The Origin of Flow Asymmetry Formation over Slender Body of Revolution at High Angle of Attack

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Summary A new near-wall PIV technique is applied to investigate the state of nearly 0.2mm thick boundary layer near the nose tip of slender body of revolution at high angle of attack. Results show that in this region where the leeside vortex pair is still symmetric, time-dependent disturbances develop asymmetrically in the boundary layer along the axis of the body and may lead to asymmetric separation.

Brief Introduction

The problem that asymmetric flow occurs over slender body of revolution at high angle of attack has been investigated intensively for more than 30years. Unfortunately, great disagreement exists in understanding the mechanism of this phenomenon. The majority of the researchers preferred to hydrodynamic instability in the potential flow. Some others, e.g. Ericsson (1980) [1] , suggested non-uniform viscous boundary-layer development. But this point is very difficult to justify experimentally for the limit of the measurement technique. The target of the work presented here is to develop an effective near-wall PIV technique and then investigate the boundary layer near the nose tip of slender body of revolution at high angle of attack.

Experiment Method and Set-up

Near Wall PIV Technique

In the most leading region of the nose, the thickness of the boundary layer is only about 0.2mm. Suppose within this distance, 10 velocity points can be evaluated using 16×16 interrogation window with 75% overlap. A space resolution of 0.01mm/pixel is needed. However, the traditional Micro-PIV techniques using microscope lens is not suitable because of the long optical distance (about 200mm) between the model and the camera. Instead, 200mm long focus macro-shot lens with extension rings nearly 200mm long is mounted ahead of the camera. With this equipment, space resolution of 0.01mm/pixel is achieved.

The interference of the laser reflection is another trouble. Scattering light from the normal glass bead particles would be overwhelmed by this laser reflection in the near-wall region. Consequently, the signal to noise ratio of the particle image is reduced. Fluorescent particle tracing technique has fundamentally resolved this problem. In this test, fluorescent particles with high concentration are seeded upstream to achieve an appropriate density of distribution on the image. Meanwhile, a piece of high-pass filter glass is mounted ahead of lens. By this technique, the interference noise of the laser reflection from the model surface is eliminated and the effective signal of the laser-induced fluorescent light emitted from the particles is preserved on the image.

Velocity field has been evaluated in multi steps with decreasing size of interrogation window. The last step is in 16pixels ×16pixels with 75% overlap. Image deformation scheme is used to improve the degree of accuracy when the evaluated region exists large velocity gradient.

Experiment Set-up

The test is conducted in the low turbulence water tunnel of College of Engineering, Peking University. The width and depth of the tunnel cross section is 400mm and 450mm respectively. The turbulence level of the coming stream is less than 5‰.The slender body model is made of plexiglass, which consists of a 1:3 fineness ratio tangent-ogive fore-body and a cylinder aft-body. The diameter of the aft-body or the base of the fore-body is 25mm. The rear of the model is mounted rigidly to avoid vibration. The angle of attack is controlled exactly by an indexing plate device. With great care, the model is placed directly to the coming stream with no side slip. To make the results of the flow asymmetry repeatable, a very small artificial spatial disturbance is fixed to the tip of the model nose. The azimuth angle of the disturbance is 45° on the starboard to the windward stagnation point. Lavision hispeed PIV is applied in our test. The camera is of CMOS histar 8G types, which maintains the recording rate from 50 to 2000Hz in full resolution. Meanwhile, hydrogen bubble visualization is applied simultaneously to make sense of the sign of the vortex asymmetry.

Main Results and Discussion

Measurements have been conducted on the cross planes at 10 axial positions from the tip with the spacing 1.25mm. The velocity of coming stream is 10cm/s. The angle of attack is fixed at 50°.The recoding rate of the PIV is 200Hz and the sampling time is 10sec.Flow visualization shows that in every case, the vortex on the port detaches from the body first and the position of the core of the asymmetric vortex is nearly the same.

Fig 1 shows the time velocity and vorticty field near wall at the position d/D=0.3.

Fig2 shows the development of the amplitude of the velocity fluctuation, especially in the boundary layer, in 10 cross sections along the axis. It is clear that the velocity fluctuations in the boundary layer increase along the axis and become more and more asymmetric on both side of the nose tip. The starboard is larger than the port. Meanwhile, vortex detaches first on the port downstream. Note that in this most leading region, the lee side vortex pair is still symmetric.

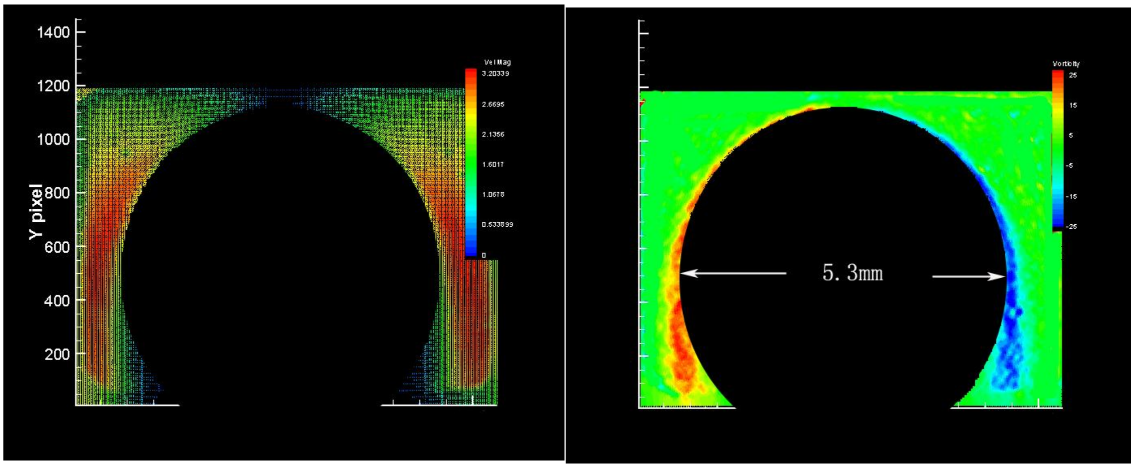

Fig1. Time Mean Velocity and Vorticity Field at Position d/D=0.3

Ericsson (1980) [1] argued that it is the asymmetric separation that induces the lee side asymmetric vortex. Boundary layer separates earlier on the port where the vortex detaches first. It seems that the level of the velocity fluctuation in the laminar boundary layer have effect on the separation location. Velocity fluctuation would modify the mean flow velocity profile in the laminar boundary layer and induce earlier separation. This result is in agreement with Marxen, O., and etc's numerical simulation (2010) [2]

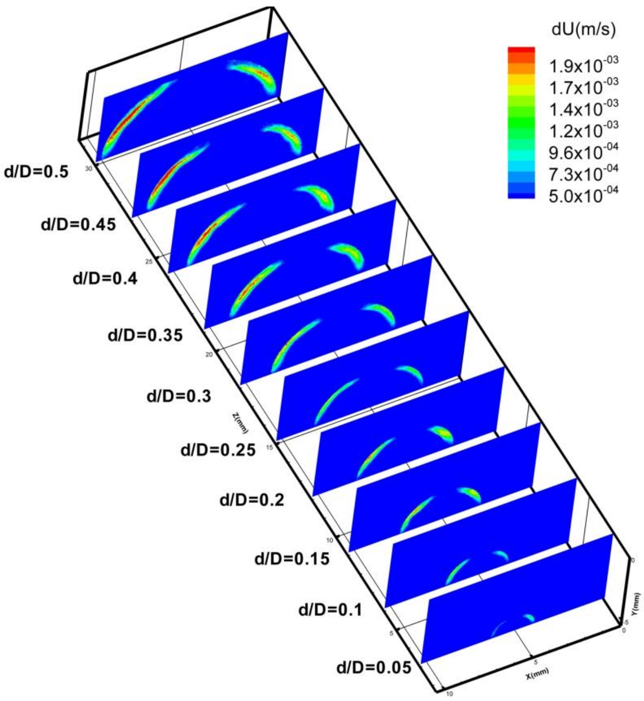

Fig 2. Asymmetric Evolution of Velocity Disturbance in the Boundary Layer in the Vicinity of the Nose Tip

Conclusion

1. Time-dependent disturbances develop asymmetrically in the boundary layer from the nose tip along the axis where the leeside vortex pair is still symmetric.
2. Asymmetrically development of disturbances may lead to asymmetric separation and induces asymmetric vortex downstream.

References

[1] Ericsson, L. E. and Reding, J. P. ,"Vortex-Induced Asymmetric Lo ads in 2-D and 3-D Flows", AIAA 18th Aerospace Science Meeting, January 14-16,1980, Pasadena, California

[2] Marxen, O. and Rist, U.,"Mean Flow Deformation in a Laminar Separation Bubble : Separation and Stability Characteristics", J. Fluid