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THE EFFECT OF DOWNSTREAM SUCTION ON THE DELTA WING LEADING-EDGE VORTEX

Zhou Ji, Jeff Marchetta, J. Hochstein and J. D. Mo
(University of Memphis, Memphis, TN 38152, USA)
K. X. He, and Alan Chow
(Alabama A & M University, Huntsville, AL 35862, USA)

ABSTRACT: An experimental study was conducted on the effects of downstream suction on the delta wing leading-edge vortex. The purpose of this investigation is to enhance the leading-edge vortices by delaying the onset of vortex breakdown. For the experiment, a small suction fan was tested in various locations and speeds to determine its effects on the stability of the vortices. Results showed that the presence of the fan in the flow field significantly enhanced the vortices over the range of attack angles. It was found that the fan's effects were optimized when it was placed directly along the centerline of the vortex core and closest to the trailing edge. The study demonstrated that the fan's influence on the vortex cores was a weak function of the angle of attack and strongly dependent on the position and speed of the suction fan.

I. Introduction

One fundamental feature of delta wing aerodynamics is the vortical flow regime generated by the vortices at the leading-edge. Previous research has shown these vortices essentially define the aerodynamics of the wing. Specifically, the vortices produce an effect called vortex lift. This enhancement on the lift benefits the wing by boosting performance particularly at high angles of attack.

As with most vortical flows, the vortex cores are susceptible to quick deterioration by external disturbances. While the natural breakdown of the vortex is expected, premature breakdown can cause a notable decline in performance or a potential stall. For these reasons alone, it is important to develop a means of controlling or enhancing the effects of vortex lift. This can be accomplished by extending the length of the stable vortex core before the imminent breakdown.

Both experimental and computational studies have been conducted which yielded highly favorable results. Shi[11] found that injecting a single jet from the surface of the wing into the flow lengthened the vortex core before breakdown. Similarly, Hong[6] et al used lateral blowing techniques to demonstrate feasibility and effectiveness as a lift and control mechanism. Tavella[12] experimented with the vortex lift on delta wings with leading edge blowing. Myose[10] found that placing canards in front of a swept back delta wing delayed the breakdown of the vortex even with varying pitch motions.

While the blowing techniques demonstrated the ability to offset vortex breakdown, they found that the effectiveness was a strong function of the angle of attack and the leading edge geometry. The motivation for this research is to find a more flexible means of controlling the vortex core and lengthen the breakdown location. Consequently, the objective of this study is to qualitatively examine the effects on the vortical flow field by inserting an external suction fan near the trailing edge of the delta wing for varying angles of attack and fan location.

II. Experimental Set-up

2.1 Wind Tunnel

The test was carried out in the 2 2 foot low speed wind tunnel at the University of Memphis. In order to visualize the leading-edge separation vortex using the smoking wire technique, a low load small fan is used in stead of the original driving fan in the wind tunnel to generate the flow with even lower speed in the test section. This small driving fan has a diameter of 20 inches and three levels of running speed. Most tests were run with the medium speed, the corresponding flow speed of which is in the range of 1m/s.

2.2 Test Model

The model used in the test is a half model of delta wing made of plastic. A rectangular plate of 15 12 inches is used as the symmetric surface of the delta wing. The half wing is fixed on the plate with a preset angle of attack of 15^o, which is the lowest angle to be tested. The chord length at the root of the wing, *c*, is 11½ inches. The leading-edge sweep angle is 60^o. The plate with the half wing is mounted on the support as a rotating part permitting variations in the angle of attack up to 35^o. See figure 1 for the set-up.

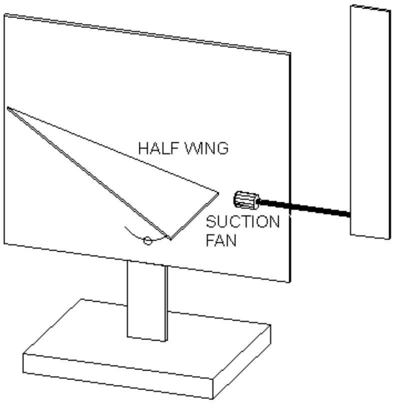

Figure 1 Side-view of the test set-up

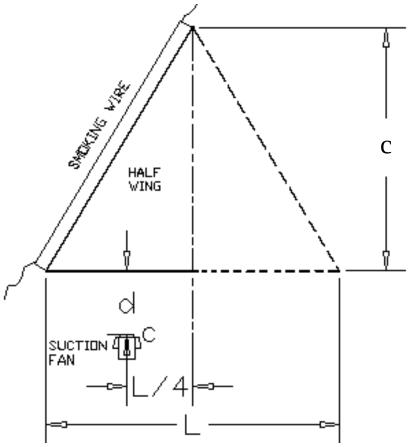

Figure 2 Top-view of the test set-up

The suction fan is positioned behind the delta wing on a movable support. It is the fan used in an ordinary hair-dryer, with the diameter of 1¼ inch. In this project, it is driven by DC power of 6V or 18V. The rotating direction of this fan is the same as the leading-edge vortex rolls and the span-wise position of the suction fan is fixed at the midpoint of the half model trailing edge, or ¼ span from the symmetric line of the delta wing. See figure 2. The position of the fan on the flow direction is designated by the horizontal distance from the trailing edge to the front central point C of the fan. This distance, *d*, is mentioned as "distance" or "horizontal distance" in the following discussion. Another length to describe the position of the fan is the vertical distance *h* from the trailing edge to point C, which is called "height".

To visualize the leading edge vortex, a straight smoke-generating wire is mounted on the leading edge of the model with a reasonable small distance about 1/4 inch. The smoke oil is usually applied only on the front half of the wire to eliminate the obstruction of view by the separation vortex generated by the aft part of the leading edge.

2.3 Test Procedure

The wind tunnel continues to run throughout the procedure of observing and taking the pictures. The alternating fan runs at a low speed steady-state condition for most cases. The smoke oil is applied manually when the observation window of the wind tunnel is open. After the window is closed, an electrical current is applied to the thin wire. The picture is taken when the smoke becomes appropriately strong. For each angle of attack, the flow is first tested without fan running. Then the fan is placed at $d/c = 0$, $h/c = 0$ position and turned on. Pictures are taken, and, then, the fan is moved to each testing position repeating the procedure.

III. Results and Discussion

3.1 Influence of the Suction Fan on the Vortex

Tests were run at the angles of attack from 15^{o} to 35^{o} with the interval of 5^{o} to compare the flow pattern without the fan running and those with the fan at different positions. A battery voltage of 6V is used for the fan in most cases.

Generally speaking, the existence of the small suction fan behind the trailing edge alters the flow pattern significantly. The leading edge separation vortex is enhanced. Not only is the vortex more stable with the suction fan running, but the breakdown position is delayed obviously as well in most cases. Because the breakdown of vortex is mainly due to the energy dissipation, the extra favorite pressure gradient generated by the suction fan will maintain stronger and lasting vortex as predicted. The fan will also induce rotating flow with its same rotation direction, but this would not be the main reason of vortex enhancement considering the fact that it could not be the major part of the energy output of the fan.

The following results from the tests verified that the downstream suction is an effective method to enhance and maintain leading edge vortex.

Figure 3 is the picture taken without the fan running at 25 angle of attack. Figure 4 is the picture with the fan running at dimensionless distance $d/c = 0$ and dimensionless height $h/c = 1/8$. The breakdown point of the vortex was delayed from about half the chord length to the trailing edge. The vortex appeared to be more stable and concentrated as well.

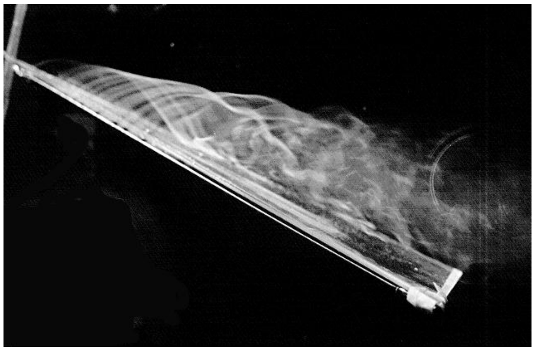

Figure 3 Vortex flow without fan running at 25^{o}

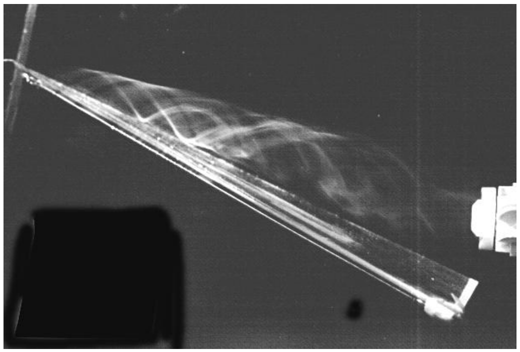

Figure 4 Fan running at $d/c=0$, $h/c=1/8$ at 25^{o}

Figures 5 through 7 are the pictures for 30^{o} angle of attack. We can see the difference of suction is more important for large angle of attack. In figure 5, the leading edge vortex roll is hardly formed at all without the fan. But with the fan running at $d/c = 0$, $h/c = 1/4$ in figure 6, the leading edge vortex was clearly formed and broke down at least after half chord length.

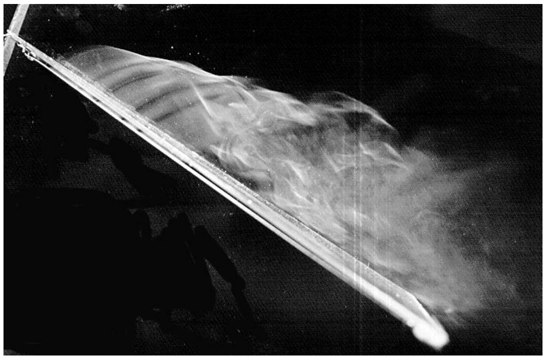

Figure 5 At 30^{o} without fan running

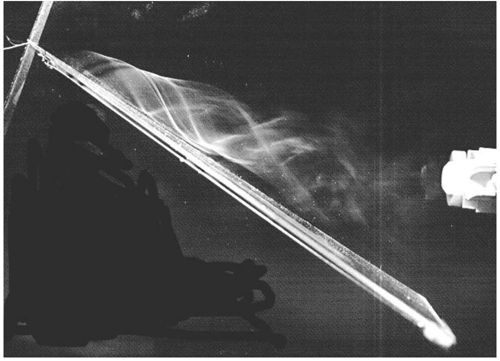

Figure 6 At 35^{o} fan running at $d/c=0$, $h/c=1/4$

Figure 7 is the same case as figure 6 except that the suction fan was driven with higher voltage of 18V. It is shown in this case that the higher rotating speed strengthens the effects on the vortex cores. The faster the fan runs, the more stable the vortex becomes and the later it breaks down.

A side effect we can see in figure 6 and 7 is the distortion of the vortex by the resistance of the suction fan. It is more apparent in figure 7. In such cases where the fan is higher from the wing, this effect will to some extent reduces the nonlinear lift of the vortex even if it does not break down.

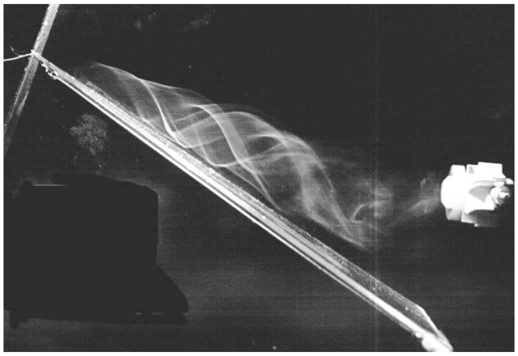

Figure 7 Same as in Fig.6, but double the fan speed

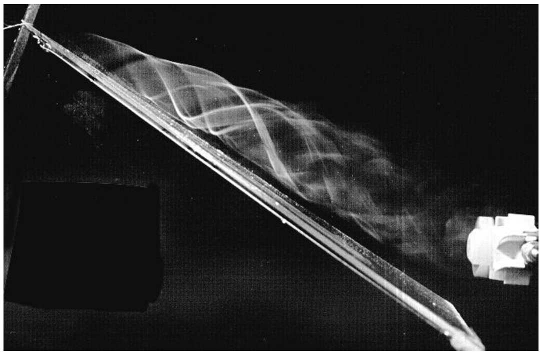

Figure 8 Same as in Fig.6, but h/c=1/8

3.2 Effect of the Relative Position of the Fan

As can be predicted, the relative position of the fan from the wing will affect the influence of the fan very much. Tests were run systematically with dimensionless distance d/c from 0 to 3/4 with the interval of ¼, dimensionless height h/c from 0 to 3/8 with the interval of 1/8 to examine that effect.

As for the vertical position of the fan, the strongest influence turned out to be seen when the fan was closest to the center of the vortex roll, or the vortex core. Figure 8 is the test with the same condition as figure 6 except h/c = 1/8. Since this height is closer to vortex core, the vortex is much more stable and lasts until the position of the fan. When the fan is at this height, it will not drag the vortex away from the wing either. So this is a much ideal position of the suction fan if more nonlinear lift from the vortex is desired.

Figures 9 and 10 were taken when the fan was at h/c = 3/8 and h/c = 0. In figure 9, even if the fan was out of the vortex roll, the vortex was still enhanced and broke down later than the case without fan (figure 5). But figure 10 shows more vortex enhancement even though the fan is only half above the wing. The distortion of the vortex by the fan can be also seen in figure 9. Figures 11 and 12 are for angle of attack 25 , h/c = ¼ and 0, respectively. Comparing with figure 4, the vortex prolongation are not as strong in both cases as for h/c = 1/8 when the fan is closest to the vortex core. But the difference from the cases with 30 angle of attack (figures 9 and 10) is that h/c = 0 is now the weakest one, since only half of the suction exerts above the wing surface while h/c = ¼ is not too far away from the vortex. For all the angles of attack which were tested, the delay of vortex breakdown are still quite significant even at h/c = 3/8.

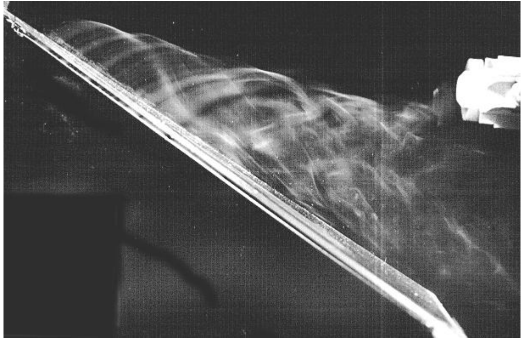

Figure 9 Same as Fig. 6, but h/c=3/8

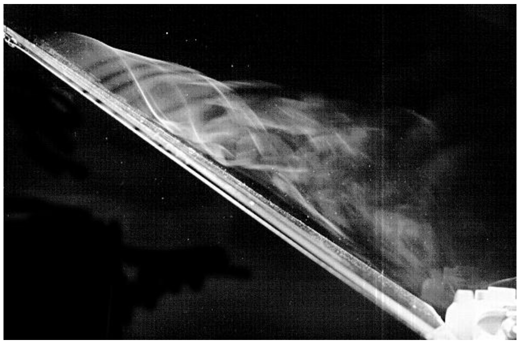

Figure 10 Same as Fig. 6, but h/c=0

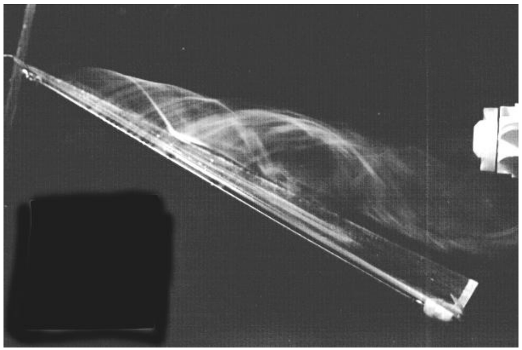

Figure 11 At 25^o, *h/c*=1/4

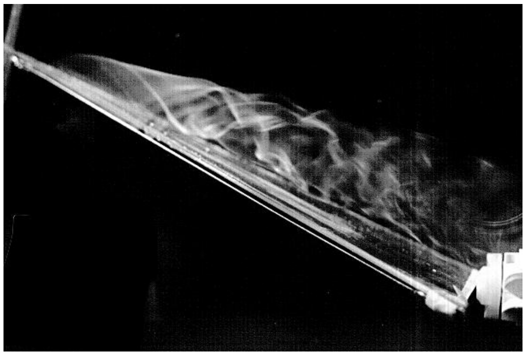

Figure 12 At 25^o, *h/c*=0

It is more straightforward that the fan will enhance the vortex more when the horizontal distance is smaller. When *d/c* = 0, the difference between the flows with fan and without fan is most obvious. Figures 13 and 14 have the same angle of attack 30 and height *h/c* = ¼ as in figure 6, but with *d/c* = ¼ and ½. For the dimensionless distance of ½, the effect of the fan is not significant. Figures 15 and 16 are for angle of attack 25 and dimensionless height *h/c* = ¼ as in figure 11, while the dimensional distance *d/c* are ¼ and ½ respectively. The difference between figures 15 and 16 is not as obvious as between 13 and 14. That demonstrates that the effect of the fan will decrease more with the distance for larger angle of attack.

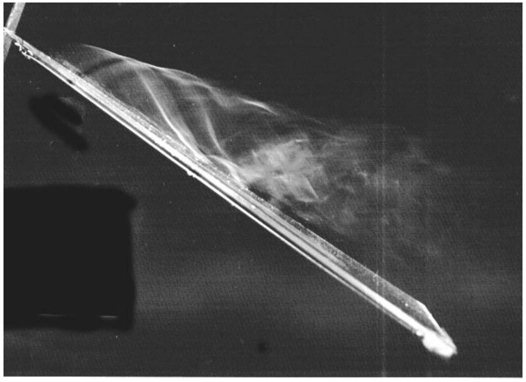

Figure 13 At 30^o, *h/c*=1/4, *d/c*=1/4

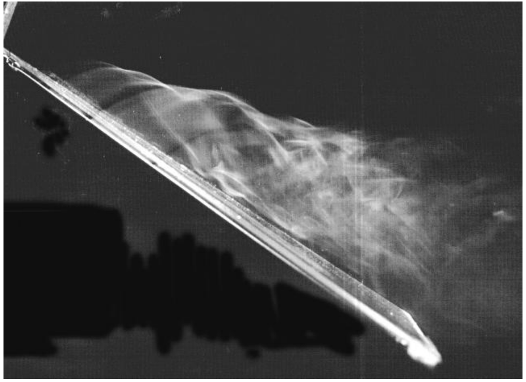

Figure 14 At 30^o, *h/c*=1/4, *d/c*=1/2

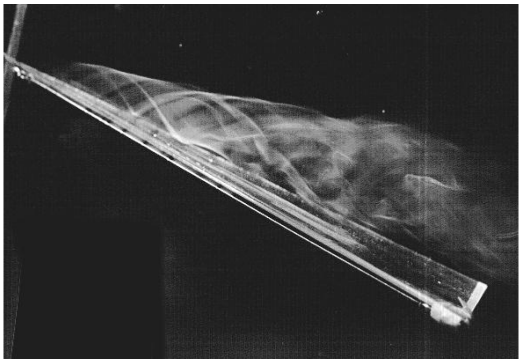

Figure 15 At 25^o, *h/c*=1/4, *d/c*=1/4

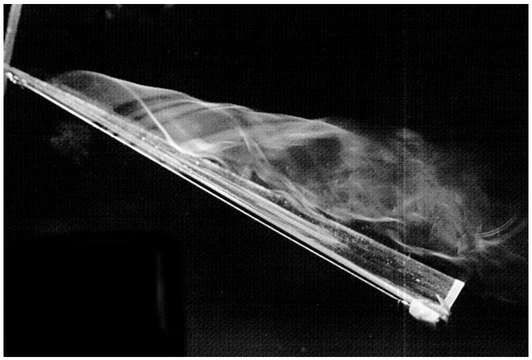

Figure 16 At 25^o, *h/c*=1/4, *d/c*=1/2

IV. Conclusion

A study has been completed to demonstrate the effectiveness of a trailing edge fan on the vortex breakdown of a delta wing. It has been shown that the vortex core can be enhanced by properly positioning a suction fan at the trailing edge of the wing. As anticipated, the fan had little effect on the vortical flow for low angles of attack. However, as the attack angle increased, the influence of the fan on the vortex core became very apparent. For higher angles where the leading edge vortex cores deteriorated quickly unaided, the fan offset the breakdown by nearly half of the wing's length. As a consequence of this general conclusion, the study proceeded towards the optimization of the fan's influence. The optimal horizontal position (*d/c*) relative to the trailing edge was found to be zero. This position is along a plane directly perpendicular to the wing's trailing edge. Furthermore, the height or vertical position (*h/c*) of the fan exhibiting the most vortical enhancement was found to be in direct line with the vortex core. The last parameter investigated was the speed of the fan. Conclusively, the fan speed was a major factor in the control of vortex breakdown. Vortex enhancement was increased proportionately with an increase in the fan's speed. Thus, the introduction of trailing edge fan into the flow over a delta wing is a feasible alternative in vortical enhancement at high angles of attack with the continued advantage of vortex-induced lift.

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