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The importance of rear pillar geometry on fastback wake structures

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ABSTRACT

The wake of a fastback type passenger vehicle is characterised by trailing vortices from the rear pillars of the vehicle. These vortices strongly influence all the aerodynamic coefficients.

Working at model scale, using two configurations of the Davis model with different rear pillar radii, (sharp edged and 10 mm radius) the flow fields over the rear half of the models were investigated using balance measurements, flow visualisations, surface pressure and PIV (Particle Image Velocimetry) measurements.

For a small geometry change between the two models, the changes to the aerodynamic loads and wake flow structures were unexpectedly large with significant differences to the strength and location of the trailing vortices in both the time averaged and unsteady results. The square edged model produced a flow field similar to that found on an Ahmed model with a sub-critical backlight angle. The round edged model produced a flow structure dominated by trailing vortices that mix with the wake behind the base of the model and is weaker. This flow structure was more unsteady than that of the square edged model. Consequently, although both models can be described as having a wake dominated by trailing vortices, there are significant differences to both the steady state and unsteady flow fields that have not been described previously. This also shows that the fastback wake structure described by Ahmed is not definitive.

1. Introduction

The structure of the wake at the rear of a road vehicle is widely known to be important in determining the overall aerodynamic characteristics of the vehicle; having a potential influence on the drag, the rear lift and hence stability and the unsteadiness of the overall flow-field. In the case of the fastback geometry the near wake is dominated by trailing vortices as identified by Morel (1978) and Ahmed et al. (1984). These vortices can be responsible for a large proportion of total vehicle drag and strongly influence rear lift. When at yaw, acceleration of the air around the rear pillar into the trailing vortices, causes low pressure on the side of the vehicle which contributes to the overall side force and yaw moment, Howell and Baden Fuller (2010).

Since Ahmed et al.'s (1984) initial paper the flow structures around the Ahmed model have been investigated experimentally and using CFD in many studies, for example, Gillerion and Chometon (1999), Guilmineau (2008), Krajnović and Davidson (2005a, 2005b) and Lienhart and Becker (2003). The time averaged flow structures first identified by Ahmed have been more fully described in this work, but it is now also understood that the instantaneous flow fields around the model are quite different from the time averaged. A clear demonstration of this is given by Bearman (1997) showing some early PIV results and Sims-Williams et al. (2001, 2006), Sims-Williams and Duncan (2003) who show that a wake dominated by trailing vortices can contain periodic features with the trailing vortex cores moving vertically and horizontally, alternately strengthening and shedding from the trailing edge of the backlight.

The Ahmed model has sharp edges on the intersections of the model surfaces at the rear but this does not accurately represent production vehicles, which often have significant curvature at the rear. Published research that uses models with rounded trailing edges is rare. Gilhaus and Renn (1986) showed that rounding the rear edges of a fastback car model reduced the drag coefficient and they commented on the sensitivity of the drag coefficient to this rear edge detail. Howell (1993) showed that rounding the rear edges of a simple car model altered the relationship between backlight angle and drag above the critical angle described by Ahmed. Buresti et al. (1997) used an axisymmetric body and commented on the limited research into rear edge rounding. Because of this lack of published research, the applicability of the Ahmed body fastback flow structures to production vehicles is currently unknown, at least in the public realm.

Flow separation from curved surfaces is typically unsteady, controlling the separation is advantageous and this can be done

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Nomenclature

L	Model length
C_D	Drag coefficient
$C_D{}^*$	Drag coefficient standard deviation
C_L	Lift coefficient
$C_L{}^*$	Lift coefficient standard deviation
C_{LR}	Rear lift coefficient
w	Distance from model centre line
W	Model width
h	Distance from floor
H	Model height
bl	Backlight length

using large scale design features to create sharp edges or with small, discrete strakes visually hidden in the rear pillars or rear light mouldings. These are found on a wide range of cars from small cars to large SUVs and there is a growing trend for their use. Dependent upon the physical location of the features they can be used to alter yaw moments, such as shown by Baden Fuller et al. (2010), to reduce drag as demonstrated by Meyer and Wickern (2011) and Beaudion and Aider (2008) or to change the lift as also demonstrated by Beaudion and Aider (2008).

Passmore and Mansor (2006) show that a Davis model with a 20° backlight angle and a square cross section rear pillar has a steady-state yaw moment gradient 33% lower than the same model with 10 mm radius on the rear pillars. Using the same models in a dynamic, oscillating yaw angle experiment, they also show that over a range of reduced frequencies, between 0.02 and 0.25, that the square edged model produced a steadier response than the round edged configuration. Both results are reasonably attributed to the rear pillar change; however the flow structures that caused these results were not investigated and while there is a body of research regarding wake structures more generally, there is no direct comparison of the effect of rear edge radius available in the literature.

The objective of this paper is to investigate the flow fields over the two 20° backlight angle Davis models used by Passmore and Mansor (2006) to demonstrate and describe the differences between the flow structures in a direct comparison. While it is clear, given the work of Ahmed et al. (1984) and the wake surveys carried out by Davis (1982), that in both configurations the wake is likely to be dominated by trailing vortices, the extent of the changes associated with the small change in geometry is not clear. The analysis in this paper focuses on the relatively large scale differences to the flows over the rear part of the models caused by the different rear pillar geometries, primarily the trailing vortices and the near wake, and concludes with sketches of the time averaged flow fields over the two models to clearly illustrate the changes and provide comparisons with published literature.

2. Models and experimental facilities

This research used two configurations of the 20° back-slant Davis model (Davis (1982)); in the first configuration all edges are rounded with a 10 mm radius; the second is identical except for the rear pillars which have sharp, square edges. The basic model dimensions are shown in Fig. 1 and Fig. 2 shows an annotated schematic labelling the main model features. While the Davis geometry is not particularly representative of current road vehicles, the model was chosen for consistency with previous studies, in particular Passmore and Mansor (2006) where changes in the rear pillar radius were shown to be important in the yaw moment gradient. The model does, however, demonstrate the important flow-field features of a fastback road vehicle, for example, separation and reattachment on the slant, a twin counter rotating vortex structure and a turbulent wake downstream of the base (Davis, 1982).

Both model configurations were mounted on the centreline of the working section of the wind tunnel, 40 mm above the ground plane. A single ⌀20mm shaft from the centre of model's floor held the model in place and was connected through the wind tunnel floor to the under-floor balance.

Preliminary tests using both model configurations found the drag coefficient to be insensitive to Reynolds number (Re) above $Re = 1.3 \times 10^6$ (30 m/s). All the results in this paper were collected at 40 m/s, giving $Re = 1.7 \times 10^6$ based on model length.

All tests were conducted in Loughborough University's 1/4 scale wind tunnel. This is an open circuit, closed working section wind tunnel. The working section has a fixed floor, 2.5 m^2 cross-section and a maximum wind speed of 45 m/s with a freestream turbulence intensity of 0.2%; for more details see Johl et al. (2004). The Davis model used in these tests gives a blockage ratio of 1.4%.

Although the fixed floor does not match the boundary layer conditions found under normal driving conditions Howell and Hickman (1997) show that the main effect of this is to change the absolute values of the aerodynamic loads, whilst the trends remain the same for both fixed and moving floors, this indicates

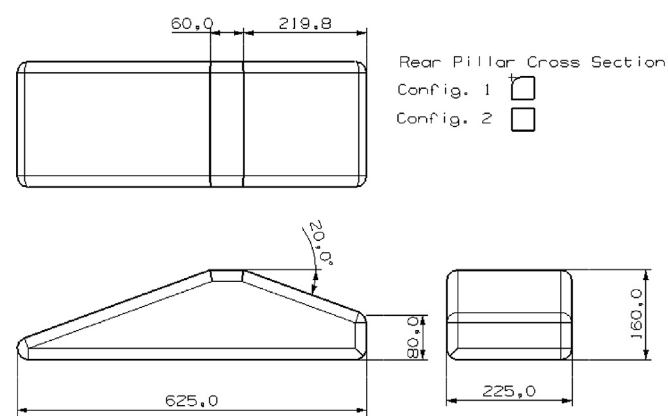

Fig. 1. Davis model geometry (dimensions in mm).

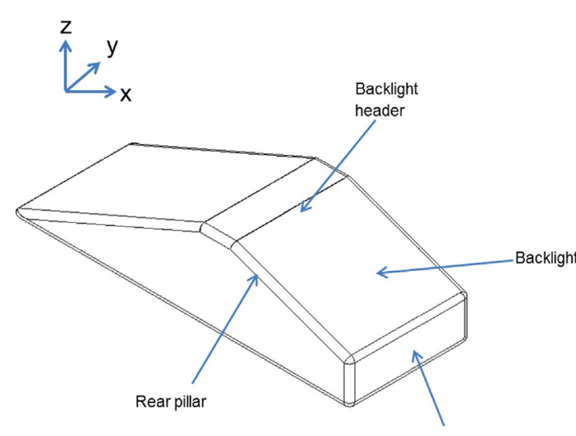

Fig. 2. Davis model – annotation of main features.