Aerodynamically Induced Vibration of Automotive External Mirrors

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Introduction:

Driving along a highway, the driver of an automobile routinely glances at the image in the external rear view mirror to assess the rear traffic conditions, if this image is blurred or unclear it is not just annoying, but unsafe. The rear view mirror is required to provide the driver with a clear, sharp image under all driving conditions. In some countries, cruising speeds of 200 km/hr or higher are not uncommon and consumer expectations are ever-increasing. Therefore, to design and manufacture a satisfactorily performing external rear view mirrors is becoming increasingly more difficult.

The external mirror vibrations can be the result of forcing functions from vehicle vibration acting upon the mirror mount. This vehicle vibration can originate from mechanical sources such as the tyres, drive shaft, transmission or engine or aerodynamic sources acting on the entire vehicle (thought to be minor). Another possible cause of vibration is transient aerodynamic forces acting directly upon the mirror's outer casing.

The automobile manufacturers establish performance parameters for the mirrors that must be met by their suppliers, these include low vibration, low weight and low cost. A step towards achieving these sometimes conflicting goals is to better understand the cause of the mirror vibration.

The objective of a research program established by RMIT and supported by Britax Rainsfords (a manufacturer of automobile mirrors) is to investigate the noise and vibration of external rear view mirrors. This program includes the effect of the aeroacoustic noise generated by the mirror on the interior cabin noise, and the effect of the mirror's aerodynamics on its vibration. An initial research question was therefore established. Do the aerodynamic loads, acting on the vehicle body, or directly on the mirror, have an appreciable effect on the mirror vibration?

Due to the highly complex nature of the airflow in the region of the mirror a series of on-road and wind-tunnel tests were preferred to a theoretical approach. The flow in this region includes a vortex originating from the base of the A-Pillar and attached flow from the windscreen that then separates over this vortex and reattaches to the vehicle on the side window. This flow is shown in Figure 1 taken from reference 1. It is further complicated by the turbulence in the approaching flow, arising from atmospheric turbulence, or from the wakes of other traffic or nearby objects.

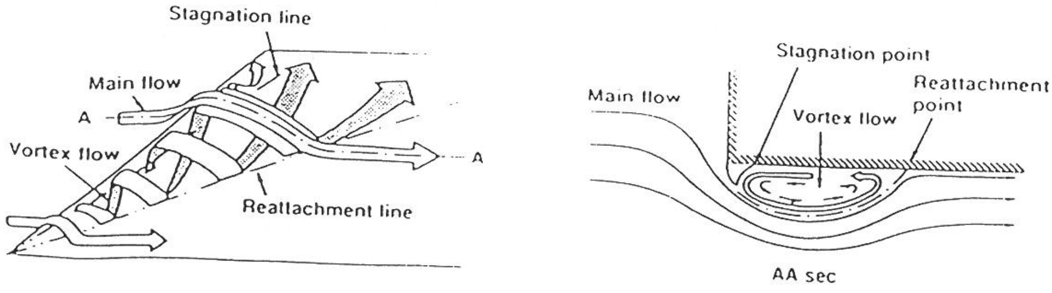

Figure 1: Air flow in the region of the external rear view mirror taken from reference 1.

Test Program:

A series of tests were performed on a production automobile fitted with a mirror which was known to have satisfactory performance. On-road tests were conducted at various speeds from 80 to 140 km/hr and on different road surfaces, followed by full-scale wind-tunnel tests at the RMIT/Monash facility. As the on-road tests were conducted at different locations to provide the variation in road surfaces, the ambient wind conditions therefore also changed from a gusty head wind of approximately 5~ 15 km/hr to a cross wind of similar strength.

The test vehicle was fitted with two triaxial accelerometers on the drivers side; one being located on the door structure at the mirror mount; and the other in the center of the mirror glass. The mirror contains a ball and socket mounting configuration at the center of the glass. Two screw jacks, attached slightly below and outboard of the center position, also support the glass (as well as providing a mechanism to adjust the mirror angle). The natural frequency of the glass on its mount was reduced by the presence of the accelerometer (50 gm mass). However, due to the supporting structure of the glass this effect will be least in the vehicle's longitudinal direction compared with the vertical or lateral directions.

Other test equipment included charge amplifiers, an oscilloscope, power inverter, filters and a 16 channel DAT recorder. The resulting six outputs from the accelerometers were monitored on the oscilloscope and simultaneously recorded for post processing on the DAT recorder for the on-road test runs. To eliminate transient response due to passing traffic, the tests were performed with no other vehicles on the road. During the wind tunnel testing, the vertical, longitudinal and lateral direction tests were each performed separately, with the outputs from the two accelerometers recorded simultaneously. Each test run was recorded for approximately a 15 second duration.

To eliminate aliasing and frequencies above which the human eye is able to detect fast motion, all the test signals were low-pass filtered at 200 Hz.

Test Results:

The voltage outputs from the accelerometers were digitised at 1000 Hz by the use of an A/D card in a PC. The power spectrum for each test run was then produced from the digitised time series. This was achieved by averaging the result of 50 FFT calculations, each of these consisted of 1024 data points to which a Hanning window was applied. This was accomplished on a PC using MATLAB software.

The spectra of the longitudinal, lateral and vertical directions show very similar distributions across the frequency range investigated, with the vertical direction marginally higher than the other two. Generally an increase in amplitude and frequency was also noted with increasing driving speed.

The vibration spectra of the mirror glass are shown in Figure 2 with an explanation of the test conditions given in Table 1. The figure indicates, except at low frequency, similar vibration levels were recorded during the wind-tunnel and on-road test runs. The peak levels for both were at approximately 33 Hz; however, the additional mass of the accelerometer on the glass would have influenced this frequency value compared to that of a mirror without the additional mass of the accelerometer.

The variation between the on-road spectra, especially at the higher frequencies, may be the effect of smooth compared to coarse bitumen road surfaces. However, at high frequencies, results for the on-road test runs 25 and 26, are also lower than the wind-tunnel results; hence the variation in on-road results may be due to the cross wind reducing the vortex from the A-pillar.

The vibration spectra at the mount location during the wind-tunnel and on-road tests are given in figure 3. The levels obtained during the wind-tunnel test are 1-2 orders of magnitude below the on-road results; as there are only aerodynamic inputs in the wind tunnel. This result was not unexpected and confirms that aerodynamically-induced vibration of the vehicle body was significantly less than mechanically-induced vibration.

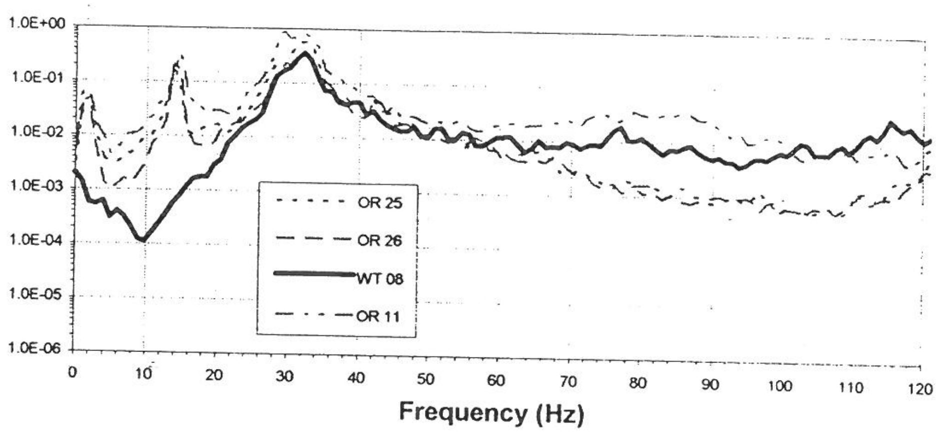

Figure 2: Comparison of the vertical vibration spectrum of the mirror glass during on-road and wind-tunnel tests at 100 km/hr

Test Run No	Type of Test	Vehicle Speed (km/hr)	Conditions
OR 11	On Road	100	Coarse bitumen, head wind
OR 25	On Road	100	Smooth bitumen, cross wind from drivers side
OR 26	On Road	100	Smooth bitumen, cross wind from drivers side
WT 08	Wind Tunnel	100	Vertical direction, 0 yaw angle

Table 1: Explanation of test run conditions

The minor peak in the on-road results at 14 Hz, is also present in the spectra of the on-road mount vibrations, as this also approximately the tyre rotational speed (rolling diameter of the tyres on the test vehicle was 650 mm), the vibration may be due to a mechanical input from the drive chain. Other possible sources of mechanical vibration include the drive shaft, approximately 45 Hz, the engine or the input from the suspension (1~2 Hz).

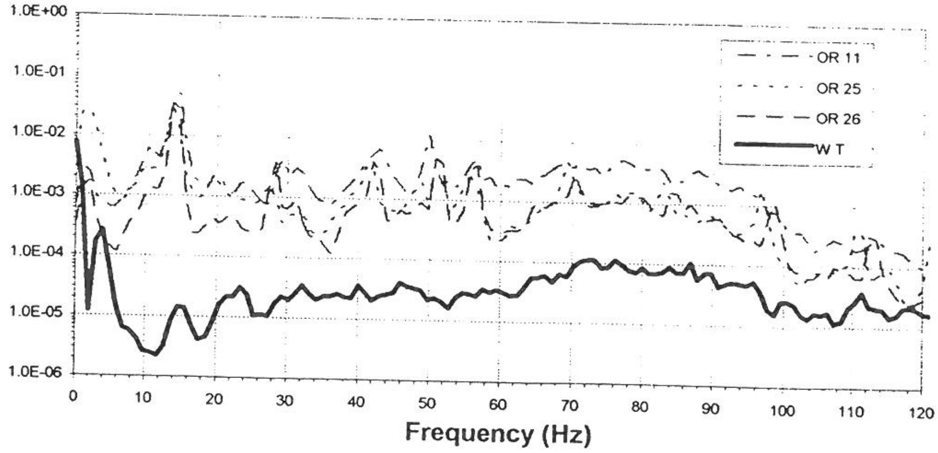

Figure 3: Comparison of vertical vibration spectrum at the mirror mount location during on-road and wind-tunnel tests at 100 km/hr

Conclusions:

The test series performed clearly indicates that on the test vehicle, at a driving speed of 100 km/hr, the transient aerodynamic loads substantially contribute to the vibration of the mirror glass. This is clearly demonstrated by comparable levels of vibration at the mirror glass, during both the on-road and wind-tunnel tests.

The peak levels of vibration occurred at a frequency of 33 Hz, with the vibrations marginally larger in the vertical direction than either the lateral or longitudinal directions. However, results were influenced by the presence of the accelerometer.

Limitations:

The data were affected by the additional mass of the accelerometer on the glass. It was assumed that its effect would be identical for the on-road and wind-tunnel results. No attempt was made to consider the human perception of vibration, except to establish the upper test frequency. Human perception of an image in a vibrating mirror is significantly effected by rotational vibrations and only marginally by small translations. The program only measured the translational vibration in the vertical, longitudinal and lateral direction, rotational magnitude was not measured.

Recommendations:

Use of a test method that did not significantly influence the dynamics of the system would be desirable. Also a method for establishing the rotational vibration instead of the translational would be of direct benefit to determine if the vibration would be detected by the human eye. This could be accomplished by use of several small low mass accelerometers or a non-contact detection method, e.g., reflected light.

As the test program concluded that aerodynamic loads are an important factor in the vibration level, an understanding of the aerodynamic structure that effects the mirror vibration is needed, combined with an assessment of the geometric factors that will augment or reduce the fluctuation forces. Therefore, different mirror shapes that would have different aerodynamic characteristics (such as an increase in the neck between the vehicle and the mirror) would be an area of future research. The influence of the airflow onto the mirror from different vehicle body configurations and details, or the minor changes to the position of the mirror relative to the vehicle, could also be other possible avenues.

The wind-tunnel tests were all conducted at zero yaw angle of the approaching air onto the vehicle; the on-road results contain varying yaw angles which is the normal driving condition. Therefore, another factor that could be investigated is the effect of the yaw as well as the turbulence scale and level on the vibration.

Another area beyond the scope of this test series is in the human perception of an image in a vibrating mirror. It is believed that the physiological factors that govern how the eye and brain detect fast motion and make a flashing light appear steady, overlap and are hard to distinguish. The term critical fusion frequency is given to the frequency at which a flashing light will appear constant, it is between 50 - 100 Hz depending on the light intensity. A greater understanding of the critical criteria for the human detection of a vibrating object would also be desirable to more precisely define the limits of allowable vibration.

Acknowledgments:

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Reference:

[1] George A.R. & Callister J.R.; Aerodynamic Noise of Ground Vehicles; **SAE 911027**.