EXPERIMENTAL COMPARISON OF TWO WING TIPS

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Introduction

In 1983, a research program was conducted to determine effects of wing tip extensions on a general aviation aircraft. The general aviation model had a wing that used NACA-6 series laminar airfoil sections. Six wing tip configurations were compared in the Texas A & M University 7 × 10 foot wind tunnel using a 1/7 scale-model (Ref. 1, 2, 3).

The tip having best performance overall, was similar in appearance to one tested by Hoerner (Ref. 4, 5). On the basis of wind tunnel results, modifications were made to a production aircraft and flight tests were made that validated improvements in climb rate, stall speed and stability as predicted by the wind tunnel results.

The outboard portion of a 15-meter sailplane wing became available for use as a wind tunnel model. This wing had a drooped tip configuration typical of several current designs and very similar to one of the general aviation tips that had been tested earlier. The outer five feet of the glider wing were used to make a wind tunnel model for comparison testing of wing tip shapes. The tip section was cut off and fitted with spars to allow tip replacement. A new tip similar to the general aviation tips was made of composite material and could directly replace the existing tip. The span of the model with the new tip was kept exactly the same to allow direct comparisons. The new tip shape also required a modification to the aileron. Aileron effectiveness was compared for the two tips.

Tests were run in the velocity range of 50-100 knots, thus providing full scale Reynolds number data for glider operations. The data presented here were obtained at a dynamic pressure of 16.2 PSF, corresponding to a velocity of about 70 knots. The model was mounted to an external balance capable of providing six component measurements through a range of angles of attack. Lift, drag, side force, pitching moment, yawing moment, and rolling moment were measured. Since the data were obtained for both tips under the same conditions using the same basic model, it was possible to make direct comparisons of the differences in performance for the two tips.

In addition to force and moment data, a later test was conducted using a three component hotwire anemometer probe to survey the flow fields behind the tip regions. Measurements were made in planes one inch behind the trailing edge and one chord downstream that produced information on the vortex flow as affected by tip shape. Because of the lengthy run time requirements for hot wire measurements, data were obtained at only 0 degrees and 10 degree angles of attack, representing cruise and climb conditions.

Model Description

As indicated in Figure 1, the model was constructed using the outer five feet of a sailplane wing. Two steel I-beam spars were fitted into the wing and bonded to the spar and inner skins. Foam was then used to fill the voids making a rigid section. An adapter plate, designed to allow variations in leading edge sweep, was attached to the steel spars. The adapter plate was mounted on the external balance beam beneath the wind tunnel floor.

A steel spar was also added to the aileron with an adjustment plate at the root which allowed discrete settings of aileron angle. A circular plate was mounted below the wing root to prevent interaction of the wing pressure flows with the wind tunnel boundary layer. This plate was positioned with the centerline leading edge two inches above the wind tunnel floor.

Dimensions for the basic model and the two tips are shown in Figure 1. Because the wing span was constant, small changes in wing area resulted. In addition, the aileron portions of the two tips differ slightly as shown. The removable sections of aileron were fitted with hardwood spar inserts that firmly joined the aileron sections into a single surface.

Two cylindrical spars embedded in the tip sections matched with machined cylinders bonded into the wing section. As these structural members carried all the shear and bending loads, it was possible to rigidly hold the tips in place and seal the joint using plastic tape.

With the wing section mounted on the balance above the floor plate, similar conditions existed for each wing tip section during testing. Tare effects were assessed with the plate only, to determine effects without the wing in place. These were subtracted from each measurement value as the method of obtaining basic wing data. While this is an imperfect method of eliminating tare effects, the fact that the wing sections were being compared on a relative basis with the same tare effects for both wing tips provided a rationale for using this aero-tare correction method.

Test Conditions

The leading edge sweep of the wing as designed was 2 1/2 degrees. This "built-in" value was used for all data presented in this paper. For each configuration, the angle of attack was varied from −6 degrees to +18 degrees in 2 degree increments. This range of angles covered the normal operating range of a wing. The data presented here were all obtained at an actual dynamic pressure of 16.2 PSF, the equivalent of about 70 knots.

Data Reduction

Wind tunnel blockage corrections and wall corrections were made in accord with standard wind tunnel correction procedures. Forces and moments were reduced to coefficient form for each of the configurations so that direct comparisons could be made in coefficient form. All quantitative data were obtained using the wind tunnel balance, which provided digital inputs directly to a data acquisition computer which applied wall corrections, blockage effects and reduced the results to coefficient form. A few flow visualization runs were made with each tip using simple wool yarn tufts to examine the streamline flow patterns at various angles of attack.

Test Results

A significant difference in lift coefficient is shown with improvements provided by the new tip (Figure 2). Maximum lift coefficient increased by about 4% and improvements were noted throughout the climb angle of attack range. The new tip exhibited slightly higher drag at negative angle of attack conditions; however, throughout the cruise range drag values were very fimilar (Figure 3).

In Figure 4, a comparison is provided for lift/drag ratio as a function of lift coefficient. As indicated, the new tip offers gains in L/D at climbing lift coefficients. At a C_L of 1.0, the improvement is on the order of 5%.

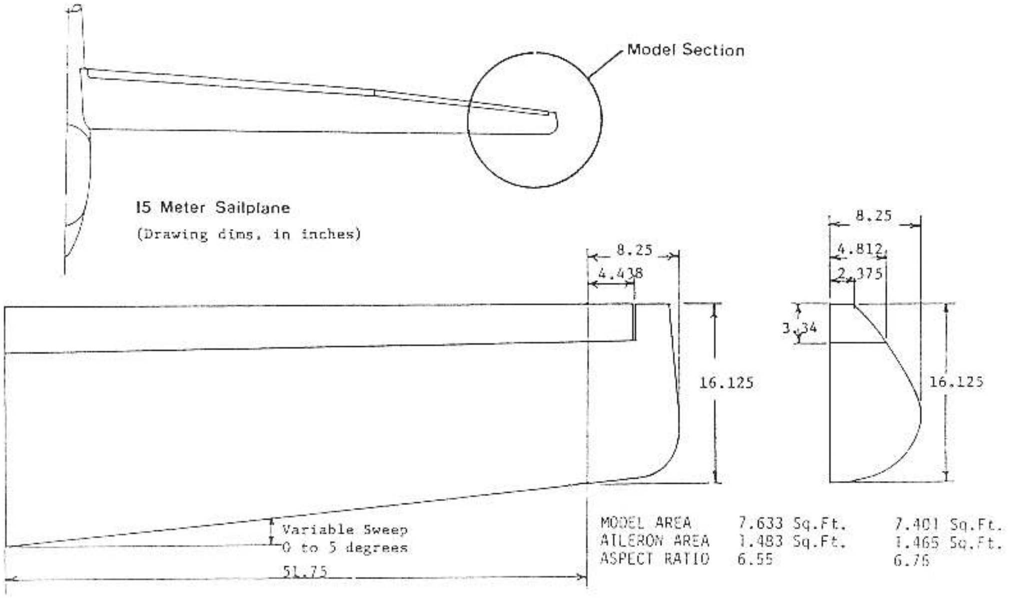
Figure 5 compares the two wing tips on the basis of climb parameter, $(C_L)^{3/2}/C_D$. This parameter is more influenced by improvements in lift coefficient than changes in drag coefficient because of the exponent effect on lift (Ref. 6, 7). As shown, improvements of about 5-6% are evident at lift coefficients above $C_L = 1.0$, where climb would normally occur.

The spanwise or side force data (Figure 6), show that the drooped tip tends to provide an outward force as angle of attack increases, and the new tip trend is the opposite. This relates to the dihedral effects shown in Ref. 3 indicating the drooped tip was destabilizing in yaw while the new tip offered effective dihedral, diminishing at high angles of attack.

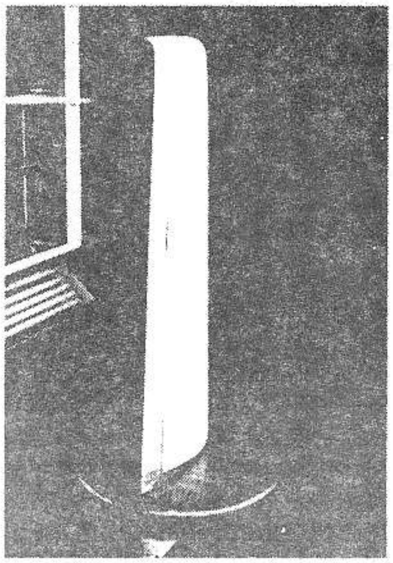
It is interesting to note in Figure 7, improvements in aileron effectiveness result for the new tip. Although the new aileron has slightly less area it produces some improvement in lift coefficient increments at higher lift conditions for either the up or down deflection, that would translate to greater rolling moment effectiveness.

Figure 1

Model Made from Glider Wing Section

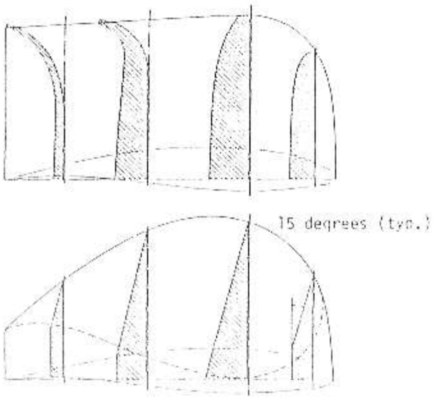


MODEL SHOWING
WIND TUNNEL MOUNT



TIP CHARACTERISTICS

ORIGINAL TIP
TIP AREA: 0.850 Sq. Ft.



NEW TIP
TIP AREA: 0.618 Sq. Ft.

Figure 2

Comparison of Lift Coefficient

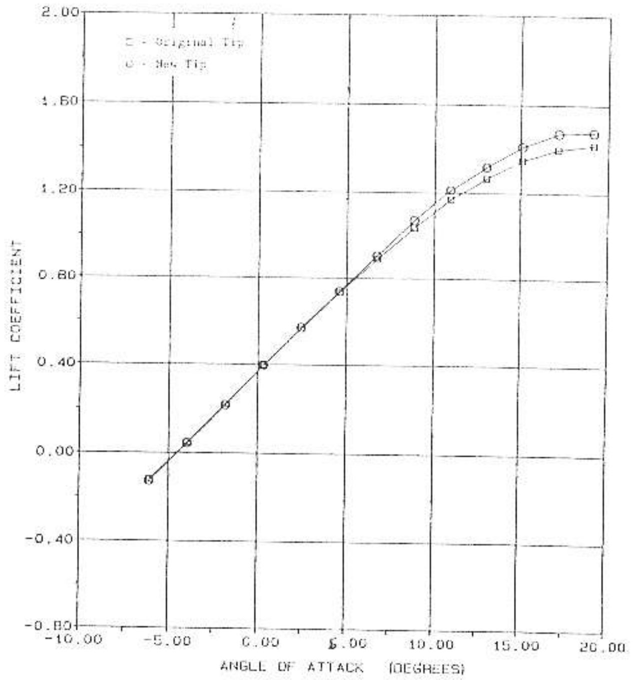


Figure 3

Comparison of Drag Coefficient

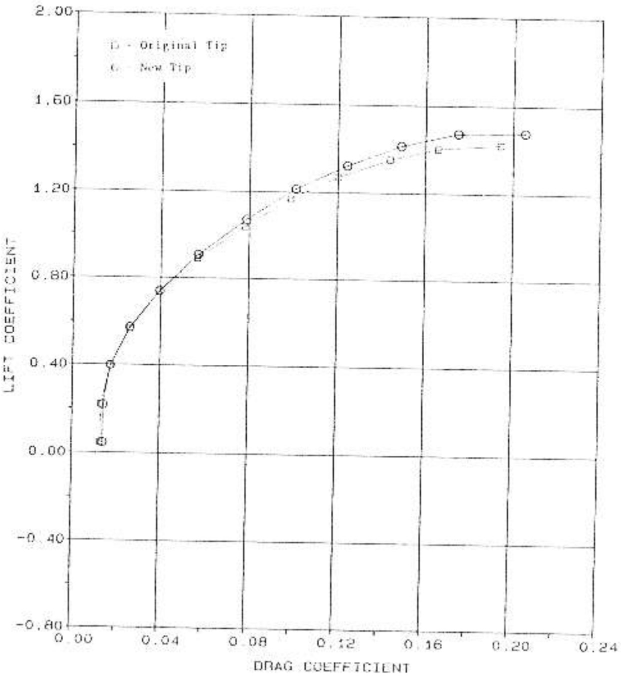


Figure 4

Comparison of Lift/Drag Ratio

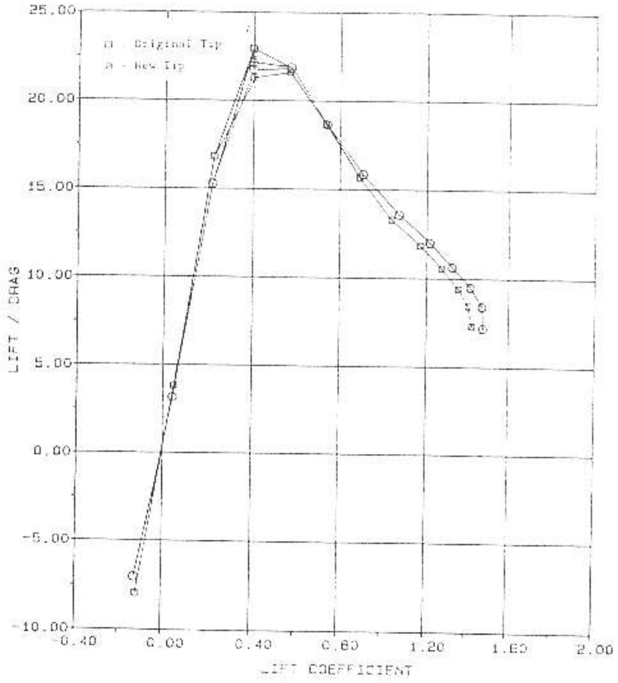


Figure 5

Comparison of Climb Parameter

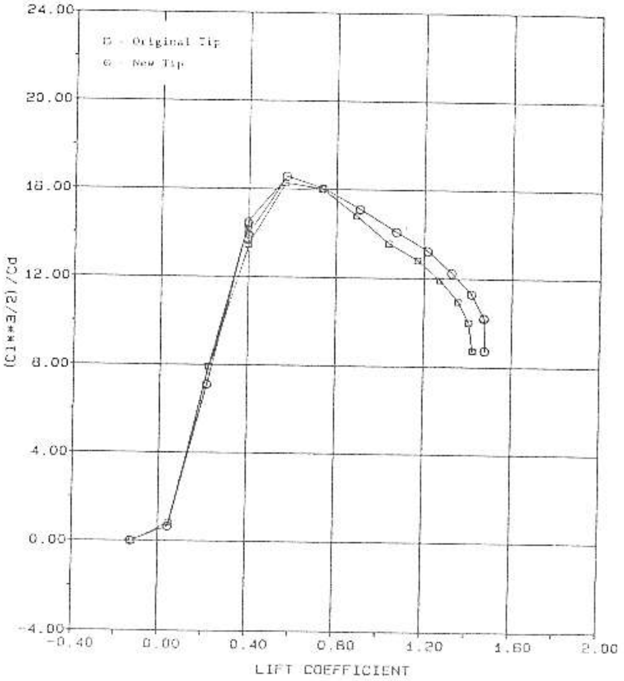


Figure 6

Comparison of Side Force Coefficient

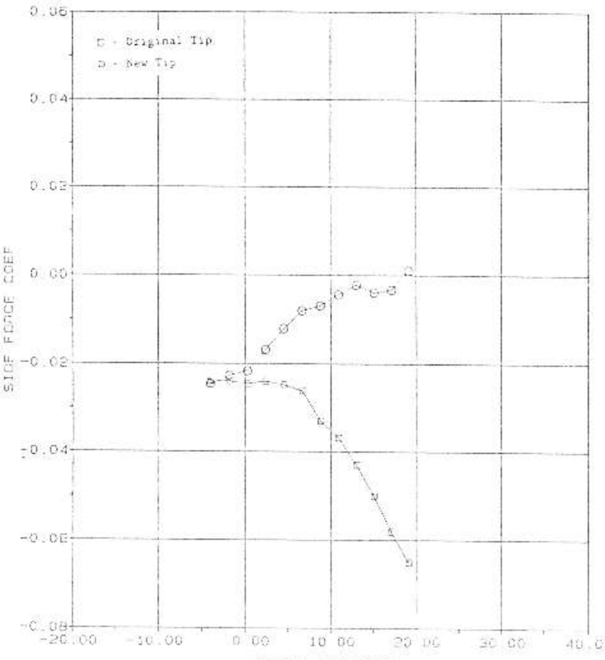
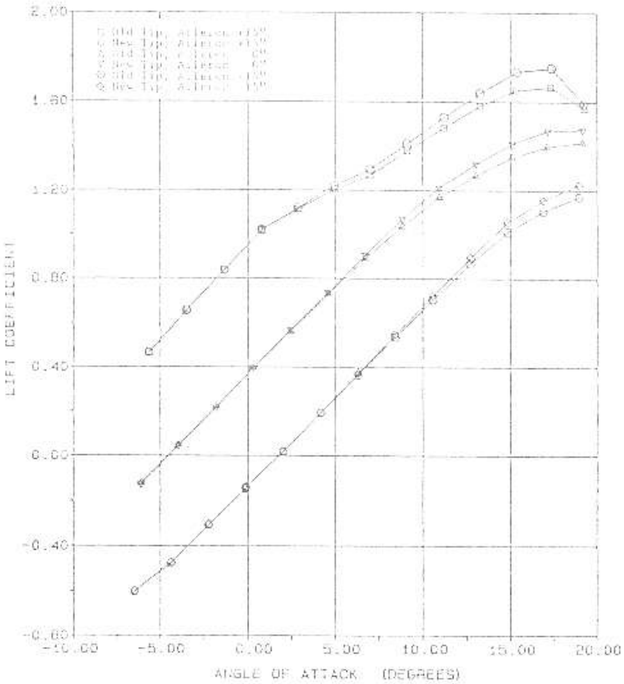


Figure 7

Comparison of Aileron Effectiveness



Flow Survey Results

Figure 8 shows the hot wire probe survey apparatus installed downstream of the model. It was positioned accurately by a remote drive system to obtain the grid velocities at various locations.

Flow survey results show the rotational velocities in planes one inch aft of the trailing edge and 16 inches or approximately one chord downstream (Figures 9 and 10). Data allow direct comparisons of the old and new tip flows for climb conditions. At a 10 degree angle of attack which corresponds to a lift coefficient of about $C_L = 1.15$, the primary vortex for the old tip appears to have its core in the region about 1.6 inches inboard of the tip position and immediately aft of the trailing edge. The new tip has a core that appears at approximately the same spanwise location and above the tip about 3.5 inches.

At approximately one chord distance aft of the trailing edge, the vortex for the old tip remains directly downstream of the trailing edge and moves inboard from the tip about three inches, whereas the vortex for the new tip remains at about the same 3.5 inches above the trailing edge and moves inboard spanwise to about three inches from the tip plane.

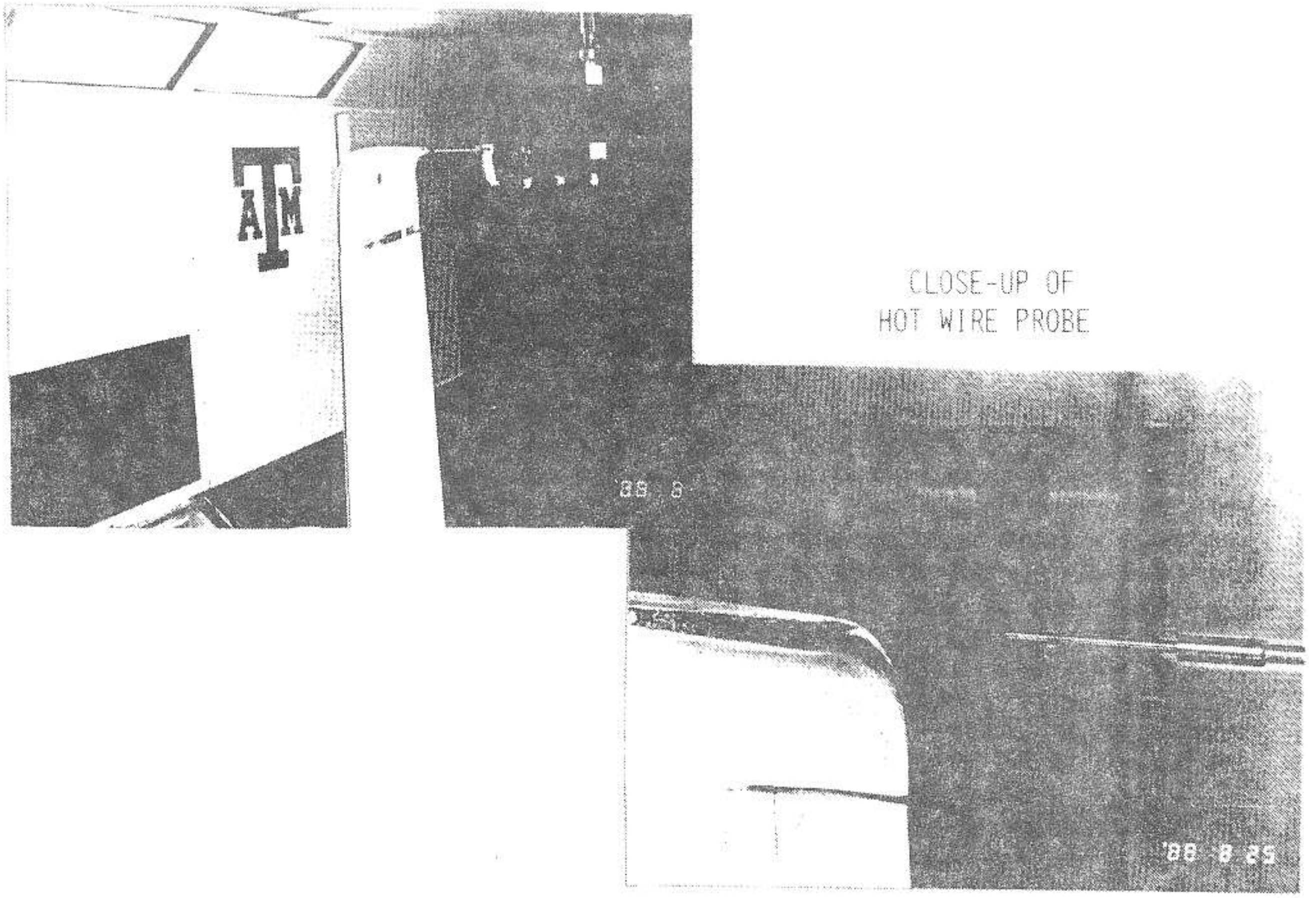
Summary

Systematic tests of six wing tip configurations chosen for a general aviation application had shown a sharp edged tip to be best for a range of conditions. A full-sized model was made from the outer five feet of a 15-meter glider wing having a drooped tip. The model was made to allow tips to be interchanged, and a sharp-edged tip like that developed for the general aviation application was tested on a direct comparison basis with the original glider tip.

At full scale Reynolds numbers, the model tests showed the new sharp-edged tip to be superior for all values of lift coefficient above 0.4. In addition to gains in L/D of up to 6%, the climb parameter, $(C_L)^{3/2}/C_D$ was significantly improved by as much as 6%, and the increase in maximum lift coefficient of 4% could offer a reduced stall speed. From earlier tests of a general aviation application, an increase in effective dihedral at high angles of attack can also be expected (Ref. 3, 11).

Flow field surveys were made of the wake downstream of the tips, to determine the nature and location of the vortices. These showed a distinct effect on the location and strength of the vortices, and appear to corroborate the higher lift of the new tip (Ref. 9).

FIGURE 8
PHOTOGRAPHS SHOWING HOT WIRE PROBE INSTALLATION



MODEL WITH HOT WIRE PROBE DOWNSTREAM

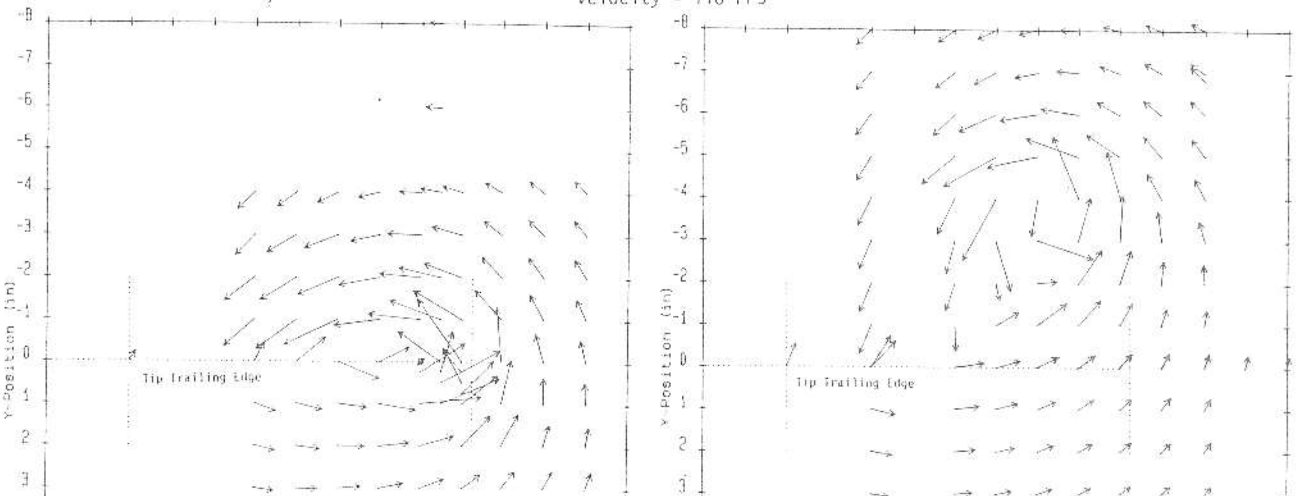
CLOSE-UP OF HOT WIRE PROBE

'88 8

'88 8 25

Figure 9

Vortex Patterns
One Inch Aft of Trailing Edge
Velocity = 116 FPS



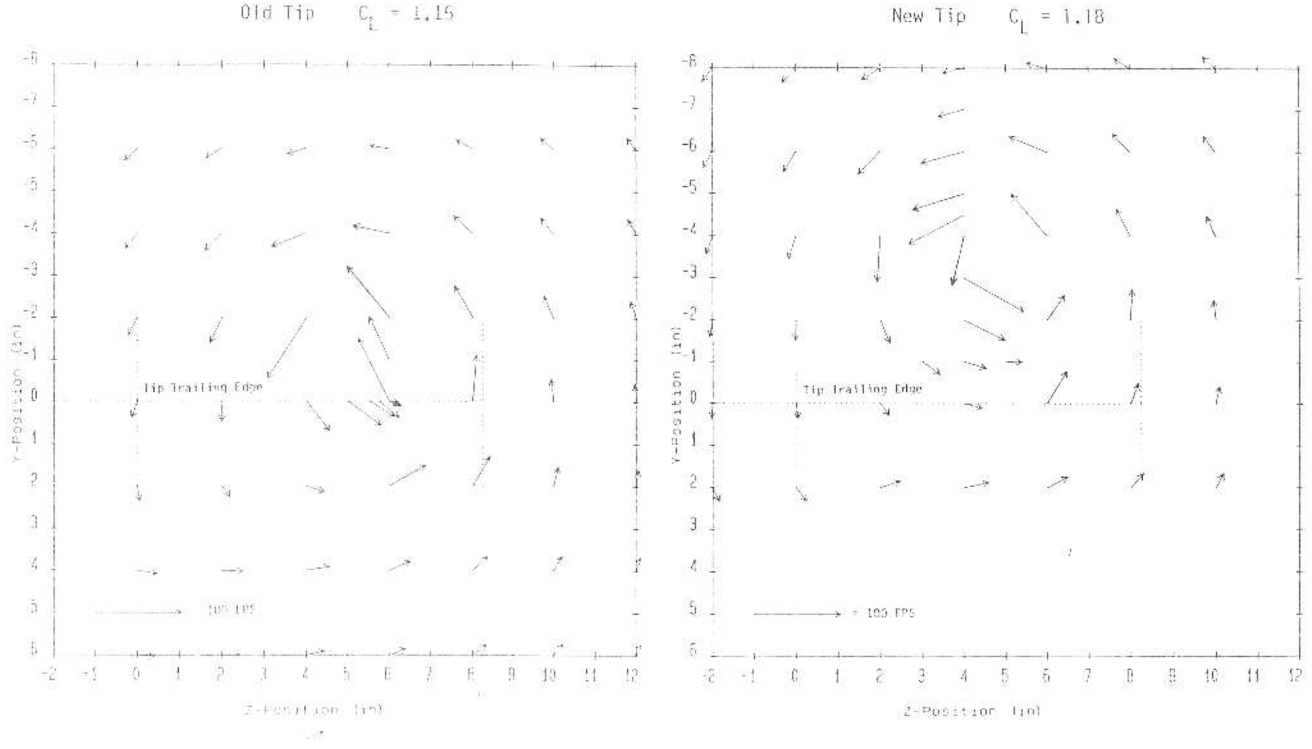
Old Tip $C_L = 1.15$

New Tip $C_L = 1.18$

Figure 10

Vortex Patterns One Chord (16 Inches) Aft of Trailing Edge

Velocity = 116 FPS



Discussion and Conclusions

Ideal two-dimensional wing performance can be approached with very high aspect ratio wings, but wing tip effects always compromise lift and increase drag as higher pressures underneath the wing leak around the tip. This flow results in the familiar vortices which swirl downstream of every wing tip (Ref. 10, 11, 12).

To date, there have been no dependable means of avoiding a loss in energy to the mixing streams of air, but the effect of flow around the tip that tends to equalize pressures on upper and lower surfaces can be reduced by a sharp edge which prevents the boundary layer of very low velocity air from remaining attached to the surface. From the comparison of a sharp tip with a conventional rounded wing tip having a drooped trailing edge, it has been shown that the upper surface flows are less compromised for the sharp tip. This appears to allow the contoured upper surface to sustain more nearly two-dimensional flows to the tip extremity.

Allowing the tip shape to be determined by a plane passage at 15 degrees through the upper contour results in a nicely faired tip very similar to bird tip feathers. This shape has less wetted area than a rectangular tip or any form of drooped tip. Since friction drag is directly related to wetted area, any additional wing area should be providing lift to offset the additional drag. These test results indicate that the rounded edge, drooped tip causes a drag penalty for the added area without attendant gains in lift. The simple sharp-edged tip does result in a small increase in aspect ratio, and adds effective dihedral.

Based on these findings, a simple but effective wing tip can be made by passing a plane parallel to the chord line from the lower through the upper surface of the wing at about a 15 degree angle. This plane passing through the upper surface defines the shape of the tip without modifying upper surface airfoil coordinates. The edge of this tip should be sharp to deter the flow of high pressure air from the lower surface to the low pressure upper surface. Full scale flight tests are needed to enable detailed tradeoffs for high aspect ratio wings, but theory shows that tip effects modify the lift distribution of the entire wing. While relative magnitudes may vary, the type of tip effects shown here should, therefore, apply to all classes of gliders.

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