Comparison Of Square, Round, And Hoerner Wing Tips

INTRODUCTION

Recent articles in *SPORT AVIATION* magazine and others concerning the effect of wing tip shape on airplane performance has prompted the author to report the results of wind tunnel tests on wing tip shapes conducted in 1966. At that time, a high performance homebuilt (now nearing completion) was being designed. A thorough literature search produced little in the way of usable tip design data. Aerodynamicists in charge of tip design at Cessna and Beech Aircraft companies offered the following information at that time during telephone conversations: (1) Neither company has quantitative test information. (2) Both have conducted flight tests of aircraft equipped with several different types of tips (including Hoerner) and have not found any measurable change in performance such as speed, climb, stall speed and characteristics, etc. (3) Certain types of "drooped" tips and canted wing tip tanks do improve lateral stability and that is their reason for being used. (4) Main factors in wing tip shape are esthetic and sales appeal. (5) **Any** wing tip shape that does not alter aspect ratio or wing area will probably not produce measurable changes in total aircraft drag.

Thus the available information did not confirm the performance claims made for certain tip shapes, but the entire issue was in doubt. To partially resolve these doubts, a wind tunnel test program, suitable for an undergraduate student project, was therefore submitted to a former teacher and friend, Professor Mel Snyder of the Wichita State University. Professor Snyder approved the project and generously provided the necessary coordination and assistance, while the author fabricated the model to be tested.

WING TIPS

From the large number of tip shapes in use today, it was decided that three basic types shown in Figure 1 were the most representative: rounded, square, and Hoerner. The planform of the round tip was composed of an ellipse from the leading edge back to one-third of the chord and a parabola from there to the trailing edge, and had a span of one-sixth of the chord. The planform of the Hoerner tip was composed of a circular arc at the leading edge having a radius of one-third the chord, and a parabola from there to the trailing edge. There are a great many wing tip shapes called "Hoerner" tips, but the one chosen for this investigation is that recommended by Dr. Houner in his original report "Aerodynamic Shape of Wing Tips" (USAF Technical Report No. 5752, available from the Library of Congress, Photoduplicating Service, Washington, D.C. 20340, L. C. Number PB-102110, $2.50, 14 pp.). The recommended planform and airfoil shapes near the tip were carefully followed.

In performing tests to determine the effect of tip shape, the question arises as to what geometric properties of the models should be made similar. Since the lift and drag are easily non-dimensionalized with respect to area, and since the span is not usually used explicitly in calculating wing performance, it was decided to hold the aspect ratio constant at a value of 4.44.

A low aspect ratio was selected to emphasize the effect of tip shape while still having an aspect ratio high enough so that the overall wing characteristics were not grossly affected. (Although no data is available, it seems reasonable that wings having aspect ratios in the normal range of 6.0 to 9.0 would be less affected by tip shape. A tapered wing of the same aspect ratio and area as a rectangular wing would probably be even less sensitive to tip shape).

Each wing tip was attached successively to a basic constant chord, untwisted wing section having a span of 30.0 in. and chord of 18.0 in. This technique reduced the amount of model fabrication necessary and eliminated the variation in wing performance arising from three different wings. The airfoil selected was the NACA 64_1-212. The basic wing section was fabricated from styrofoam and covered with two layers of 181 style fiberglas cloth using epoxy resin. A single, full depth wooden spar was used. The wing tips were also fabricated from styrofoam and fiberglas. The finished wing tips are shown in Figure 2. Grid lines 2.0 inches apart were inked on the bottom surfaces to illustrate the contours.

TESTING

Tests on the model with each tip attached were performed in the Wichita State University 7 x 10 ft. low speed wind tunnel at angles of attack from —8 to +20 degrees at a Reynolds number of 1.6×10^6 (about 100 mph).

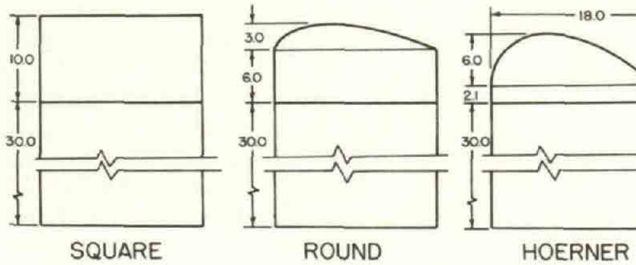

FIG. 1 Types of wing tips tested.

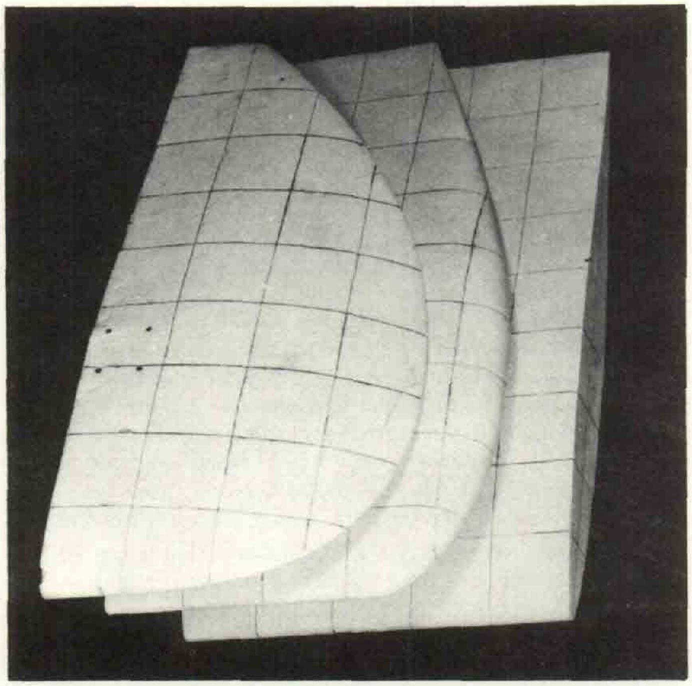

FIG. 2 Wind tunnel models

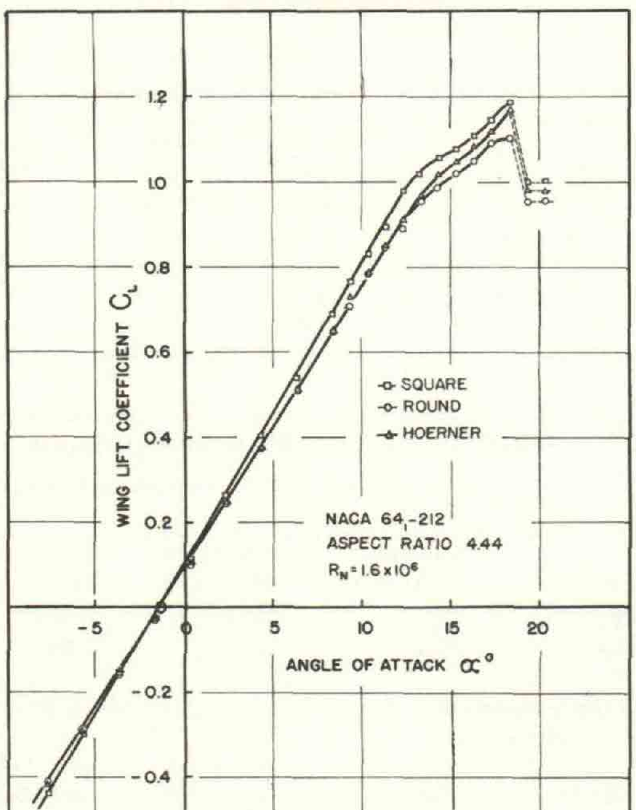

FIG. 3 Lift Coefficient vs. Angle of Attack

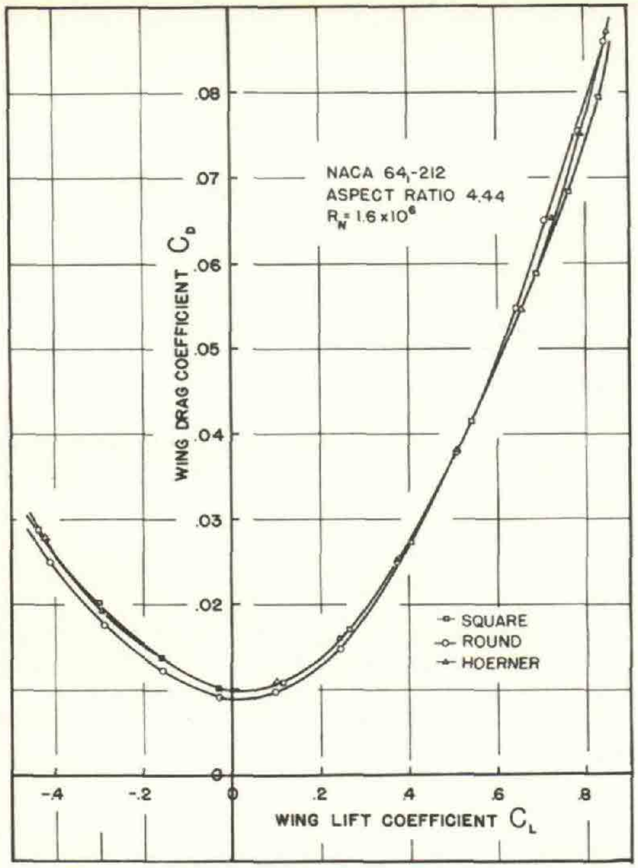

FIG. 4 Drag Coefficient vs. Lift Coefficient

Additional tests were made with tufts attached were made from —4 to +20 degrees for flow studies at the tip. Photographs of the upper and lower surfaces of each tip were taken at each 2 degree change in angle of attack.

RESULTS

Results of the tests are shown graphically in Figures 3 and 4. Tabulated results and other information are included in a report by Mr. Rodger Ellis, the student who performed the testing, entitled "A Wind Tunnel Investigation of Wing Tip Shapes" Engineering Seminar 413II, Dept. of A. E., Wichita State University, 13 Jan. 67.

As can be seen from the graphs, the differences in lift and drag coefficients are small, but measurable. For a given lift coefficient less than 0.4, it is seen that the rounded tip has the lowest drag coefficient; for high lift coefficients, the square tip has the least drag. The largest difference is in the maximum lift coefficients, which were taken to be 1.19 for the square tip, 1.10 for the round tip, and 1.17 for the Hoerner tip. Data for each tip is summarized in Table 1.

DISCUSSION

To see what these data mean in performance changes, it is necessary to perform an analysis of the individual airplane being considered. It is also necessary to realize that the data given is for a particular wing and airfoil, and would have to be corrected for aspect ratio, Reynolds number, surface roughness, etc. It may be significant that at the design lift coefficient for the airfoil tested ($C_L = 0.4$), all tips had the same drag coefficient. In other words, this simple series of tests will by no means settle the wing tip question, but it does provide some factual information on the subject.

As examples, the effect of tip shape on stall speed, maximum speed, and rate of climb were calculated using

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WING TIPS . . .
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approximate methods for the following cases: (1) A VW powered racer having specified minimum wing area, and (2) a typical two-place homebuilt where wing area is based on a specified landing speed. The results of these calculations are summarized in Table 2. All calculations are based on standard sea level air.

For the racer powered by a Volkswagen engine, the minimum wing area, S, is specified as 75.0 sq. ft. The gross weight, W, is assumed to be 700 lbs. Further, assume that an aspect ratio of 4.5 is used, and no corrections are applied for scale effect.

The stalling speed, V_s, as calculated by equating the weight and lift, using the maximum lift coefficient, C_{Lmax};

$$V_s = \sqrt{\frac{2W}{\rho\, C_{Lmax}\, S}}$$

where ρ is the density of air, and V_s is in feet/sec. The stall speed is calculated to be 55.5, 57.7, and 56.5 mph for the square, round, and Hoerner tips, respectively.

Based on a preliminary drag analysis, the drag coefficient is assumed to be

$$C_D = 0.02 + C_{D\ wing}$$

The power is assumed to be 65 hp with a propeller efficiency of 0.80 so the power available is 52.0 hp. The maximum speed in level flight is then found, using an iteration process, by equating the power available to the power required, where the power required is given by

$$P_{req} = \frac{\rho\, V^3\, C_D\, S}{1100}$$

The maximum speed is then 146.3, 148.0, and 145.6 mph for the race with square, round, and Hoerner tips.

Rate of climb would not be of major importance in a racer, but is related to loss of speed while cornering, and would also be important to other similar VW-powered designs. To find the maximum rate of climb, it is assumed that the best climb speed is 1.3 times the stall speed, taken as 72 mph for this example. The power available is estimated to be 39.5 hp. The rate of climb in ft./min. is calculated from the difference in the power available and the power required by the equation

$$R.C. = \frac{60 \times 550}{W}\left(P_{avail} - P_{req}\right)$$

The maximum rate of climb is 1136, 1107, and 1126 ft./min. for a racer with square, round, and Hoerner tips, respectively.

For the second example, consider a typical two-place homebuilt design having a gross weight of 1200 lbs. and an 85 hp engine. As in the first example, assume an aspect ratio of about 4.5 and neglect Reynolds number effects, wing-body interference, etc. Suppose the designer sets the desired stall speed out of ground effect, and with no flaps, at 60 mph. Using the maximum lift coefficient of Table 1, the required wing area is calculated as 109.9, 118.9, and 113.7 sq. ft. for the square, round, and Hoerner tips, respectively.

For any given lift coefficient, assume the total drag coefficient is given by

$$C_D = 0.03 + C_{D\ wing}$$

The propeller efficiency is estimated at 0.87, so the power available is 74.0 hp. We can then solve for maximum speed in level flight by equating power available and power required. These calculations show that the maximum speed for the airplane with square, round, and Hoerner tips is 128.6, 126,7, and 127.4 mph, respectively.

For climb at 1.3 times the stalling speed, the available power will be about 56.0 hp. Using these approximations, the maximum rate of climb is found to be 743, 715, and 732 ft./min. for the airplane with square, round, and Hoerner tips.

CONCLUSIONS

From the data shown in Figures 3 and 4 and the results of calculations summarized in Table 2, it is concluded that the effect of wing tip shapes on the speed and climb of light aircraft considered in this report is negligible in comparison to very small changes in the many other variables available to the designers of light aircraft such as wing area, aspect ratio, streamlining, power, etc.

A possible exception would be the case of a race plane where engine and minimum wing area is specified and where a difference in maximum level flight speed of a fraction of a mile per hour would be extremely important. In this case, the round tip would provide the maximum level flight speed, but a more complete analysis is required taking into account the amount of time spent at high lift coefficients (cornering) where the square tip is superior, etc. Also, since such a plane would probably not use the airfoil used in these tests, the direct application of the data would be questionable.

The flow visualization tests showed that none of the three tips tested had unusual flow separation which would adversely affect stall or aileron control characteristics.

The author would be interested in learning the results of other experimental or analytical work on the subject of tip design.

TABLE 1. Wing Tip Data Summary

	Square	Round	Hoerner
b/2	40.0	39.0	38.1
S/2 (in.^{2})	72.0	686.0	654.0
Chord (in.)	18.0	18.0	18.0
Aspect Ratio	4.44	4.44	4.44
C_{Lmax}	1.19	1.10	1.17
C_D @ $C_L = 0.4$	.027	.027	.027

TABLE 2. Tip Shape Effect on Performance

Formula V Racer: Weight 700 lbs.; Wing Area 75.0 sq. ft.; Power 65 hp VW

	Stall Speed	Max. Speed	Rate of Climb
Square	55.5 mph	146.3 mph	1136 ft/min
Round	57.7	148.0	1107
Hoerner	56.5	145.6	1126

Typical Homebuilt: Weight 1200 lbs.; Stall Speed 60 mph; Power 85 hp.

	Wing Area	Max. Speed	Rate of Climb
Square	109.9 ft.^{2}	128.6 mph	743 ft/min
Round	118.9	126.7	715
Hoerner	113.7	127.4	732