# Airfoils for the Variable Geometry Concept

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**Introduction**

All aircraft designed to fly at both high and low speeds are subjected to trade-offs which usually result in less-than-optimal performance in both flight ranges. One way to improve this situation is the variable geometry concept, in which the aircraft assumes two different aerodynamic configurations depending upon the current speed range. The mechanical and structural complexities associated with such a design often reduce the aerodynamic advantages of this concept. It is therefore important to optimize the aerodynamic characteristics as much as possible. This is especially true for sailplanes which have to be aerodynamicaly clean not only in the high speed but also in the low speed flight ranges. Practical considerations restrict the variable geometry of sailplanes to a variable chord concept. Speaking in terms of airfoil design the problem now reduces to the problem of finding two airfoils which perform well in both speed ranges and are geometrically compatible. It is the aim of this paper to show the benefits of one solution which was developed for and in cooperation with the British Sigma project [1].

**Basic considerations**

Because the variable chord concept yields extremely high aspect ratios for the high speed mode, the airfoil with reduced chord which may be called the basic airfoil should have a reasonable thickness and relatively low pitching moments. The drag of the basic airfoil should be as low as possible and the low drag bucket should be large enough to fly between maximum speed and maximum glide angle without changing the airfoil. On the other hand the low speed mode with the extended chord should allow for high values of the climbing factor $c_L^3/c_D^2$. It is obvious that a low drag of the basic airfoil can only be achieved when the front part of the airfoil surface is smooth and uninterrupted to maintain laminar flow. Any high lift devices in this region cannot be tolerated. With respect to the chord extension at the trailing edge, there are several possibilities, one of which is the well-known Fowler flap. The usual form, for which the flap is stored in a cavity on the lower side of the basic airfoil, is ruled out, because the drag penalty which results from the disturbed contour of the basic airfoil cannot be tolerated. Even a modified form of this flap which does not change the basic airfoil both in the stored and the extended version may be questionable. Another and more favorable solution seems to be a thin flap sheet which extends from the trailing edge tangential to the upper surface slope of the basic airfoil without any slot.

PROFILKOORDINATEN FX 67-VC-170/1.00

| NR | X/T | YO/T | YU/T |
|---|---|---|---|
| 1 | 1.00000 | .00000 | .00000 |
| 2 | .99893 | .00033 | -.00010 |
| 3 | .99039 | .00204 | -.00018 |
| 4 | .97347 | .00556 | -.00092 |
| 5 | .94844 | .01118 | -.00310 |
| 6 | .91573 | .01924 | -.00725 |
| 7 | .87592 | .02995 | -.01364 |
| 8 | .85355 | .03630 | -.01758 |
| 9 | .82967 | .04327 | -.02177 |
| 10 | .80438 | .05065 | -.02605 |
| 11 | .77779 | .05895 | -.03022 |
| 12 | .75000 | .06745 | -.03409 |
| 13 | .72114 | .07614 | -.03754 |
| 14 | .69134 | .08469 | -.04050 |
| 15 | .66072 | .09279 | -.04292 |
| 16 | .62941 | .10015 | -.04478 |
| 17 | .59755 | .10658 | -.04612 |
| 18 | .56526 | .11199 | -.04702 |
| 19 | .53270 | .11630 | -.04757 |
| 20 | .50000 | .11950 | -.04783 |
| 21 | .46730 | .12161 | -.04782 |
| 22 | .43474 | .12271 | -.04759 |
| 23 | .40245 | .12287 | -.04712 |
| 24 | .37059 | .12216 | -.04646 |
| 25 | .33928 | .12060 | -.04558 |
| 26 | .30866 | .11822 | -.04452 |
| 27 | .27866 | .11505 | -.04327 |
| 28 | .25000 | .11113 | -.04184 |
| 29 | .22221 | .10650 | -.04025 |
| 30 | .19562 | .10123 | -.03850 |
| 31 | .17033 | .09534 | -.03659 |
| 32 | .14645 | .08892 | -.03454 |
| 33 | .12408 | .08202 | -.03233 |
| 34 | .10332 | .07471 | -.03000 |
| 35 | .08427 | .06707 | -.02753 |
| 36 | .06699 | .05918 | -.02493 |
| 37 | .05156 | .05112 | -.02220 |
| 38 | .03806 | .04305 | -.01939 |
| 39 | .02653 | .03513 | -.01646 |
| 40 | .01704 | .02761 | -.01339 |
| 41 | .00961 | .01956 | -.01045 |
| 42 | .00428 | .01323 | -.00671 |
| 43 | .00107 | .00660 | -.00303 |
| 44 | .00000 | .00000 | .00000 |

DICKF/T....= .,70 RUECKLAGE/T= .435
WOELBUNG/T = .038 RUECKLAGE/T= .402

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PROFILKOORDINATEN FX 67-VC-170/1.36

| NR | X/T | YO/T | YU/T |
|---|---|---|---|
| 1 | 1.36000 | -.20400 | -.20400 |
| 2 | 1.32000 | -.18350 | -.18700 |
| 3 | 1.28000 | -.16320 | -.16900 |
| 4 | 1.24000 | -.14300 | -.15150 |
| 5 | 1.20000 | -.12300 | -.13400 |
| 6 | 1.16000 | -.10360 | -.11800 |
| 7 | 1.12000 | -.08420 | -.10320 |
| 8 | 1.08000 | -.06600 | -.08900 |
| 9 | 1.04000 | -.04780 | -.07600 |
| 10 | 1.00000 | -.02980 | -.06380 |
| 11 | .96000 | -.01230 | -.05200 |
| 12 | .94840 | .01118 | -.00310 |
| 13 | .91570 | .01924 | -.00725 |
| 14 | .87590 | .02995 | -.01364 |
| 15 | .85360 | .03630 | -.01758 |
| 16 | .82970 | .04327 | -.02177 |
| 17 | .80440 | .05065 | -.02605 |
| 18 | .77780 | .05895 | -.03022 |
| 19 | .75000 | .06745 | -.03409 |
| 20 | .72110 | .07614 | -.03754 |
| 21 | .69130 | .08469 | -.04050 |
| 22 | .66070 | .09279 | -.04292 |
| 23 | .62940 | .10015 | -.04478 |
| 24 | .59750 | .10658 | -.04612 |
| 25 | .56530 | .11199 | -.04702 |
| 26 | .53270 | .11630 | -.04757 |
| 27 | .50000 | .11950 | -.04783 |
| 28 | .46730 | .12161 | -.04782 |
| 29 | .43470 | .12271 | -.04759 |
| 30 | .40250 | .12287 | -.04712 |
| 31 | .37060 | .12216 | -.04646 |
| 32 | .33930 | .12060 | -.04558 |
| 33 | .30870 | .11822 | -.04452 |
| 34 | .27890 | .11505 | -.04327 |
| 35 | .25000 | .11113 | -.04184 |
| 36 | .22220 | .10650 | -.04025 |
| 37 | .19560 | .10123 | -.03850 |
| 38 | .17030 | .09534 | -.03659 |
| 39 | .14640 | .08892 | -.03454 |
| 40 | .12410 | .08202 | -.03233 |
| 41 | .10330 | .07471 | -.03000 |
| 42 | .08430 | .06707 | -.02753 |
| 43 | .06700 | .05918 | -.02493 |
| 44 | .05160 | .05112 | -.02220 |
| 45 | .03810 | .04305 | -.01939 |
| 46 | .02650 | .03513 | -.01646 |
| 47 | .01700 | .02761 | -.01339 |
| 48 | .00960 | .01956 | -.01045 |
| 49 | .00430 | .01323 | -.00671 |
| 50 | .00110 | .00660 | -.00303 |
| 51 | .00000 | .00000 | .00000 |

DICKE/T....= .170 RUECKLAGE/T= .435
WOELBUNG/T = .204 RUECKLAGE/T= 1.360

The flap sheet increases the total camber to nearly 10%, but the additional drag is low because the flap is «hidden» in the boundary layer of the basic airfoil. Both theoretical and experimental evidence shows that $c_L$-values of 1.8 to 2.0 and $c_D$-values at this lift of about 1 to 1.5% are attainable. (The values are related to the extended chord.) The influence of these data on the glide-performance is given in [2]. Figure 1 shows the airfoil configuration which finally evolved for the Sigma project. The coordinates of the basic airfoil and the flap extension are given in table I. The large flap sheet has a small plain flap at the trailing edge, which forms in the retracted version the last 10% of the basic airfoil. The small flap is a very effective means of shifting the low drag bucket of the basic airfoil as well as reducing the pitching moment at high speeds. The Sigma airplane uses it also as an aileron. The chord of the flap sheet is 36% of the basic airfoil chord. On the lower side of the basic airfoil there is an elastic part, which adjusts to the different flap thicknesses. There is some freedom with respect to the lower contour of the flap and the flap thickness.

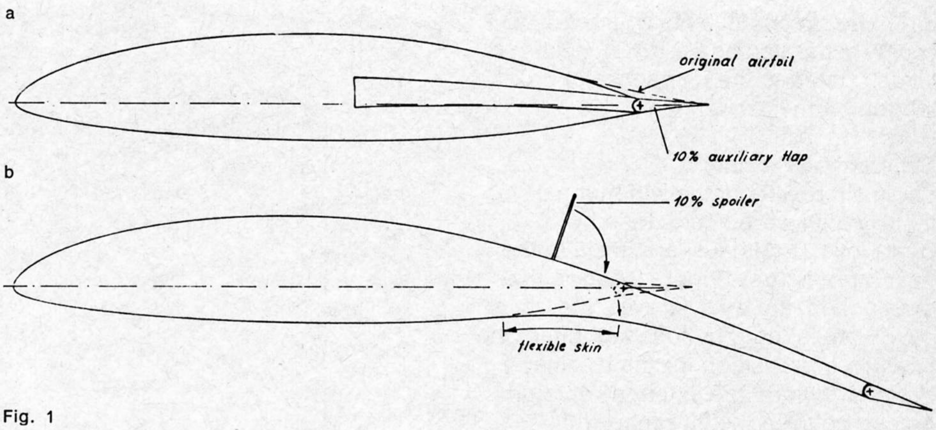


Fig. 1

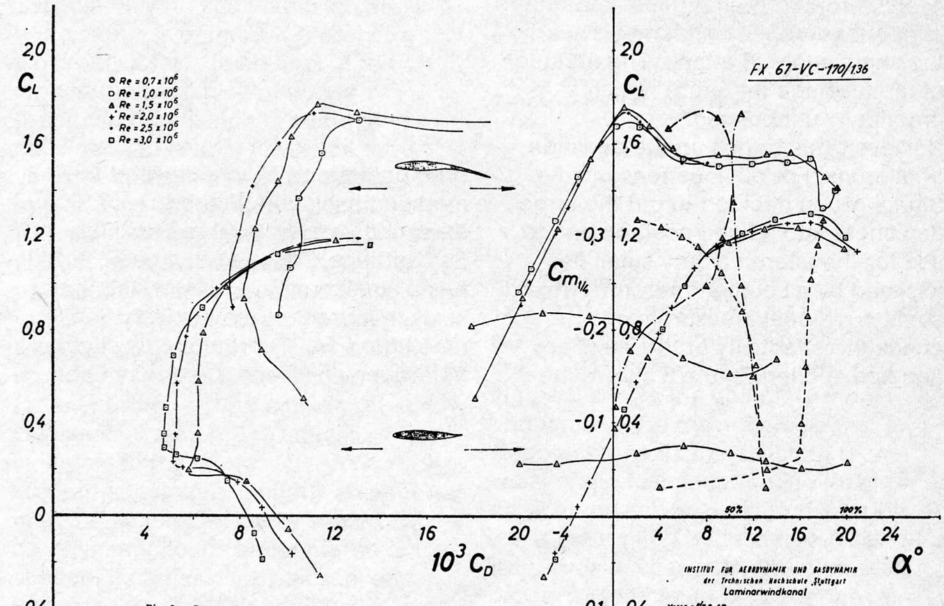


Fig.2. Drag polars and $c_{L(\alpha)}$ and $c_{m_{1/4}(\alpha)}$ curves of the original airfoil (lower group) and the extended version (upper group) at several Reynolds numbers.
The dashed lines give the position of transition at Re = 1.5 x $10^6$.

## Airfoil design

When the flap configuration, the flap extension rate, the thickness and the $c_L$-range of the basic airfoil are more or less fixed, the search for a convenient airfoil can start. The first condition is that the form of the rear upper surface of the basic airfoil fits well into the flap sheet extension at least up to the 90% chord station of the basic airfoil. In other words, the adverse pressure gradient in this most critical region should have a smooth and reasonable distribution to avoid any premature separation of the turbulent boundary layer at high lift values. When an appropriate airfoil is found the geometry of the flap sheet is given and the airfoil can now be optimized. This procedure is similar to the one previously used for the optimization of flapped airfoils [3] and means tailoring the pressure distribution to get the maximum width of the low drag bucket. This implies two conditions for a constant pressure distribution in the front part of the basic airfoil: when the flap is retracted and the $c_L$-values go down to roughly 0.2 then the lower side of the airfoil is the critical one and the pressure distribution on this side should develop monotonously into a constant distribution. For the upper side this should happen when the flap is out. It is interesting to note that this condition can be realized with a 17%

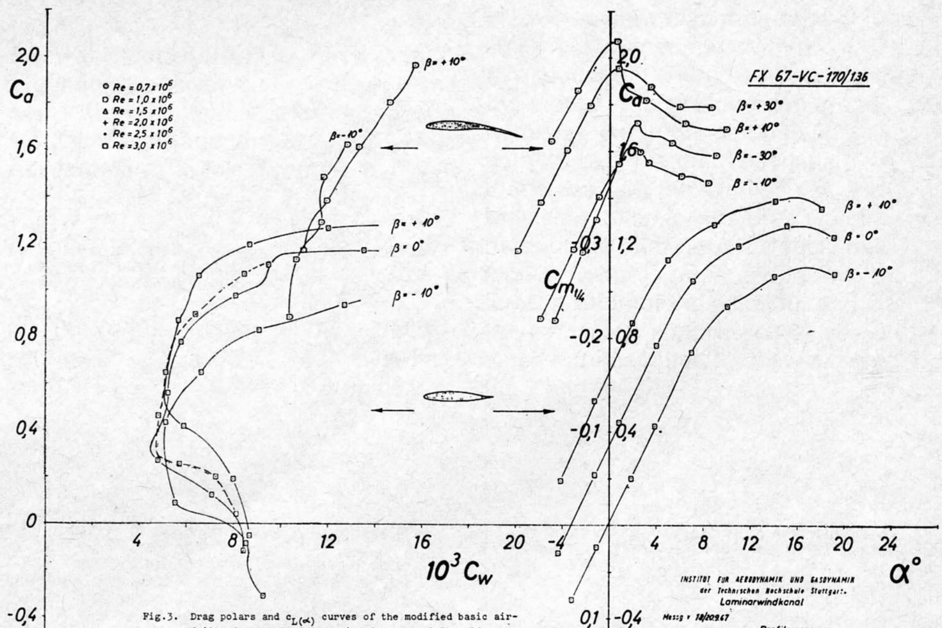


Fig.3. Drag polars and $c_{L(\alpha)}$ curves of the modified basic airfoil and the extended version for several Reynolds numbers and flap angles of the auxiliary flap.

airfoil for lift coefficients which are as widely separated as 0.2 to 1.8, each value related to the respective chord length.

## Experimental results

The main results of the wind tunnel tests, which were again done by Dipl.-Phys. D. Althaus, are given in the next three figures. Figure 2 shows the drag polars, the $c_{L(\alpha)}$ curves, the $c_{mc/4}$ values and by dashed lines the position of transition for the original basic airfoil and the extended version. As can be seen the lift range with small drag values is considerably larger than can be expected with any fixed airfoil. The reference line of the angle of attack is the chordline of the basic airfoil for both airfoils, and the high and low speed flight need nearly the same angle of attack. The attitude of the fuselage therefore remains practically unchanged.
However, this brings up the question of ailerons. For obvious reasons the Sigma group decided to put the large flap sheet into a fixed position and to use for the aileron a very small flap assisted by a spoiler. Therefore we did some additional measurements to check the effectivity of this auxiliary flap and spoiler. Figure 3 shows the

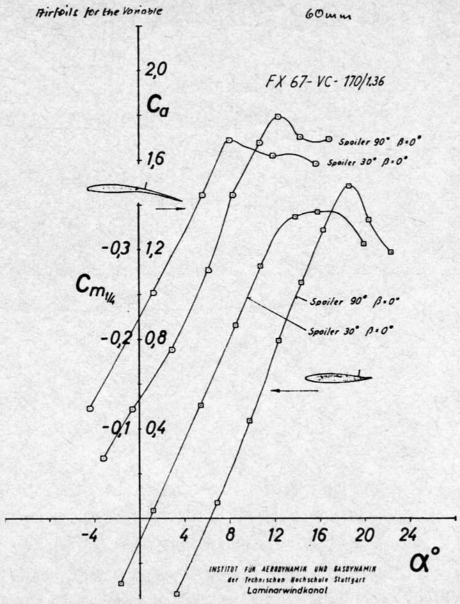

Fig.4. Lift variation with two spoiler angles of 30° and 90° for the basic airfoil and the extended version at two Reynolds numbers.

drag polars and $c_{L(\alpha)}$ curves of the modified basic airfoil and the extended version for three auxiliary flap settings. The modified basic airfoil has a small concave kink on the upper surface in front of the auxiliary flap (see figure 1a). There are only slight differences between the original and the modified airfoil as shown by the dashed line in the drag polar of figure 3. The effect of a two-dimensional spoiler (see figure 1b) located on the upper side at a chord station of 80% of the basic airfoil is given in figure 4 for two spoiler angles of 30° and 90°. The few results show $\triangle c_L$-values of 0.4 at 30° and nearly 1.0 at 90°. For the extended chord the $c_L$-values are slightly smaller. They seem to be proportional to the spoiler length/chord ratio and, together with the auxiliary flap, assure adequate roll control.

## Conclusions

A pair of geometrically compatible airfoils has been designed for the variable chord concept. Wind tunnel data confirm the theoretical expectations and show that with such airfoils a variable chord sailplane promises an excellent performance.


1. N. Goodhart: Sigma-design of a super sailplane. Flight 95 (1969), No. 3133, p. 475.
2. N. Goodhart: The application of high lift devices to competition gliders. XII. OSTIV Congress, Alpine, Texas.
3. F. X. Wortmann: Optimization of airfoils with flaps. XI. OSTIV Congress, Leszno, Poland. – Swiss Aero-Revue 44 (1969), No. 2. – Soaring 34 (1970), No. 5, Los Angeles.