NASA TECHNICAL MEMORANDUM NASA TM-75752

NASA-TM-75752 19800013773

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Translation of "Transsonischer Tragfluegel DFVLR-F4 als europaeisches Testmodell," DFVLR-Nachrichten, June 1979, pp. 36-39

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JANUARY 1980

STANDARD TITLE PAGE

1. Report No. NASA TM-75752	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
TRANSSONIC WING DFVLR-F4 AS EUROPEAN TEST MODEL

5. Report Date
January 1980

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

10. Work Unit No.

9. Performing Organization Name and Address
Leo Kanner Associates
Redwood City, California 94063

11. Contract or Grant No.
NASW-3199

13. Type of Report and Period Covered
Translation

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration, Washington, D.C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes
Translation of "Transsonischer Tragfluegel DFVLR-F4 als europaeisches Testmodell", DFVLR-Nachrichten, June 1979, pp. 36-39

16. Abstract
Commercial aircraft of the next generation, flying at high subsonic speeds in the neighborhood of 0.8 Mach will have transsonic wings. Such a wing, the DFVLR-F4 was designed and tested as a model in European transsonic wind tunnels and was found to give performance improvements over conventional wings. One of the reasons for the improvement was the reduction or elimination of compression shocks in the transsonic region as the result of improved wing design.

17. Key Words (Selected by Author(s))

18. Distribution Statement
Unclassified-Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

TRANSSONIC WING DFVLR-F4 AS EUROPEAN TEST MODEL

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GARTEur (Group for Aeronautical Research and Technology in Europe) is an institute with several expert groups in the area of aeronautics in Europe. In group 6 "Supercritical Wings" the Federal Republic of Germany, Great Britain, France, and the Netherlands are working on the technology of the transsonic wing whose function is to make subsonic travel more economical by savings of fuel, by increases in range, and by increases in pay load. At the last meeting of the GARTEur group 6 in November 1978 the decision was made to test the wing DFVLR-F4 as a wind tunnel model in several European wind tunnels. At the same time the GARTEur 6 partners are carrying out aerodynamic calculations on this wing shape; valuable results in the field of computers as well as in the area of wind tunnel technology are expected herefrom. The following report will briefly explain the technology of the transsonic wing and will report the efforts of the Institute for Aerodynamic Design which, within the framework of the civilian component program (ZKP) and in the program "airplanes" of the Research and Development Program of the DFVLR (German Research and Test Institute for Air and Space Travel) led to the design of the transsonic wing DFVLR-F4.

Technology of the Transsonic Wing

Commercial aircraft of the next generation flying at high subsonic Mach numbers of Ma=0.8 (e.g., the Airbus 310, figure 1) will have transsonic wings. Here a considerable fraction of the lift at the wing will be achieved by reduced pressures on the upper surface of the wing which are brought about by local supersonic fields. The potential for increasing lift with supersonic fields is generally known; however, a compression shock develops in conventional wings on the upper surface during transition from supersonic to subsonic conditions (figure 2, left). This often leads to flow separation and increased drag at the wing so that an economical and safe flight is not possible with conventional wings in the transsonic region.

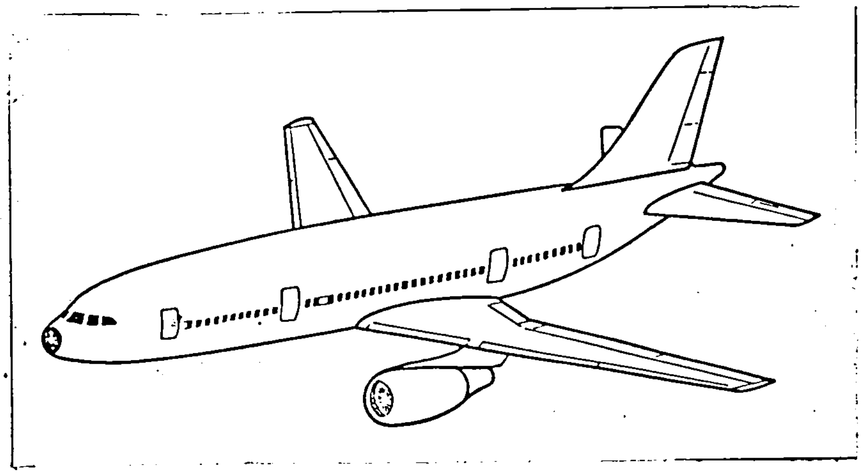
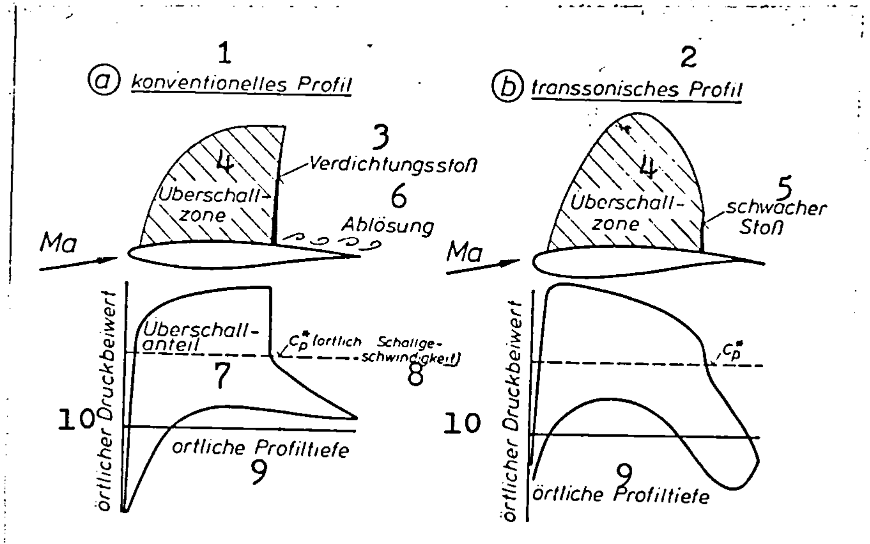


Figure 1: Typical commercial airplane for high subsonic speeds

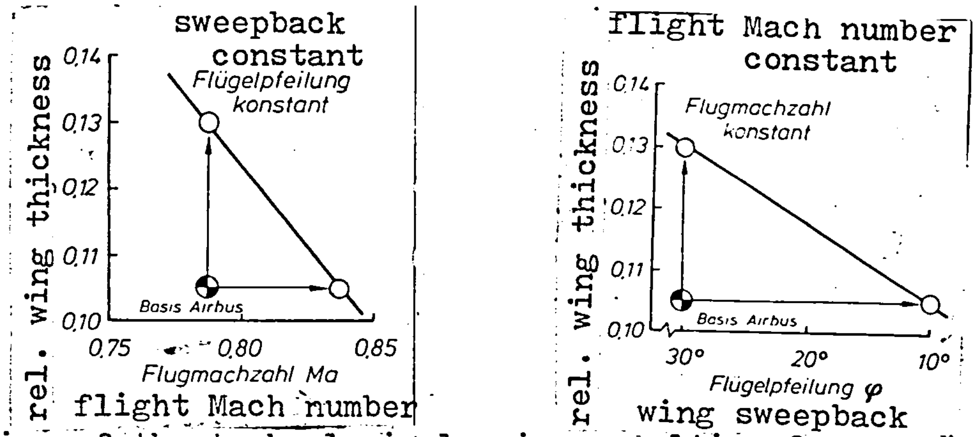
However, with the new wing shapes based on transsonic wing technology it has become possible to reduce extensively these unfavorable effects. Here pressure distributions at the wing are generated which have large supersonic contributions and which generally experience no or only very weak compression shocks (figure 2, right) and which thus produce a sensibly economic flight. These improvements in the aerodynamic characteristics can be utilized in various ways to increase the economics of commercial aircraft as can be seen schematically in figures 3 and 4.

Figure 3 shows that, by keeping the basic wing cross section and the flight Mach number constant (wing sweepback ϕ and flight Mach number Ma constant), the wing thickness can be increased, for instance, from a current δ =10.5% to δ =13% which results in a decrease in wing weight, resp. an increase in pay load; or if the wing thickness δ is kept constant, the flight Mach number Ma can be increased from, e.g., a current Ma=0.78 to Ma=0.83. This produces an increase in transport performance.



1 - conventional profile
2 - transsonic profile
3 - compression shock
4 - supersonic zone
5 - weak shock
6 - flow separation
7 - supersonic portion
8 - local sonic velocity
9 - local wing depth
10- local pressure value

Figure 2: Flow field and pressure distribution on conventional and on the transsonic wing.



Figures 3 and 4: Evaluation of the technological gains resulting from the use of the transsonic wing (left, for unchanged wing cross section; right, for constant flight Mach number).

An additional possibility is shown in figure 4. By keeping the wing thickness δ constant the additional aerodynamic potential can be utilized to reduce the wing sweepback from, e.g., a current $\phi = 30^{\circ}$ to $\phi = 10^{\circ}$. This again produces constructional advantages for the wing which, because of the shortened wing strut, lead to a weight saving. The question as to which of the possibilities or combinations thereof discussed here should be used in an individual case depends on the demands made of the aircraft.

Civilian Component-Program and Wing Design of the DFVLR

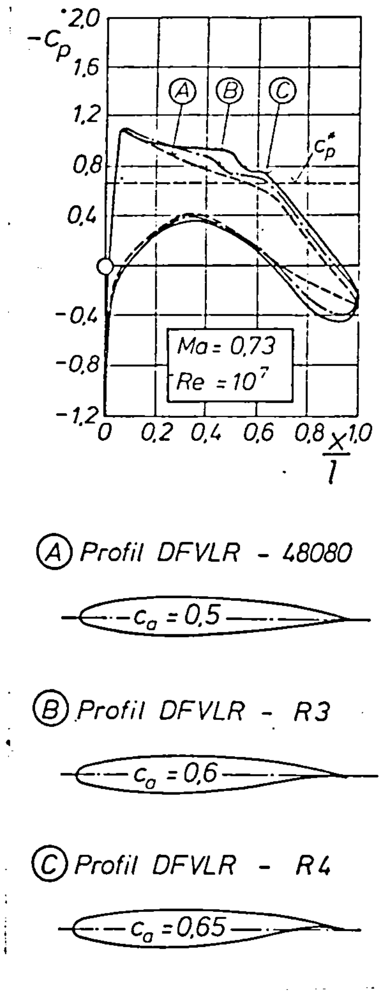


Figure 5: Development of the transsonic wing DFVLR-F4.

In 1975 the ZKP "Wing section" panel of the BMFT was initiated for the purpose of safety and further development of the transsonic wing and of decreasing the development risks in new airplane projects; this panel, for one, has the goal of constructing an experimental carrier with a transsonic wing for the large transsonic wind tunnel S1 of the ONERA in Modane, South France, and for another, attempts to improve the aerodynamic development processes. In this program considerable contributions were made not only by the German aircraft industry which, in the course of their efforts, leaned heavily on the Airbus variation 310, but also by the DFVLR within the framework of its FuE program "airplanes". For this purpose the Institute for Aerodynamic Design, in addition to a continued development of aerodynamic design methods in the years 1975 to 1978 also produced the design of a transsonic wing for a demonstration airplane similar to the Airbus and tested it with good results in the transsonic wind tunnel of the DFVLR in Goettingen.

Transsonic Wing DFVLR-F4

For the development of a transsonic wing one must proceed in steps so that initially the wing cross section for a new airplane does not differ basically from that of today's planes (compare figure 1). It will be a swept-back wing of high aspect ratio. However, the wing shape will change decisively since "supercritical" or transsonic wing shapes with a relatively blunt nose and a flattened upper wing surface and increased curvature in the rear wing section will be employed here. Designs of commercial aircraft are mostly directed toward the cruise condition, i.e., the requirement exists to transport a pay load over a given distance at a given flight altitude with a given flight speed. If one starts from the premise that the size and the cross section of the wing were optimized by preliminary tests of wing loading, sweepback angle, aspect ratio, and taper with respect to wing weight and fuel costs, then a design criterion for the lift coefficient and the flight Mach number of the wing can be derived.

For airplanes with large aspect ratios Λ =10 under consideration here, the pressure distribution at the wing is determined, size wise, by the cross-sectional shape of the wing in the direction of the flight. Thus first a wing shape, always depending heavily on the demands made of the wing, is developed so that first the complex structure of a three-dimensional wing can be expressed as a two-dimensional problem.

Figure 5 shows the development of a transsonic wing shape. Starting with a profile design DFVLR 48080 (case A) with an average lift coefficient of c_a=0.50, a profile (cases B and C) is developed, by appropriate modifications, which satisfies the design requirements for the wing. Here the lift coefficient of c_a=0.50 is increased stepwise to c_a=0.65 for the case of profile C without noticeable deterioration of the profile characteristics. This is achieved, as shown by the pressure distribution c_p along the profile depth x/1, by an expansion of the shock-free supersonic field and by a change of the pressure distribution on the lower wing surface near the trailing edge. By means of special shapes in this region, pressure differences between the upper and lower surfaces are achieved near the trailing section which contribute in great measure to the lift and which are known as "rear loading". The decision as to whether a profile is suited for the given job is made after extensive design calculations with a high-speed computer using various incident-flow conditions and by experimental check tests in the wind tunnel.

Figure 6 shows the results of such a pressure-distribution test made on the profile DFVLR-R4 in the transsonic wind tunnel of the DFVLR in Braunschweig. For the profile incident-flow Mach number of Ma= 0.73, reduced because of the sweepback effect, the pressure distribution along the profile depth x/l is shown for two lift coefficients c_a and is compared with the design calculations. Here it is shown clearly that, on the one hand, the measurements confirm the desired pressure distributions, but that, on the other hand, the design calculations also give very reliable results. The profile DFVLR-R4, shown here, was used as the base profile for the wing design.

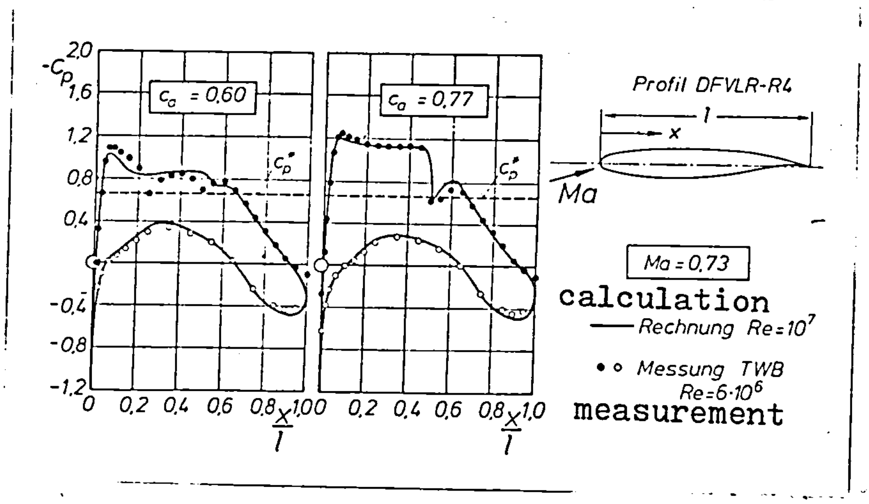


Figure 6: Experimentally determined pressure distributions at the wing DFVLR-R4.

The design of the wing was carried out under the following points of view:

- minimal induced drag through elliptical distribution of lift along the span width;
- utilization of the good properties of the profile DFVLR-R4 through realization of the profile pressure distribution, also on the wing
- inclusion of airplane fuselage in the wing design.

With the aid of a turbulence-ladder process in which the wing is composed, for theoretical potential calculations, of many horseshoe-shaped vorices arranged in ladder form, a preliminary design was first made which produced information with regard to the distribution of distortions along the span width, i.e., the mutual twisting of the individual wing cross sections. After the extent of this distortion distribution had been determined, the wing contour was generated by building up the afore-described profile DFVLR-R4 into four definition sections of the basic wing cross section.

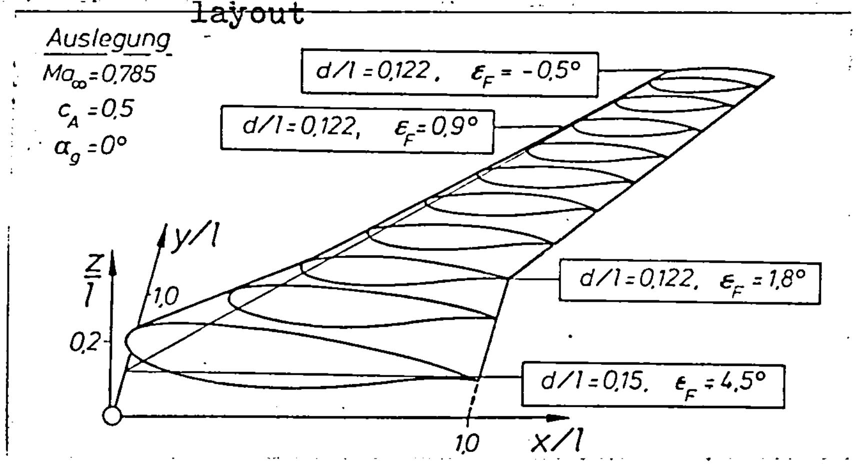


Figure 7: Construction of the wing DFVLR-F4

Figure 7 shows several profile sections in a perspective drawing of the wing where the four definition sections are specially marked by the local thickness $\delta = d/l$ and by the distortion angle ε_F. Between these sections the wing contour was established by linear fairing. In the area of the transition from fuselage to wing the profile-shaping of the wing was improved by iterative after-calculations of the wing using a three-dimensional process for calculating the wing-fuselage layout in the transsonic range. The wing DFVLR-F4 thus developed was also tested by extensive calculations in the off-design region, i.e., for flight numbers and angles of attack deviating from those specified. An example of a pressure distribution, obtained by calculations, for an initial cruise condition at a flight Mach number of Ma=0.785 and a lift coefficient of c_A=0.50 is shown in figure 8. This shows clearly that a local supersonic field with shock-free recompression exists along the entire span width.

The wing designed here was fabricated as a half-model of a wing-fuselage layout and was tested in the transsonic wind tunnel in Goettingen. The model (figure 9) has a half-span width of s= 587.77 mm and a fuselage length of L= 1192 mm. Pressure tap holes for the measurement of the static pressure along the contour are drilled in 36 places each at each of the five span width sections 1 to 5. An example of such a pressure distribution measurement is shown in figure 10. The pressure distribution along the local wing depth is plotted, for each of the five span widths, in the perspective wing cross section drawings. It can be seen that for the incident-flow conditions Ma= 0.785 and c_A= 0.5 there appears, even experimentally, an extended local supersonic field which exhibits only weak compression shocks.

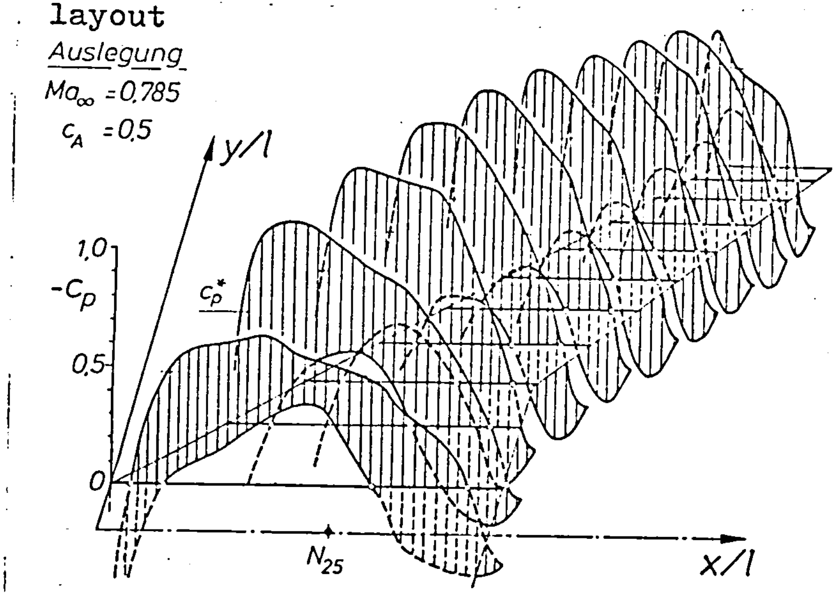


Figure 8: Computationally determined pressure distribution at the DFVLR-F4 wing at the initial conditions.

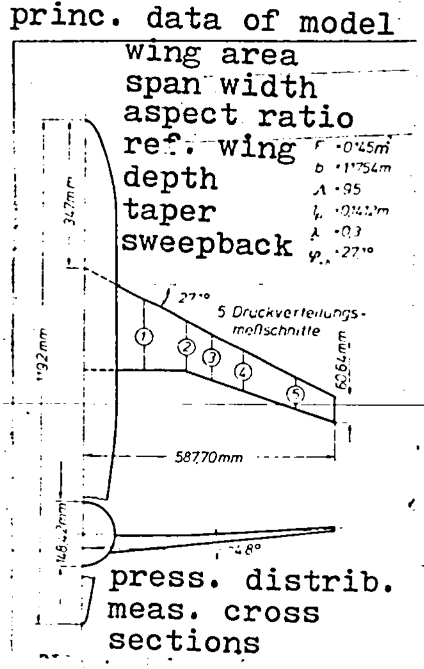


Figure 9: View of the wind tunnel model

A summarizing calculation of the wing DFVLR-F4 can be made with the aid of figure 11. In a lift coefficient-Mach number diagram lines of constant aerodynamic efficiency are plotted with the parameter (c_A/c_W) Ma= constant which relates lift, drag, and flight Mach number to one another. The higher the plotted value, the better is the aerodynamic efficiency of the wing. In the region around Ma= 0.78 and c_A= 0.5 to 0.6 one can detect a maximum which includes the design value. Thus the experimental testing of this wing shows that the highest aerodynamic efficiency is attained in the range of the design requirements. Also plotted in figure 11 is the curve showing the increase in drag which limits, in an economic sense, flight at still higher Mach numbers.

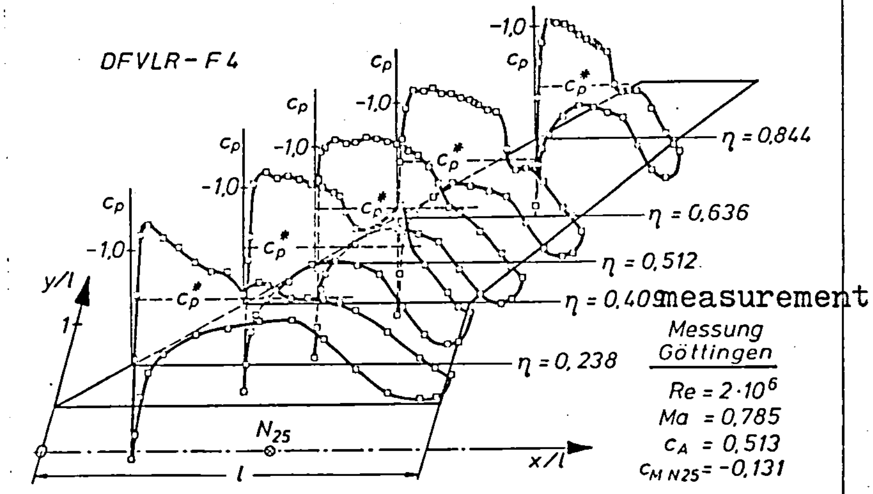


Figure 10: Experimentally determined pressure distribution at the DFVLR-F4 wing at the initial conditions.

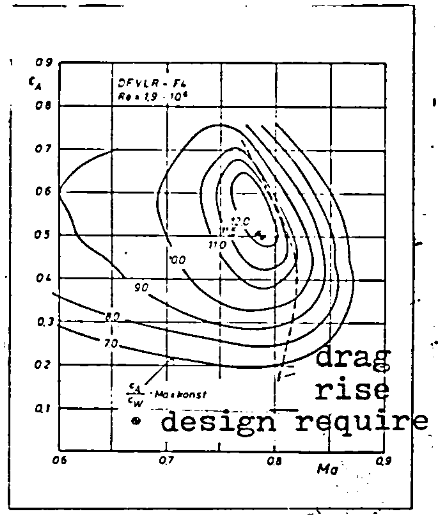


Figure 11: Measured performance values of the aerodynamic quality of the DFVLR-F4 wing.

These results clearly point out that the wing DFVLR-F4 satisfies the design requirements and that, on hand of the existing knowledge of the transsonic wing, improvements are possible in the aerodynamics of today's commercial aircraft. For the wing DFVLR-F4 the potential of the transsonic was utilized in a direction whereby, compared to the Airbus standard, the average wing thickness was increased from δ = 10.5% to 12.5% and the wing sweepback was decreased from $\phi = 30^\circ$ to $\phi = 27^\circ$.

Outlook

Based on the good results obtained and on the fact that a wing of the latest technology was developed here, the GARTEur group "supercritical wings" decided to use the DFVLR-F4 wing as a test model. This wing will be tested during 1979/1980 in the transsonic wind tunnels of the ONERA (France), the NLR (Netherlands), and the RAE (England) as a full model. Valuable information with regard to wind tunnel corrections are expected from this. Theoretical calculations for this wing, made concurrently, are expected to give an overview of the state of the aerodynamic, transsonic computer methods in Europe.