The Sailplane

By F. X. Wortmann
Institut für Aerodynamik und Gasdynamik der Universität Stuttgart

Presented at the 12th OSTIV Congress, Alpine, USA (1970)

Introduction

The aerodynamic advantages of the variable chord concept for sailplanes look very attractive and this attraction may well increase when Sigma and its successors eventually demonstrate their capabilities. But a rigid flap has its own limits, primarily in that the flap extension may not exceed 40% of the basic chord length. Since structural and mechanical complexities associated with such a design are quite expensive, there will probably exist only a few superships of this type. A different type of flap is proposed here which is made of sailcloth and is able to exploit the variable chord concept to its full extent. Why shouldn't the sailplane fly with sails, when those giant prehistoric saurians like the pterodactylus had once used this principle? The combination of a fixed wing with a sailcloth extension is by no means new. Figure 1 shows the famous British racing catamaran «Lady Helmsman», one of the fastest sailboats in the world[1].

Modern sailcloth is a highly engineered material which can easily stand the aerodynamic loads encountered at low speeds. It can easily be stored, and flap sizes up to 100% and more are no problem. (Such large flap extensions however will only be rewarded if the radius of circling is below 200 ft.) The additional weight and the mechanical difficulties to hoist and to reef the sail are minimal. The modulus of elasticity in the warp and weft directions of some types of sailcloths are given in table I.

But will it work safely? To get a preliminary answer we have done some two-dimensional wind-tunnel tests to encourage further developments in this direction.

Table I
Coordinates of the airfoil FX 70-VC-194/2.0

No	X	y_u	y_L
2	.99893	.00032	-.00010
4	.99039	.00286	-.00004
6	.97347	.00791	-.00042
8	.94844	.01537	-.00211
10	.91573	.02512	-.00577
12	.87592	.03698	-.01178
13	.85355	.04365	-.01579
14	.82967	.05077	-.02071
15	.80438	.05831	-.02600
16	.77779	.06623	-.03184
17	.75000	.07451	-.03743
18	.72114	.08340	-.04296
19	.69134	.09184	-.04808
20	.66072	.09985	-.05282
21	.62941	.10682	-.05673
22	.59755	.11303	-.06005
23	.56526	.11790	-.06233
24	.53270	.12208	-.06399
25	.50000	.12509	-.06482
26	.46730	.12756	-.06536
27	.43474	.12871	-.06527
28	.40245	.12884	-.06495
29	.37059	.12770	-.06416
30	.33928	.12571	-.06312
31	.30866	.12287	-.06171
32	.27886	.11919	-.06007
33	.25000	.11452	-.05812
34	.22221	.10910	-.05594
35	.19562	.10309	-.05351
36	.17033	.09645	-.05087
37	.14645	.08916	-.04804
38	.12408	.08134	-.04497
39	.10332	.07331	-.04177
40	.08427	.06496	-.03834
41	.06699	.05649	-.03485
42	.05156	.04790	-.03108
43	.03806	.03968	-.02729
44	.02653	.03162	-.02322
45	.01704	.02418	-.01920
46	.00961	.01716	-.01482
47	.00428	.01127	-.01045
48	.00107	.00551	-.00510

Table II
Modulus of elasticity, kilopond per mm cloth width, of different sailcloths, Vereinigte Seidenwebereien AG[2]

weight (g/m²)	145	225	280
weft	6.5	8.0	16.6
warp	6.7	8.0	8.3

Fig. 1
Racing catamaran «Lady Helmsman» with airfoil mast and sailcloth extension

Experimental results

The tests were done with an old airfoil No. 30, similar to the FX 60-126 [2], and a light sailcloth (145 g/m²). Figure 2 shows the complete model and figure 3 the main dimensions. Two wooden struts fix the sailcloth to the walls of the test section. The forward edge of the sail is glued to the airfoil, while the trailing edge is free. The warp runs in spanwise direction. This model was fastened between the tunnel walls in such a way that the cloth tension in the spanwise direction and the flap angle could be changed[3]. The first tests revealed a tendency of trailing edge flutter beyond a certain dynamic pressure. This flutter is practically independent of the angle of attack. The frequency at the usual cloth tension was in the range of 50 cycles per second. With a stroboscope it could be observed that the cloth at the trailing edge in the midspan region bends up to 90°. The amplitude of the cloth oscillation increases with the wind speed, and the same holds for the drag which can be doubled this way. Obviously this type of flutter is restricted to only the latter portion of the sailcloth and can be completely suppressed by some small battens glued to the cloth (see fig. 2 and 3).

---

[1] By courtesy of R. W. Purser, KH-Publicity Ltd.

[2] There are not too many firms which produce sailcloth. It may be sufficient to cite three: DuPont (Dacron), Wilmington, Delaware 19898, USA; F. Webster & Sons Ltd., Alma Works, Arbroath, Great Britain; Vereinigte Seidenwebereien AG, Krefeld, Western Germany.

[3] I am indebted to Mr. M. Strunz and cand. aer. H. Flueh, who performed the wind tunnel work.

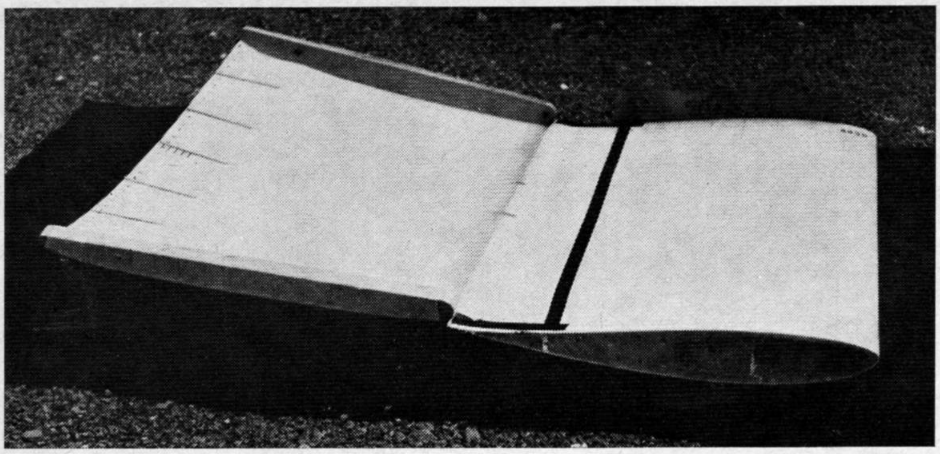

Fig. 2
100% sail flap on a rigid airfoil model

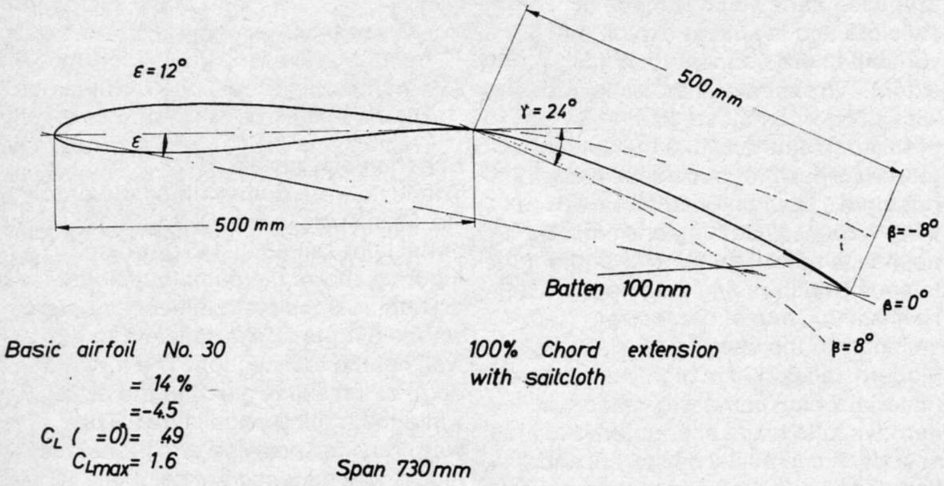

Fig. 3
Form and dimensions of the airfoil – sail combination

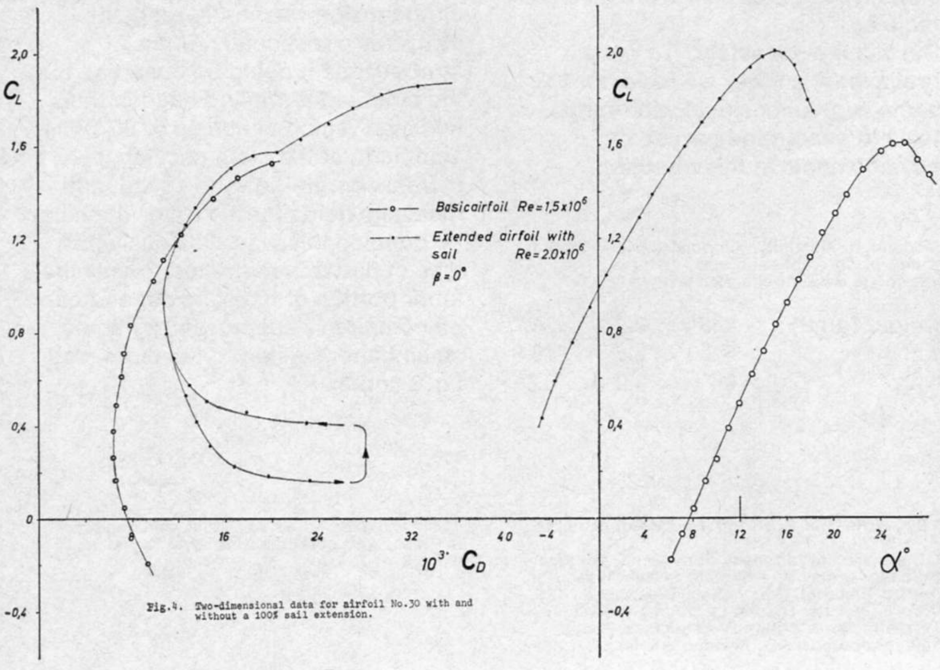

Fig. 4. Two-dimensional data for airfoil No.30 with and without a 100% sail extension.

Another type of flutter develops when the angle of attack is lowered to such a degree that the positive pressure difference between lower and upper side of the sailcloth becomes negative. The forces which evolve from the buffeting sail are much stronger than with the trailing edge flutter and may be dangerous. However, the main function of the sail is at low speed flight ranges having lift coefficients of 1.5 to 2 but not a c_L of 0.5 or lower. The drag polars and $c_{L(\alpha)}$ curves of the basic airfoil and the airfoil-sail combination of figure 2 with stabilized trailing edge at a Reynolds number of 2×10^6 are given in figure 4[4]. At low lift coefficients, the drag polar exhibits a hysteresis which comprises the buffeting regime. The loop is pointed out by small arrows.

At high lift coefficients the drag values are higher than with the rigid flap of the FX 67-VG-170/1.36 airfoil [3]. This is partly caused by different transition points, but also the porosity of the sailcloth has a detrimental effect on the drag. When the lower side of the sailcloth was covered with a thin plastic foil in order to avoid any porosity, the drag polar improved considerably, as shown in figure 5. Therefore the sailcloth should be airtight. The pitching moments are not measured. They should be similar to the FX 67-VG-170/1.36 airfoil.

One of the most promising qualities of the sailflap lies in the fact that the extension can also be used as aileron. The aerodynamic qualities, especially the buffeting boundaries which are pointed out by arrows, are given in figure 6 for four different flap settings. It can be seen, that the buffeting boundaries are low enough to assure a workable lift range for adequate roll control. The common technique to differentiate the up and down movements of the ailerons has also its benefits for the sail-extended aileron.

The variable chord concept with sails

Some further remarks may be given to this concept without going into technical details. It is suggested to fit the wing along the trailing edge including the ailerons with five to seven struts which define the camber of the sail and transmit aerodynamic forces to the wing. On the ground they may be removed for an easier handling of the wings. The additional

---

[4] All angles of attack in this paper are related to the chordline of the flap model, see figure 1. The $c_{L(\alpha)}$ curve of the basic airfoil therefore is shifted to the right by 12 degrees.

drag of these struts in the high speed mode will be proportional to the additional wetted surface. The sail is stored on a circular cylinder inside the basic airfoil at a chord station of roughly 75%. To extract the sail out of the lower side needs only a pull on the extreme rearward corners of the sail at the wing tip and root. The sail then slides from below along the cambered struts and the lift forces press the cloth against the struts. When the sail is out it should be possible to increase the tension of the sailcloth in spanwise direction up to between 50 and 100 kp. A slack sail is not particularly bad, but a tight one works better. It is not necessary to apply a special tension in the chordwise direction. The aileron should be hinged in such a way that the cloth tension can be transmitted into the wing without hampering the turning motion. On the inboard side the aileron chord should slowly reduce to zero, otherwise the sailcloth in this region will separate from the lower side of the wing, when the aileron goes down. To reef the sail the cloth tension is reduced and the circular cylinder in the main wing is rotated as long as the two trailing edges coincide. The part of the sail which is stiffened by the battens stays on the lower side of the airfoil.

The whole concept should not be performed in one step. It is probably better to test the low speed configuration by a modification of a suitable existing glider and to develop the in-out mechanism of a new wing on the basis of this experience. There is always the danger of overengineering such a project and to lose the basic simplicity. Presumably, at least with respect to gear and gadgets, much can be learned from the world of racing yachts.

Finally, the coordinates of a 19% thick airfoil which has been designed to match the conditions of a 100% flap extension are given in table II. The form of the flap is simply a circular arc with 3.5% camber which runs tangentially into the upper surface slope of the basic airfoil. The aerodynamic qualities should be similar to the data given here, except the drag values which should be lower.

It is hoped that this suggestions may help to realize the benefits of the variable chord concept. From the point of view of the author it seems the most natural and logical way to new horizons of soaring.

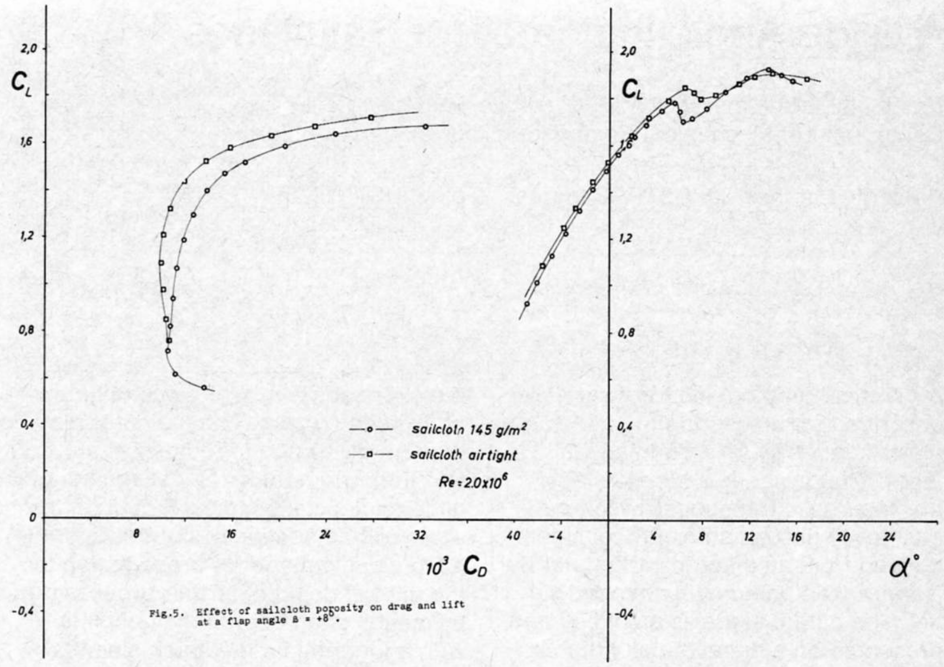

Fig.5. Effect of sailcloth porosity on drag and lift at a flap angle β = +8°.

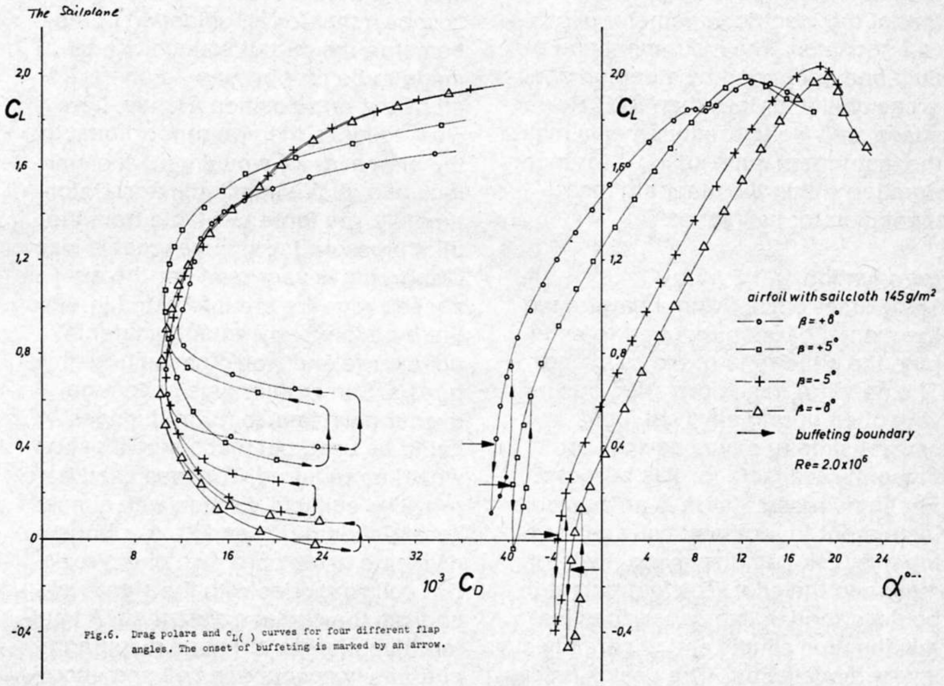

Fig.6. Drag polars and $c_{L(\ )}$ curves for four different flap angles. The onset of buffeting is marked by an arrow.

1. F. G. Irving: Variable geometry gliders. Soaring 30 (1966), No. 9, Los Angeles.
2. F. X. Wortmann: Einige Laminarprofile für Segelflugzeuge. IX. OSTIV Congress, Junin, Argentine. – Swiss Aero-Revue 38 (1963), pp. 647–651. – Soaring 28 (1964), No. 1.
3. F. X. Wortmann: Airfoils for the variable geometry concept. XII. OSTIV Congress, Alpine, Texas.