	mm	14.4

Table 1: *Flow Quality Summary for* $U_\infty = 28m/s$.

The Reynolds number based on vehicle length, for all tests, was 10.9 x 10^6.

Full scale automotive testing was undertaken on an actual vehicle – in this case a modified EF Ford Falcon. The rear window was replaced with an identical fibreglass copy to enable pressure taps to be drilled. All cooling inlets and details were sealed using tape. Tests were conducted at zero yaw angle and constant ride height. See ***Figure 1*** for tapping locations.

High frequency scanning of the 128 pressure taps was undertaken using the Scanivalve ZOCENCL2100 rack mounted electronic multi-channel pressure measurement system. Sampling frequency for all tests was 1kHz.

Frequency response of tubing system was calculated using a computer program (D.R.O.P. Tubes). However, no correction for tubing response was made. The frequency response of the system was adequate for frequencies below 30Hz.

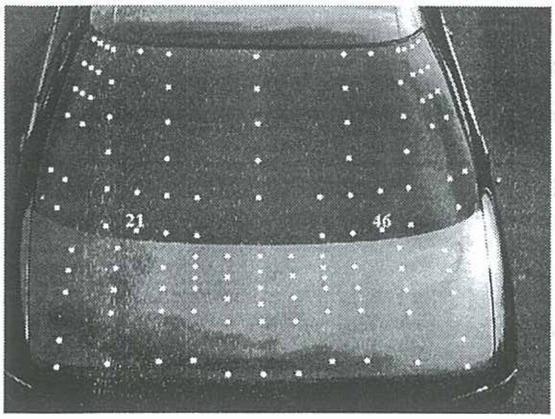

Figure 1: *Pressure Tapping Locations on Rear of Notchback Vehicle.*

RESULTS AND DISCUSSION

Average Surface Pressure

An averaged surface pressure plot of the rear of the notchback vehicle can be seen in ***Figure 2***. The average surface pressure distribution is slightly asymmetric. The most likely cause is due to the asymmetry of the exit jet. The centreline average pressure closely matches those given in several published papers with similar notchback configurations.

It can be seen that there is a large high-pressure region at the interface between the rear-window (backlight) and the boot lid. This high-pressure area can be attributed to pressure recovery in the separated region.

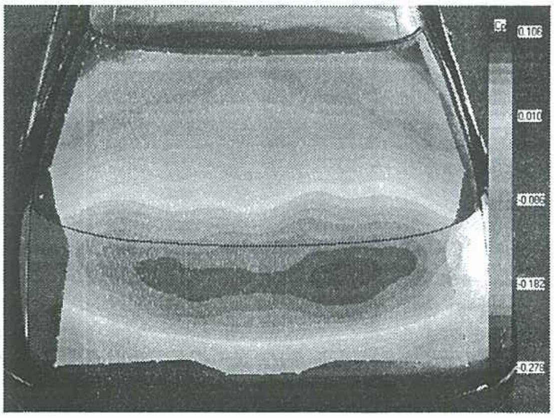

Figure 2: *Averaged Surface Pressure Distribution over Rear of Notchback.*

Unsteady Surface Pressure

Accurate time histories of surface pressures in areas of unsteadiness can yield valuable insights about the flow regime.

Surface pressure data were examined for the presence of periodicity. Two tapping locations were chosen on opposite sides of the vehicle, tapping 21and 46 (***Figure 1***). The autospectral density function was calculated for both tapping locations and is shown in ***Figure 3***. The autospectral analysis results showed that there were two dominant frequencies, 1.5Hz and 4Hz. However, further analysis of the other surface pressure data is required before definite conclusions can be drawn.

It is interesting to note that the 4Hz frequency identified corresponds to a Strouhal number of approximately 0.06 based on backlight height. The Strouhal number found for a backward facing step was observed to be 0.04-0.06 Nezu et al.(1989). The same periodicity was also observed in duct step flow by Eaton et al.(1982) – Strouhal number of 0.065. The Reynolds numbers for these flows were much lower than that for this study.

If the surface pressure periodicity is to be linked with any coherent flow mechanism, the fluctuations on opposite sides of the vehicle should be correlated. The magnitude of the cross-spectral density of two tappings on opposite sides of the vehicle (tapping 21 and 46) show the dominant frequencies to be 0.5Hz and 4Hz (See ***Figure 4***). The cross phase of 0.5Hz is 160° and 4Hz is 4°. These preliminary results show that the 0.5Hz periodicity is anti-symmetric and the 4Hz periodicity is symmetric about the centreline of the vehicle.

Figure 5 shows the sequential time-dependent surface pressure distributions over the rear of a notchback vehicle. The pressures have been digitally low-pass filtered at 5Hz. It can be seen that surface pressure fluctuations are symmetric about the centreline of the vehicle. Approximately 41% of the pressure fluctuation energy is observed below 5Hz. It should be noted that the 0.5Hz peak observed in the cross-spectrum contains very little energy.

The sequential instantaneous pressure distribution in ***Figure 5*** shows the apparent periodic growth of two high-pressure spots from the centreline of the boot lid. These two high-pressure spots both migrate outward toward opposite sides of the boot. Then at a critical location both these high-pressure regions disappear simultaneously hence indicating a symmetric phenomenon.

The periodic symmetric phenomena shown in ***Figure 5*** may be related to coherent vortex shedding behind the rear window. Nouzawa et al.(1992) speculated from direct integration of the unsteady, three-dimensional, incompressible Navier Stokes equations the existence of an 'arch' vortex located directly behind the rear window with its feet impinging on the boot lid. From experimental work undertaken by Nouzawa et al., in

1992, wake velocity fluctuations and rear surface pressures did not show any clear characteristic frequencies. Nouzawa et al.(1992) claimed that the 'arch' vortex intensified and shed alternatively, similar to the Karman vortex shedding process, however, no evidence was provided for this assertion. The results displayed in ***Figure 5*** appears to show the opposite - symmetric phenomena.

Goh (1995) showed, for a fastback vehicle, that the vortex cores of the two c-pillar vortices moved in a symmetric manner with respect to the centreline. This infers that the unsteadiness associated with the wake for a fastback vehicle is symmetric about the centreline of the vehicle.

Recent Particle Image Velocimetry investigations of the wake (Harvey(1995) and Bearman(1997)) have revealed what appears to be multiple vortex structures in the wake of fastback vehicle. The above authors have suggested,, that the two contra-rotating turbulent vortices are in fact the sum of numerous smaller contributory vortices.

The energy of the surface pressure fluctuations below 5Hz contributes only 41% of the total standard deviation. If the pressure fluctuations below 5Hz are dominated by a symmetric phenomenon then the remaining 59% of the energy may be a result of the pressure fluctuations from other apparently random turbulent structures shed from various parts of the complex bluff body. Further work is required to quantify this.

Estimated Unsteady Integrated Force Fluctuations

The fluctuating lift force acting on the vehicle due to the unsteadiness over the rear of the vehicle can be estimated directly through integration the instantaneous pressures.

The lift force spectral properties are very similar to those of the pressure. The dominant frequency is again 4Hz. It can be seen from a time history plot of the force that the 4Hz frequency dominates the fluctuating force and contains most of the energy of the spectrum (>95%). The fluctuating lift force is calculated to be approximately 65N - maximum to minimum. This fluctuating force equates to a fluctuating lift coefficient of 0.063 occurring at 4Hz. This fluctuation may be enough to excite structural natural frequencies and hence affect handling and control of the vehicle.

CONCLUSIONS

Unsteady surface pressure measurements and spectral analysis techniques have been employed to investigate the periodicity of the backlight and boot lid region of a notchback vehicle.

Preliminary unsteady surface pressure data indicates the possible existence of a symmetric coherent structure behind the backlight of a notchback vehicle. The symmetric pressure fluctuations appear to have a periodicity of approximately 4Hz at 100km/h. This corresponds to a Strouhal number of 0.06 based on backlight vertical height. The source of the periodic unsteadiness needs to be investigated further.

Approximately 41% of the fluctuating energy is contained below 5Hz. A large portion of the energy is not found to be associated with any spectral peaks, hence indicating random pressure fluctuations contain significant energy. Further work is required to ascertain the source and structure of the surface pressure fluctuations.

The experimental results suggest that a fluctuating lift coefficient of approximately 0.063 (max-min) has a dominant frequency of approximately 4Hz.

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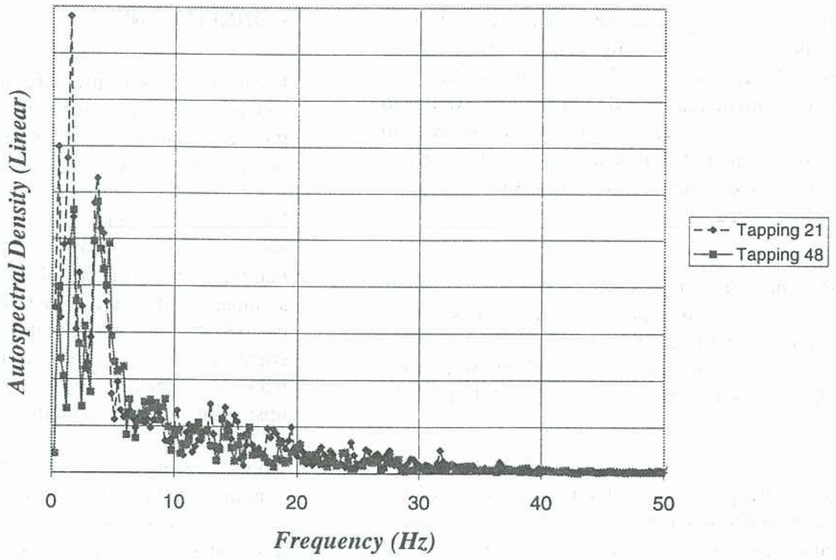

Figure 3: *Autospectral Density Magnitude for Selected Locations on the Rear of Notchback Vehicle.*

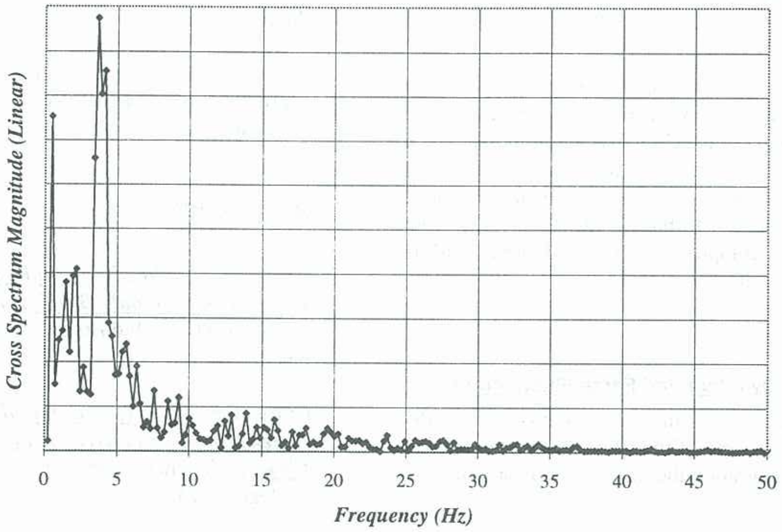

Figure 4: *Cross-Spectral Density Magnitude for Two Points on Opposing Sides of Vehicle.*

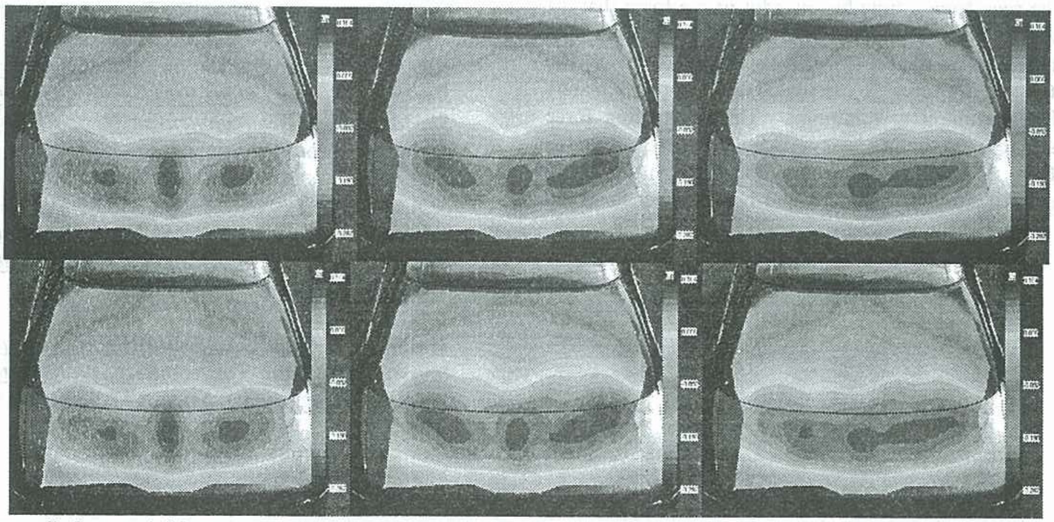

Figure 5: *Sequential Instantaneous Pressure Distribution Over Rear of Notchback Vehicle. (Frames @ 0.04s pitch)*