# AN ON-ROAD TESTING PROCEDURE FOR DETERMINING UNDERBODY PRESSURE DISTRIBUTIONS ON VEHICLES

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## Introduction

The flow underneath a vehicle occurs in a complex region defined by the rough underside of the vehicle and the road surface. This underbody flow field interacts with and influences the external flow field. It is in turn influenced by the pressure distributions established by the forebody and afterbody flow fields. Accordingly the management of the underbody flow and its effect on the overall aerodynamic loading of a road vehicle is now being investigated.

This paper presents the findings of experiments which were undertaken to determine if modifications to a vehicle's underbody area could be assessed by analysing the static pressure history recorded as a vehicle approaches and passes a measurement point located on the road surface. Full-scale on-road testing is preferred to wind tunnel testing in the investigation of underbody flow fields because it eradicates errors caused by imperfect modelling of road boundary effects and wheel rotation.

## Description of Test Technique

A literature review indicated that the underbody flow field effects produced by various treatments, such as altering ride height or the addition of airdams, could be determined by carrying out underbody pressure measurements. Most of the published data referred to wind tunnel tests of models using a series of pressure tappings on the underbody to determine the pressure distribution on the underside of the vehicle. In addition, there were some reports of using the 'ground plane' (i.e. road level) pressures as a measure of an airdam's performance [1], although no full-scale test results were found.

As a relatively simple test method was required, it was decided to experiment with the use of a pressure transducer, located so that it measured the static pressure of the road as a vehicle was driven over it. This method, first suggested by Buckley [2], was found to work well, the effect of minor modifications such as a 10 millimetre change in front axle ride height being detected. In addition, it was found that the pressure distributions were repeatable, with good agreement obtained for the pressure magnitudes over the front third of the underbody.

Prevailing wind appeared to have little effect on the underbody pressure distributions and was thus not considered to be a factor which affected the repeatability of the results.

In order to automate the testing process a computer was used to sample the output from the pressure transducer at high speed, sampling being initiated automatically by a vehicle detector located some 15 metres in front of the measurement point. A second vehicle detector, in-line with the transducer, was used to indicate when the car passed over the transducer. The computerised sampling system allowed testing to be carried out at speeds between 50 and 150 km/h with adequate resolution.

Software was developed to allow the data obtained from these runs to be analysed quickly as the testing proceeded. This system allowed the pressures to

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be normalised by the vehicle speed (determined by the time the car took to pass the vehicle detector), resulting in direct calculation of both the underbody pressure coefficient profile along a longitudinal section of the vehicle and the lift force acting on the section. By analysing the data in this manner, results from runs at various speeds could be easily compared.

## Equipment

The transducers used for the measurement of underbody pressures were Setra 0.1 psi differential pressure transducers. These have a high frequency response (in excess of 1000 Hz) and provide good resolution over the range of pressures encountered during this type of testing.

The system used to detect the presence of a vehicle consisted simply of a photo-electric cell driving a switching circuit, and a high powered lantern. This system was arranged to give a nominal output of zero volts with no interruption to the light source, and 5.0 volts when the light beam was interrupted.

The computerised sampling system consisted of a Digital Equipment Corporation PDP 11/23 Plus computer running under the RSX-11M operating system. Data acquisition was by way of a 12 bit analogue-to-digital converter.

Software was developed specifically to allow the inputs from the pressure transducer and vehicle detectors to be monitored or recorded as required. In the monitor mode 500 samples were taken from each channel at a rate of 500 Hz and the data then analysed to give the mean, minimum and maximum values for each of the three channels. As soon as the information was displayed on the VDU the process was repeated. In the recording mode the system monitored the input from the first vehicle detector continuously. As soon as the presence of the vehicle was indicated the system then began recording the output from the pressure transducer and the second vehicle detector at a rate of approximately 1400 Hz, taking 1000 samples for each channel. This data was then written to disk for later analysis.

## Results

### (1) Comparison with Published Data

Although there is relatively little published data available on full-scale measurements of underbody pressure, one paper by Carr [3] was found which included both road and wind tunnel pressure measurements. As results from tests on a 1967 VW Fastback were included in this paper, and a similar vehicle was available for testing at Central Laboratories, a comparison was carried out of the two underbody pressure profiles.

The method used by Carr to measure the underbody pressure was different from that used at Central Laboratories. In his tests Carr used a total of nine pressure tappings on the underbody of the car, the pressures being measured by an inclined manometer, which was clamped to record the reading after the test speed had been maintained for some 30 seconds.

In spite of the difference in the measuring techniques, the agreement between the two sets of results is relatively good (see Figure 1). In particular, the point at which the minimum pressure occurs is the same in both cases and the initial rate at which the pressure decreases is almost identical. The large high frequency fluctuations in pressure occurring in the data obtained at Central Laboratories were caused by a faulty exhaust, the resultant noise being recorded by the transducer.

(2) Flow Field Effects Produced by an Airdam

Ground plane centreline pressures for a 1985 Toyota Corolla hatchback, with and without a 45 mm deep airdam fitted, are given in Figure 2. These results, which represent approximately a one second history of the ground plane pressures, enable the effect of the airdam on the approach, underbody, and wake flow fields to be examined.

Referring to Figure 2, the ground pressures ahead of the vehicle are positive due to the vehicle's decelerating effect on the approach flow as it has to change direction to pass over, around and under the vehicle. The addition of the airdam in this case does not appear to raise the upstream pressure levels.

Investigation of the pressures in the vehicles underbody region indicates that the airdam also causes the flow to converge under the airdam, the resulting flow acceleration reducing the static pressures forward of the front axle. This has the desirable effect of decreasing the front axle lift and the vehicle pitching moment. However, the pressure reduction at the nose of the vehicle is partially offset by the increase in pressure on the floor pan and so only a small change in the overall lift force acting on the underbody results.

Ideally, if the base pressure of the wake is increased, the net drag on the car will be reduced. From the pressure data given in Figure 2, it can be seen that the base pressures are relatively unaffected by the addition of the airdam, although the extent of the far wake appears to have increased. This may be due to an increase in the intensity of the trailing vortices brought about by the airdam deflecting more air along the sides of the vehicle.

In general, the results of these on-road measurements are in close agreement with the wind tunnel findings presented in [1].

## Conclusion

This study has verified the feasibility of using ground surface pressure measurements to investigate the airflow beneath a road vehicle and its interaction with the external flow field. The resulting on-road procedure developed for obtaining the required aerodynamic data has the following advantages when compared with other test methods:

(1) no vehicle modifications are required;
(2) since all measurements are taken from the road surface, not from the vehicle, instrumentation noise problems normally associated with full-scale testing have virtually been eliminated;
(3) calm wind conditions, although desirable, are not necessary to obtain useful results; and
(4) being computer based, preliminary analysis of the data can be carried out while the tests are in progress so configuration changes can be rapidly assessed.

The procedure is therefore particularly applicable to the investigation of various methods used for reducing underbody drag and for improving handling through 'ground effects'.

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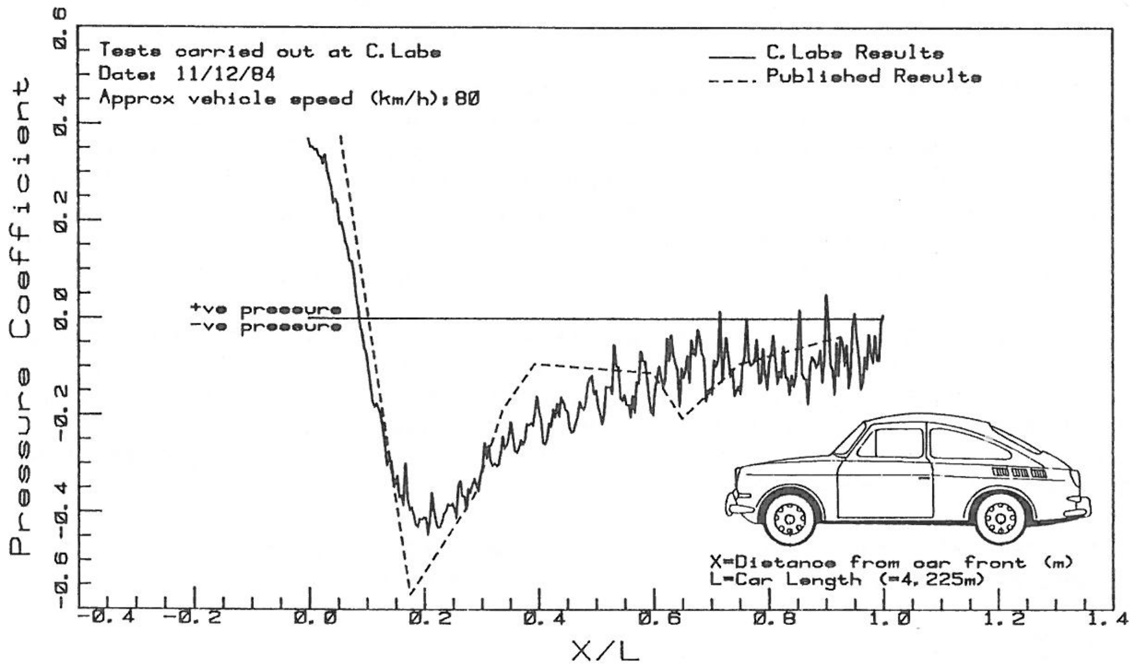


Figure 1: 1967 VW FASTBACK underbody pressure comparison

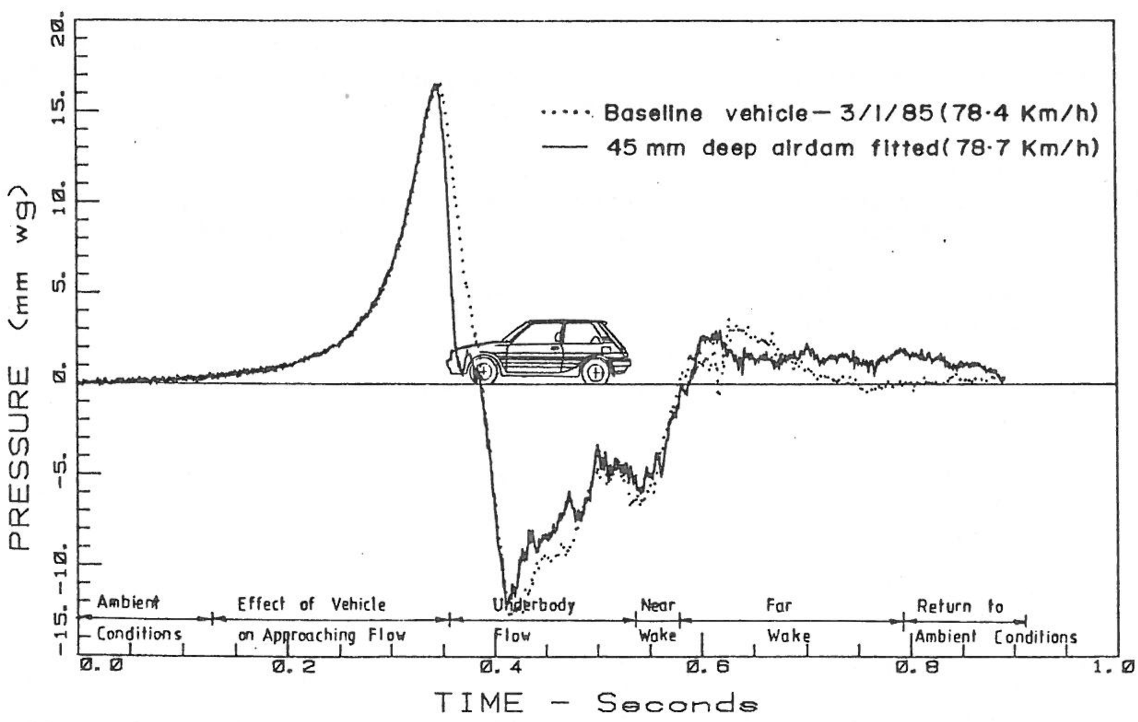


Figure 2: Centreline ground pressure changes produced by an airdam