WINGLETS FOR SAILPLANES

By D.J. Marsden

Department of Mechanical Engineering, University of Alberta

INTRODUCTION

Winglets have appeared on many business jets and are even starting to be used on large jet transports, such as the Boeing 747-400, the MD-11, and the European Airbus, but surprisingly glider designers who are usually in the fore-front of aerodynamic refinements have been slow to take advantage of the idea. This may be partly due to a lack of a good theoretical explanation of how winglets work, and due to misconceptions such as "Winglets won't be effective on a sailplane which already has a very high aspect ratio," or "They are useful at low speed but the drag penalty is too great at high speed." How many Nimbus 3 pilots fly without the 0.8 meter tip extensions because the high speed performance of the 22.9 meter span configuration is better?

A very significant portion of the drag of a sailplane is due to the trailing vortex system generated by the wing in producing lift. This lift induced drag typically1 accounts for more than half the drag in climbing flight, and about 20% in cruising flight. This relative importance of induced drag is not reduced by very high aspect ratio. For example, flight test data shows that when the Nimbus 3 is flown at a typical climbing lift coefficient of 1.2, 70% of the drag is induced drag.

Airfoil tests in wind tunnels are conducted with the model wing spanning the tunnel to eliminate the trailing vortex system, in effect making the test wing appear to have infinite aspect ratio. It is tempting to put end plates on a finite wing to reduce the induced drag and attempts to do this have been made since the early days of aviation. End plates can not eliminate the trailing vortex system. Instead, the vorticity trails off the edges of the end plate, and while this will reduce the induced drag somewhat, it does so at the expense of skin friction drag of the end plate itself.

The drag of non-planar wings was investigated by Clarence Cone[2] who found that the optimum shape was elliptical viewed from the front. Some of the earlier 20 meter span sailplanes tended to approximate to this shape due to wing bending, but elliptical dihedral is obviously not very practical from a construction point of view. This shape could be approximated by bending the wing tips up, and this was done by the Akaflieg Braunschweig in putting winglets on an ASW-19 as reported by Udo Dressler[3]. He found that the one meter high wing tip extensions did increase the maximum L/D from 39 to 41, but realized that the gain would have been greater if the span had simply been extended in the plane of the wing.

Modern work on winglets started with Richard Whitcomb at NASA in 1976[4]. He replaced the inefficient end plates with effective lifting surfaces to divert part of the wing vorticity away from the wing tip producing multiple vortex cores in the wake. His winglet has a chord of about 40% of the wing tip chord, and a height equal to the tip chord. These winglets were found to reduce induced drag by 20% when applied to the KC-135 transport aircraft. The effectiveness of course reduced by the profile drag of the winglet itself, and an increase in wing bending is produced which reduces the payload that can be carried. This latter defect may be offset by a reduction in required fuel load. Whitcomb found that winglets were about twice as effective as wing tip extensions from the same root ending moment, and this has been confirmed by a number of subsequent studies[5].

Work at Cranfield[6] in England showed that multiple winglets, which Spillman called wing tip sails, were even more effective than the Whitcomb winglet. Reduction in induced drag of as much as 40% was measured in flight tests of a "PARIS" small jet aircraft.

WINGLETS ON SAILPLANES

The first production sailplane to have winglets was the French ASW-20 FP. These winglets were 0.8 meters high on a 15 meter span. Theoretical studies based on the usual vortex panel methods showed that even higher winglets would be more effective, and 0.8 meters was chosen as a practical compromise. In fact, they were probably too large and suffered from the penalty of skin friction drag at high speed, but they were effective. Comparison flight tests carried out by the British team in preparation for the 1981 World Championship showed that the ASW-20 with winglets had a lower sink rate up to about 80 knots, and greater sink rate above that speed.

A set of Whitcomb style winglets 0.30 m high were fitted to the aspect ratio 30 wings of the two-place variable geometry sailplane "GEMINI" in 1981. No performance measurements were carried out, but comparison flights indicated an easily noticeable improvement in climb performance.

In 1983, Dick Brandt agreed to try a winglet on his Nimbus 3. This winglet was attached in place of the 0.8 meter tip extension giving 22.9 meters span and an aspect ratio of 32. The winglet was 0.30 m high, only 2.7% of semi-span. Flight tests[7] carried out on this aircraft showed it to have the same performance as it had with the tip extensions to 24.5 meters span, which is equivalent to a 13% increase in effective aspect ratio due to the winglets. In addition, the winglets greatly improved the roll rate[8]. Logically, this Nimbus should have beer performance at high speed than it had with the standard tip extensions since wing tip extensions with a planform area of 0.465 square meters were being replaced with winglet surfaces with a total planform area of 0.0744 square meters. Ray Gimmey proved the performance of this aircraft to his own satisfaction by flying with other Nimbus 3 aircraft in Nevada, and has flown it in several U.S. Nationals Competitions and World Championships with the winglets.

The question of whether winglets would be effective on a high aspect ratio wing appears to be answered by the experience with the Nimbus 3, ASW-20 and Gemini.

ANALYSIS OF FLIGHT TEST RESULTS

There is a reasonable theoretical basis[1] for the assumption that the polar for a sailplane will be a quadratic over the range of flight speeds where the wing is in its "laminar bucket." For a sailplane with camber changing flaps the low drag ranges for a series of flap settings form an envelope where the quadratic polar is valid. This can be seen in Figure 1, taken from reference 9. Note the zero flap setting fits the envelope between 85 and 110 km/h and lies below the envelope at higher and lower speeds.

Experimental results tend to support the assumption that the drag coefficient can be represented by the equation:

$$C_D = C_{Do} + KC_L$$

where C_{Do} is the zero lift drag coefficient and K represents the lift dependent part made up of wing profile drag, vortex drag, and some interference drag. A plot of measured C_D against C_L^2 will confirm this relationship if it forms a good straight line, and will provide values of the constants C_{Do} and K based on an average over the whole range of flight speed of the aircraft. In addition, a value of maximum glide ratio is given by the expression:

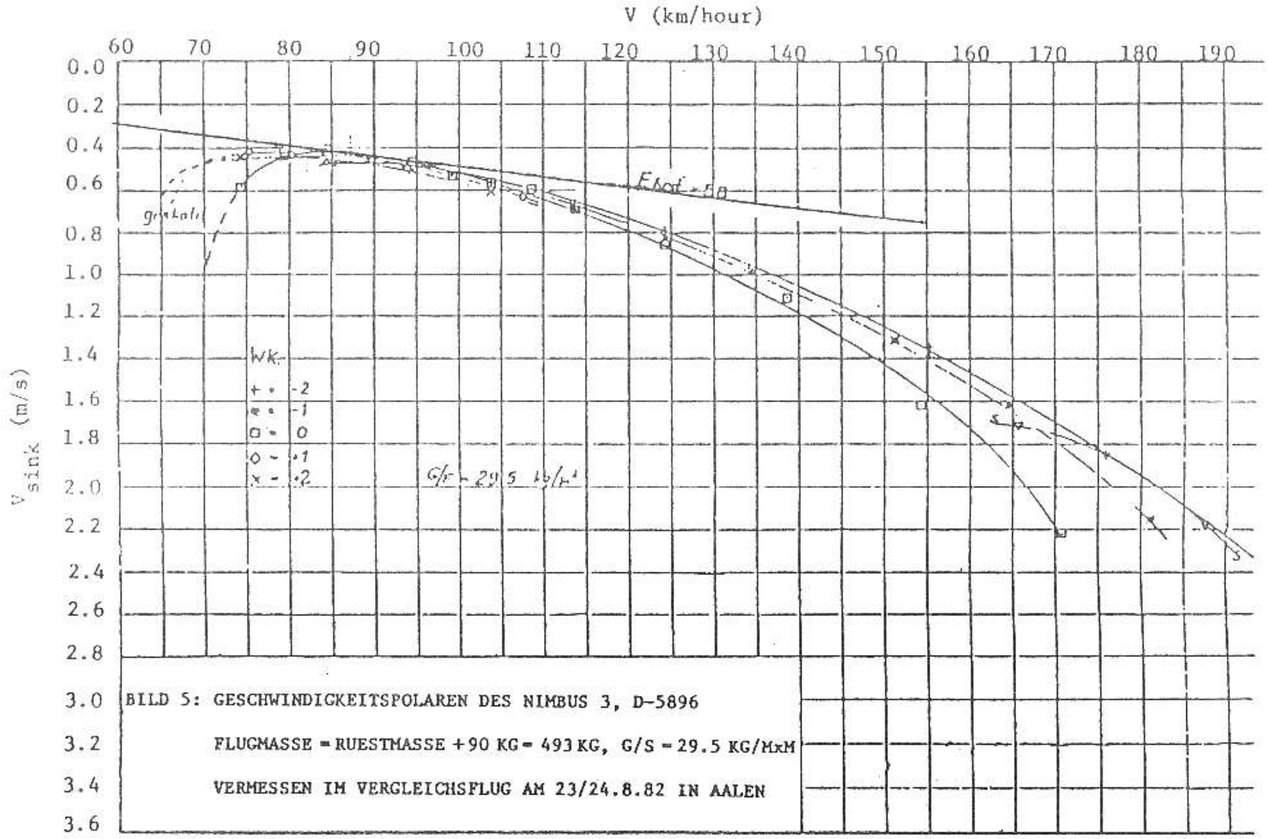
$$L/D_{max} = \sqrt{\frac{1}{4C_{Do}K}}$$

which is representative of data taken from the entire flight polar rather than just a few points near the speed for best L/D.

For example, flight test data on the Nimbus 3 measured by the DFVLR, as published in the book "Segelflugzeuge" by Peter F. Selinger[9], is shown plotted in Figure 2. This data has very little scatter and does in fact show good linearity. The analysis of this graph shows C_{Do} = 0.0070 and K = 0.012 for a L/D_{max} = 54.6. At best L/D speed the difference in sink rate between 58:1 (given in reference 9) and 54.6:1 is only 25 mm per second. The more conservative value derived from the whole polar curve is a better measure of overall performance and a more reliable result.

Graphs of C_D against C_L^2 in Figures 3 and 4 show that the 22.9 meter Nimbus 3 (Johnson, 1982)[10] and the 22.9 meter Nimbus 3 with winglets (Marsden, 1985)[7] both show good linearity. A comparison of the values produced is:

		C_{Do}	K	$LD/_{max}$
Nimbus 3	22.9 m span	0.0075	0.0137	49.5
Nimbus 3	winglets	0.0076	0.0115	53.5



Gleitflugpolare des Nimbus 3 mit 24,5 m Spannweite (gemessen von der DFVLR).

FIGURE 1. RESULTS FROM 'SEGELFLUGZEUGE'.

These results indicate a 20% reduction in the value of K due to winglets, for a total gain in L/D_{max} of 4 points. Figure 5 shows a comparison of these two polars, corrected to the same wing loading of 32.2 kg/m². There does not appear to be any significant difference in high speed performance.

A similar analysis of flight tests results published by R.H. Johnson11 for the DG-600 with and without winglets is as follows:

		C_{Do}	K	L/D_{max}
DG 600	15 m span	0.0081	0.0189	40.3
DG 600	winglets	0.0080	0.0174	42.3

While these winglets provide less improvement than in the case of the Nimbus 3, performance gain is distinctly measurable and worthwhile. The data analysis shows essentially no measurable increase in C_{Do}, and an 8.6% increase in the effective aspect ratio.

15 METER SPAN RULE

It has been suggested that winglets violate the intent of the 15 meter class, in effect being more span turned up at the end of the wing[12]. The winglet experiments with an ASW-19 at Braunschweig University were just that concept[3]. However, winglets are quite different from vertical span extensions. They function by dividing the wing tip vortex up into multiple vortices, and require a discontinuity in chord at the wing tip - winglet junction. A winglet is a drag reduction device much like turbulator holes or a retractable undercarriage.

The intent to limit cost by the 15 meter span limit is still valid with winglets, because a winglet can only provide an increment of drag reduction. A winglet can make a 15 meter span equivalent in induced drag to 17 meters, for example, but not equivalent to 25 meters no matter how big they are. Winglets are inherently fairly small and since it is counterproductive to make them larger, they provide an effective performance improvement with a limited cost.

WING ROOT BENDING MOMENTS

A winglet changes the spanwise load distribution on a wing, resulting in more load carried by the wing tips. There is typically a 5% increase in wing root bending moment. Adding more structural material to compensate for this additional load would add about 1% to the empty weight of the aircraft, a fairly negligible amount on a sailplane. In fact, most sailplane wings are designed on the basis of stiffness and are somewhat conservative in actual strength. Some comparative studies of the relative effectiveness of winglets and span extensions on the basis of equal increase in wing root bending moment found the winglets to be roughly twice as effective as a wing span extension[4,5].

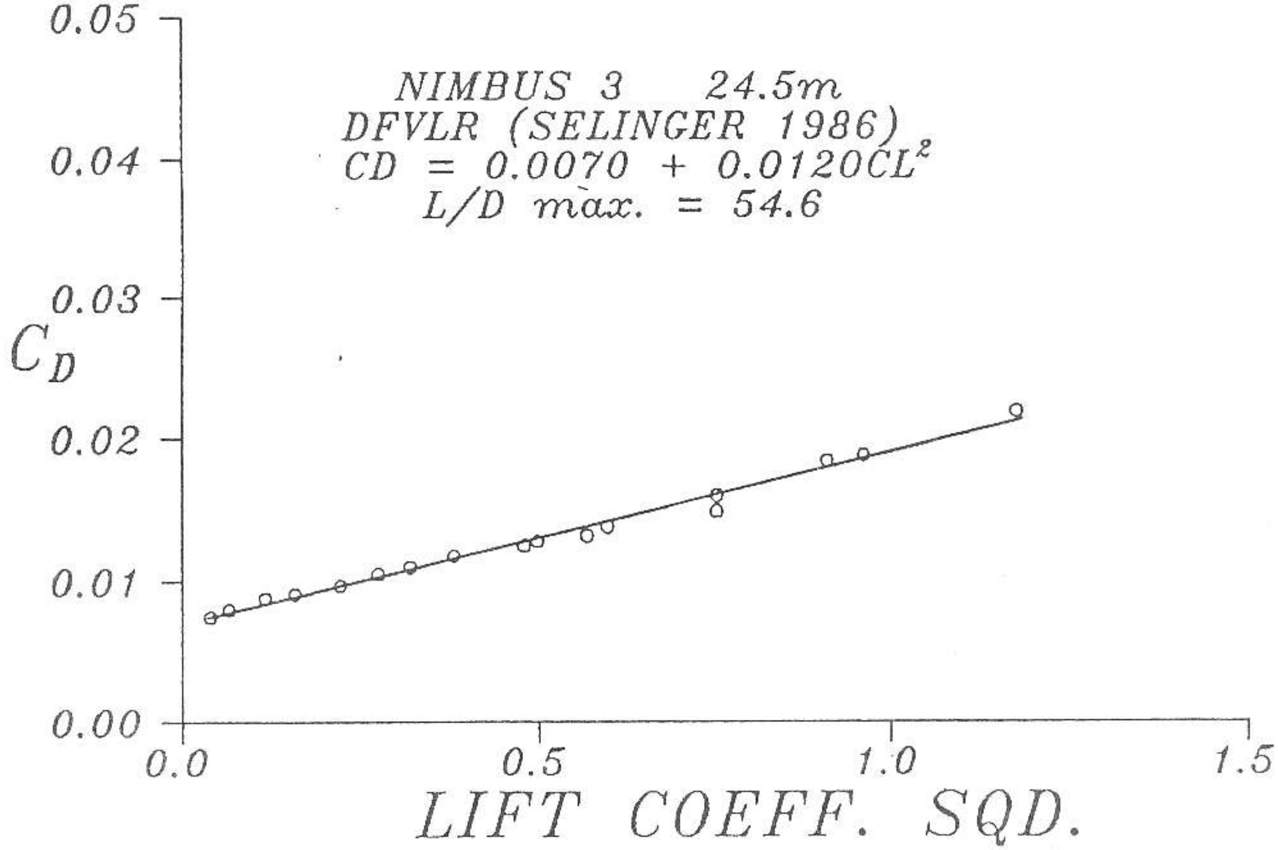


FIGURE 2. GLIDEPOLAR DATA DERIVED FROM FIGURE 1

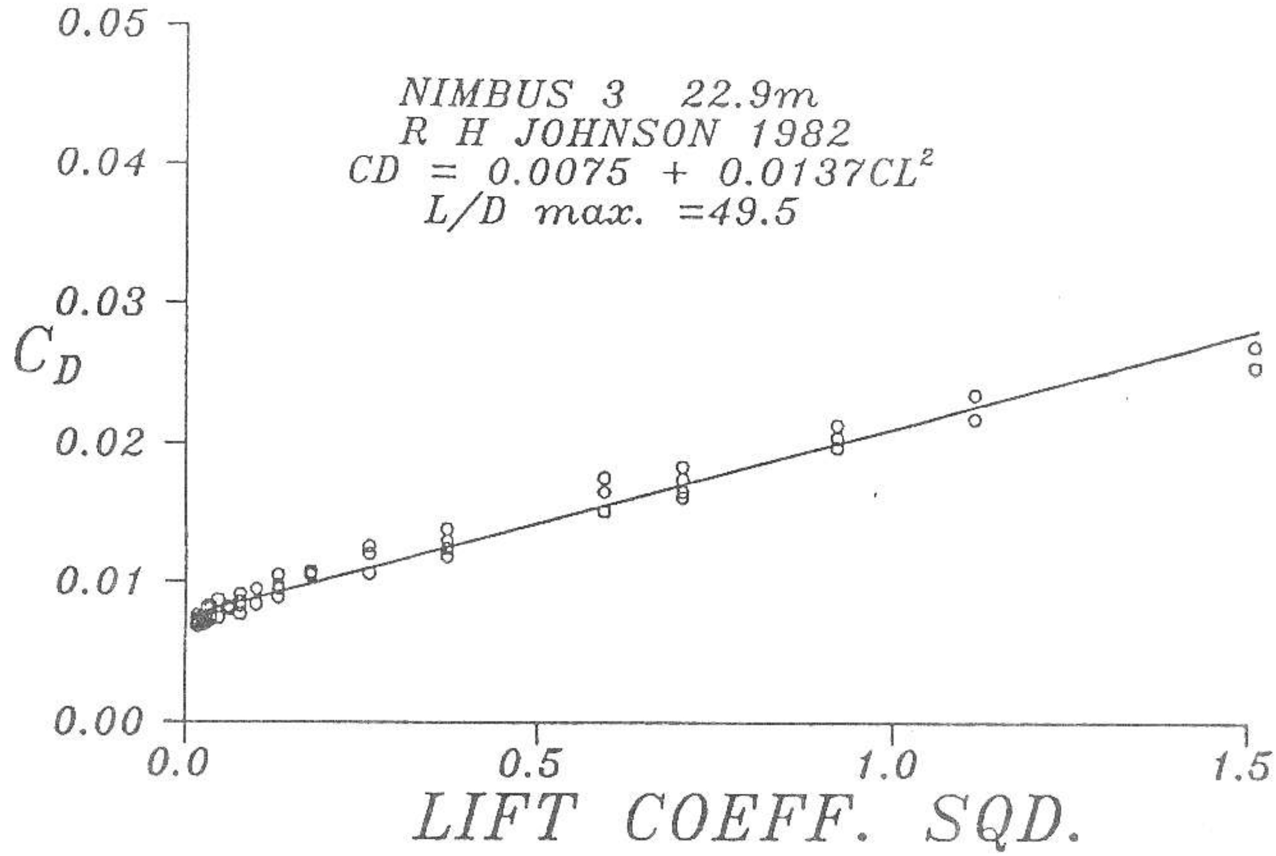


FIGURE 3. GLIDEPOLAR DATA FOR THE NIMBUS 3, 22.9 m IN SPAN

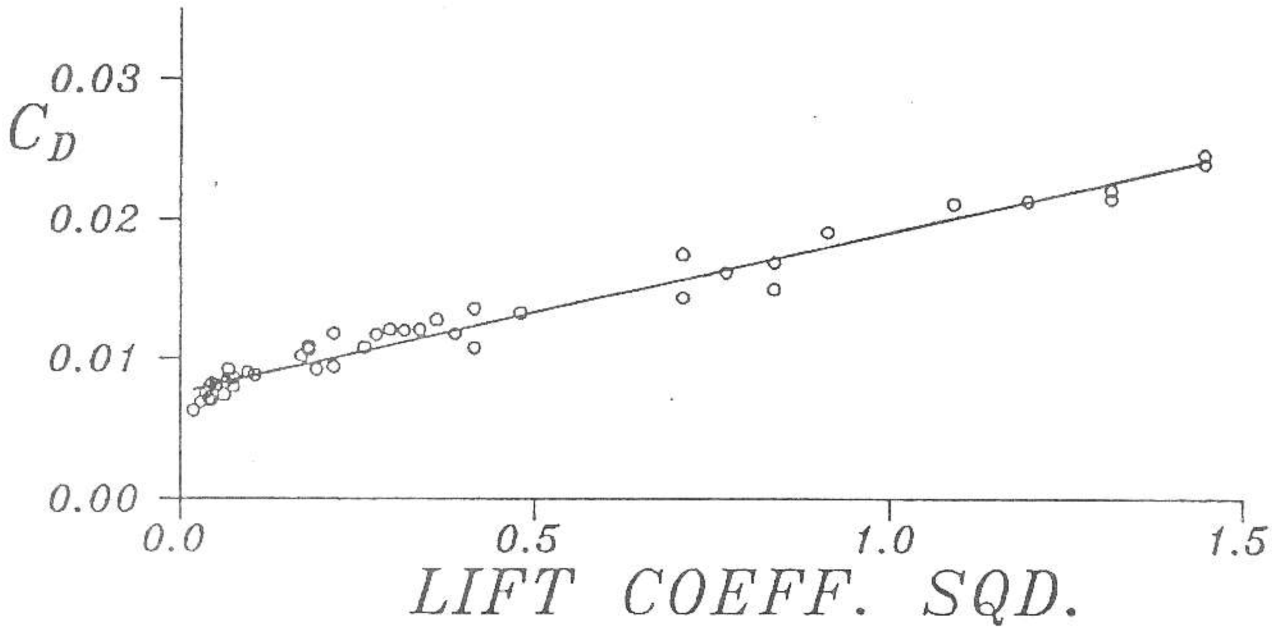


FIGURE 4. GLIDEPOLAR DATA FOR THE NIMBUS 3, WITH WINGLETS.

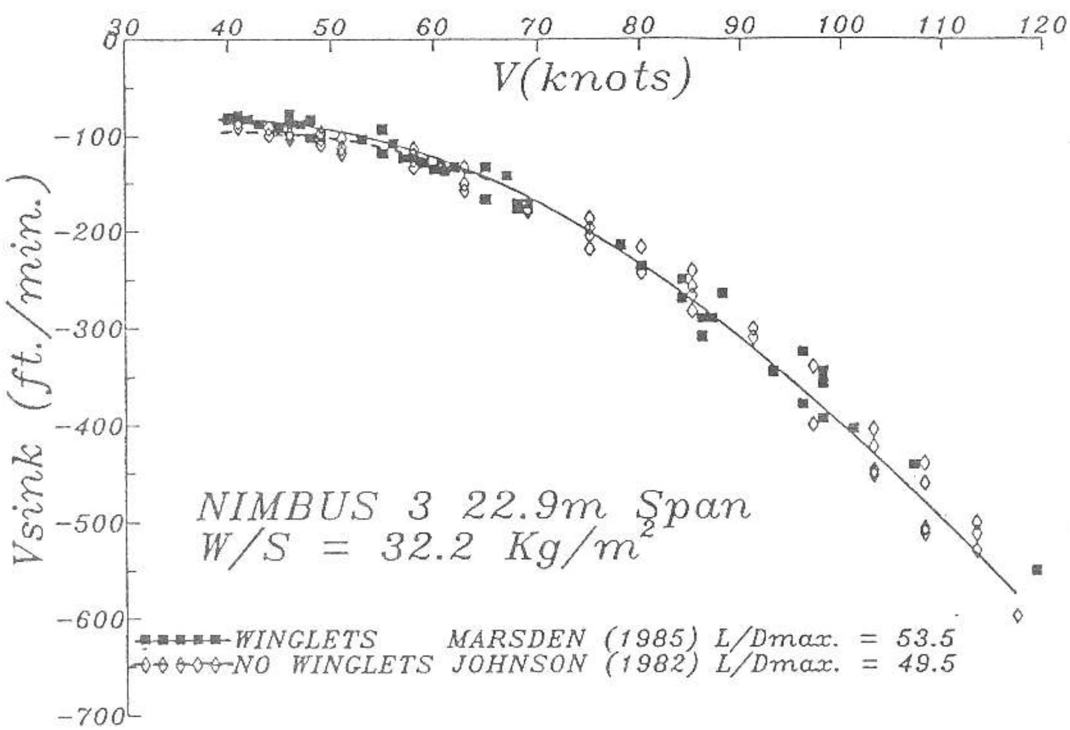


FIGURE 5. COMPARISON OF MEASURED POLARS WITH AND WITHOUT WINGLETS.

PROFILE DRAG

Winglets add to the wetted area of the wing and as a result, the winglet skin friction drag detracts from their effectiveness in reducing overall aircraft drag. Flight test results with winglets of the size used on the Nimbus 3[7] and DG-600[11] show the loss in high speed performance is barely detectable. Calculation of the total contribution to drag from winglets indicates that the drag reduction should be positive down to a lift coefficient of about 0.25 (170 km/hr for a wing loading of 34.2 kg/m^2).

HANDLING

Experience with winglets on sailplanes indicates that winglets tend to "clean up" airflow over the tip section of the wing, providing improved roll rates and less tendency to drop a wing at stall. In most cases, winglets make no detectable change in directional stability because they are relatively small. For the ASW-20FP the directional stability was reduced a little, which was just noticeable. The Nimbus 3 with winglets on the 22.9 meter span has a much improved roll rate compared to the 24.5 meter configuration.

CONCLUSIONS

There is a good deal of reliable experimental evidence that winglets can increase sailplane performance with measured improvements of 2 to 5 points in glide ratio. Adding winglets to an existing sailplane will increase skin friction drag which is most important at high speed. However, with properly designed winglets, the speed at which skin friction drag of the winglets cancels out the induced drag reduction is well above normal cruising speed, and even at higher speeds the drag increment is almost too small to measure.

The concept behind the 15 meter span limitation is not violated by winglets because winglets only provide a finite performance increase. Winglets are inherently small in size which limits both their cost and the cost of supporting structures. In contrast, performance increase due to increased span is limited only by weight, structural problems and cost.

Winglets provide a substantial improvement in aerodynamic efficiency without an increase in wing span, both for the open class case where span is limited by structural considerations, and for 15 meter and Standard Classes where there is an arbitrary span limit.

Winglets are particularly attractive for retrofit on the many aircraft which already have short span extensions, such as the ASW-20, Nimbus, Ventus, DG-600, LS-3, for example. The winglets allow the low speed advantage of the span extension to be retained while at the same time keeping the high speed advantage of the shorter span.

REFERENCES

1. D.J. Marsden, "Sailplane Performance Estimation," OSTIV Publication XV (1978).

2. C.D. Cone, "The Theory of Induced Lift and Minimum Induced Drag of Non-Planar Lifting Surfaces," NASA TR-139 (1962).

3. U. Dressler, "Aerodynamic Design of Winglets for a Standard Class Glider," OSTIV Publication XVII (1983).

4. R.T. Whitcomb, "A Design Approach and Selected Wind-Tunnel Results at High Subsonic Speeds for Wing Tip Mounted Winglets," NASA TN D-8260 (1976).

5. H.H. Heyson, G.D. Riebe, and C.L. Fulton, "Theoretical Parametric Study of the Relative Advantages of Winglets and Wing Tip Extensions," NASA TP-1020 (1977).

6. J.J. Spillman, "The Use of Wing Tip Sails to Reduce Vortex Drag," Aeronautical Journal (1978).

7. D.J. Marsden, "Sailplane Performance Flight Testing," Technical Soaring Vol. IX No. 1 (1985).

8. Ray Gimmey, Private Communication Re: Roll Rate (1989).

9. Peter F. Selinger, "Segelflugzeuge," Motorbuck Verlag, Stuttgart (1986).

10. Richard H. Johnson, "A Flight Test Evaluation of the Nimbus 3," Soaring, December 1982.

11. Richard H. Johnson, "A Flight Test Evaluation of the DG-600," Soaring, 1989.

12. Gerhard Waibel, "Nonsense of Winglets," Technical Soaring, Volume XII, No. 4 1988.