FLIGHT TESTING/PERFORMANCE IMPROVEMENTS THROUGH WING PROFILE CORRECTION

by R.H. Johnson

Dallas Gliding Association, Dallas, Texas U.S.A.

Presented at the XX OSTIV Congress, Benalla, Australia (1987)

Introduction

Flight test polar measurements were performed with two modern sailplanes, a Ventus A/16.6 and a Nimbus 3/24.5, to compare their polars when measured in original factory delivered condition to those recently measured after their wing surfaces had been carefully profiled to within about +/− 0.5 mm.

Discussion

Sailplane wing moulds are very carefully constructed these days; however, wing surface distortions of 1 or 2 and sometimes up to 3 mm do exist on even the best sailplane wings. Those unwanted distortions degrade the aerodynamic characteristics of the sailplane, principally by increasing the profile drag. The wind tunnel test models, from which the airfoil characteristics are derived, are constructed to a tolerance of about +/− 0.1 mm or less; and that is about 10 to 20 times more accurately than current sailplane production techniques apparently permit.

Therefore, any reduction in a sailplane airfoil distortions should result in improved performance. The purpose of the recent Ventus A and Nimbus 3 flight test measurements was to measure the magnitude of the performance improvements that were achieved through improving the wing surface contour to match more closely those of the airfoil wind tunnel models.

Description of wing surface modifications

The approximately true coordinates for the Ventus and Nimbus 3 Wortmann FX 79-K-144/17 proprietary airfoils were measured from full scale factory Mylar drawings, and

TABLE 1
APPROXIMATE COORDINATES FOR WORTMANN FX 79-K-144/17 AIRFOIL

$\delta_f = -9.3°$

POINT NO.	X/C	Y/C UPPER	Y/C LOWER	POINT NO.	X/C	Y/C UPPER	Y/C LOWER
1	.00000	.00000	.00000	26	.53270	.09560	-.04250
2	.00107	.00480	-.00430	27	.56526	.09270	-.04160
3	.00428	.00990	-.00870	28	.59755	.08880	-.04010
4	.00961	.01510	-.01250	29	.62941	.08450	-.03840
5	.01704	.02060	-.01590	30	.66072	.07980	-.03640
6	.02653	.02650	-.01920	31	.69134	.07350	-.03430
7	.03806	.03270	-.02230	32	.72114	.06580	-.03190
8	.05156	.03910	.02520	33	.75000	.05690	-.02880
9	.06699	.04540	-.02790	34	.77779	.04780	-.02470
10	.08427	.05160	-.03030	35	.80438	.03970	.02030
11	.10332	.05770	-.03250	36	.82967	.03340	-.01570
12	.12408	.06370	-.03440	37	.85355	.02930	-.01170
13	.14645	.06950	-.03610	38	.87592	.02540	-.00840
14	.17033	.07480	-.03760	39	.89668	.02200	-.00560
15	.19562	.07990	-.03880	40	.91573	.01880	-.00330
16	.22221	.08480	-.03990	41	.93301	.01560	-.00160
17	.25000	.08910	-.04080	42	.94844	.01270	-.00030
18	.27886	.09260	-.04160	43	.96194	.01000	.00050
19	.30866	.09550	-.04240	44	.97347	.00760	.00100
20	.33928	.09780	-.04300	45	.98296	.00570	.00100
21	.37059	.09920	-.04340	46	.99039	.00410	.00080
22	.40245	.10000	-.04370	47	.99572	.00280	.00040
23	.43474	.10010	-.04380	48	.99893	.00220	.00010
24	.46730	.09930	-.04370	49	1.0000	.00200	.00000
25	.50000	.09770	-.04330				

with the kind permission of Klaus Holighaus, the approximate basic coordinates for that new airfoil are presented here in Table 1. A scaled drawing of that new 14.4 percent thick airfoil section is shown in Figure 1.

These preliminary coordinates have not yet been completely smoothed by the currently available airfoil aerodynamic flow computer programs. However, Dan Somers of NASA/Langley has kindly run the Table 1 coordinates through his airflow program and he concluded that though there was some waviness in the upper and lower surface pressure distributions, no large errors existed. His computed chordwise pressure distributions for the FX 79-K-144/17 airfoil coordinates are shown in Figure 2. It is likely that the usual wing surface sanding and smoothing will further reduce the magnitude of the small airfoil coordinate errors, and thus the expected extensive laminar flow regions can hopefully be achieved in practice.

The Table 1 airfoil coordinates were used to construct 25 upper surface and 25 lower surface templates, spaced approximately 500 mm apart, which were then used to correct discrepancies in the factory produced airfoil surfaces. The Ventus appears to use exactly the same airfoils as the Nimbus,

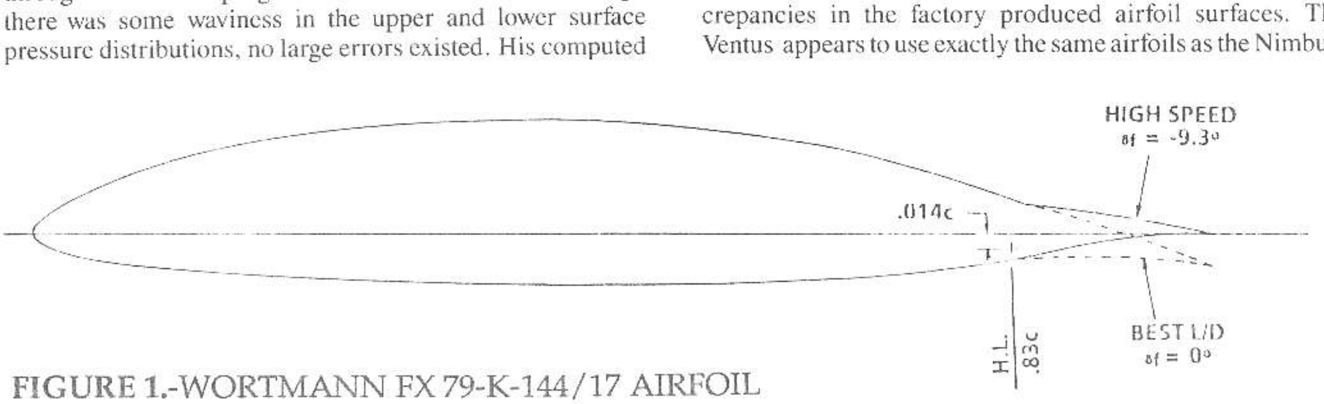


FIGURE 1.-WORTMANN FX 79-K-144/17 AIRFOIL

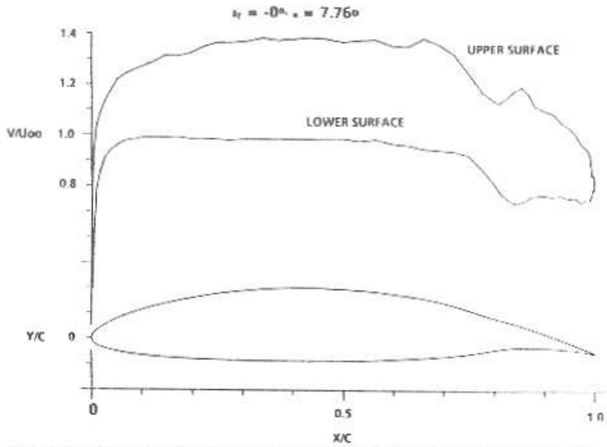


FIGURE 2.-VELOCITY DISTRIBUTION FOR WORTMANN FX 79-K-144/17 AIRFOIL

except that its 8 meter shorter wingspan omits the Nimbus 3/24.5 inboard panels.

Each template was prepared by plotting the appropriate full-scale coordinates on graph paper, cementing those to aluminum sheets, then carefully sawing and filing the sheet aluminum to faired lines through the coordinates. Both the upper and lower surface templates overlap the wing leading edge by about 1 cm to provide better shape continuity in that region. The templates ended at about .80 chord and no attempt was made to carry airfoil corrections onto the moveable flap and aileron surfaces.

The wing surface corrections were accomplished by sanding down any high points on the wing surfaces at each template station; being very careful to limit surface removal to excess gelcoat finish material only, and not disrupting any structural fibers below. A filled epoxy resin, such as DURO EPF-39 or SEARS No. 80605 was then used to make a 5 to 6 mm wide bead to fill any remaining low regions under each template. In fitting the templates to the wings, care must be taken to keep the leading edges relatively straight and symmetrical between the left and right hand wing panels because wing heaviness may result.

Once each wing station has its correctly formed "rib" in place, then it is relatively easy to place a spanwise oriented straight edge between the corrected "rib" stations and again remove only excess gelcoat at any high regions. The remaining low regions between the ribs are then filled with a light weight mixture of epoxy resin and small hollow glass spheres, such as EMERSON & COMING ECCOSPHERES IG-101. This epoxy-microballon mixture is prepared sufficiently thick to not run before hardening, and any excess amounts are carefully screeded off while soft by slowly drawing the spanwise oriented straightedge in a chordwise direction while held firmly against the correctly formed ribs.

About five successively more thinly mixed screeding coats of the epoxy-microballon mixture were required to fill the low regions between the "ribs" properly. After each coat hardened, all high points were carefully sanded flush so that the following coat could be smoothly screeded. Following that, a polyester surfacer, such as SIMTEC 2081 white sanding surfacer was sprayed on the modified wing surfaces to fill any remaining voids. Before final painting, the wings were carefully wet sanded, and a chordwise oriented wave gauge was used to identify any waves in excess of +/− 0.1 mm for elimination.

The final spray finishing was performed with SIMTEC PRESTIC 2381 polyester gelcoat on the Nimbus wings and with DUPONT IMRON polyurethane enamel on the Ventus wings. Both finishes appear to be very satisfactory, but the polyester gelcoat was much easier to final sand and smooth. It is estimated that the entire profiling sequence added about 18 pounds (8.2 kg) to the weight of the Nimbus wings, and about 12 pounds (5.5 kg) to the Ventus wings.

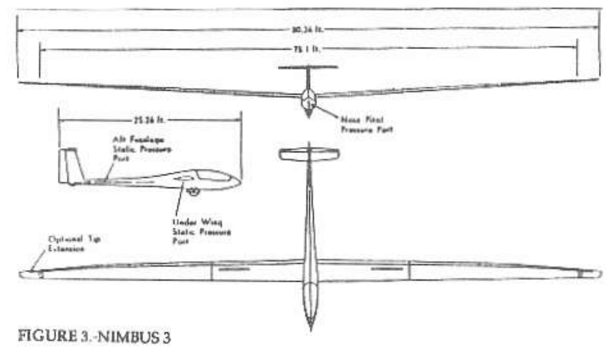


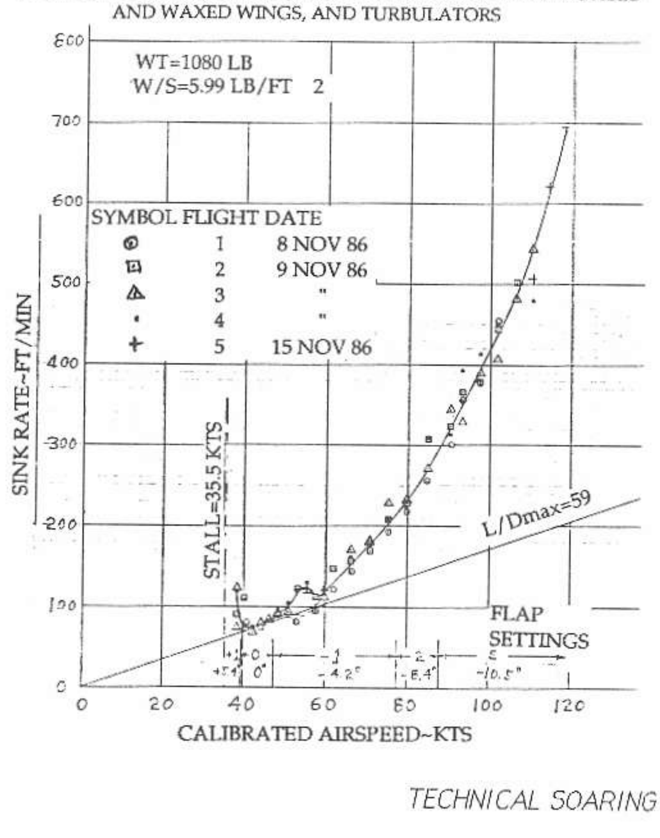
FIGURE 3.-NIMBUS 3

Nimbus 3 results

Figure 3 is a three-view drawing of the Nimbus 3 sailplane that was flight tested in its 24.5 meter span configuration. The unmodified airfoil testing was performed by the Dallas Gliding Association during the late summer of 1982 when the sailplane was about six months old, and those test data are shown in Reference A. The recent test data for the same sailplane four years later, but with the profiled wings, are shown in Figure 4.

The 1982 testing determined optimum flap settings for each test airspeed by actually measuring sink rates for several flap angles and then using those which resulted in the lowest sink rate at each airspeed. Since then, we have developed and

FIGURE 4.-NIMBUS 3/24.5 N49JD POLAR TEST DATA-WITH PROFILED AND WAXED WINGS, AND TURBULATORS



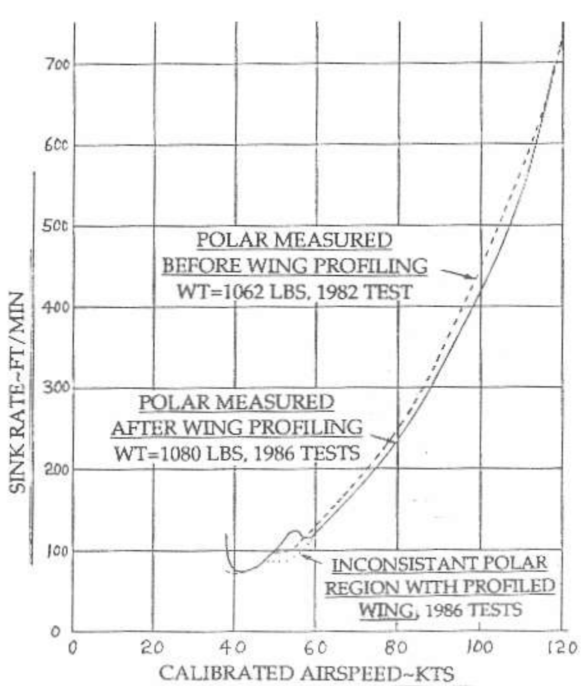
sufficiently tested the Reference B wing relative profile drag probe to have fairly good confidence in its ability to indicate near optimum flap settings for our flight test polar measurements. Therefore, that instrument was installed during all recent flight tests and used to determine the best flap setting at each airspeed. Those flap angles are noted on the lower portion of Figure 4.

The effects of the wing profiling on the Nimbus 3 were gratifying in that 2 to 3 knot speed increases were measured at airspeeds between 60 and 110 kts for the same sink rates, as shown in Figure 5. Between 42 and 46 kts the L/D_{max} measured a solid 59, which is exceptionally good for a modern open class sailplane, without ballast.

Between 48 and 59 kts an anomalous behavior of the sink rate polar was observed, where during two of the five data test flights the measured sink rates were unusually low, but during the remaining three test flights, the measured sink rates were unusually high. Little data scatter existed in that region and the sink rate data points seemed to fall either on the higher or lower curve, and not in between. It did not appear to matter if the test data were measured there while increasing or decreasing airspeed from the previous test point. That is, no repeatable hysteresis effect were shown, and that was checked during the flight testing by taking the sink rate data from both increasing and decreasing airspeed test run schedules. Perhaps future testing will answer the anomalous sink rate questions there.

The above described Nimbus 3 flight testing was performed with normal 1 mm high by 5 mm spaced dimpled turbulator strips installed on the wing lower surfaces at about .80c. Also, the wing surfaces were carefully polished and waxed with paste wax, and well rubbed into both top and bottom wing surfaces.

FIGURE 5.-NIMBUS 3/24.5 POLAR COMPARISON PLOT
DALLAS GLIDING ASSOCIATION MEASUREMENTS



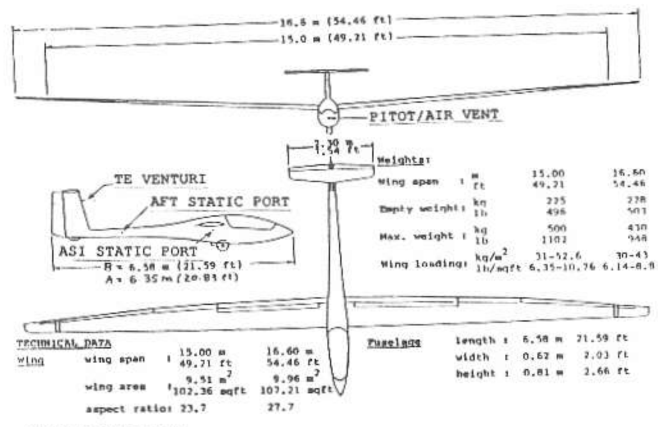


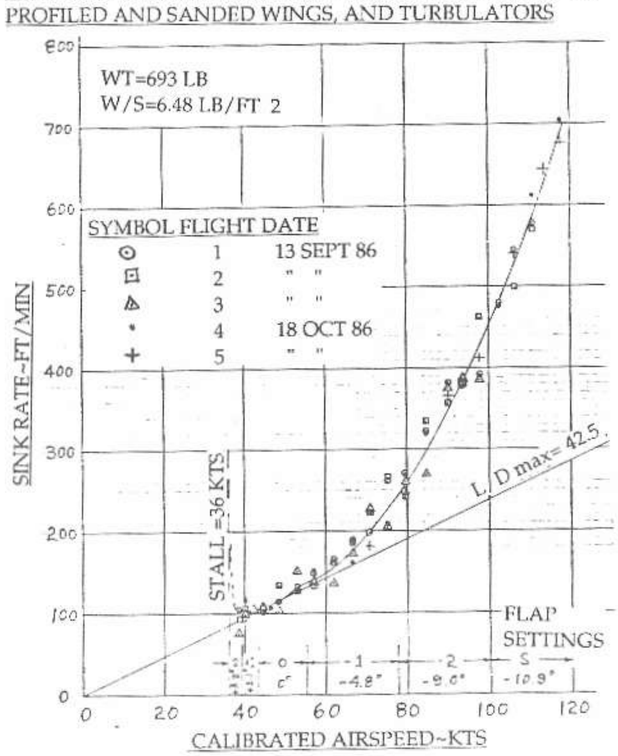
FIGURE 6.-VENTUS A

Ventus A results

Figure 6 is a three-view drawing of the Ventus A sailplane that was flight tested in its 16.6 meter wingspan configuration. The unmodified testing was performed by the DGA during the winter of 1983-84 and those test data are shown in Reference C. The recent test data for the same sailplane three years later, but with the newly profiled wings, are shown in Figure 7. The optimum flap settings used were determined through use of a wing drag probe, as they were for the Nimbus 3 testing, and those angles as shown on the lower portion of Figure 7.

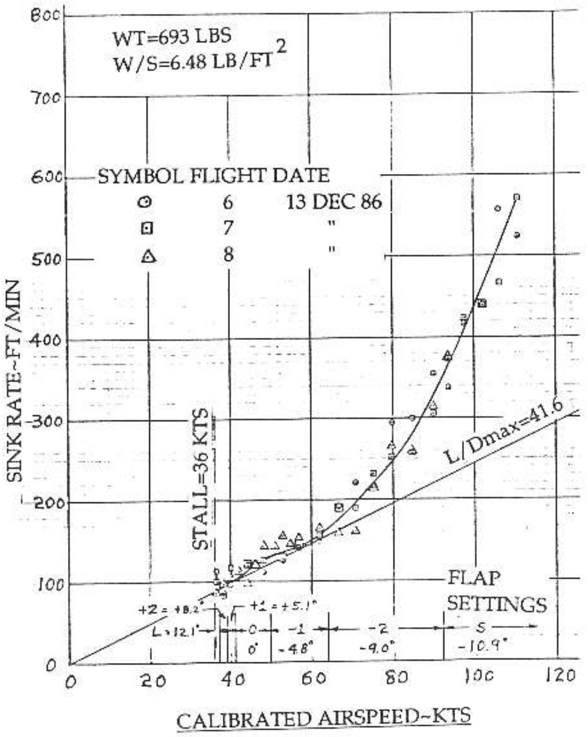
The same type of dimpled turbulator strips were installed at about .80c on the wing lower surfaces, but the wings were not polished and waxed, only fine sanded with 400 grit wet paper. Here the flight tests results were disappointing with an L/D_{max} of only about 42.5 shown at 45 kts. However, between 60 and 80 knots, and above 100 kts the airspeeds increased by about 2 to 3 knots for the same sink rates. The climb performance was relatively poor and that definitely needed to be improved.

FIGURE 7.-VENTUS A/16.6 N47JD POLAR TEST DATA-WITH PROFILED AND SANDED WINGS, AND TURBULATORS



The Ventus wings were then carefully polished and waxed to place its wing surfaces in the same condition as those of the successfully tested Nimbus 3, discussed above; and the Ventus was re-tested. Those test data are shown in Figure 8. The effects of polishing and waxing on the Ventus performance were again disappointing with an L/D_{max} of only about 41.6, shown at 40 kts. However, at airspeeds above 70 knots, an additional 1 to 2 kts were shown for the same sink rates. That was quite encouraging; however, between 40 and 60 kts the performance was worse than before, with even poorer climb capability noted.

FIGURE 8.-VENTUS A/16.6 N47JD POLAR TEST DATA-WITH PROFILED, WAXED AND POLISHED WINGS AND TURBULATORS



When the Ventus A was initially tested in 1981, it was in its 15 meter wingspan configuration (Reference D). At that time sink rate tests were performed both with and without the factory supplied dimpled turbulator strips installed at .80c. Better performance was measured without the turbulators installed, so they were then removed for the following 15 meter and 16.6 meter wingspan testing; where excellent L/D_{max} values of about 45 and 50, respectively, were measured.

Since the factory had observed better Ventus performance with the turbulators installed, it was assumed that small differences in our test sailplane's wing surfaces had resulted in the lack of need for the turbulators. After profiling the wing should have had an airfoil profile that was very close to that of the Nimbus 3, where early flight testing has shown the turbulators to be beneficial (Reference A) and recent profiled wing testing had shown excellent results.

Since our test Ventus 16.6 had repeatedly refused to show good performance with turbulators installed, they were removed for our final testing, and those data are shown in Figure 9. The effect of the turbulator removal was an unexpectedly large improvement in the Ventus' low speed polar below 65 kts. An L/D_{max} of about 48.8 was shown at 44 kts, with equal or slightly better sink rates measured at airspeeds above 70 kts. This unexpectedly large performance improvement to the Ventus' polar is puzzling, especially since the recent Nimbus 3 testing with the same airfoil had shown excellent performance with the turbulators installed.

FIGURE 9.-VENTUS A/16.6 N47JD POLAR TEST DATE-WITH PROFILED, WAXED AND POLISHED WINGS, NO TURBULATORS

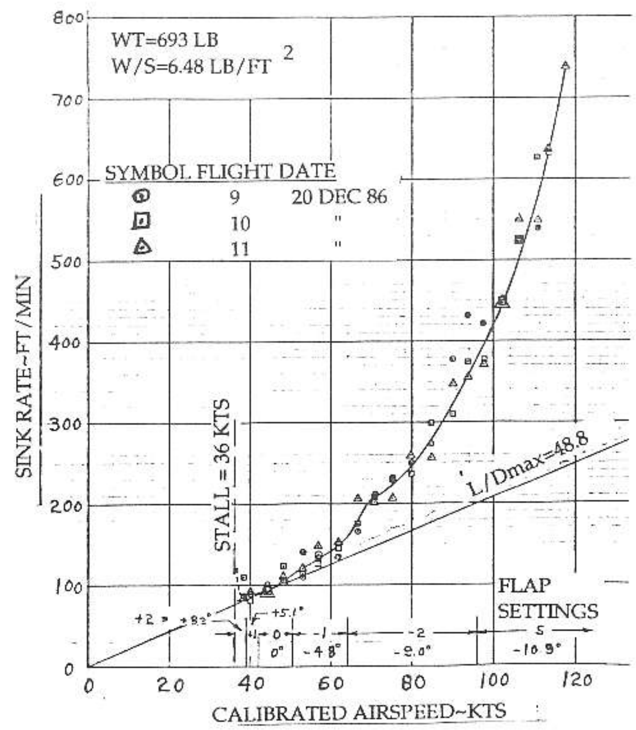


FIGURE 10.-VENTUS A/16.6 POLAR COMPARISON PLOT DALLAS GLIDING ASSOCIATION MEASUREMENTS TURBULATORS REMOVED

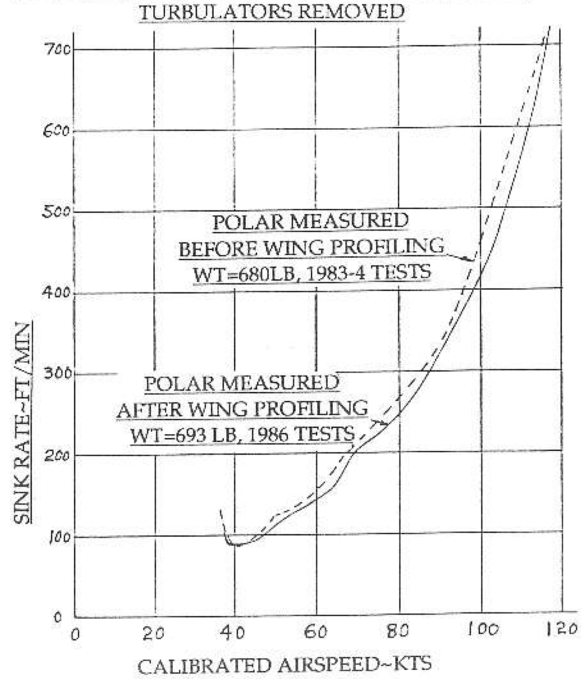


Figure 10 compares the Ventus 16.6 polar measured before wing profiling to that recently measured with the profiled, waxed and polished wings. Both polars are without turbulators because better performance was measured in that configuration. Below 43 kts both polars show excellent performance with minimum sink rates of 87 to 89 FPM (.44 to .45M/S). Above 43 kts the profiled wing configuration showed significantly lower sink rates at given airspeeds, or viewed from an airspeed standpoint the cruise airspeeds improved from 1.5 to 4 kts at a given sink rate. The largest gains were measured in the 80 kt and the 105 kt regions of the polar, where 4 kt airspeed improvements are shown.

Conclusions

Significant drag reductions in the Nimbus 3 and Ventus A polars can be achieved through carefully profiling of the wing sections, to match more closely those of the airfoil wind tunnel test models. Factory production accuracy of the wing profiles are now much better than they used to be where distortions of up to about 8 mm have been measured by DGA in the past. However, even the current 1 to 3 mm production and/or post mold curing accuracies are not sufficiently good to provide sailplanes with their full performance potentials. That can be remedied by either further improvements in the manufacturing process, or by laborious post manufacture profiling.

References

A. Johnson, R.H., "A Flight Test Evaluation of the Nimbus 3, *Soaring* Dec. 1982

B. Johnson, R.H., "At Last: An Instrument that Reads Drag," *Soaring* Oct. 1983

C. Johnson, R.H., "A Flight Test Evaluation of the Ventus 16.6," *Soaring* April 1984

D. Johnson, R.H., "A Flight Test Evaluation of the Ventus A," *Soaring* Dec. 1981