

# Experimental Data for the Validation of Numerical Methods - SAE Reference Notchback Model

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## ABSTRACT

The use of simulation tools by vehicle manufacturers to design, optimize and validate their vehicles is essential if they are to respond to the demands of their customers, to meet legislative requirements and deliver new vehicles ever more quickly. The use of such tools in the aerodynamics community is already widespread, but they remain some way from replacing physical testing completely. Further advances in simulation capabilities depend on the availability of high quality validation data so that simulation code developers can ensure that they are capturing the physics of the problems in all the important areas of the flow-field.

This paper reports on an experimental program to generate such high quality validation data for a SAE 20 degree backlight angle notchback reference model. This geometry is selected as a particularly powerful test case for the development and validation of numerical tools because the flow exhibits a realistic impingement and A pillar regime, significant three dimensional structures and the backlight/boot-deck exhibits a local separation and reattachment. The paper includes force and moment data, surface pressures for the centerline, slant, boot-deck and base and detailed PIV data for the impingement region, model centerline, A pillar and multiple planes on the slant and boot-deck. Time averaged, statistical and instantaneous data are presented.

Results are discussed with regard to the overall flow features, the correlation between the different data sets and the accuracy and limitations of each of the experimental techniques in this particular application. Example data is included throughout the paper and full data sets are freely available in the Loughborough University Institutional Repository as a resource for future code development.

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## INTRODUCTION

Vehicle manufacturers face considerable challenges in the design, optimization and delivery of their products to meet the needs of their various stakeholders. They must respond to the demands of their customers for ever higher quality and value, they must meet complex and changing legislative requirements and deliver new vehicles increasingly quickly. The use of simulation tools is essential if these demands are to be met and consequently manufacturers and suppliers have invested heavily in simulation capability. The use of simulation tools in the aerodynamics community is already widespread, but they remain some way from replacing physical testing completely. In the aerodynamics community this is clear from the continued development of existing wind tunnel facilities and the construction of new ones.

Simulation capability within aerodynamics has improved over the last several decades but further advances require a shift away from validation using a *bottom line* drag figure to a much more complete assessment of the performance. For example, it is not uncommon for a numerical prediction to generate a drag coefficient within only one or two percent of an experimental value, but the same prediction to be 30% or more adrift in the mean base pressure. Computational methods inherently generate a wealth of detailed data that has considerable value in the design and optimization process but the value this offers will only be realized if there is full confidence in the output. High quality validation data generated from experimental work has an important part to play because code developers can use it to demonstrate that they are capturing the physics of the problems in all the important areas of the flow-field, or to identify areas of significant error. The purpose of this paper is to make high quality validation data available to the wider community. Initially this is for the SAE geometry that captures the most important aspects of a vehicle

flow-field but there is the potential to add to this resource. This paper does not attempt to present any CFD results as the intention is to provide the resource rather than another Experimental/CFD comparison.

The data can be downloaded free of charge from the Loughborough University Institutional Repository [1]. The download includes details of the geometry, full descriptions of data and its location in the model frame of reference.

## EXPERIMENTAL METHODOLOGY

The approach taken is to use a standard reference model that is already widely available and accepted as a reliable test case for vehicle aerodynamics. The use of simple bodies and simplified vehicle models is well-established within the automotive aerodynamics community because they provide a means of capturing the important flow-field structures and physics without the distraction of specific vehicle details. The most resonant examples are those of Morel [2] and Ahmed [3]; these examples considered just one aspect of vehicle aerodynamics, but have proved invaluable since, both in the insight provided into the flow-field and also in generating understanding that is applied to real vehicle development. LeGood and Garry [4] provide a thorough summary of the use of reference models, including simple bodies, basic car shapes and production series cars.

In this work the SAE 20 degree backlight angle notchback reference model is selected, having been designed as a basic car shape rather than a simple body such as the Ahmed model. It therefore exhibits a realistic impingement and A pillar flow, significant three dimensional structures and the backlight/boot-deck region exhibits a local separation and reattachment; making this geometry a powerful test case for the development and validation of numerical tools.

It is worth noting that the new widely available generic car model, Heft et al, [5] is not considered suitable for this work. The proposed vehicle contains many of the features seen on a typical vehicle while seeking to make a realistic, but non-manufacturer specific, geometry widely available. The more complex geometry may be useful for broad evaluation purposes but is not justified here because the additional detail and complexity do not add significant new numerical challenges over a more simple geometry, they do however increase computational load and introduce difficulties of interpretation.

The experimental program consists of force and moment measurements, surface pressures for the centerline, slant, boot-deck and base and detailed PIV data for the impingement region, model centerline, A pillar and multiple planes on the slant and boot-deck. Time averaged, statistical and instantaneous data are presented.

## Wind Tunnel

All data was acquired in the Loughborough University  $\frac{1}{4}$  scale wind tunnel illustrated in Figure 1. Additional details including inlet profile and detailed geometry can be found in Johl, [6]. The working section has a  $1.92\text{m} \times 1.32\text{m}$  cross section expanding to  $1.94\text{m} \times 1.32\text{m}$  over its  $3.2\text{m}$  length to negate the effects of boundary layer growth on axial pressure distribution. The walls and a section of the roof are constructed from toughened glass allowing optical access. The floor is fixed, generating a boundary layer thickness ( $\delta^{99}$ ) of  $60\text{mm}$  at the model location.

Test section working velocity is  $40\text{m/s}$ , turbulence intensity at this velocity is  $0.2\%$  and the deviation from the bulk flow velocity is  $\pm 0.4\%$ . The temperature, free-stream static and dynamic pressure are measured at the start of the working section with a pitot-static tube and thermocouple; all of this data is delivered digitally to the control computer which is used to control tunnel speed and to calculate force and moment coefficients. The atmospheric pressure is measured with a Druck DPI 142 barometer located in the wind tunnel control room.

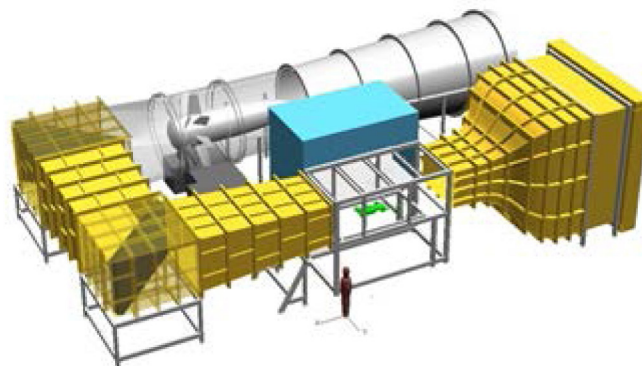


Figure 1. Loughborough University wind tunnel layout.

## Model Description

The SAE reference model has been utilized by previous investigations in work such as the development of open jet wind tunnel boundary corrections [7], parametric studies analyzing the effects of ground simulation in wind tunnels [8], experimental work validating CFD simulations [9] and the investigation of dynamic yaw behavior [10]. These have been conducted across a range of scales from  $1:5$  up to full scale. The  $1:5$  scale is employed here as it provides a suitable compromise between factors such as wind tunnel blockage, manufacturability, achievable Reynolds number and the field of view that can be reasonably resolved with PIV.

The SAE reference model is an evolution of the MIRA family of reference models and incorporates a number of small but significant improvements. The front end is simplified and formed from a  $30^\circ$  slant with a large leading edge radius. This feeds a flat floor with a small  $6^\circ$  centrally mounted diffuser starting at the rear axle centerline designed to counteract the large negative pitching moment generated by the front slant.

Surface intersections are blended with large radii minimizing flow separation and providing a degree of similarity with production vehicles, where flow typically remains attached as it transitions between the forward facing and longitudinal surfaces. The longitudinal radii are, however, of a slightly more complex, elliptical design incorporating a sharp edge intended to fix the location of separation over a range of yaw angles and reduce the models Reynolds sensitivity at yaw. The design omits wheels and wheel arches and is instead mounted via 4 slender cylindrical pins. Full details of the model are available in the validation data set available for download.

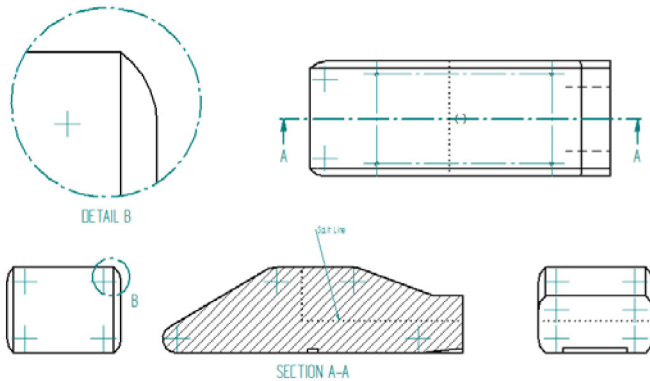


Figure 2. Model geometry - SAE reference model saloon with 20 degree back-slant.

### Balance Measurements

Force and moment measurements were made using an under-floor 6 component virtual center balance fitted with an integrated yaw drive system. The model is mounted to the balance via four 8mm diameter pins protruding through 10mm clearance holes in the tunnel floor. These are located 245mm forward and rearward of the model centerline and 35mm inboard of the edges. The ranges and accuracies of the forces and moments are contained within [table 1](#), and refer specifically to the calibration performed when the balance was installed. When testing a  $\frac{1}{4}$  scale automotive model; a repeatability of  $\pm 2$  drag counts is typical when fully removing and reinstalling the model. All force and moment data reported in this paper is averaged over a 30 second sampling period.

Table 1. Under-floor balance force and moment accuracy.

| Component                 | Force and Moment Ranges | Accuracy (% of full scale) |
|---------------------------|-------------------------|----------------------------|
| Drag, $C_d$               | $\pm 120\text{N}$       | 0.010                      |
| Side Force $C_y$          | $\pm 420\text{N}$       | 0.005                      |
| Lift $C_l$                | $\pm 500\text{N}$       | 0.010                      |
| Roll Moment, $C_{mx}$     | $\pm 150\text{Nm}$      | 0.010                      |
| Pitching Moment, $C_{my}$ | $\pm 60\text{Nm}$       | 0.010                      |
| Yawing Moment, $C_{mz}$   | $\pm 45\text{Nm}$       | 0.015                      |

### Pressure Measurements

The model incorporates 110 pressure tappings formed from 25mm long, 0.9mm I.D. brass tubes fitted flush to the surface enabling a pair of 64 channel scanners to acquire surface pressure remotely via lengths of small bore flexible tubing. The pressure scanners had a manufacturer quoted accuracy of  $\pm 1.47\text{Pa}$ . The pressure tappings are arranged in a grid formation across the backlight, boot-deck and base and are distributed over half the model up to the centerline to increase the spatial resolution afforded by the finite number available. In addition, 30 tappings are distributed around the upper body on the centerline enabling over-body centerline pressure distribution to be obtained. An illustration of their arrangement is shown in [figure 3](#).

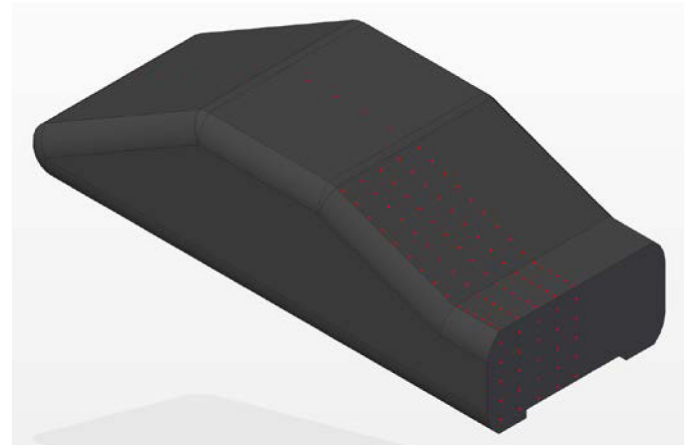


Figure 3. Model pressure tapping distribution.

At each pressure tapping 8192 pressure samples were collected at 260Hz, representing 31 seconds of data. Pressure signal distortion caused by the tubing linking the model surface to the pressure scanner was removed using an experimentally derived correction function found using a similar method as Sims-Williams and Dominy [11]. The surface pressures are presented as pressure coefficients based on free-stream dynamic pressure and were corrected for blockage using the MIRA blockage correction.

### PIV Measurements

Images were collected using two 4 Mega-pixel dual-frame cameras with 14bit 2048×2048 pixel CCD sensors. The light sheet was generated using a dual pulse 532nm Nd-YAG 200mJ laser with the beam conditioned through spherical and cylindrical lenses. The light sheet is approximately 1mm thick across the measurement plane. The flow was seeded in both the tunnel contraction and through the floor at the start of the working section with atomized olive oil, generating particles with diameters between 1 and 2  $\mu\text{m}$ .