

Effects of On-Road Turbulence on Vehicle Surface Pressures in the A-Pillar Region

Andrew A. Lawson, David B. Sims-Williams and Robert G. Dominy
Durham University

Copyright © 2008 SAE International

ABSTRACT

There is increasing concern about potential differences in aerodynamic behavior measured in steady flow wind tunnel conditions and that which occurs for vehicles on the road. As tools become available for better simulation of on road conditions there is a growing practical value in understanding what range of conditions are important to simulate.

Surface pressures measured on the sideglass of a European hatchback vehicle in the MIRA full scale wind tunnel are compared with those measured on-road. The on-road data corresponds to relatively calm, low yaw conditions and the time averaged pressure distributions on-road and in the wind tunnel at zero yaw were very similar.

Variations in instantaneous aerodynamic yaw angle produces fluctuations in surface pressures but the sensitivity of instantaneous pressures to yaw angle was lower for the on-road measurements compared with steady state wind tunnel tests. Also, surface pressure unsteadiness was larger than could be attributed to yaw angle fluctuations alone.

The response of instantaneous surface pressures to yaw angle fluctuations is reduced for higher frequency fluctuations as small scale turbulence gusts are less able to modify the flow over the entire vehicle. Examination of the spectral relationship between surface pressure and yaw angle indicates that the impact of yaw angle fluctuations at is reduced by a factor of 2 for reduced frequencies above unity.

INTRODUCTION

Aerodynamic development of road vehicles is generally undertaken under steady flow conditions, whether this is in a wind tunnel or using computational fluid dynamics (CFD). The traditional focus has been on the acquisition of repeatable data in order to make it possible to reliably resolve the effects of detailed shape changes.

There is increasing concern that these simulations do not represent the real-world environment with respect to externally imposed unsteadiness. In order to assess the limitations of these tools it is important to understand both the natural wind environment and the sensitivity of typical vehicles to these real-world conditions. The issue of the characterization of on-road turbulence conditions is ably reviewed by Cooper and Watkins [1]. They conclude that, although a substantial body of data exists, further research is required specifically on typical low wind conditions with average traffic. In [2] they further conclude that additional data is required to assess the importance of these phenomena on the vehicle's aerodynamics.

As wind tunnel simulations of turbulent conditions more representative of on-road driving become available (eg: [3], [4]) there is a growing practical value in understanding what range of conditions are important to simulate.

Externally imposed aerodynamic unsteadiness can be categorized into a number of different sources.

The natural wind contains vector fluctuations, or turbulence. Taylor's Hypothesis [5] states that turbulence in the natural wind can be considered to be a frozen set of perturbations or eddies convected with the mean wind velocity so that a stationary observer sees fluctuations in time. In the case of a moving vehicle the point of observation is actively traversing through this frozen turbulence field which will modify the time scales associated with these eddies. This source of on-road turbulence has received the greatest attention and can be estimated based on stationary measurements used extensively in the wind engineering community.

Road side furniture will give rise to natural wind fluctuations which are distributed in space but which would be invisible to a stationary observer. The moving vehicle will therefore also see these fluctuations as it traverses through the spatial field. One extreme case which has been the subject of several studies [6, 7] is the sharp edged gust which a vehicle might traverse

on exit from a tunnel into a region of strong cross wind. The same fundamental effect will, however, give rise to a spectrum of fluctuations seen by the moving vehicle. The relative motion of the vehicle with respect to other vehicles will give rise to similar fluctuations.

Unsteady wakes from other vehicles, as discussed in [9],[10] will give rise to time varying fluctuations even if there is no relative motion between the source vehicle and the observer.

Lawson et al [11] presented comparisons between wind tunnel and on-road measurements for the vehicle discussed here. This showed differences in the time averaged flow at the bonnet leading edge which were attributed to a change in stagnation point location due to the ground simulation of the wind tunnel tests, rather than to turbulence effects. On the backlight, only minor differences were seen between the wind tunnel and on-road tests, despite the vehicle having a backlight flow which is known to be sensitive to small geometry changes. The greatest effects were observed on the front sideglass in the region of the a-pillar flow. The a-pillar region was also found to be the area of greatest sensitivity to on-road effects in a study by Lawson et al [12] on a compact SUV. The a-pillar flow impingement on the sideglass is well established as an area of complex and important flow, particularly due to its contribution to cabin noise [13]. This paper therefore seeks to investigate effects in the sideglass / a-pillar region. Road conditions with low wind and “average” traffic conditions have been selected based on the conclusions of Cooper and Watkins [1] which called for further data under these conditions.

EXPERIMENTAL TECHNIQUE AND METHODOLOGY

Test Vehicle

The vehicle used was a production, UK specification Rover 214Si as shown in figure 1. This vehicle is outwardly typical of many European mid-sized hatchbacks. Key dimensions are given in table 1. This geometry has been used as a test case at Durham for a number of different studies (eg: [10],[11]).

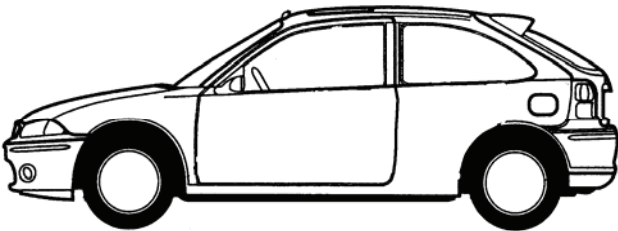


Figure 1: The Test vehicle

Frontal area	2.01m ²
Height	1.42m
Front track	1.470m
Rear track	1.470m
Width (not inc. mirrors)	1.690m
Wheelbase	2.500m
Overall length	3.970m

Table 1: Key vehicle dimensions

Wind Tunnel Measurements

Wind tunnel measurements were performed in the MIRA full-scale wind tunnel, details of which can be found in [14]. The wind tunnel data were corrected for blockage using an area ratio method as detailed in [15].

Road Testing

The vehicle was driven at an indicated velocity of 26.8ms⁻¹ (60 mph) on public roads in the north of England. Traffic conditions were “average” (ie: other cars were present on the road but it was possible to maintain constant speed). The terrain most closely corresponds to the middle of the categorizations provided in ESDU 85020 [16], “Countryside with many hedges, some trees and some buildings”. Only data under light wind (~2.5 m/s), near zero-yaw conditions has been included here.

Air Speed Measurement

The relative air speed and yaw angle for the on-road measurements was determined using a roof-mounted 3-hole probe. Probe calibrations were performed both for the probe in isolation in Durham’s probe calibration facility and with the probe in-situ on the roof of the vehicle in the full size wind tunnel. When in-situ on the car the probe sees both a local speed-up of the airflow and a modification of the local yaw as illustrated in Figure 2. The in-situ calibration was therefore used for the on-road tests to best represent the free stream conditions away from the vehicle. The probe remained in position throughout the collection of the data presented here to maintain the calibration accuracy.

Non-dimensionalisation was performed using data from the probe calibrated to tunnel reference conditions in order to allow direct comparison of pressure coefficient data on-road and in the wind tunnel.

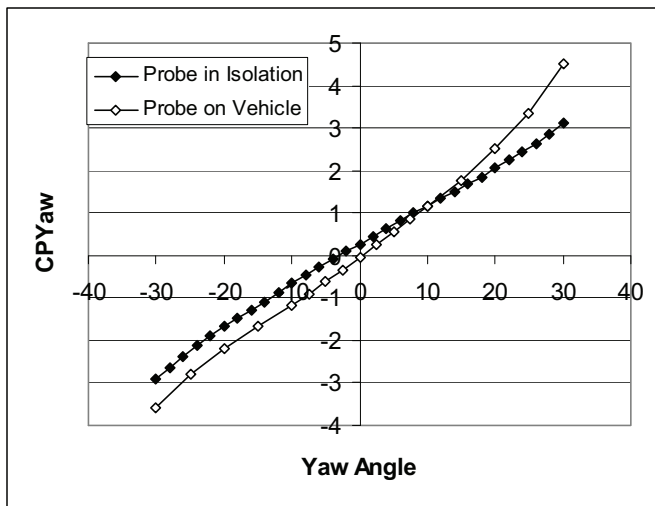


Figure 2: Probe calibration comparison

Surface Static Pressure Tappings

Surface pressures on the vehicle were measured using stick-on disc probes as illustrated in figure 3. The devices used are 1.63mm thick, 20mm diameter aluminium alloy discs which have a centrally located pressure tapping. The discs were attached using purpose-made self-adhesive, circular patches which had the benefit of smoothing the square edge of the disc and ensured aerodynamic symmetry in the event of changed flow direction. Good repeatability of disc position has been demonstrated with this approach but for this study the wind tunnel and on-road measurements were made without removing and reattaching the discs. Pressures were measured relative to the cabin pressure but pressure coefficients are defined based on the 3-hole probe's determination of free-stream static pressure, which avoids any corruption of reported pressure levels by changes in cabin pressure (eg: due to different levels of leakage/ventilation).

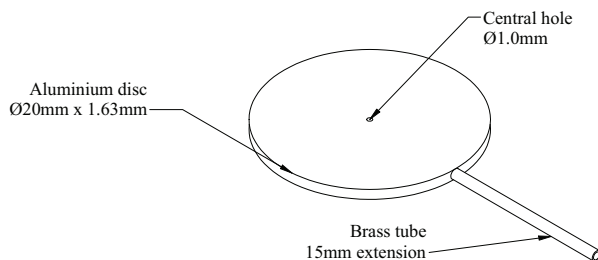


Figure 3: Surface static pressure disk probe [11]

Although the focus of this work is on the vehicle sideglass the vehicle was fitted with approximately 150 pressure tapping positions including the centerline and backlight. Figure 4 illustrates the installation of pressure tappings on the vehicle sideglass. The 3-hole probe installation on the vehicle roof is also visible.



Figure 4: Test vehicle with pressure tappings

Pressure Measurement

Pressures were measured using Sensor Technics PXLA12X5DN pressure transducers. Surface pressures were generally measured sequentially via a 48 port scani-valve while the three-hole probe used dedicated transducers to allow simultaneous measurement with all surface pressures (eg: for non-dimensionalisation).

All pneumatic connections were made using 1mm ID, PVC tubing and care was taken to use identical tube lengths for all surface pressures. For the on-road measurements, a tubing transfer function correction was applied for magnitude and phase, as described by Irwin et al [17], Sims-Williams and Dominy [18] and elsewhere. Figure 5 illustrates the tubing transfer function calibration of a disc probe. Although only a simplified tubing arrangement is shown in the figure this process needs to include the entire tubing system (ie: including scani-valve etc). A similar calibration was performed for the three hole probe and associated tubing.

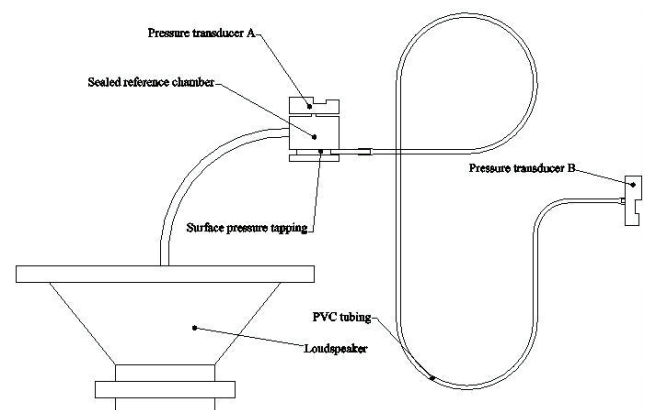


Figure 5: Probe & tubing transfer function correction calibration system