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Flow Visualization on the Steady and Unsteady Flow Structures around Ahmed Model

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Keywords : flow structures, Ahmed, steady and unsteady, sub-vortex.

ABSTRACT

Ahmed model is a simplified vehicle model for aerodynamic characteristic investigation. To understand the steady and unsteady flow structures, some flow visualization experiments have been carried out to show the flow structures under wake. Ahmed model will with high air drag or low air drag according to the slant surface angle. In low drag regime, the flow above the slant surface is shown by the smoke flow. The flow begins to separate at the upper edge of slant surface and forms a shear vortex of K-H instability due to the velocity difference in wake separation regions and forms a backwards flow and recirculation bubble at the slant surface. In the high drag regime, the presence of the C-pillar vortex is shown by the smoke flow visualizations. Based on the study of K-H instability of low drag model, it is speculated that the formation of C-pillar vortex is accompanied by the existence of shear vortex. Further PIV experiments show that the structure of the C-pillar vortex is studied on a smaller scale, and the vortex of the C-pillar is found. The C-pillar is a steady flow structure, and its sub vortices are unsteady shear vortices. This sub vortex is first report in automotive aerodynamics.

INTRODUCTION

Previous studies have greatly advanced our understanding of the flow structure behind the Ahmed model (Ahmed et al. 1984). But in different experiments, the former researchers found different flow structures (Ahmed et al. 1984; Lienhardt et al.2000; Sims-Williams et al.1998), which raised a number of issues to be resolved or clarified. The wake of Ahmed vehicle model is still not so clear especially unsteady flow structures. Our knowledge of the flow fields has yet to be improved, which is important for thorough understanding and control of vehicle aerodynamics and also crucial for the validation of numerical models.

With the issues identified above, this project focuses on the Ahmed body with 25 degree and 35 degree slant angle. To gain a better picture of the flow structures around the Ahmed vehicle model, the PIV measurements and flow visualizations were conducted in three orthogonal planes behind the model.

EXPERIMENTAL SETUP

Wind tunnel and vehicle model

The experiments were carried out in the wind tunnel which is well described by Huang et al. (2006).The working tunnel is a closed circuit with a test section 2.4 m × 0.6 m × 0.6 m. In the absence of the vehicle model, the flow non-uniformity in the test section is 0.1% and the stream-wise turbulence intensity is less than 0.4% for the present velocity range. To enhance the signal-to-noise ratio in PIV measurements, the optical glass was applied on the working section wall. Fig.1 shows the setup of wind tunnel experiments. The position of laser and the camera will be changed for different planes.

The 3-D Ahmed model, is a reference model for the aerodynamicist to study the flow structure of vehicle. The One-third Ahmed model is 0.348 m in length (L), 0.13 m in width (B), and 0.096 m in height (H), placed on a flat plate (length × width × thickness = 2 m × 0.59 m × 0.02 m) raised from the floor of the working section. The details of the Ahmed model could be found in Ahmed et al. (1984).

Pinholes are set up on the three surfaces of Ahmed model, which eject the smoke to be figured by PIV, seeing Fig.1 right picture. In each line, there are several of pinholes 1 mm in diameter, at an interval of 2 mm. The line is 7 mm distance to the nearest edge. At the underside of Ahmed model,

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smoke was injected into the cavum, and then travelled to the pinholes.

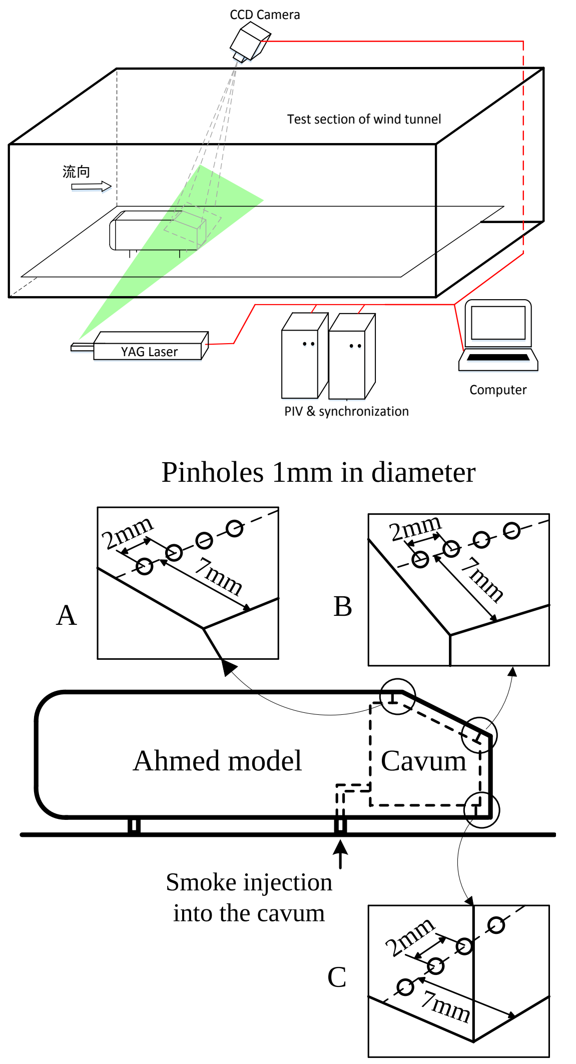


Fig.1. Experiments setup (top) and Ahmed model (under)

The coordinate system follows the right-hand rule and is defined such that x, y, and z are directed along the mean flow, vertical (transverse), and span-wise directions, respectively. Our measurements were conducted at the free stream velocity U∝ = 3 m/s.

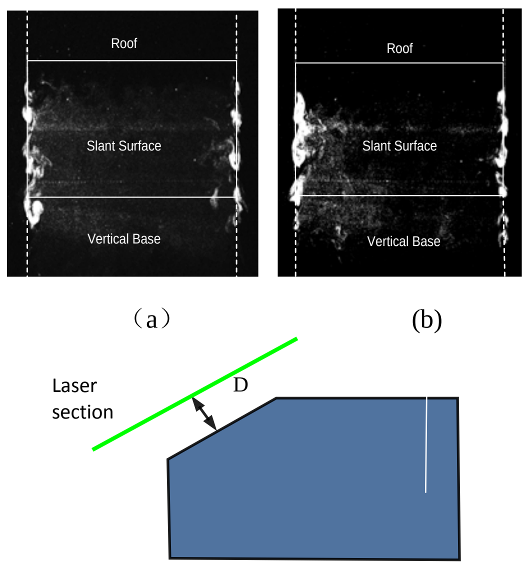
PIV measurements

PIV system was used to measure flow around the Ahmed model in order to observe visualizations of flow structures. Two New Wave standard pulsed laser sources of 532 nm wavelength, the maximum output energy of each being 120 mJ/pulse, were used to provide flow illumination. Each laser pulse lasted for 0.01μs. The interval between two successive pulses was set at 50 μs for measurements in the x–z plane, x–y plane, y–z plane and the slant plane. A CCD camera (HiSense type 4 M, double frames, 2,048 × 2,048 pixels) was used to provide the particle images. Synchronization between image taking and flow illumination was provided by the Dantec Flow Map processor (System HUB).

The flow is highly three-dimensional (Ahmed et al.1984). In order to capture accurately the flow structure, we should conduct measurements around the model in a large number of planes along each of the x, y, and z directions.

EXPERIMENTAL RESULTS

Fig.2 shows the flow display images, which is parallel to the slant surface, at D= 15mm and 20mm. From the Fig.2 (a) and (b), we can see Kelvin-Helmholtz (K-H) vortex formed by K-H instability in the upper side of the slant surface. The K-H instability can occur when there is velocity shear in a single continuous fluid. This instability has parallels with the cross-flow instability that occurs in three-dimensional boundary layers. The free shear layer exists across an interface separating layers of fluid with different densities. It's known that the free shear layer is subject to a number of instability phenomena. The most obvious is the classic K-H instability of a two-dimensional free shear layer. Because this instability travels around the shear layer, the key feature of it is that it cannot be seen with the naked eye, and can only be observed through flash photography or equivalent techniques. At the plane of D=20mm, the K-H instability is stronger than that of D=15mm.

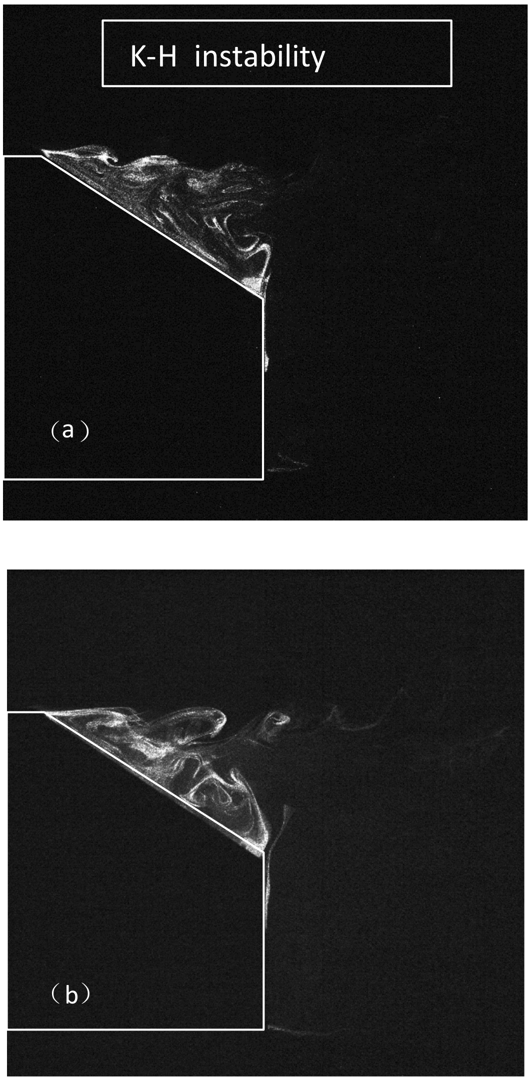


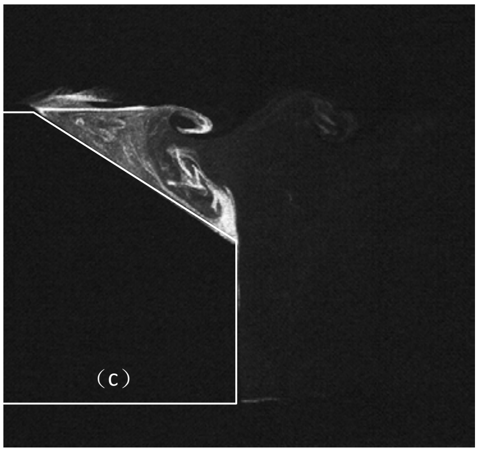
（a） (b)

(c)

Fig.2. Typical photographs from flow visualization in the plane parallel to the slant surface and the distance is (a) D=15mm, (b) 20mm, (c) the laser section.

Fig.3 (a) (b) (c) is the distribution and development of the K-H vortex in the plane of xz, y=0mm. It is evident that on the slant surface, exists the K-H instability. Those pictures of (a) (b) and (c) are captured in different time separately. Why not chose some pictures in different time instance consecutively? The reason is that this PIV is not high speed PIV, its frequency is about 3Hz. But the more than 1000 pictures show the phenomenon. Developing from the initial weak K-H instability in Fig.3 (a), the K-H vortex of Fig.3 (b) grows increasingly clear and huge, and following with the combination of the neighboring K-H vortex in Fig.3 (c). Fig.3 (d) shows the iso-contours of vorticity in the x–z plane at y = 0.The vorticity shows that flow separates from the upper edge of the slant, with α= 35°, rather than the lower edge. Characterized by the negative iso-contours, a recirculation of the separation flow is obvious on the slant surface. There is a small region of positive iso-contours attached to both the slant and vertical base at α= 35°, induced by the negative circulation.





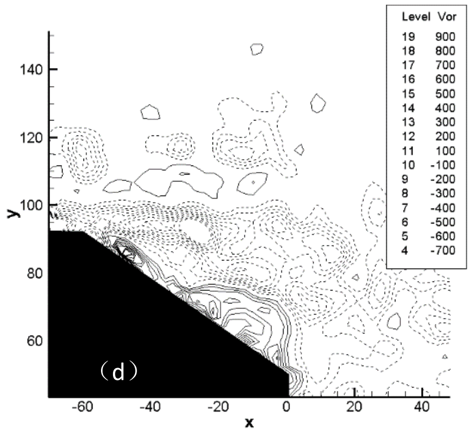


Fig.3. Typical development of the K-H instability from flow visualization(a) (b) (c) and the iso-contours of vorticity level（d）in the x–z plane at y= 0

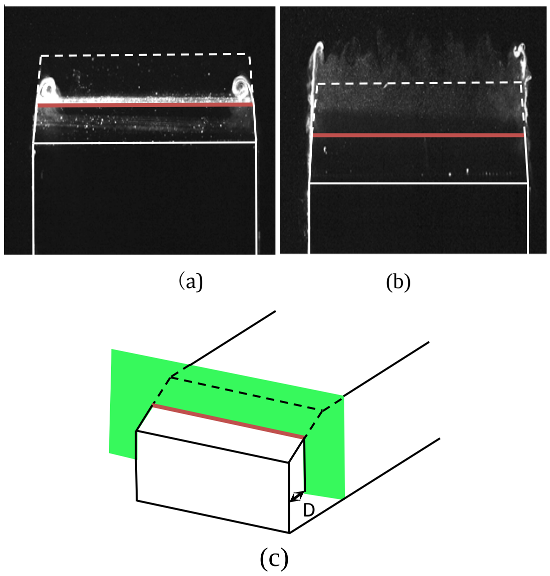
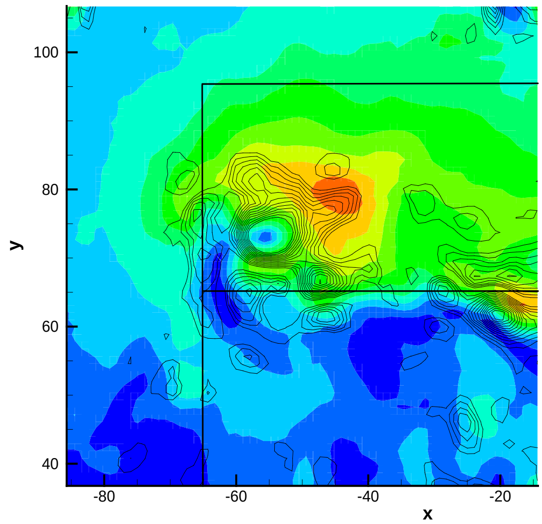


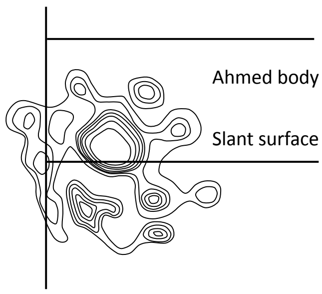
Fig.4. Typical photographs from flow visualization in the plane parallel to the vertical base and the distance to it is D=30mm, (a) is the 25°configuration and (b) is the 35°configuration.

Fig.4 is the typical photographs from flow visualization in the plane parallel to the vertical base and the distance to it is D=30mm, with (a) is the 25° slant angle and (b) 35°. We can see clearly there are two most concentrated C-pillar vortices at α= 25°, while there is no C-pillar vortex at α= 35°. With flow blowing over the vehicle body, the shear layers over the C-pillars roll up into the longitudinal or C-pillar vortices at α= 25°. At α= 35°, flow separates from the upper edge of the rear slant surface, and the C-pillar vortices burst (Ahmed et al. 1984).The C-pillar vortex at α= 25° is steady, though there exist many unstable structures around it, seeing Fig.5.

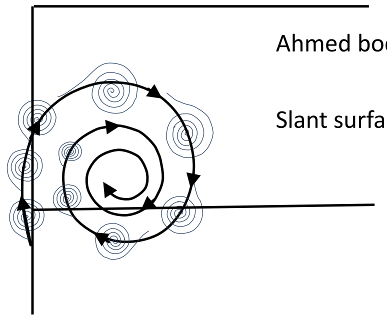
In fig.5 (a), it can be observed that the C-pillar vortex of the flow is essentially identical in y-z plane at x=5mm, with the iso-contours of vortex level and the colour of vortex velocity. And around the C-pillar vortex, in the schematic description of Fig.5 (b), there are many small vortices, which is called sub vortex. The sub vortex structures, which can be recognized as pockets of low-momentum flow, form in the C-pillar vortex and are a characteristic instability of the free shear layer. This is consistent with the observation in the previous experiment eg. JFM (1998) of Fig.5 (c). The sub vortex, rotating around the main vorticity, is one part of the main vorticity.



(a)



(b)



(c)

Fig.5. A system of steady co-rotating vertical structures of y-z plane at x=5mm, (a) is the vorticity contour, (b) (c) respectively are the schematic drawing of the C-pillar vortex from (a) and the sub-vortex structure in JFM (1998)

CONCLUSIONS

In conclusion, these experiments were conducted to investigate the flow structure of the Ahmed body, using the PIV system. In this paper, the fine structures of flow in different planes are given visually. Besides, we found the K-H instability on the slant surface as well as its growing process. And for the 25° Ahmed model, many unstable structures, the sub vortexes, embrace and rotate around the C-pillar vortex.

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Ahmed 模型的穩態和非穩態尾流結構的流動顯示研究

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摘 要

Ahmed 模型是一個用於汽車空氣動力學研究的簡化汽車模型。為了深入的研究 Ahmed 模型的穩態和非穩態的尾流流動結構，本研究進行了大量的可視化試驗。Ahmed 模型根據尾部傾斜角度，分為高阻模型和低阻模型。對於低阻模型，通過煙流顯示了氣流在尾部傾斜面的流動。流動在尾部傾斜面上楞處就開始分離，並且在所有尾部分離區域由於速度差形成 K-H 不穩定性的剪切渦，並在傾斜面下楞處形成回流渦。對於高阻的模型，通過煙流顯示顯示了 C 柱拖拽渦的存在。通過對低阻模型 K-H 不穩定性的研究，推測 C 柱渦的形成也伴隨了剪切渦的存在。進一步的 PIV 流動顯示，對 C 柱渦的結構進行更小尺度的深入研究，C 柱渦的子渦被發現。 C 柱渦是一種穩定的拖拽渦，而其子渦是非穩態的剪切渦。這個流動對於研究汽車空氣動力學是一個新的發現