VARIABLE WING CAMBER CONTROL FOR CIVIL TRANSPORT AIRCRAFT

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Abstract

The rapid inflation of fuel prices, their disproportional share in the Direct Operating Cost and the continously changing market requirements with respect to number of passengers, range, a.s.o. are a challenge for both aeronautical research and aircraft design. Developing an increasing number of variants and derivatives could not always be the economical solution for this problem. It is therefore necessary to look for technologies which not only provide potentials for performance improvements but also better operational flexibility for new aircraft designs. The Variable Camber Wing Concept described in this paper represents a promising contribution to this target. In addition to the considerable improvements in performances of all aircraft this method provides an extention of the buffet boundary normally limiting the potential for further increase in weight resulting from stretching the aircraft and/or extending the range.

I. Introduction

In spite of the high technological standard already realized in modern transport aircraft such as Airbus A310 the urgency to continously develop new technologies for future aircraft is beyond question. A comprehensive list of solutions which can be realized in short or longer term is displayed in numerous publications. In [1] some of the AI-technological aims are stated.

Beside the classical motivation to reduce the share of fuel in the direct operating cost which is, despite the fact that there is currently a stagnation in fuel prices, quite high [2] , other criteria for the execution of a development of an aircraft become more and more dominant. On one hand high development cost are limiting the number of developments and also the steps in which further developments can be carried out - on the other hand market requirement are subject to continous changes. This could cause that reaching production numbers adequate for an economical successful program is uncertain. For the time beeing there is one obvious solution for this problem - the development of variants and derivatives. In case of larger necessary modifications this is not always the cost effective solution. It is therefore desirable to look for new technologies which provide a flexible adjustment to the actual needs of the airlines. The variable camber wing technology described here after represents a contribution to the realization of the target to achieve a higher performance level and better operational flexibiliy under all conditions.

II. The Variable Camber Wing Concept

All over the world work on technological advances contributing to the improvement in aircraft performances is done. In Germany this research is included in the Civil Component Programme (civiles Komponenten Programm -ZKP-), sponsored by the German Ministry of Research and Technology. Investigations which are part of this programme carried out at MBB have shown the significant effect of camber on the performance characteristic of advanced transonic wing design. Even by means of a "fixed" modification of camber in conjunction with altered design criteria the aerodynamic standard e.g. the lift/drag ratio can be improved quite considerably. Furthermore limits such as buffet-onset and drag divergence Machnumber can be extended [2], [3], [4]. These investigations lead to the variable camber wing concept (see fig.1).

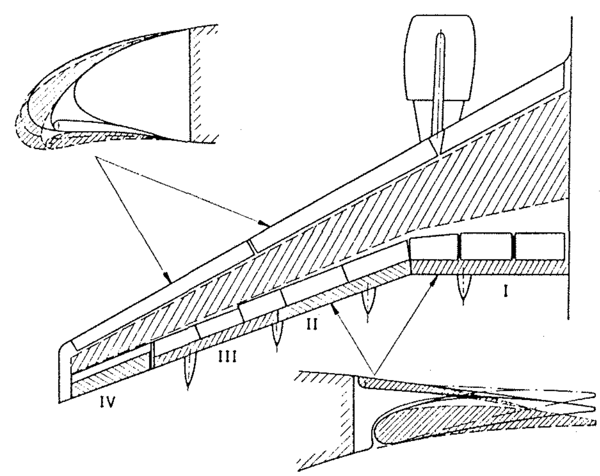

FIG. 1 VARIABLE CAMBER CONCEPT

A flexible skin allowing modifikation of camber over the entire chord is not a practical solution taking into account today's material and structural design technologies. Thus in the concept shown here solely the high lift devices and control surfaces already existing are used to provide the requisite camber variation.

The division of the wing trailing edge in the segments I to IV renders a camber variation along the span. In case of using additionally the leading edge devices the L.E has to show a division corresponding to the one at the trailing edge.

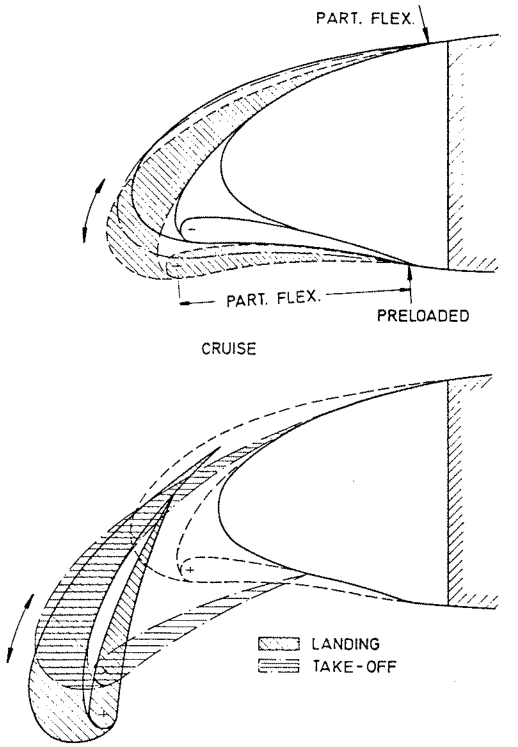

FIG. 2 PRINCIPLE SOLUTION FOR THE LEADING EDGE

The design principle for the leading edge is shown in fig. 2. This solution is characterized by the introduction of a partly flexible auxiliary flap at the lower surface of the profile which prevents the occourance of a slot in cruise and take-off position of the slats. In addition take-off and landing performances would be improved by this solution. But the practical realization suffers from a rather high degree of complexity.

Figure 3 shows the principle of providing the camber variation by use of the moveable parts at the trailing edge of the wing. In this case the suitable camber is obtained by corresponding operation of flaps and spoiler/airbrakes. For some flap systems limited fowler travel has to be accepted which could give an additional increase in operational flexibility due to the resulting increase in wing area.

According to the investigations carried out so far the combined adjustment of the leading and trailing edge devices will provide optimum results.-

The flexible skin mentioned before will not be a practical solution for civil transport aircraft wings within the foreseeable future. But nevertheless even a restriction to the trailing edge devices - because of the difficulties in designing the suitable system for the leading edge - will produce advantages in aerodynamic standard and operational flexibility of an aircraft sufficient for the introduction of this system.

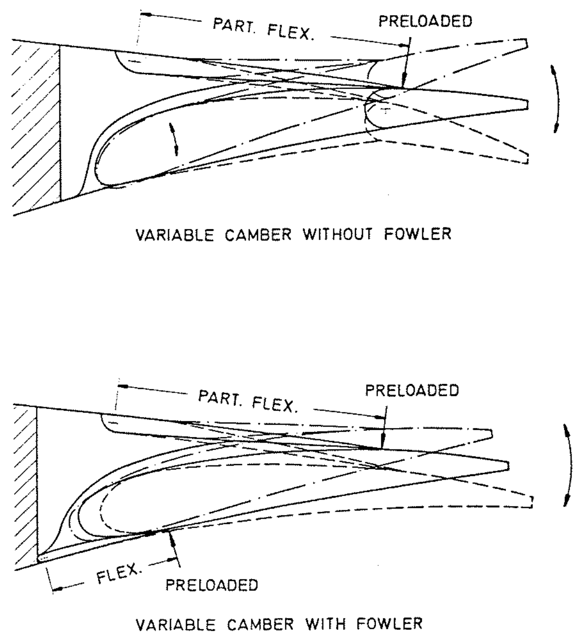

FIG. 3 PRINCIPLE SOLUTION FOR THE TRAILING EDGE

III. Aerodynamic aspects

The following example shows the effect of variable camber realized by means of deflection of the flaps and the control surfaces at the trailing edge of the wing on the aerodynamic characteristics of modern wing design. The results and conclusions are based on wind-tunnel tests. The wind-tunnel model used had exchangeable parts aft of the wing box representing the datum wing - for test comparison - and a number of camber configurations. The effect of discontinouities in the upper and lower contur in included in the results. However the sensitivity of profiles to those perturbations depends on the pressure distribution of the datum wing. For all camber configurations the upper and lower surface has to be lofted to the according flap position by adjusting the spoiler/airbrakes and the deflector door surfaces.

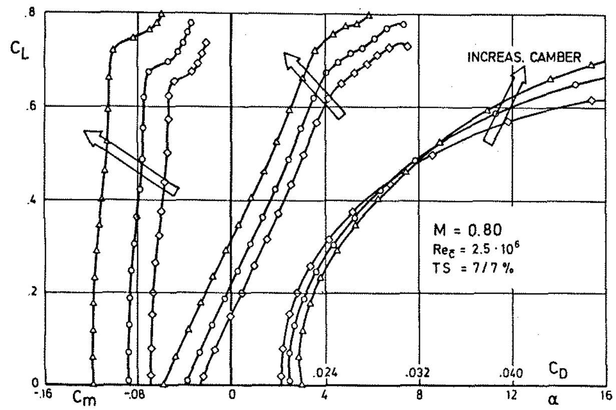

FIG.4 : EFFECT OF CAMBER INCREASE ON POLARS

The effect of variable camber on the lift, the pitching moment and the polars is shown in fig.4.

Beside a nearly parallel shift in lift with the expected increase in zero-lift, the characteristics remain unchanged over the angle of attack range. The lift increment results in higher buffet onset because the stronger nonlinearities occur at nearly the same angle of attack.

Similar to the lift curves the pitching moment characteristics are unchanged, however an increase in nose down pitching moment with increasing camber is observed, resulting in higher tail loads and trim losses.

Fig.4 also contains the drag polars for three camber configurations. A higher minimum drag value is measured due to the additional camber, however, a remarkeable decrease in lift depended drag is noticed leading to a crossover of the drag polars at about the design lift-coefficient of the datum wing. This results in a favourable drag reduction at higher lift. For the determination of the design loads it is important to mention that larger camber will be used normally in the region of high lift coefficients e.g. at higher altitudes.

The wind-tunnel results were trimmed and transformed to an aircraft configuration of the standard of civil transport for the early 90's. The change in trimmed lift/drag ratio is presented in fig.5 for a typical cruise Mch number. The curve indicated as VC is the envelope of a number of camber positions achieved by aft wing variation with a limited amount of fowler travel (about 5% at maximum camber) only.

An improvement in aerodynamic efficiency of about 3% is gained at the design C_L of the basis aircraft. The maximun L/D is shifted to higher C_L-values.

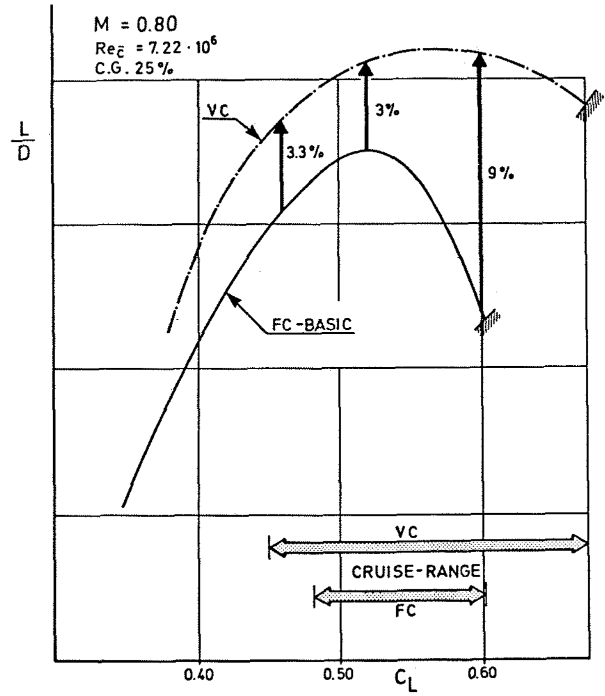

FIG.5 : VARIABLE CAMBER EFFECT ON L/D

An indication for the gains in the operational flexibility of the aircraft with variable camber is shown in fig.6.

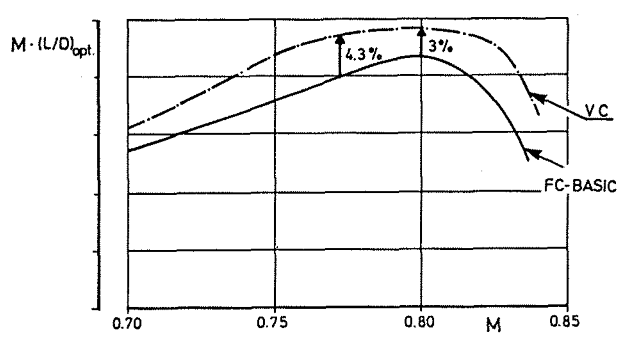

FIG.6: VARIABLE CAMBER EFFECT ON $M \cdot (L/D)_{opt.}$

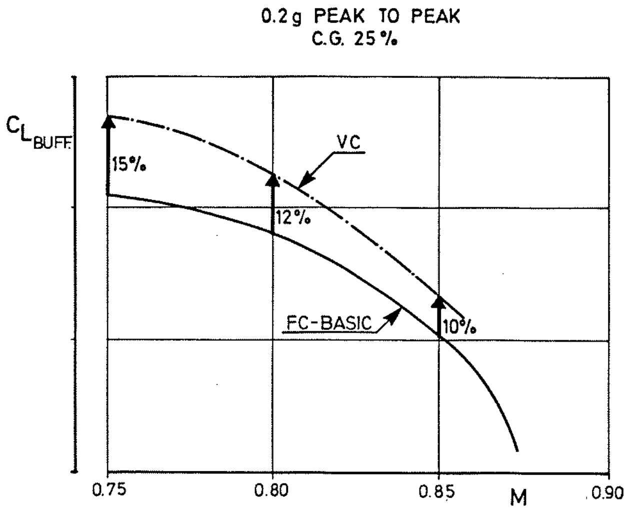

FIG.7 : VARIABLE CAMBER
EFFECT ON BUFFET

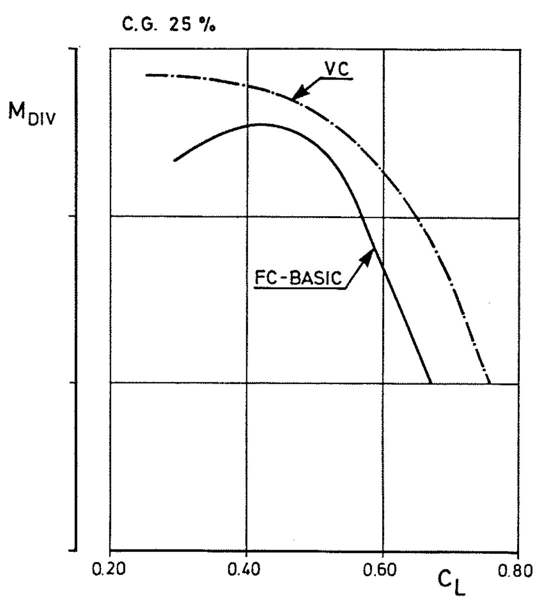

FIG.8 : VARIABLE CAMBER
EFFECT ON COMPRESSIBILITY

The results shown are confirmed by a comparison of the buffet onset and the drag divergence Mach number of the wing variable camber and those of the datum wing (see fig.7 and fig.8). The shift of maximum L/D previously shown fits to the buffet onset gains indicated here.

Beside the effect on the performance characteristics the spanwise camber variation provides the ability to change the spanwise lift distribution for the manoeuvre case accordingly. Fig.9 shows an example in the region of high lift-values (e.g. near buffet) where the root bending moment can be reduced by up to 12%. In the case shown the inboard wing is more cambered than the outboard wing and therefore aerodynamically better utilized.

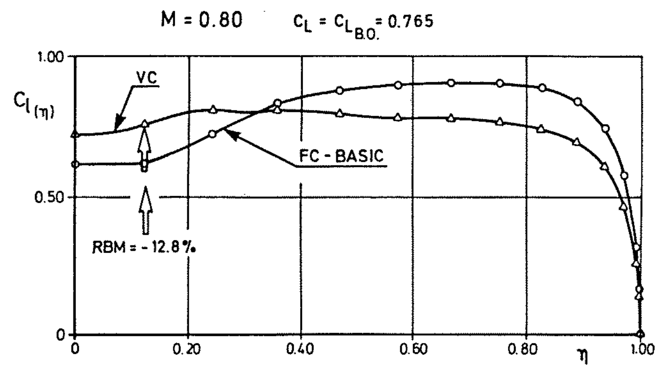

FIG.9 : VARIABLE CAMBER, MANOEUVRE-LOAD-CONTROL

IV. System Proposals

The primary function of the control surfaces at the wing trailing edge is to provide the required moments for the roll control and the lift increase necessary for take-off and landing. These general functions have to be superimposed to the concept outlined before. Under all possible operational and failure conditions the primary function should not be effected.

Thus conventional trailing edge configurations with flaps, spoiler/airbrakes and deflector or maintenance doors which are located at the lower surface between the rear spar and the leading edge of the flaps are used as the basic moveable parts for VC. In general all known flap systems can be adapted for the additional function of variable camber. Differences can only occur in the effective proportion of chord, the achieveable contour (i.e. the discontinouity) and in the complexity of the control system.

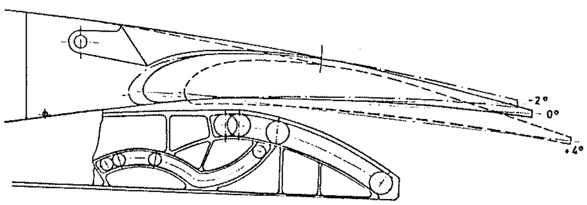

FIG. 10 OUTER FOWLER FLAP -TRACK SYSTEM-

The tracksystem shown in fig.10 has the advantage that by suitable design of the roller track a combination of camber and fowler effect can be achieved. In retracted position the flap has a negative deflection, e.g. the wing is decambered. During deflections the flap passes the neutral position (0° flapsetting). For this solution there is no need for an additional actuator for the camber variation.

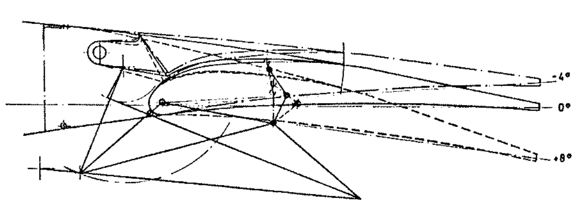

FIG. 11 OUTER FOWLER FLAP -LINKAGE SYSTEM-

Other systems, like the linkage system (see fig.11) developed by MBB, are characterized by the circular or elliptical deflection curve aggravating the combination of camber and fowler effect. Thus an additional actuator would be required for the L/D- and buffet control. The flap deflection required for camber modifikation can be provided either externally by lengthing and shortening respectively the lower link or by flap rotation using an actuator located in the flap structure.

In order to modify the camber over a portion of the chord as big as possible and to minimize the discontinouity in the contour means have to be provided to adjust spoiler and the fixed trailing edge surface to the flap deflection.

The generation of changes in spanwise lift distribution can be achieved in two ways. On the basis of the distribution of flaps and control surfaces at the wing trailing edge resulting from structural and system considerations a kind of stepwise camber-variation can be achieved, but losses in aerodynamic quality at the flap interconnection have to be accounted for. More optimum results could be obtained with a flexible flap structure which would provide a continous spanwise camber distribution.

V. Summary

The gains resulting from the application of the variable camber wing technology can be used in more than one way. These improvements can be used to achieve a better operational flexibility, a better performance standard, to increase the aircraft weight, e.g. allowing additional payload or more fuel for an extention in range.

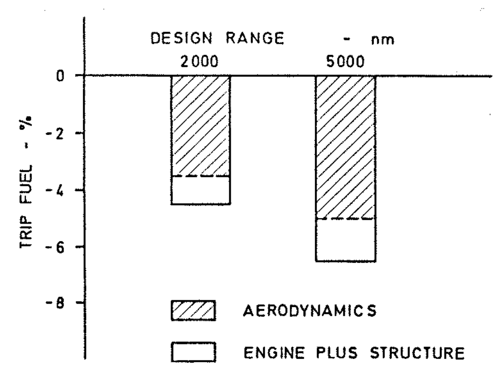

FIG. 12 BENEFITS FROM VARIABLE CAMBER

The combination of these concepts best suited for a practical project is depending on the product strategy adapted and the marlet requirements for the specific type of aircraft. Therefore the final assessment of the variable camber wing technology is only possible in a simplified way for a fictious example. On the basis of the performance improvements shown a comparison of an aircraft with a conventional wing design (i.e. compromised for design and off design cases) and ne with variable camber was carried out for a typical medium and long range mission. The results are shown in fig.12. Reductions in blockfuel up to 5.0 % indicate the potential gains provided by this technology.

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