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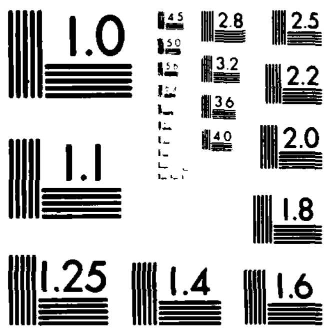
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FOREIGN TECHNOLOGY DIVISION

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by

Wang Zixing, Wu Genxing

HUMAN TRANSLATION

FTD-ID(RS)T-0267-86 7 July 1986

MICROFICHE NR: FTD-86-C-001991

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English pages: 12

Source: Konggi Donglixue Xuebao, Vol. 3, Nr. 1, 1985, pp. 49-53

Country of origin: China
Translated by: SCITRAN
F33657-84-D-0165
Requester: FTD/TQTA
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PREPARED BY:

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THE EFFECT OF A WINGLET ON THE SPATIAL VORTEX OF A SLENDER BODY AT HIGH ANGLE OF ATTACK

Wang Zixing, Wu Genxing

Nanjing Aeronautical Institute

ABSTRACT

The experimental investigation of the effect of a winglet on the spatial vortex of a slender body at a high angle of attack is presented. This investigation clearly shows that the circulation of the body vortex is minimized by the winglet and the vortex position is lower than that without the winglet, so that the asymmetric problem can be solved.

INTRODUCTION

The side force on a slender body at a high angle of attack and without slip in the side direction is mainly caused by the asymmetry of the vortex system. In order to eliminate and postpone the appearance of such undesired side force, many researchers have carried out force testing experiments in wind tunnels and suggested several

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This paper was received May 28, 1984 and the revised edition was received September 5, 1984.

methods, such as the fluorescent micro-wire technique [3-6], to solve this problem. But the whole situation of the vortex system was still not investigated. Based on the work of [2] we applied the fluorescent micro-wire technique [1] to investigate the situation of the spatial vortex on the lee side of a slender body and the tail vortex of the winglet, to understand the function of the winglet in eliminating the asymmetry problem of the vortex.

We have tested five types of winglets with different shape and arrangement. The test was made in a low speed wind tunnel. The spatial vortex of a slender body with a sharp end, high attack angle, and without side slip, was studied. The results have shown that the winglets can control, in certain degree, the asymmetry problem which occurs under a high attack angle. Among the winglet types which we have tested, the small side strip with high backward angle is the most effective one.

We also investigated the change of the separating lines of several models, after the winglets were installed, by use of the traditional oil stream method for some models.

TESTING EQUIPMENT, MODELS, AND METHODS

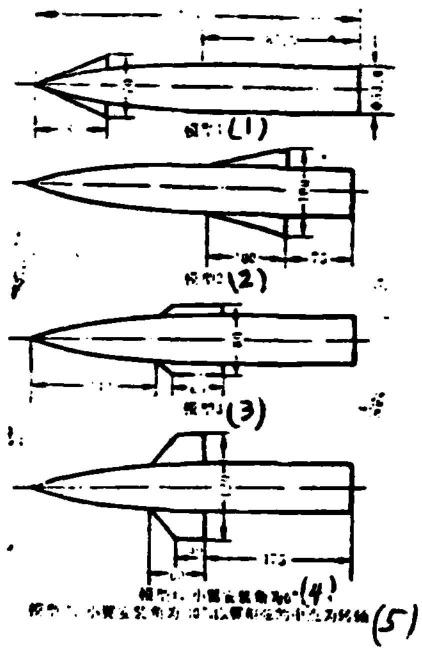
1. The test was carried out in a 0.75 m open end wind tunnel. The wind speed for the testing was 30 m/sec. With the diameter of the model as reference, the Reynolds' number

is: $Re=1.2 \times 10^5$.

2. The position of the vortex was determined by use of a three dimensional coordinate mechanism which has a probe with fluorescent micro-wire. The detailed method of this position determination technique can be referenced to [1]. The coordinates of the vortex locus was normalized with reference to the length of the slender body.

3. For all the five models the ratios of the length to diameter are all equal to 7, and the ratios of the length to diameter in the end part are all 3.5 . The rear parts of the models are all cylinder-like, the head is sharp, and the generatrix lines are all arcs. The sizes and positions of winglets are listed in the following figure. The types of the winglets are all NACA 64 A 004. The installation angles of winglets are all 0° (except model 5).

4. The testing angles are from 15° to 60°.



1-model 1; 2-model 2; 3-model 3; 4-model 4. The installation angle is 0°; 5-model 5. The installation angle is 30° and the rotation axis is at the middle point of the chord of the innermost part of the winglet.

RESULTS AND ANALYSIS

1. The situation of model 1 (the strip -like winglets were installed at the head of the winglet).

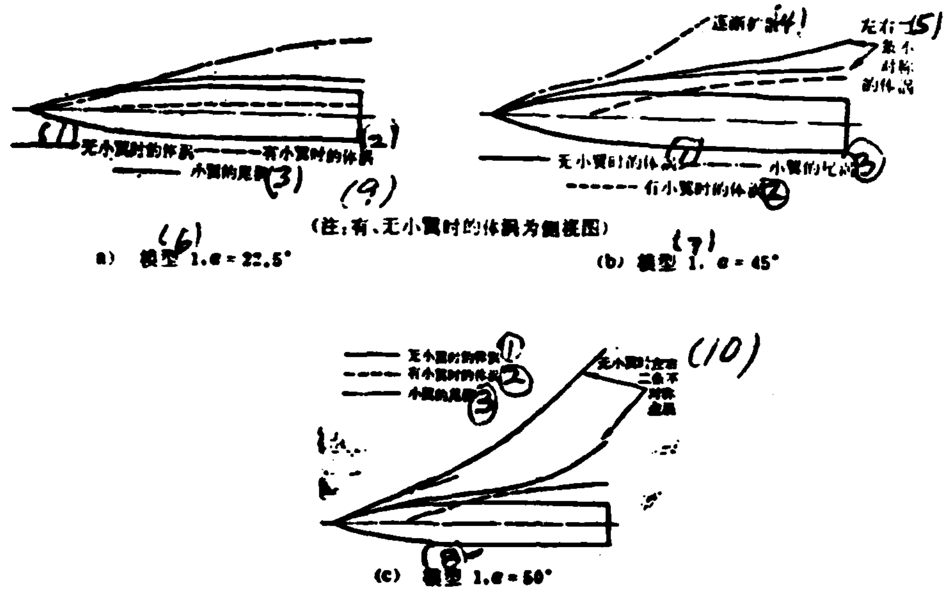


Fig. 1.

1-body vortex without winglet; 2-body vortex with winglet; 3-tail vortex of the winglet; 4-disperse gradually; 5-two asymmetric body vortexes on left and right sides respectively; 6 - model 1, α=22.5°; 7 - model 1, α=45°; 8 - model 1, α=50°; 9 - (Note: The body vortex with and without winglets are side views); 10 - two asymmetric growth vortexes on left and right without winglets.

Figure 1 shows the changes of the vortex along with the changes of the angle of attack of a sharp head slender body with and without stripe-like winglets at the head. When the small strips were installed at the head and the angle of attack was not large, (for example, $\alpha=10°$), because the tail vortex of the winglet is near the axis of the slender body, the separation of the slender body will be postponed and therefore no vortex was formed. When α=22.5°, the winglets at the head causes the vortex to be formed behind the winglet and the circulation of the vortex is less than that of the same model but without winglets; furthermore the height is also lower.

When the angle of attack increases (α > 30°), the winglet vortex expands gradually, the height and intensity of the body vortex are depressed by the winglets and, consequently, the body vortex cannot develop into an asymmetric vortex system. The tail vortex of the winglet will not be mixed with the body vortex.

Figure 2 is taken from a photograph of the surface oil flow. From figure 1 we can know that the existence of the head winglets causes the position of the separating line to be lower and therefore makes the development of the body vortex slow.

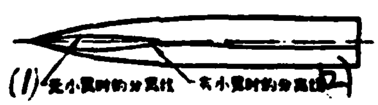


Fig. 2. The separating line with and without winglets
1-without winglets; 2-with winglets.

On the rear part of the body, besides a pair of main vortexes, there are a pair of second order vortexes which have opposite direction and a pair of second vortexes which are relatively weak. In order to avoid confusion we have omitted the opposite second order vortexes and the second vortexes, leaving only the main vortex in the figure.

2. The situation of model 2 (the winglets are installed in the middle of the slender body).

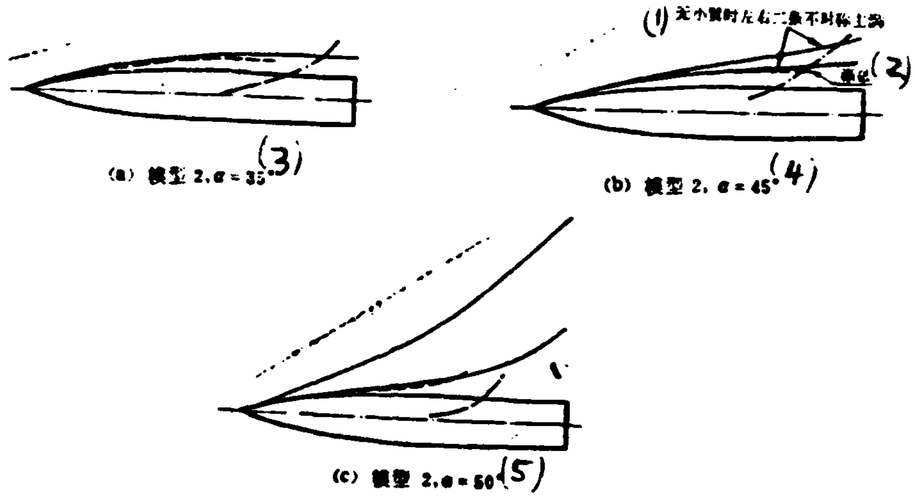


Fig. 3.

1-the asymmetric main vortex when no winglets are installed; 2-gradually broken; 3-model 2, α=35°; 4-model 2, α=45°; 5-model 2, α=50°.

From figure 3 we can know that when the angle of attack is larger (for example, α > 22.5°), two strong front body vortexes are generated; besides that, because of the existence of the winglets there are strong wing vortexes in the middle of the slender body. Under the influence of these wing vortexes, the winglet part of the slender body separates the vortex generated, preventing them to be mixed with the front body vortex and forming a new body vortex behind the winglet. The body vortex is influenced by the winglet vortexes. Both the circulation and height are depressed and therefore the asymmetry problem is depressed. When the angle of attack is larger than 50°, both winglet vortex and body vortex are broken gradually, therefore no asymmetric vortex exists. When α=60°, all the winglet vortexes are broken and the body vortex only exists at the head. Because of the influence of the low pressure region produced by the broken winglet tail vortex, this body vortex will not curve upwards as in the case without winglets.

Figure 4 shows the separating line and the influence to the body vortex by the winglets.

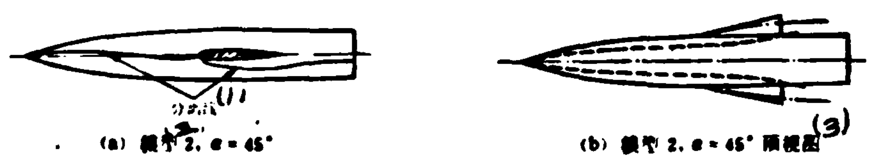


Fig. 4.

1-separating line; 2-model 2, α=45°; 3-model 2, α=45°, top view.

3. The situation of model 3 (a pair of small size trapezoid-like winglets are installed at the middle of the slender body).

The situation of model 3 is basically the same as the situation of model 2. The winglets cause the body vortex to be lowered. When α=30°, the body vortexes are drawn downwards and mixed together. When α further increases, the winglet vortexes are broken, then the body vortex enters the broken region and will also be broken. Because the angle of attack of separating the broken ones is smaller than the triangle winglets, the effect of eliminating the asymmetry problem is less effective than the triangle winglets, but will not cause an asymmetry problem.

4. The situation of model 4 (a pair of trapezoid-like winglets are installed at the middle of the slender body).

The winglet vortex generated by the winglets also has a relatively large influence on the body vortex, making the body vortex compress downwards to form a flat shape and weaken gradually. (This is because at the position of the winglets the body vortex can not be added to the original body vortex.) When α=22.5°, the body vortex is attracted by the winglet vortex and dispersed gradually; at the same time the winglet vortexes keep flowing downwards. When α=30°, the winglet vortexes are broken, the body vortex is left-right symmetric and also will be broken gradually (as shown in figure 5).

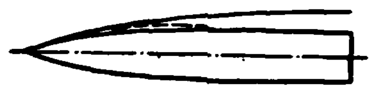


Fig. 5. Model 4, α=30°, the winglet vortex is broken and the body vortex is left-right symmetric.

5. The situation of model 5 (a pair of small trapezoid-like winglets with an installation angle).

We already found that in the case of model 4 the separation begins at α=30°. Therefore we chose the installation angle as -30°. When α=35°~40°, because the angle of attack is only about 5°~10°, the winglet vortexes are relatively weak and have no obvious influence on the body vortex. When α=45°, the winglet vortexes become strong and the body vortex is attracted downwards. When α increases further, the winglet vortexes become more strong and therefore the body vortex will be attracted and dispersed. Therefore by keeping the angle of attack of the winglets less than 30°, the asymmetric vortex system, of the slender body, which is separated from the body and is generated at a large angle of attack and without side slip, can be depressed effectively.

CONCLUSIONS

This paper introduces the study of the vortex system, which are separated from the body of five slender bodies with winglets. The experiments were done in a low speed wind tunnel by using a fluorescent micro-wire technique. A more direct understanding was obtained for the depressing effect of winglets to the development of the asymmetric vortex system of a slender body.

1. Because of the non-vortex input of the winglet and the lowered position of the separating line, winglets can depress the development of the body vortex at the location where they were installed (the shadowed part of downstream). When the winglet vortexes reach a certain circulation, they can effectively attract the leaving body vortex of a slender body and prevent it curving upwards; therefore no asymmetric vortex system will be developed. Thus the undesired side force can be avoided for the case without side slip.

2. Too large angle of attack will produce a separating problem. Although this is not favorable for the consideration of resistance, the separating region will lead to the attraction and dispersion of the body vortex of a

slender body; therefore, the development of an asymmetric vortex system can be avoided.

3. The tail vortexes of any protruding object on the two sides of a slender body can, in some degree, depress the leaving body vortex, therefore relieving, postponing, or eliminating the development of the asymmetric vortex system.

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