J. Wind Eng. Ind. Aerodyn. 147 (2015) 95–103

Contents lists available at ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Effect of aspect ratio on the near-wake flow structure of an Ahmed body

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ARTICLE INFO

Article history:
Received 23 January 2015
Received in revised form
10 September 2015
Accepted 16 September 2015

Keywords:
Ahmed body
Aspect ratio
C-Pillar vortex

ABSTRACT

Through numerical simulations, the interaction between the longitudinal c-pillar vortices and the flow over the rear slant surface is established for an *Ahmed-body* geometry as its aspect ratio is varied. In turn this affects the flow structure and topology of the near wake, and has a significant effect on the drag.

In particular, aspect ratio was found to influence the critical angle at which flow fully separates on the rear slant surface due to the interaction of the c-pillar vortices with the rear slant flow. This appears to be a consequence of the influence that downwash generated by the c-pillar vortices has on promoting rear slant flow reattachment. By isolating the pressure drag associated with individual surfaces, it is shown that the drag discontinuity is almost entirely due to a sudden change in the pressure field on the rear slant surface. On increasing the aspect ratio, once the flow becomes fully separated, c-pillar vortex strength and position change considerably, inferring a mutual relationship between flow reattachment and c-pillar vortex generation mechanisms for the Ahmed-body geometry.

1. Introduction

The aerodynamic forces experienced by a body are directly affected by its wake structure. To make this point explicit, several methods exist to evaluate the force components from velocity field data on a control-volume surface enclosing the body (e.g., Noca et al., 1999; Tan et al., 2005), inferring that a change in wake structure will have a direct influence on the forces experienced by the body. Furthermore, the individual contributions of identifiable flow structures to the overall force can be quantified (Onorato et al., 1984; Roshko, 1954).

The dominant wake structures of a body are highly dependent on geometry. Spanwise vortex structures, such as Kármán vortices, are commonly observed for quasi-two-dimensional bodies, such as high aspect-ratio circular and rectangular cylinders (Okajima et al., 1992; Williamson, 1996). Three-dimensional bodies often exhibit more complex wake structures comprised of coexisting streamwise and spanwise vortices (Baker, 2010; Gilhome et al., 2001; Payne et al., 1986). An important component of three-dimensionality of the wake in the case of three-dimensional bodies is due to the influence of the end boundaries on the vortex shedding mechanism (Gerich and Eckelmann, 1982).

The forces on different automotive geometries vary considerably. This is often the result of large changes in wake structure caused by geometrical differences, though detailed shape optimisation also plays a key role in overall body forces (Janssen and Hucho, 1975). In the case of the hatchback vehicle, identical critical wake flow behaviour can be generated though the use of simplified models (Morel, 1978). These simplified reference models allow fundamental aerodynamic characteristics to be analysed without the added complexity caused by detailed body shape (Good and Garry, 2004).

Of the numerous simplified automotive reference models available, the Ahmed body (Ahmed et al., 1984) is one of the most widely adopted in research undertaken to study the effect of constrained geometry changes on aerodynamic flow fields and loading. The Ahmed body is a simplified hatchback automotive model that exhibits the characteristic critical wake flow behaviour of hatchbacks first observed by Janssen and Hucho (1975), while its simplified geometry aims to achieve separation-free flow over the front of the model and relatively uniform flow through the middle section. The Ahmed body drag curve (Fig. 1) demonstrates the discontinuous change associated with a change in flow regime as the slant angle (θ) is varied; a phenomenon characteristic of hatchback vehicles.

The Ahmed body wake flow structure under high drag conditions ($\theta < 30^\circ$, see Fig. 2) is dominated by a large pair of counter-rotating vortices emanating from the c-pillars of the model (F in Fig. 2) (Ahmed et al., 1984; Lienhart et al., 2002). Flow over the slant surface detaches at its leading edge and reattaches further downstream (E), while at the base of the model there are two recirculating flow regions situated one above the other. It has been suggested that the c-pillar vortices play a strong role in promoting

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http://dx.doi.org/10.1016/j.jweia.2015.09.006
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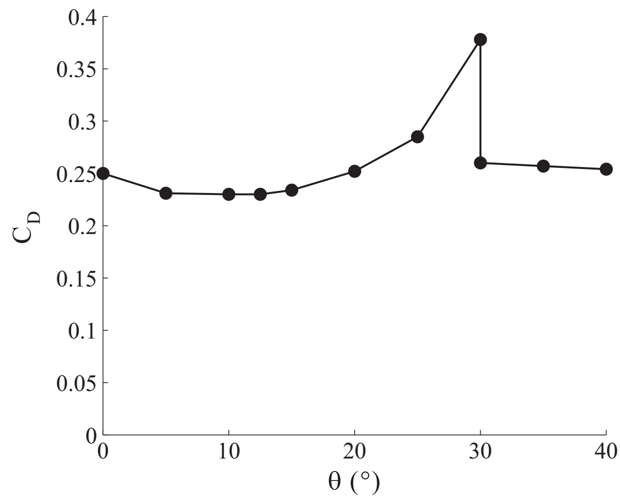

Fig. 1. Characteristic Ahmed-body drag profile (Ahmed et al., 1984).

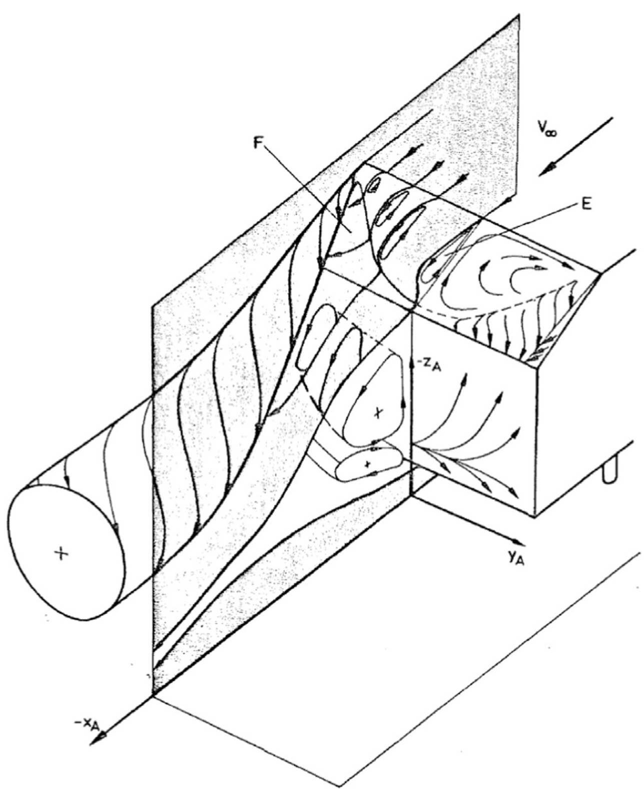

Fig. 2. Characteristic Ahmed-body wake flow for high-drag flow regime (Ahmed et al., 1984). Reprinted with permission from SAE paper 840300 © 1984 SAE International.

flow reattachment over the slant surface of the model (Hucho and Sovran, 1993; Wang et al., 2013), due to the associated downwash onto the slant surface.

Early work by Morel (1978) touched on the influence of c-pillar vortices on flow reattachment. A difference in critical slant angle of 12° was observed between an axisymmetric cylinder with a slanted base and a simplified automotive hatchback model. The shift was attributed to a change in aspect ratio of the slant surface, resulting in a decrease in the influence of the c-pillar vortices on the overall flow over the slant and a breakdown of attached flow at a lower slant angle.

This paper investigates the effect that aspect ratio has on the interaction of c-pillar vortex structures in the wake of an Ahmed model. It is anticipated that this will lead to new insight on the influence that c-pillar vortices have on promoting flow reattachment on the rear slant of the model at high slant angles.

2. Numerical methodology

The geometry used was the simplified automotive hatchback model introduced by Ahmed et al. (1984). Dimensions remain identical with length, width and height of $L=1044$ mm, $W=389$ mm and $H=288$ mm, respectively (Fig. 3). Unless otherwise specified, the rear slant was fixed at an angle of 25° from the horizontal for the present work, which corresponds to a wake dominated by large counter-rotating longitudinal vortices generated at the c-pillars (Ahmed et al., 1984). Only half of the body was simulated due to the symmetrical nature of the problem when observed through the time-mean state. The model was set at a height of 50 mm above a stationary ground board of length 3.68L and width 0.75L in the symmetry model, which extends 1.12L in front and 1.56L behind the body. The cylindrical stilts used to suspend the model for physical testing were omitted for simplicity.

To investigate the influence of longitudinal vortices on rear slant flow reattachment, the frontal aspect ratio of the Ahmed model was varied by widening or narrowing the body while the height remained fixed. It is proposed that varying the aspect ratio in this manner will influence the interaction between the c-pillar vortices and the flow over the rear slant. The definition of aspect ratio adopted in this paper is the ratio of the cross-sectional aspect ratio of the Ahmed model to the cross-sectional aspect ratio of the standard-dimension Ahmed model (Eq. (1)), and from hereon will be denoted simply as aspect ratio (AR). Since the height of the model is fixed for all cases, this effectively reduces to a ratio of model widths. Aspect ratios between 0.6 and 1.6 were simulated in increments of 0.1, with additional increments where increased resolution was required:

$$AspectRatio\ (AR) = \frac{AR_{model}}{AR_{standard}} = \frac{W_{model}}{W_{standard}} \tag{1}$$

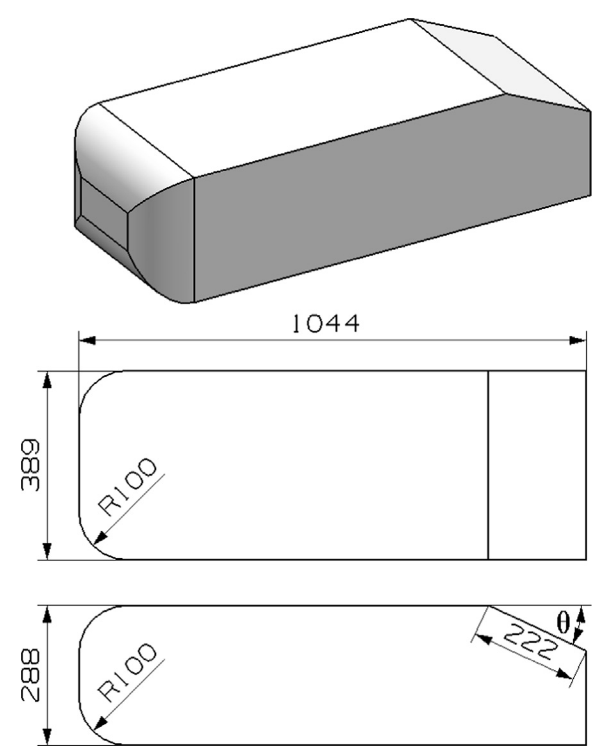

Fig. 3. Ahmed-body geometry (dimensions in mm).