Symmetrical Airfoils Optimized for Small Flap Deflection

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Symmetrical airfoils are of interest for all aerodynamic control surfaces such as rudders, elevators and ailerons. Very often these control surfaces are divided into a fixed part and a movable part. The deflected flap yields an airfoil with positive or negative camber and the associated lift produces the desired steering control force. The kink in the meanline usually causes a higher drag than a smoothly cambered airfoil. This is due mainly to the unfavorable pressure distribution which emerges from the flap deflection on the «upper» side, namely a velocity peak at the leading edge and at the hinge. The first has an influence on the transition point and the latter promotes flow separation on the flap. As long as the flap angles and the flap sizes are small, say 15° for the 20% chord flap, this situation can be rectified by a suitable thickness distribution which counteracts the undesirable velocity peaks. In other words, the airfoil may be designed not as a symmetrical but as a cambered airfoil with a deflected flap, and the velocity distribution is then optimized for a certain prescribed flap configuration. In two previous papers [1] [2] the author has shown that this technique leads to a remarkable improvement in such airfoils optimized for deflected flaps. Table I gives ordinates for three nearly identical airfoils of 15% thickness with different flap chords, and Fig. 1, 2 and 3 show the windtunnel results* for a Reynolds number of one million. In Fig. 4 the typical differences of the velocity distribution and the form of the NACA 64-012 and the FX 71-L-150/20 airfoils are shown. In Fig. 5 the results for the FX 71-L-150/20 are compared with some measurements of the NACA 64-012 airfoil. The drag polars of both airfoils with no flap deflection have the same qualitative appearance. However, the situation changes drastically when the flap is deflected 15 degrees. The optimized airfoil shows only a shift of the drag polar, whereas the NACA airfoil has always not only a higher drag out also a much more complicated drag polar. This type of drag polar with two minimum drag points is not restricted to this specific airfoil, but is of a more fundamental

FX 71-L-150

NR	X	YO flapchord 20%	YO 25%	YO 30%
2	.99893	.00009	.00010	.00010
4	.99039	.00083	.00087	.00089
6	.97347	.00210	.00223	.00227
8	.94844	.00384	.00426	.00435
10	.91573	.00626	.00731	.00756
12	.87592	.00931	.01140	.01177
13	.85355	.01116	.01377	.01448
14	.82967	.01346	.01628	.01709
15	.80438	.01643	.01921	.02040
16	.77779	.02050	.02265	.02347
17	.75000	.02527	.02771	.02742
18	.72114	.03034	.03299	.03140
19	.69134	.03582	.03854	.03729
20	.66072	.04137	.04413	.04264
21	.62941	.04696	.04949	.04850
22	.59755	.05244	.05457	.05363
23	.56526	.05771	.05891	.05845
24	.53270	.06225	.06320	.06271
25	.50000	.06630	.06689	.06667
26	.46730	.06950	.06998	.06969
27	.43474	.07204	.07227	.07219
28	.40245	.07369	.07386	.07372
29	.37059	.07482	.07483	.07486
30	.33928	.07501	.07501	.07500
31	.30866	.07470	.07462	.07477
32	.27886	.07360	.07355	.07369
33	.25000	.07214	.07204	.07229
34	.22221	.06997	.06991	.07014
35	.19562	.06753	.06742	.06774
36	.17033	.06445	.06438	.06467
37	.14645	.06114	.06105	.06136
38	.12408	.05731	.05724	.05753
39	.10332	.05337	.05326	.05354
40	.08427	.04887	.04880	.04902
41	.06699	.04442	.04431	.04450
42	.05156	.03953	.03944	.03958
43	.03806	.03471	.03457	.03465
44	.02653	.02952	.02941	.02945
45	.01704	.02463	.02446	.02442
46	.00961	.01917	.01903	.01896
47	.00428	.01474	.01455	.01437
48	.00107	.00829	.00822	.00813

Table I. Coordinates of three symmetrical airfoils with different flap chord. The crossection of the flap of the windtunnel models was simplified to a wedge.

Fig.1 Windtunnel results for the 20% flap airfoil FX 71-L-150/20 at Re = 1.0 x 10^6 with different flap angles

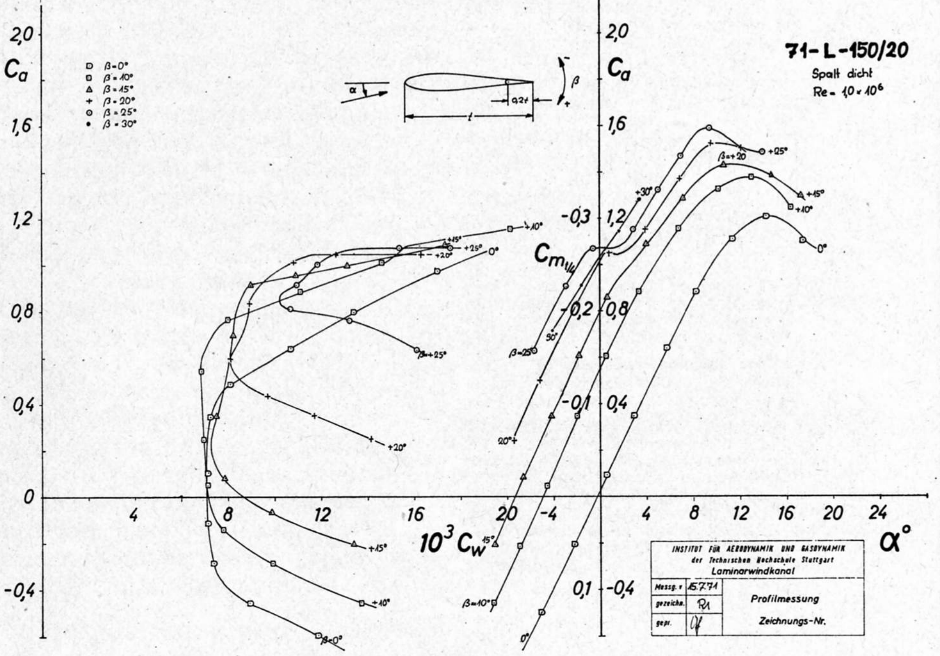
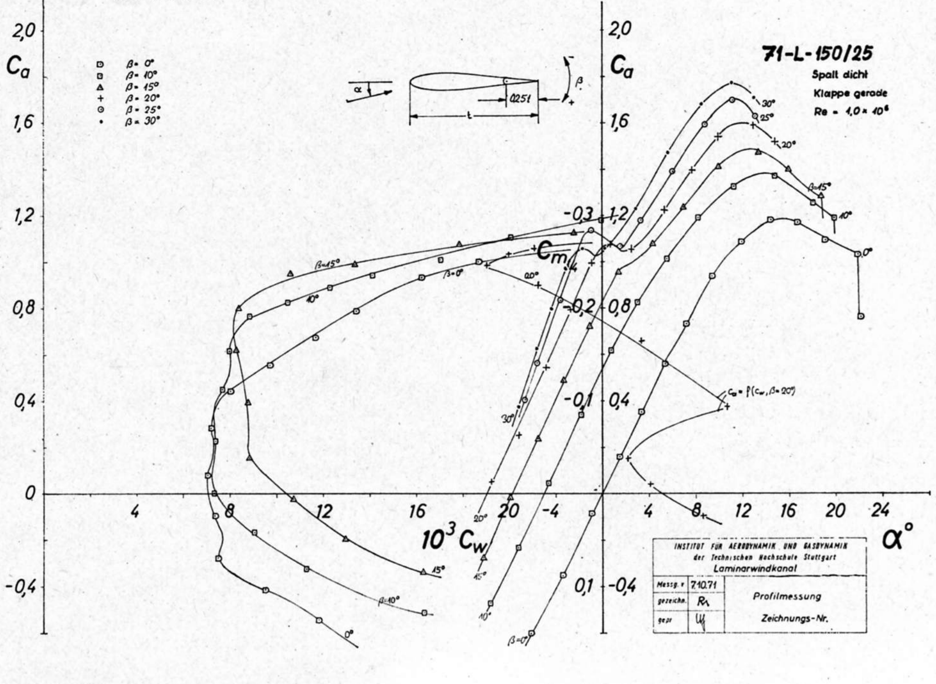


Fig.2 Windtunnel results for the 25% flap airfoil FX 71-L-150/25 at Re = 1.0 x 10^6 with different flap angles



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* As in all previous papers I am indebted to Dipl. Phys. D. Althaus, who performed these measurements in the laminar windtunnel of the Institute.

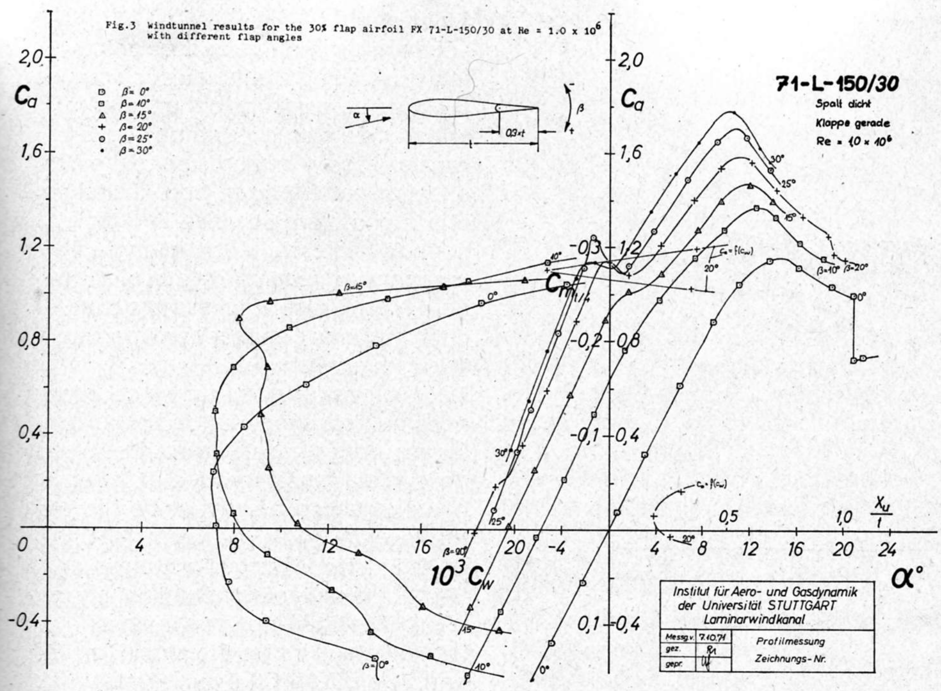
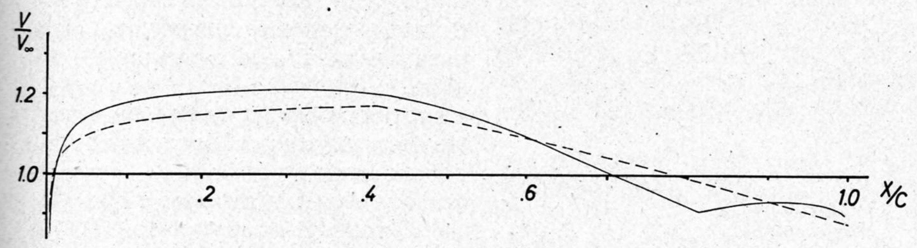


Fig. 3 Windtunnel results for the 30% flap airfoil FX 71-L-150/30 at Re = 1.0 x 10^6 with different flap angles



Velocity distribution

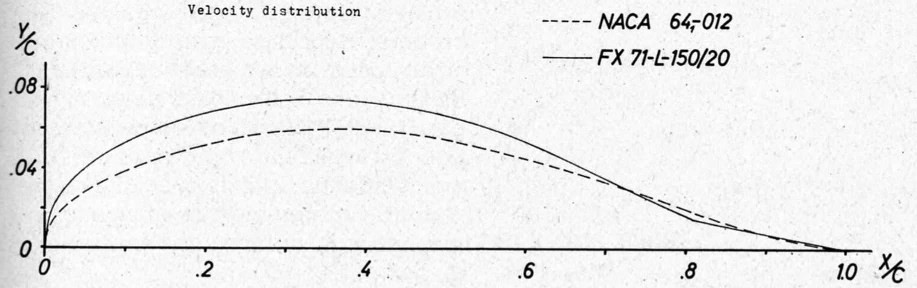


Fig. 4 Thickness distribution

nature. It can be detected also in Fig. 2 and 3 for the higher flap deflection, i.e. for off-design conditions, and also on cambered airfoils with flaps [3].

The drag increase outside the low drag points is simply caused by the velocity peak at the leading edge: the transition jumps forward and the thicker turbulent boundary layer will soon separate from the flap. The minimum drag peaks occur when the transition on both surfaces is just in front of the hinge.

The Z-form of the drag polar between the low drag points is not so easy to understand. Therefore we investigated the NACA 64-012 airfoil with a 25% flap at a flap setting of 15° in this lift range and measured the transition position, the boundary layer profile on the «upper» surface at the end of the bubble at x/c = 0.82 and near the trailing edge at c/x = 0.95. The results are given in Fig. 6.

There is a striking correlation between the drag polar and the boundary layer thickness at the trailing edge and at the end of the bubble; however the transition position and the length of the laminar separation bubble is practically unaffected below the upper minimum drag point. Therefore the Z-form of the drag polar can only be interpreted as the result of the variation of the bubble thickness.

Starting at angles of attack slightly below the upper low drag point, the transition on the upper side goes behind the hinge and forms a laminar separation bubble, which spoils the initial conditions of the turbulent boundary layer.

With further decreasing incidence there are now two counteracting effects which determine the thickness of the laminar separation bubble, or more precisely the height of the transition nucleus above the airfoil surface.

1. the stability of the laminar boundary in front of the separation point increases, which delays the transition at the outer boundary of the bubble.
2. the wedge angle of the separated flow in the front part of the bubble, which is associated with a local constant pressure, decreases continuously.

The first effect leads to the drag increase below the upper minimum drag peak. The second one is responsible for the drag reduction at lower incidences as long as the transition on the lower (concave) side of the airfoil stays near the flap hinge. Due to the adverse pressure distribution in the neighbourhood of the concave kink, the transition on the lower side is always ahead of the hinge, see Fig. 6. Therefore the second drag minimum is not as low as the upper one.

From Fig. 5 it can be decuded that the general practice of selecting an airfoil for control surfaces mainly on the basis of the plain airfoil data may be rather misleading. An advanced airfoil properly designed for a small flap deflection will be more promising, especially in cases where the flap is used for extended periods as for trim purposes.

Zusammenfassung

Symmetrische Profile mit Klappen, wie sie für Leitwerke benützt werden, haben meist höheren Widerstand als leicht gewölbte Profile: das kommt von den Geschwindigkeitsspitzen an der Nase und am Klappenknick. Für mässige Werte von Klappenwinkel und -tiefe können die Spitzen abgebaut werden durch eine geeignete Dickenverteilung. Ordinaten für drei Beispiele sind tabelliert und Windkanalmessungen werden in Fig. 1, 2 und 3 gezeigt. Fig. 4 bis 6 vergleichen eines dieser Profile FX71-L-150/20 mit NACA 64-012. Ohne Klappenausschlag hat das NACA-Profil den gleichen Minimalwiderstand wie das optimierte, wenn auch die Dellenbreite geringer ist. Mit 15-Grad-Klappen hat das NACA-Profil nicht nur einen grösseren Minimalwiderstand, sondern auch eine komplizierte Form der Widerstandskurve. Die Umschlagpunkte beider Oberflächen und die Grenzschichtdicken in der Nähe des Klappenknicks und der Hinterkante an der Oberseite wurden bei NACA 64-012 mit einer 25% tiefen Klappe gemessen. Es ist eine auffällige Wechselbeziehung zwischen der Widerstandspolare und der Grenzschichtdicke; jedoch bleibt bei CA-Werten unter 0.7 der Umschlagpunkt konstant. Deshalb kann die Z-Form der Polare nur erklärt werden als das Ergebnis einer Veränderung der Dicke der Ablöseblase.

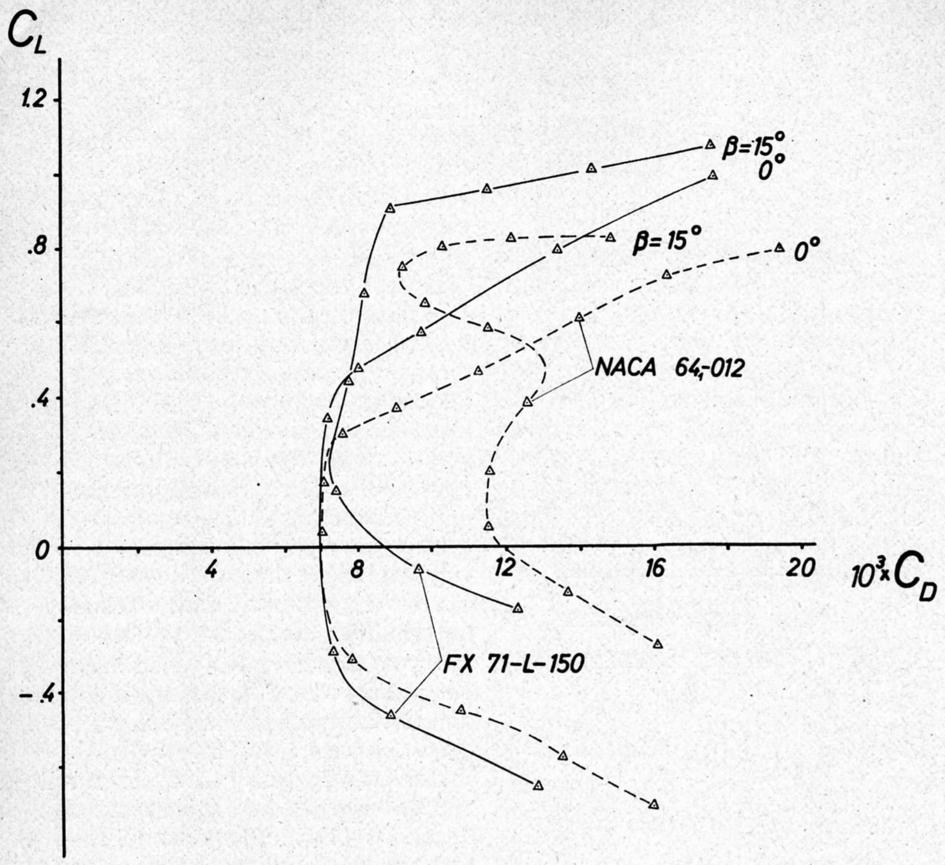


Fig. 5 Comparison of an NACA and an optimized airofoil for two flap settings $Re = 1.10^6$.

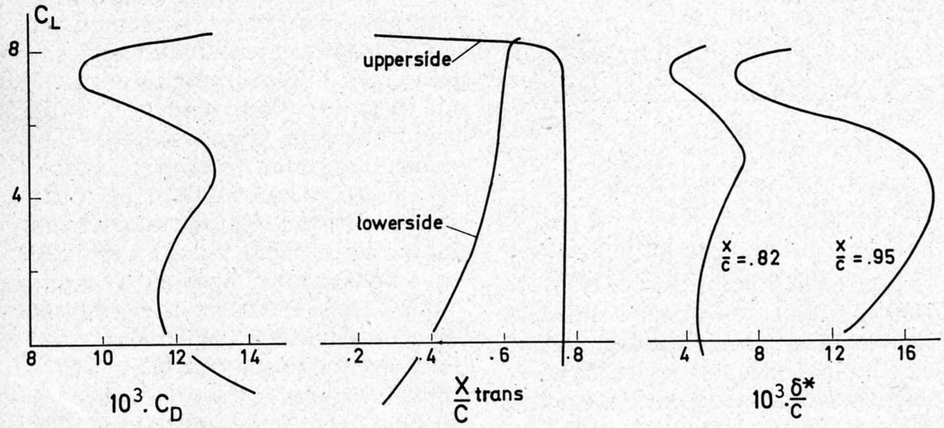


Fig. 6 Drag, transition and boundary layer displacement thickness of the NACA 64-012 with 15° flap angle. $Re = 1.0 . 10^6$.

So führt also die Auswahl eines Leitwerkprofils nach üblichen (klappenlosen) Profildaten auf den falschen Weg. Ein passender Entwurf für einen kleinen Klappenausschlag ist wirkungsvoller, besonders dort, wo die Klappe über längere Zeit ausgeschlagen sein muss (z. B. zu Trimmzwecken).

Sommaire

Les profils symétriques avec volets, tels que ceux qui sont utilisés pour les surfaces de contrôle, ont en général une traînée plus importante que les profils «lisses» cambrés par suite des effets de survitesse au bord d'attaque et à la charnière du volet. Toutefois, pour de faibles valeurs de l'angle de braquage et de la corde du volet, on peut éliminer les survitesses par un choix judicieux de la répartition des épaisseurs relatives.
Des tableaux fournissent les coordonnées de trois exemples de profils dont les résultats d'essais en soufflerie sont donnés sur les figures 1, 2 et 3. Les figures 1 à 6 comparent un de ces profils, le FX71-L-150/20, avec le NACA 64–012. Avec les volets rentrés le profil NACA a la même traînée minimale que le profil optimal bien que la bosse laminaire soit moins étendue. D'autre part, le profil NACA avec le volet braqué à 15° a non seulement une traînée minimale plus importante mais aussi une polaire de forme compliquée.
La position du point de transition sur les deux surfaces et l'épaisseur de la couche limite à proximité de l'articulation du volet et à l'extrados du bord de fuite ont été mesurées sur le NACA 64-012 équipé d'un volet ayant une corde de 25%. Il y a une corrélation étroite entre la traînée et l'épaisseur de la couche limite. D'autre part, la position de la transition est constante pour C_L supérieur à 0,7. Par conséquent la forme en Z de la polaire ne peut être interprétée que comme le résultat de la variation de l'épaisseur du bulbe.
En conclusion, on peut se tromper si le choix d'un profil de surface de contrôle est effectué à partir des caractéristiques d'un profil lisse. On peut établir un projet plus intéressant dans le cas d'un faible braquage du volet, notamment quand ce dernier doit être utilisé comme trim pendant de longues périodes.

References

1 F. X. Wortmann:
«Zur Optimierung von Klappenprofilen»
Schweizer Aero-Revue 44 (1969), p. 89–92
OSTIV-Publikation IX
Soaring 34 (1970), No. 5

2 F. X. Wortmann:
«Airfoils for the variable geometry concept»
Schweizer Aero-Revue 46 (1971), p. 303–305
OSTIV-Publikation X

3 F. X. Wortmann:
«Einige Laminarprofile für Segelflugzeuge»
Schweizer Aero-Revue 38 (1963), p. 647–651
OSTIV-Publikation VII
Soaring 28 (1964), No. 1