

Continuously variable Aerofoil shapes

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1. Introduction

The present-day layout of sailplanes is still a compromise limited by the likelihood of meeting certain up-current forms and strengths. Particularly in the case of fast long range sailplanes the determination of optimum circling flight in weak up-currents by finding the most favourable radius of turn is important. With the aid of suitable lift-increasing camber flaps, particularly those which increase wing area, the airspeed can be reduced and a smaller radius of turn used. This results in a reduction of sinking speed.

Considering the optimum circling flight and best cruising speed (Ref. 1, 2) we must concern ourselves with the influence of the suitability of the wing section for the various parts of the long distance flight. We assume a sailplane with high wing loading and see what advantages in cruising and circling can be devised. In the following, the well-known idea of variable aerofoil shape is discussed.

2. Circling Flight

The well-known equations for sinking speed, airspeed and radius of turn are as follows:

$$V_z = (2W/\rho b^2)^{0.5} \cdot \frac{C_D}{C_L^{1.5}} \sqrt{A} \sqrt{\cos^3 \phi}$$

$$V = (2W/\rho b^2)^{0.5} \cdot \frac{1}{C_L^{0.5}} \sqrt{A} \frac{1}{\sqrt{\cos \phi}}$$

$$r = 2W/\rho g b^2 \cdot A \frac{1}{C_L \sin \phi} \quad (A)$$

The ratio $\xi = C_D/C_L^{1.5}$ must be a minimum in circling flight so that V_z is also a minimum. When one differentiates ξ

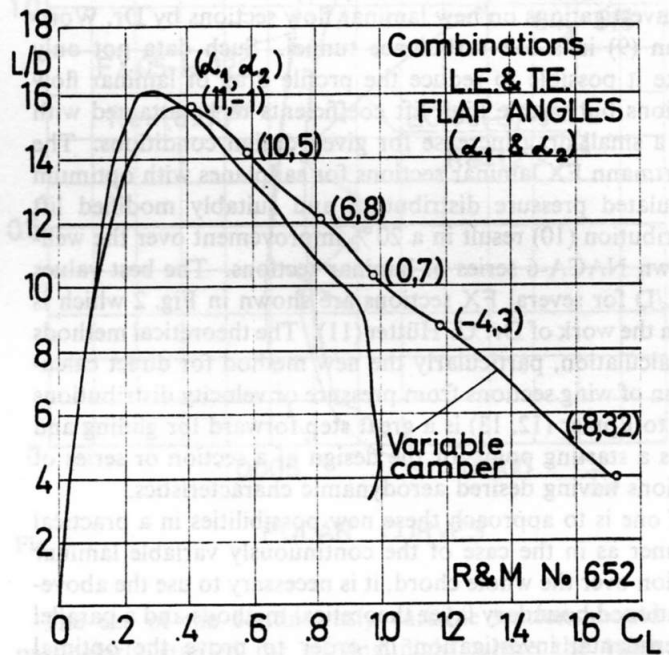
$$\log \xi = \log C_D - 1.5 \log C_L$$

$$\frac{d\xi}{\xi} = \frac{dC_D}{C_D} - 1.5 \frac{dC_L}{C_L} \quad (B)$$

It is seen that the sinking speed can be reduced at higher lift coefficients only if the drag increase can be reduced. Lift-increasing flaps (3) have already been used on many types of sailplane. The question then arises: can one improve the circling flight of a heavily loaded sailplane by using a continuously variable wing section? It is assumed that for all other parts of the flight and flight regimes, such a wing would have the best shape and be certainly better than when using present-day camber flaps.

3. Variable Wing Section Shape

As early as 1919 Dr. Levy in England reported in R and M No. 652 on a wing with discontinuously variable camber by using leading and trailing edge flaps. Data on this are given in Fig. 1.



L/D curve for a variable camber aerofoil

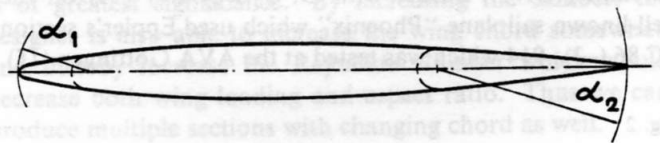


Fig. 1

During the first Rhön Experimental Contest (4) the Akaflied Darmstadt demonstrated their "Hesse" sailplane, equipped with a partially variable wing section. The wing chord was divided into three parts: the leading edge up to the spar was fixed in itself and so was the trailing part from trailing edge forward to an auxiliary spar. But the flexible middle part was so devised that the section shape could be modified. The wing could be adjusted exactly to G. 430 and G. 432 and to a close approximation of G. 429 and G. 431, and one could alter the camber to a considerable degree. The wing was so designed as to provide a linkage between section shape and wing setting so that by operating a single lever, both changes could be arranged.

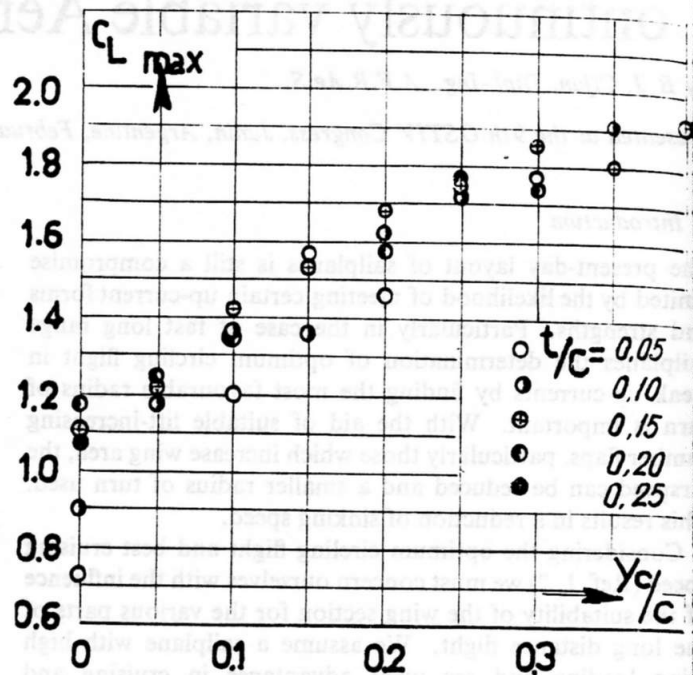
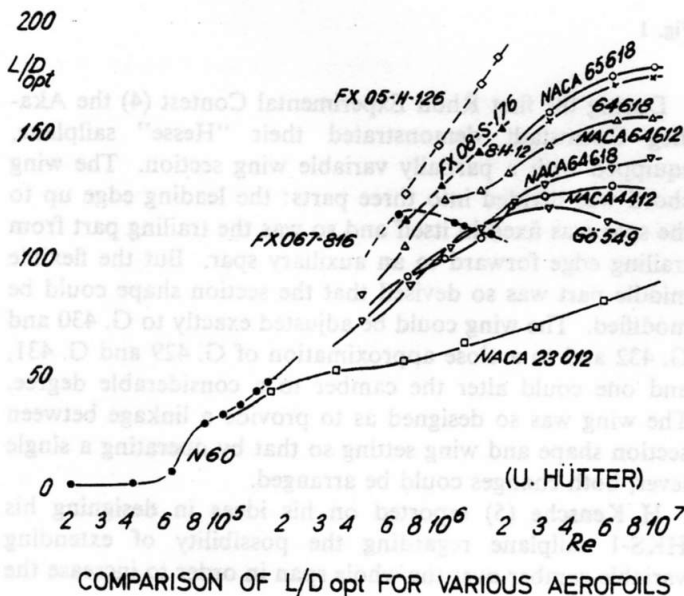
H. Kensche (5) reported on his ideas in designing his HKS-1 sailplane regarding the possibility of extending variable camber over the whole span in order to increase the

maximum lift coefficient to a figure not attainable by flaps because of flow discontinuities and other losses caused by section centre-line discontinuities. HKS-1 lateral control was by camber change. Kensch (6) also reported on the arrangement for wing camber variation on the "Condor IV" sailplane. A different scheme, using small-chord flaps (10%) with no gap losses was applied successfully to the Swiss "Elfe" designed by Dr. Pfenninger and also to the Yugoslav "Meteor", the American "Sisu" and other sailplanes (7).

There is now important new knowledge about laminar sections for sailplanes, particularly Dr. Eppler's new basic ideas for calculating such sections for the Reynolds Numbers suitable for sailplanes (8) and the theoretical and experimental investigations on new laminar flow sections by Dr. Wortmann (9) in a low-turbulence tunnel. Such data not only make it possible to reduce the profile drag of laminar flow sections but enable high lift coefficients to be attained with but a small drag increase for given design conditions. The Wortmann FX laminar sections for sailplanes with optimum calculated pressure distribution and suitably modified lift distribution (10) result in a 20% improvement over the well-known NACA-6 series of laminar sections. The best values of L/D for several FX sections are shown in Fig. 2 which is from the work of Dr. U. Hütter (11). The theoretical methods of calculation, particularly the new method for direct calculation of wing sections from pressure or velocity distributions due to Eppler (12, 13) is a great step forward for gliding and gives a starting point for the design of a section or series of sections having desired aerodynamic characteristics.

If one is to approach these new possibilities in a practical manner as in the case of the continuously variable laminar section over the whole chord, it is necessary to use the above-mentioned boundary layer theoretical methods and a parallel experimental investigation in order to prove the optimal design. The differences between theory, wind tunnel results and flight tests, particularly at very high lift coefficients can be considerable. This sort of thing was confirmed by investigations by the American pioneer of high performance sailplanes, Dr. A. Raspet with D. Györgyfalvy (14) on the well-known sailplane "Phoenix" which used Eppler's section EC 86 (-3) -914 which was tested at the AVA Göttingen (15).

Fig. 2



Variation of $C_L \max$ with camber for J-aerofoils

Fig. 3

With a fixed wing section one cannot really simultaneously achieve very high lift and very low drag, and therefore one can hardly achieve optimum conditions for circling and fast cruising with such sections. The "double laminar" section due to Eppler, where two ranges of lift coefficient occur with low drag, is certainly an advance, but with a continuously variable section one can achieve a multiple laminar section which could produce optimal laminar flow for all parts of a flight.

It is well known that wing camber increase is a factor in lift increase, however the section shape according to boundary layer theory is critical. Even old systematic investigations of Joukowsky sections (16) show an increase of maximum lift with increase in camber, the wing thickness having a lesser influence (Fig. 3). The effect of camber on maximum lift for the NACA-6 series is given in the Table from a compilation by Prof. T. Nonweiler (17) at $R = 9 \times 10^6$.

Section	$C_D \min$	$C_L \max$	$C_D \min$	$C_L \max$	$C_{p \text{ aft}}$	C_{mo}
			$\left(\frac{C_L}{C_D}\right)_{\max}$	$\left(\frac{C_L}{C_D}\right)_{\max}$	LE	
65-018	0.0042	1.38	328	87	0.267	0
65-218	0.0042	1.49	354	105	0.263	-0.030
65-418	0.0044	1.55	352	145	0.265	-0.060
65-618	0.0045	1.67	371	180	0.276	-0.105

The influence of camber on high lift coefficients is favourable, but at very high lift coefficients the boundary layer influences and losses play a leading rôle. By just increasing camber, the right answer is not achieved, as particularly the tests on NACA-71 (26.7% camber) have shown.

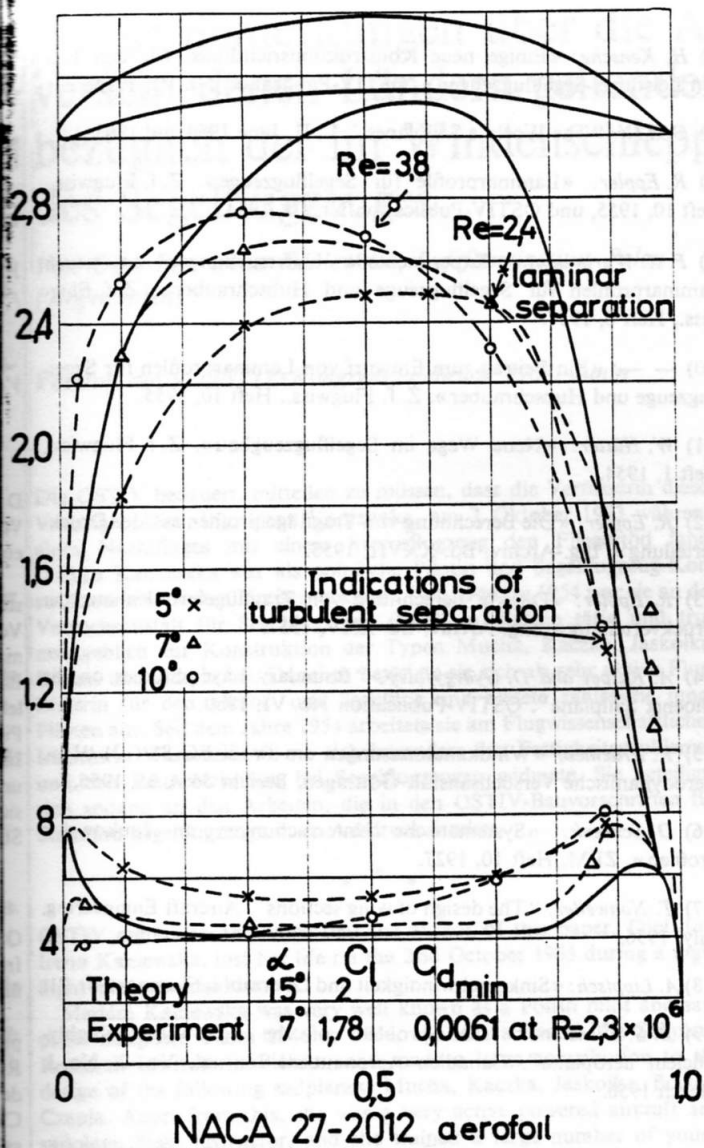


Fig. 4

To give an example of continuously variable sections let us assume there is a sickle-shaped section rather like the 12% thick NACA 27-2012 which has a 14% camber and a maximum thickness at 60% chord aft of the leading edge (Fig. 4). According to E. Jacobs, NACA results indicate that at an incidence of 7°, Reynolds Number 2.3×10^6 , a $C_L = 1,78$ (theoretically 2.0) is achieved at $C_{D0 \text{ min}} = 0.0061$. This means a maximum $L/D = 290$ (19). If one took such a fixed-shape sickle-form section which has a very good maximum lift coefficient with low drag (although very sensitive to Reynolds Number) and applied it to circling flight and modified it for high speed flight by using a continuously variable section shape and camber, taking into account the simultaneously changing wing setting, one comes a little closer to the solution for the optimum value of the desired design lift coefficient (Fig. 5). This figure shows polars for the two extreme conditions of the variable wing section for circling flight (C_{L1}) and for high speed flight (C_{L2}) giving each its best value. For comparison a curve for a camber flap is also shown.

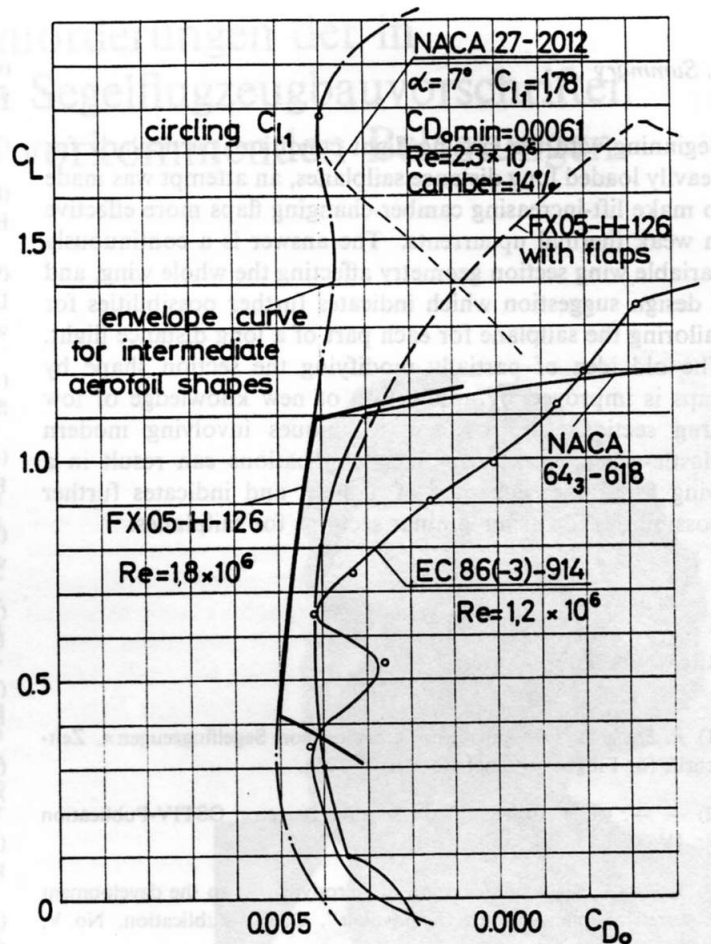


Fig. 5

POLAR CURVES

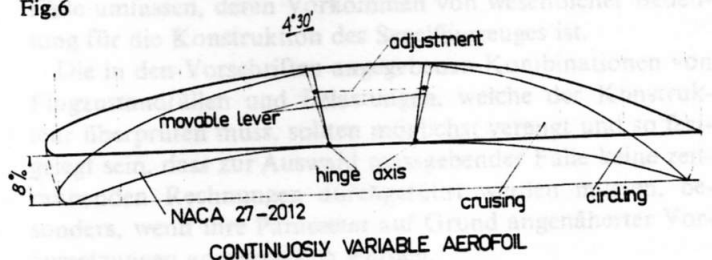
The use of the continuously variable section should be particularly studied for circling flight where the value of

$$\frac{C_D}{C_L^{1.5}} \sqrt{A}$$

is of greatest significance. By increasing the camber, the designer is also able to increase the wing chord somewhat, and thereby increase the Reynolds Number which would decrease both wing loading and aspect ratio. Thus we can produce multiple sections with changing chord as well.

The structural realization of such a wing arrangement could be achieved nowadays by using elastic plastics, in a manner rather like Wortmann's scheme for dealing with insects sticking on wings. Fig. 6 shows a general arrangement of a continuously variable aerofoil. It will be obvious that the various stages of the continuously variable section must be calculated in detail so that all the essential parameters (particularly pitching moments) are known.

Fig. 6



CONTINUOUSLY VARIABLE AEROFOIL

4. Summary

Beginning with the circling flight condition, particularly for heavily loaded long distance sailplanes, an attempt was made to make lift-increasing camber-changing flaps more effective in weak thermal upcurrents. The answer is a continuously variable wing section geometry affecting the whole wing, and a design suggestion which indicates further possibilities for tailoring the sailplane for each part of a long distance flight. The old idea of partially modifying the section shape by flaps is improved by application of new knowledge of low drag sections and of new techniques involving modern plastic-elastic materials. Such applications can result in a wing fitted for each part of a flight and indicates further possibilities for using laminar sections for sailplanes.

REFERENCES

- (1) R. Eppler: «Der günstigste Kreisflug von Segelflugzeugen», Zeitschrift für Flugwissenschaften, Heft 1, 1954.
- (2) — —: «Die Auslegung von Segelflugzeugen». OSTIV-Publication Nr. IV, 1956.
- (3) J. Vesely: «The contribution of Aerodynamics to the development of recent sailplanes in Czechoslovakia». OSTIV-Publication, No. V, 1958.
- (4) W. Schlink: «Der erste Rhön-Versuchswettbewerb». ZFM, Heft 33, 1926.
- (5) H. Kensch: «Die Entwicklung des Segelflugzeuges HKS 1». Z. f. Flugwiss., Heft 1, 1954.
- (6) H. Kensch: «Einige neue Konstruktionsrichtlinien für den Bau von Leistungs-Segelflugzeugen». OSTIV-Publication Nr. III, 1954.
- (7) OSTIV: «The World's Sailplanes,» I., II, June 1958 and 1963.
- (8) R. Eppler: «Laminarprofile für Segelflugzeuge». Z. f. Flugwiss., Heft 10, 1955, und OSTIV-Publication Nr. III, 1954.
- (9) F. X. Wortmann: «Experimentelle Untersuchungen an neuen Laminarprofilen für Segelflugzeuge und Hubschrauber». Z. f. Flugwiss., Heft 8, 1957.
- (10) — —: «Ein Beitrag zum Entwurf von Laminarprofilen für Segelflugzeuge und Hubschrauber». Z. f. Flugwiss., Heft 10, 1955.
- (11) W. Hütter: «Neue Wege im Segelflugzeugbau». Z. f. Flugwiss., Heft 1, 1954.
- (12) R. Eppler: «Die Berechnung von Tragflügelprofilen aus der Druckverteilung». Ing.-Archiv, Bd. XXVII, 1955.
- (13) R. Eppler: «Direkte Berechnung von Tragflügelprofilen aus der Druckverteilung». Ing.-Archiv, Bd. XXV, 1957.
- (14) A. Ráspet and D. Györgyfalvy: «Boundary Layer Studies on the Phoenix Sailplane». OSTIV-Publication No. VI, 1960.
- (15) K. Kraemer: «Windkanalmessungen am Profil EC 86 (-3)-914». Aerodynamische Versuchsanstalt Göttingen, Bericht 56 A 05, 1956.
- (16) O. Schrenk: «Systematische Untersuchungen an Joukowski-Profilen». ZFM, Heft 10, 1927.
- (17) T. Nonweiler: «The design of wing sections». Aircraft Engineering, July, 1956.
- (18) A. Lippisch: «Sinkgeschwindigkeit und Gleitzahl», Flugsport Nr. 21.
- (19) B. S. Shenstone: «The problem of the light-weight, highly-efficient aeroplane». Canadian Aeronautical Journal, Vo. 2, No. 3, March 1956.

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COMPARISON OF LIFT AND DRAG COEFFICIENTS