Effect of Width-to-Height Ratio on Wake Structures of Simplified Vehicle Geometry

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Abstract

The effect of the change of the width-to-height ratio of an Ahmed Body on its time-averaged wake structure behind the Ahmed Body was investigated experimentally using Particle Image Velocimetry (PIV). The width of the model was varied with a fixed rear slant angle of 25º, which has been shown to produce a pair of strong trailing vorticies in the wake. The Reynolds number in this experiment was 7.42×10^4 based on the freestream flow velocity and the model length. The results indicate that the change in the width-to-height ratio influences the vorticity field in the wake. This has significant implications in designing road vehicles, showing that the width-to-height ratio, as well as the rear slant angle, must be considered as an important geometrical parameter.

Introduction

Means of reducing the aerodynamic drag force on road vehicles has been one of the key issues in the design process over the years. Reduced drag results in improved fuel consumption, stability and handling particularly at high speeds [1]. It is well known that a large proportion of the drag is the result of pressure drag produced at the rear end of the vehicle and the understanding derived from the study of the wake structure is crucial in improving the road vehicle aerodynamic performance [2].

Road vehicles are basically three-dimensional bluff bodies in proximity to the ground, which are bound to produce a very complex separation region in the wake. One of the most significant discoveries in the last several decades in this area of research has been the finding of a pair of strong trailing vortices in the wake. Although it has not been quantified in a definite manner in the published literature, the strength of those trailing vortices and their interactions with the near-wake region are understood to influence the aerodynamic drag.

The effect of the change in the base slant angle of hatch back vehicles was first noticed and studied by Janssen and Hucho in 1975 [3]. A series of parametric studies on the slant angle effect have since been conducted, with the most famous and significant being the work by Ahmed et al. [4], in which a simplified vehicle model ('Ahmed Body", Figure 1) was introduced for detailed parametric investigations.

Almost all the studies in the past have considered the rear slant angle as the main geometric parameter that affects the wake structure. The 30° angle is commonly thought to be the critical rear slant angle, which produces a highly unstable, high drag state. [3][4][5][6] (Figure 2) However the effect of the aspect ratio (AR, either the width-to-height ratio of the cross-section or the width-to-length ratio of the rear slant) on the wake structure has seldom been reported in spite of the earlier investigation by Buchheim et.al [7]. Morel [5] made an assumption that the AR had an inversely proportional effect on the drag since the interaction between the trailing vortices and the flow coming over the rear slant gets smaller with increasing AR. Johnson et al.[8] however examined computationally the AR effect and proposed a critical AR using the Ahmed Body.

In this present work the effect of the AR of the Ahmed Body is experimentally studied with its width taken as the independent variable and the rear slant angle kept constant at 25°, which has been shown to produce strong trailing vortices emanating from near the top corners of the rear slant. Particle Image Velocimetry (PIV) was employed to quantify the wake structure as well as for visualisation. Peak vorticity and circulation of the vortices were compared for different model aspect ratios.

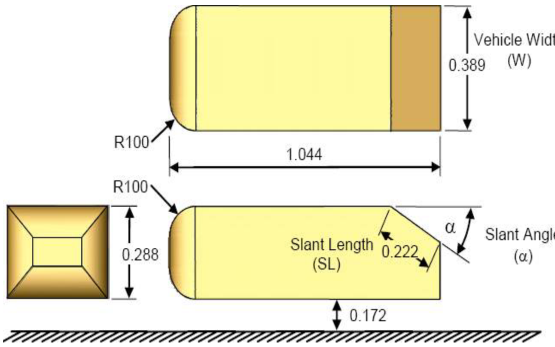

Figure 1 Geometry of "Ahmed Body"

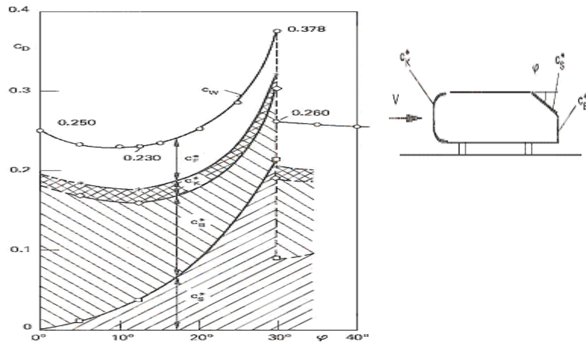

Figure 2 Variation of C_D with Slant Angle of Ahmed Body [4]

Experimental Method

The experiments were conducted in the *FLAIR* Monash University water tunnel. The working section has the cross section of 600mm width and 800mm height (maximum water depth). The maximum flow velocity of the tunnel is 0.45 m/s with the turbulence intensity level of 1.0%.

The models used were 25% scale of the original Ahmed Body geometry shown in Figure 1 to give sufficiently small blockage. Three different widths were used; the original Ahmed Body width-to-height ratio, 75% width and 125% width. A slant angle of 25º was used for all of the three models since the 25° slant has in the past been shown to produce strong trailing vortices. It was tested in the fixed ground condition. The blockage effect was considered negligible here. The Reynolds number was 7.42×10^4 based on the freestream flow velocity and the model length.

A synchronised system of Mini-Yag Lasers and Kodak Magaplus CCD camera (model ES 4.0, the image resolution of 2048×2046 pixels) was used for the PIV image capturing. The images were then processed using a PIV software developed in-house at Monash University. Image pairs were captured at the framing rate of 4 Hz for over 220 image pairs. The interrogation window size used was 32×32 pixels. The PIV results using the PIV software mentioned above were then time-averaged.

The 2D velocity vectors obtained from the PIV processing were converted to vorticity and the circulation was calculated by integrating the vorticity in the longitudinal direction over the cross section of the trailing vortices. The edge of the vortices was defined to be the contour of the points of 20% of the local extreme value of the vortictiy as defined by McWilliams [9]

The vorticities and circulations were non-dimensionalised based on the freestream velocity and the height of the model.

Results and Discussion

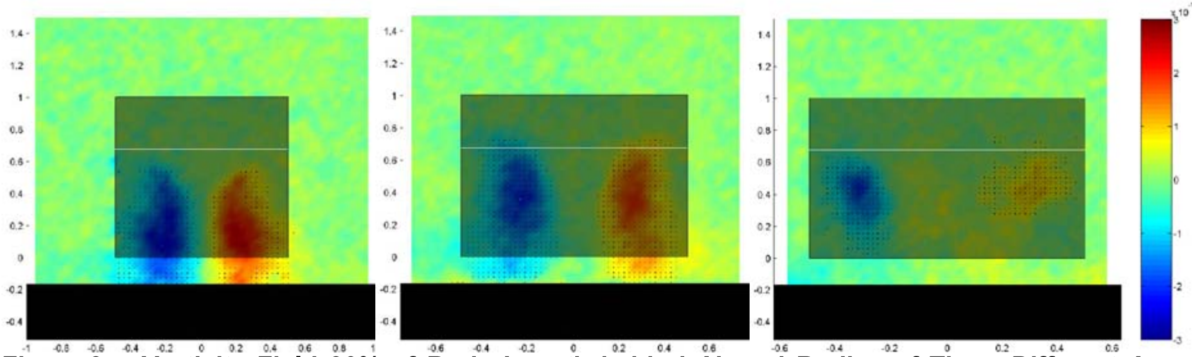

Figure 3 Vorticity Field 30% of Body Length behind Ahmed Bodies of Three Different Aspect Ratios

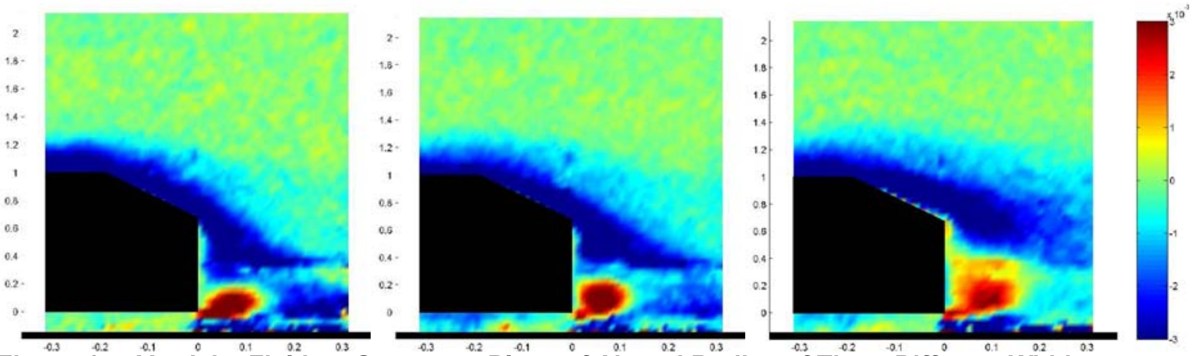

Figure 4 Vorticity Field on Symmetry Plane of Ahmed Bodies of Three Different Widths (75%, Original Width, 125% from left to right)

	75%	Original	125%
Peak Vorticity	0.002404	0.002019	0.001771
Circulation	0.128325	0.14766	0.027746

Table 1 Comparison of Peak Vorticity and Circulation between Three Different Widths

In Figure 3 the regions where the dots are shown are the areas, over which the vorticity is integrated to calculate the circulation.

A pair of strong vortices are quite obvious for the 75%-width (narrow) and original-width versions while for the 125%-width (wide) the cross section of the vortices is much smaller. The vortices behind the narrow model are found slightly below where they were found for the original-width case.

Table 1 compares the peak streamwise vorticity and the streamwise circulation between the three widths. For both the peak vorticity and circulation, the average value was taken between the absolute values of the positive and negative peak vorticities and circulations. While the peak vorticities are approximately inversely proportional to the width, the circulation is not. The circulation value is comparable between the original and narrow model however for the wide model the circulation value is far smaller.

Figure 4 shows the spanwise vorticity field on the symmetry plane for the three models. Regions of concentrated high vorticity are apparent above the rear slant. It is noticed that the top edge of the high vorticity region is roughly parallel to the slant surface while for the wide model the region spreads out and is dispersed into the downstream. This indicates that the flows over the narrow model and original version are attached to the slant surface for the most part while the full separation occurs for the wide model.

The strong downwash created by the two counter-rotating vortices behind the narrow and original versions appears to encourage the flow to stay attached to the surface or to reattach to the surface if the flow has already separated from the top edge of the slant. As the model widens the interaction between the vortex pair progressively weakens up to the point (or the “critical width”) where the downwash near the symmetry line is not strong enough to induce the downward momentum into the oncoming flow to keep it attached or force it to reattach to the slant. The wide model used here is assumed to be above this critical width. By the same token, it may be possible to delay the critical slant angle to above 30° by making the body narrower. The critical slant angle therefore may vary with the width-to-height ratio of the body.

The above results and observations indicate a very different flow regime for the wide version to the other two models at the same rear slant angle. This does not agree with the assumption made by Morel [5] that the effect of the C-Pillar vortices on the wake structure gets proportionally smaller with the width of the model. However it supports the argument by Johnson et al [8] that there is a critical aspect ratio, above which the flow regime changes completely.

Conclusion

It has been demonstrated in this present work that the rear slant angle is not the only main geometric parameter that affects the near-wake and wake structure behind a simplified vehicle model. The ratio of the width and height has also to be considered when discussing the critical geometry.

Further Work

The PIV measurements were taken only at two locations in this experiment. Further PIV experiments are planned at different locations. Also the rear slant angle has been fixed at 25° in this present work. The investigations on other combinations of body width and slant angle are planned in the future.

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