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THE QUEST FOR HIGH-LIFT

by
F. X. WORTMANN
University of Stuttgart
Stuttgart, Federal Republic of Germany

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THE QUEST FOR HIGH-LIFT

F.X.Wortmann
Institut für Aerodynamik und Gasdynamik
Universität Stuttgart, West-Germany

Abstract

Exploratory tests were done with four highly cambered single element airfoils designed for high lift and large lift-drag ratios at Reynolds numbers of one up to three millions. Windtünnel results show maximum lift coefficients of 2.0 - 2.4 and glide ratios of 150 - 200. The endurance ratio go well up to values of 200 - 250. Despite the high maximum lift the stall charakteristics can be considered as acceptable.

Introduction

The quest for High-Lift airfoils is at liberty depending on the flow environment i.e. Reynolds and Machnumber and refering to the goals which should be attained. Usually not only the maximum lift itself, but also the stall behaviour and the airfoil thickness and/or its pitching moment at high lift are of importance.

In other cases the glide ratio or the high endurance quality or the insensitivity to roughness are the most wanted attributes. Obviously there does not exist any solution which can do everything. It is the purpose of this paper to make some remarks on the design and the experimental investigation of some airfoils at Reynoldsnumbers of $1.0 - 3\cdot10^6$ which aim primarily to combinate high lift and large glide ratios. The airfoil thickness was held at 14 - 15 %.

Design Philosophy

As long as the local Machnumber stays below one the maximum lift is largely determined by the interaction of the upper surface pressure distribution and the boundary layer. The necessary pressure recovery can only be reached by a turbulent boundary layer. It is an old experience that a "concave" pressure distribution with continously decreasing gradients has a favourable effect on the development of the turbulent boundary layer (1). Therefore it is not surprising to see that this idea was applied also to the generation of high lift as shown in the publications of A.M. O.Smith (2), R.H.Liebeck (3,4) and A.I. Ormsbee (4).

The typical upside pressure distribution consists then of a more or less flat forward part followed by an abrupt pressure rise which flattens towards the trailing edge. Going to the extreme the pressure rise can be chosen in such a way that there is everywhere a nearly separating turbulent boundary layer. This is called an "optimized" pressure distribution.

The abrupt break in the pressure distribution implies one difficulty: if the boundary layer stays laminar up to this point then in all probability it will separate forming a laminar separation bubble. Due to the extremely severe pressure gradient the separation angle is large and even a short lenght of the bubble will lead to a large initial thickness of the turbulent boundary layer. Following a recent research of Dobbinga e.a. (5) the author (6) was able to derive an empirical relationship for the separation angle

$$\tan \gamma = \frac{64\,p}{re_s} \qquad (1)$$

with $p = \frac{\vartheta_s^2}{\nu}\frac{\Delta U}{\Delta S}$ and $re_s = \frac{\vartheta_s U_s}{\nu}$, where ϑ_s is the momentum thickness and U_s the velocity at separation. ΔU and ΔS are the velocity and length differences over the bubble length and ν is the kinematic viscosity.

In the case of a "concave" pressure or velocity distribution the effect of the initial thickness on the development of a turbulent boundary layer is much stronger than for pressure rises with smaller initial gradients. Typical examples for this observation can be found in (1) and (7). The author therefore prefers a more cautious approach by a closer control of the transition in order to avoid or at least to reduce the adverse effect of the laminar separation bubble.

One solution is the instability range, a region of small adverse pressure gradient inserted between the expected laminar and turbulent flow which will promote the transition. However the angle of attack changes the pressure gradients and usually this model of an instability range will only work for a certain combination of angle of incidence and Reynoldsnumber.

To improve the situation it is sometimes possible to approach such instability ranges for different angles of incidence at different positions of the airfoil chord, as can be seen in Fig.1. Here the inviscid velocity distribution on the upper side of the CL5 airfoil (see Fig.2) is given for c_L-values between 0 - 2.6. It can be seen that there exists always a rounded transition region in front of the steep gradients of the concave velocity distribution. Such a "rounded" region is not an ideal instability range and may not prevent a separation bubble at $Re < 5\cdot10^6$. However in any case the p-values in equation (1) are reduced and this implies a smaller initial thickness of the turbulent boundary layer.

On the other hand the concave distribution of the turbulent part of the boundary layer is no longer "optimized".

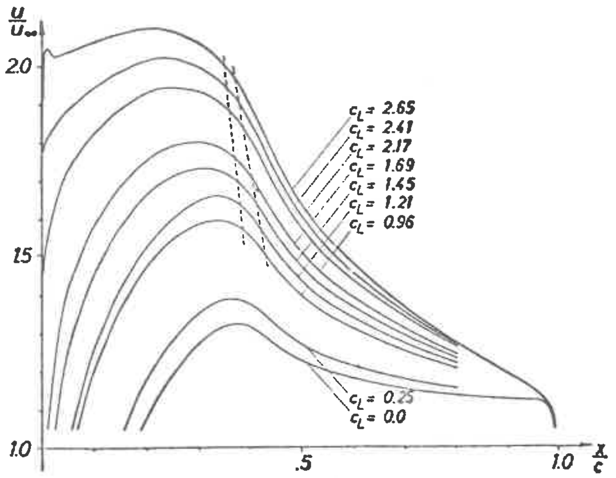

Fig.1 Upper side inviscid velocity distribution of the FX 74-CL5-140. The dotted lines enclose the observed length of the laminar separation bubble.

It can not be stated if the improved initial conditions outweight the non optimized pressure distribution. The Reynoldsnumber and the position of the pressure rise may be the prime variables. In windtunnel experiments the freestream turbulence level is certainly the most important quality which controls the transition.

Following the type of velocity distribution of Fig.1 two airfoils, the FX 74-CL5-140 and FX 74-CL6-140, were designed for high lift and large glide ratios. Fig.2 shows the form of these two airfoils. The only difference between them is the amount of camber, which is 9.9 % and 7.2 % respectively.

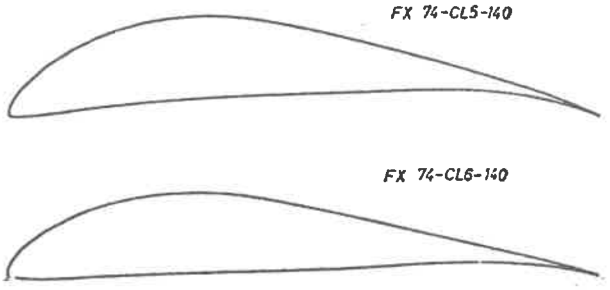

Fig.2 Contour of the FX 74-CL5-140 and FX 74-CL6-140 airfoil.

Experimental results

The windtunnel investigations which again were performed by D.Althaus (8) comprised four airfoils, the CL6 and CL5 and the FX 72-MS-150A and MS-150B. The two MS-airfoils are previously described in (9). All measurements were done with boundary layer control by blowing into the turbulent wall boundary layer of the two dimensional testsection. Fig.3 compares the maximum lift coefficients for Reynoldsnumbers between 0.7 - $3 \cdot 10^6$. All airfoils show the unusual behaviour of an increasing maximum lift with decreasing Reynoldsnumber. This can be interpreted as typical for the "fast trailing edge stall", which is caused by a fast moving transition in connection with a contiously high loaded turbulent boundary layer (see also Fig.5, 6 and 7).

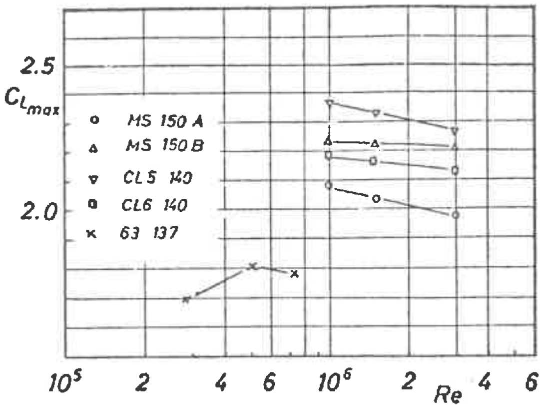

Fig.3 Maximum lift coefficient of the CL and MS airfoils as function of the Reynoldsnumber. The data of the FX 63-137 are taken from (8).

The CL5 airfoil approaches a maximum lift value of nearly 2.4. Fig.4 shows the glide ratios and the endurance figures $c_L^{1.5}/c_D$ as function of the Reynoldsnumber.

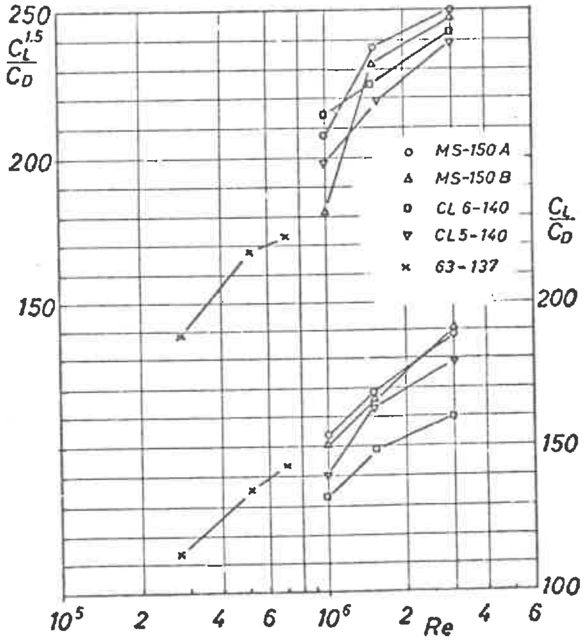

Fig.4 Twodimensional glide ratio (lower group) and endurance ratio of five airfoils as function of the Reynoldsnumber.

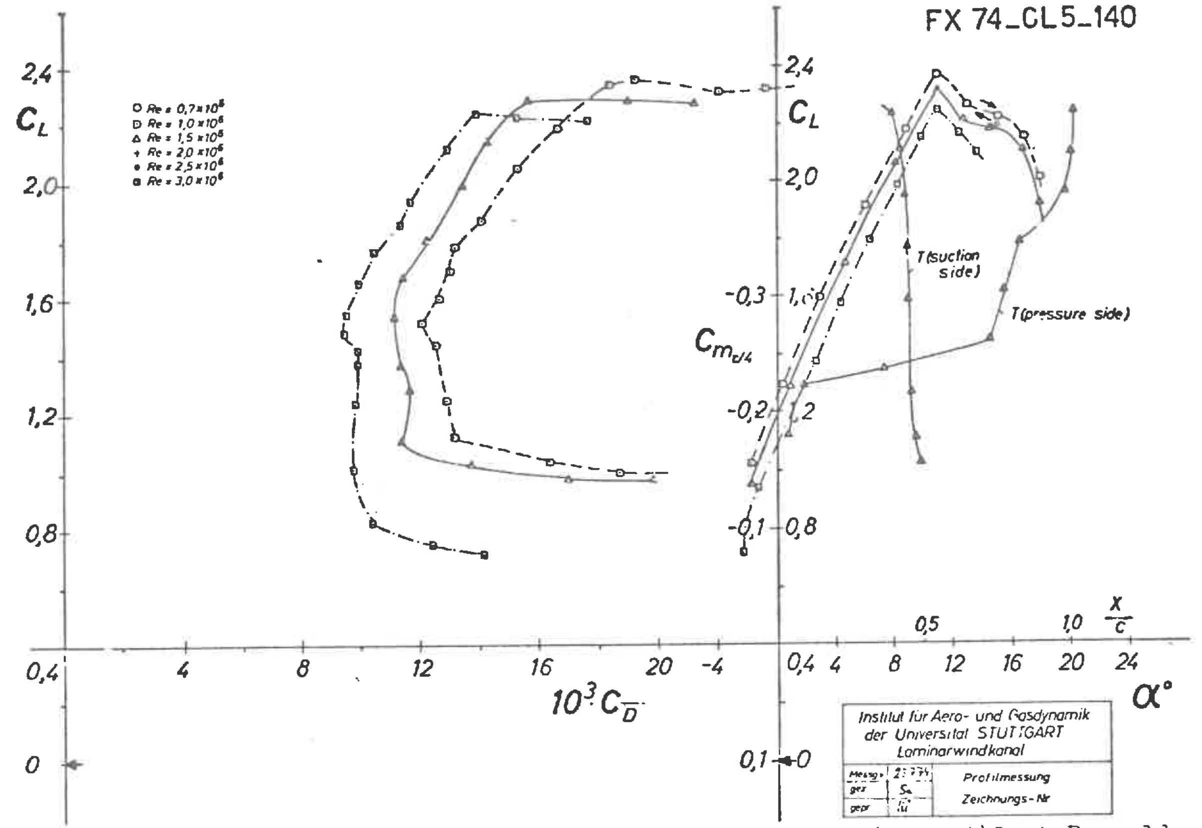

Fig.5 Drag polar, $c_L(\alpha)$ and transition position of the FX 74-CL5-140 at Reynolds-numbers of 1.0, 1.5 and 3.0·10^6.

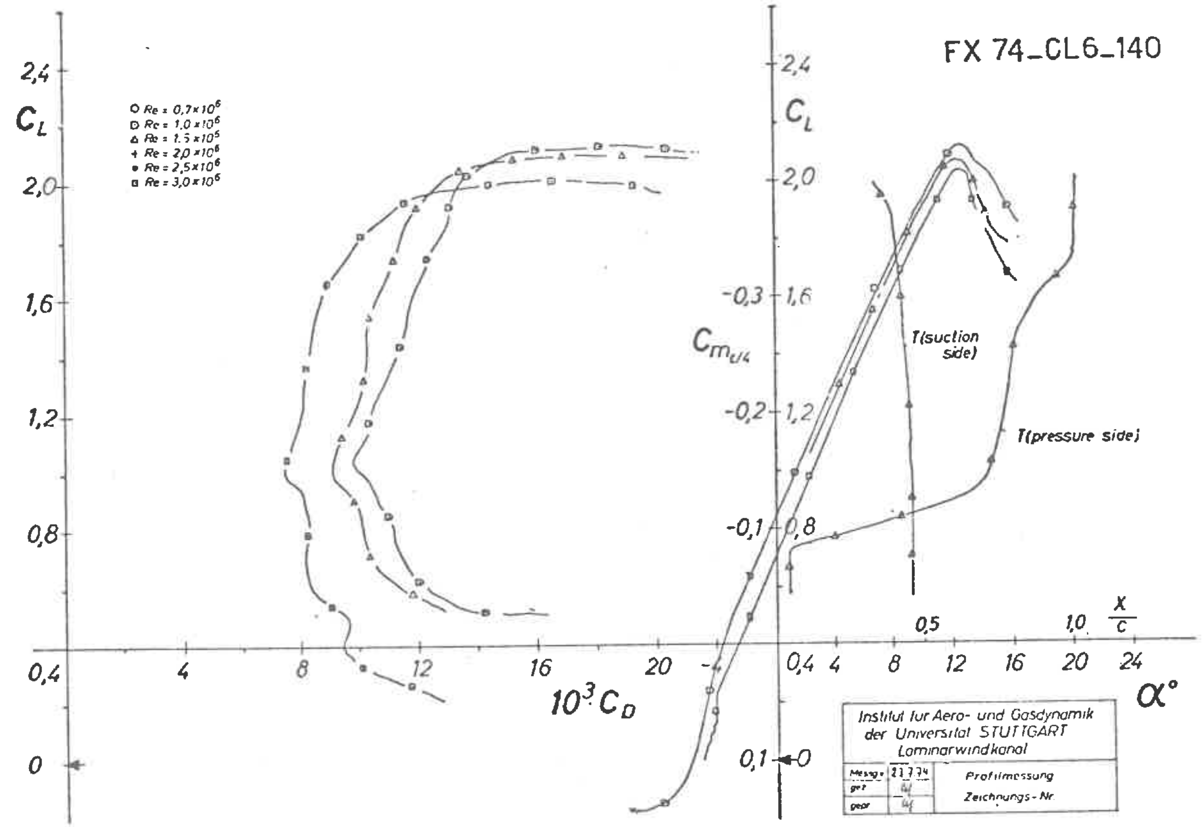

Fig.6 Drag polar, $c_L(\alpha)$ and transition position of the FX-CL6-140 at Reynolds-numbers at 1.0, 1.5 and 3.0·10^6.

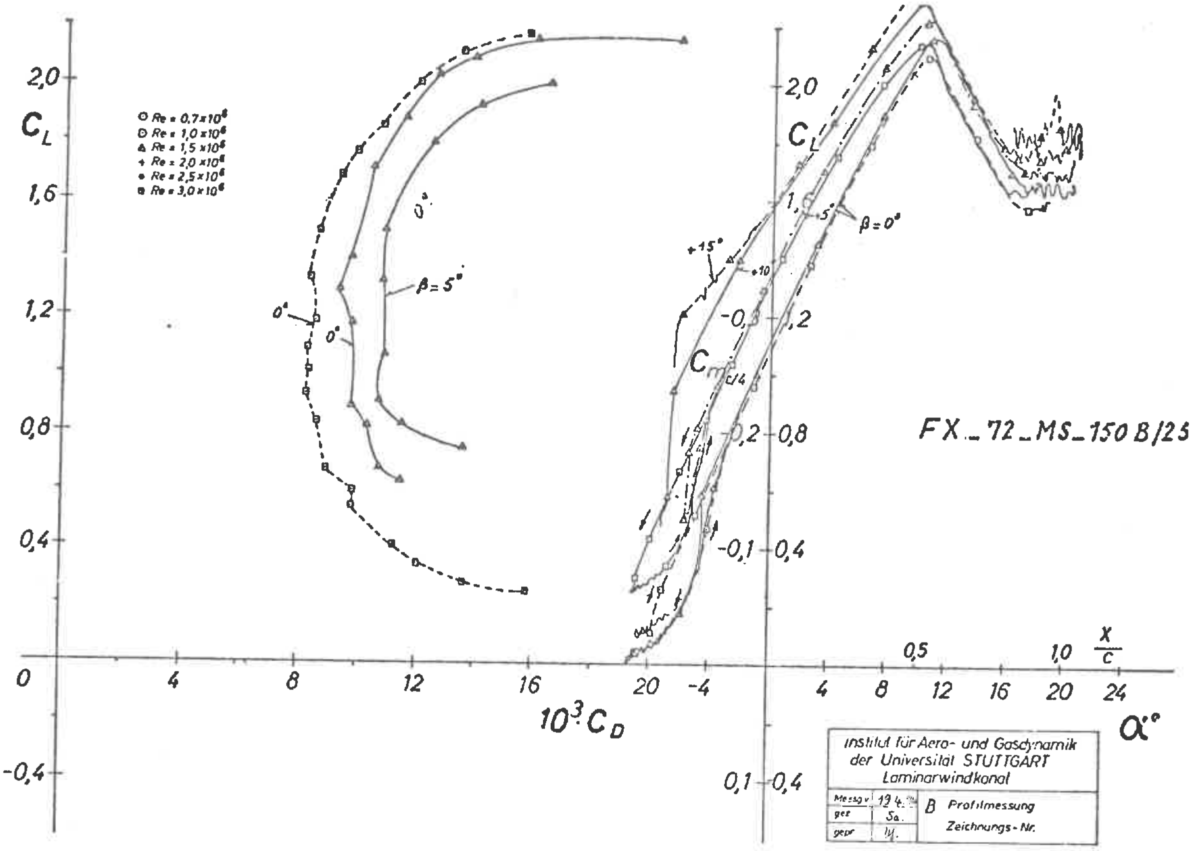

Fig.7 Drag polar, $c_L(\alpha)$ of the FX 72-MS-150B at Reynoldsnumbers of 1.5 and $3.0\cdot10^6$.

The individual windtunnel data including the dragpolar, the $c_L(\alpha)$ and the position of transition of the airfoils CL5, CL6 and MS-150B are represented in Fig.5, 6 and 7. All measurements hold true for smooth surfaces. Roughness at the nose will have a pronounced and detrimental effect since up to the maximum lift the transition on the smooth upper surface is behind the 40 % chord station. However such rather long laminar flow seems to be indispensible to get glide ratios between 150 and 200 in this Reynoldsnumber range. In Fig.7 some additional measurements are given with a 25 % chord flap. The flap has no benefits for the drag polar, but increases the lift for flap angles of ß larger than 10°.

Conclusion

Some exploratory experiments with single element airfoils of 14 - 15 % thickness have shown that it is possible to get lift coefficients between 2.0 - 2.4 even at low Reynoldsnumbers of about one million. The glide ratio of 150 - 200 at such high lift values are as high as the best values of more conventional airfoils. The endurance ratio for these airfoils reach well into values of 200 - 250. The stall characteristic is a fast version of the trailing edge stall.

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