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Dr. Otto Wagner

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16. Abstract

This paper discusses the profile wing design for supercritical structures. Emphasis is placed on the flow of air surrounding the wing and variations in flow fields are examined. Modifications to the profile for flight below transonic level are presented that increase the uplift pressure and permit the achievement of critical Mach numbers on the order of 0.85. The uplift pressure along the upper side of the profile is compared for a classical and a Peaky profile. A comparison of classical and supercritical wing cross sections indicates a flatter upper side, a larger nose radius, and a thicker profile to the supercritical wing.

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THE SUPERCRITICAL PROFILE OF THE SUPERCRITICAL WING

Dr. Otto Wagner* **/105

Over the last few years, the supercritical wing has been discussed more and more. This is a profile shape of a wing, which has proven itself at high speeds below the speed of sound. Therefore, we can predict that it will have an interesting future in future aircraft.

In the last few months, the term "supercritical wing" has often been mentioned in specialist literature in connection with the new features to be introduced on aircraft. From the many examples, we will only mention the fact that for 1981 test flights of the German-French subsonic aircraft Alpha Jet have been announced and that it has a new supercritical wing. The firm McDonnell Douglas is carrying out a test of the supercritical wing within the energy efficient transport (EET) program supported by NASA.

The reason why the supercritical wing is so interesting will now be discussed, that is, the properties or advantages which it has compared with conventional wings.

INTRODUCTION

The supercritical wing is especially well suited for the transsonic flight range (the flight speed, therefore, is close to the speed of sound). This is because, compared with previously used wings, it has more favorable aerodynamics (especially regarding the aerodynamic drag). This is achieved by a modified profile shape which then brings about a more favorable flow around the wing.

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For better understanding, we will discuss the most important points of the flow around a profile.

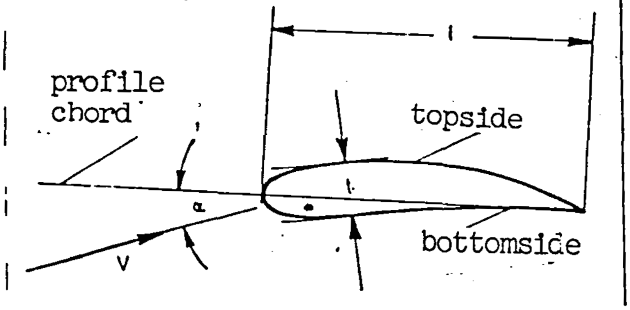

Figure 1: l: profile length; t: largest profile thickness; α: incident angle of attack; V: incident speed (equals flight speed); profile chord: connects the leading edge and the trailing edge

FLOW AROUND A WING PROFILE

If a wing is cut open perpendicular to its leading edge, for example, one obtains an intersection surface which is called wing profile or profile for short.

In Figure 1 we show a profile in a flow having a speed V which is coming in at the angle of attack α. Due to the flow which results, speeds occur along the top side of the profile which are greater than V. The pressure there is then smaller than the pressure of the undisturbed flow (far away from the aircraft). On the bottom side of the profile, one attempts to make the speeds smaller than V (at least, they have to be smaller in general than those along the profile topside). This makes the pressure on the average along the profile bottom side larger (for positive angles of attack) than on the profile topside. This is the reason for the aerodynamic force which is decomposed into the components lift and drag. The velocity increase along the topside usually increases as the profile thickness increases and as the angle of attack increases. /106

Depending on the magnitude of the incident flow speed V, one distinguishes three types of flow fields around the wing profile:

(Since the flow phenomena depend on Mach number, we will now transfer from the incident flow speed V to the Mach number Ma which is found by dividing V by the corresponding speed of sound).

a) The incident Mach number is so small that in the profile flow $\mathrm{Ma} > 1$ does not occur anywhere. We then have pure subsonic flow.

b) The incident Mach number is so large that in the profile flow, we have $\mathrm{Ma} < 1$ nowhere. Then we are talking about pure supersonic flow.

c) When in a purely subsonic flow the incident Mach number is increased continuously, we then obtain a case where on the profile topside the speed increases so much (assuming positive angles of attack) that locally the speed of sound is reached (that is, $\mathrm{Ma} = 1$) (usually close to t in Figure 1). The corresponding incident Mach number is called the critical lower Mach number. It forms the boundary to the downside for the transsonic Mach number flight range. For unswept wings with thick subsonic profiles, the lowerlower critical Mach number is at $\approx$ 0.6. When the incident Mach number is increased above the critical Mach number, then a supersonic region similar to Figure 2 is created along the topside (this is true for conventional profiles). A composite flow field is then created out of the pure subsonic flow. In this flow, a particle of the fluid is first accelerated along the indicated streamline until it reaches $\mathrm{Ma} = 1$ at the sonic line. Then it enters the supersonic region, and it then emerges with a compression shock again and enters the subsonic region for conventional profiles. There it is delayed again.

If the incident Mach number is increased further, one obtains the upper critical Mach number (second boundary of the transsonic flight range) where $\mathrm{Ma} < 1$ occurs nowhere over the profile, assuming a sharp leading edge of a supersonic profile. In the case of

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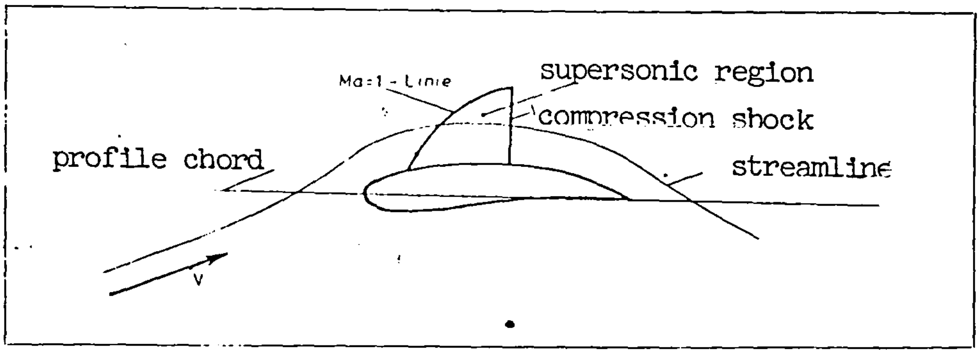

Figure 2. 2

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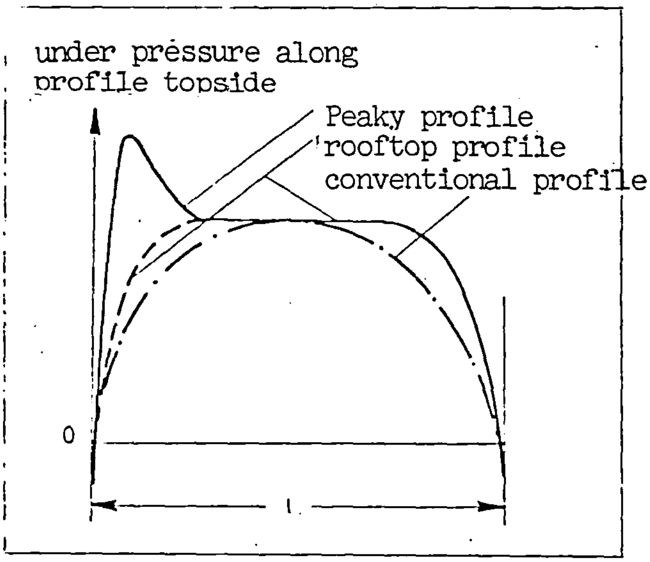

Figure 3. Pressure distribution of different profiles

blunt leading edges of subsonic profiles, there is then only a local subsonic region around the profile node .

The pure flow fields a) and b) are accessible to theoretical analysis. The composite field c) of the transsonic flight range requires a very difficult analytical treatment:

FLIGHT NEAR THE TRANSSONIC FLIGHT REGION

Earlier experimental tests of conventional subsonic profiles showed that the compression shocks resulted in a strong drag increase, shock-induced flow separations from the profile and elastic oscillations of the aircraft (so-called buffeting). For this reason, for commercial aircraft using the conventional subsonic profiles at the time, whose cruise speed was in the high subsonic range, it did not make sense to have a flight condition with the typical transsonic effects. However, in order to achieve the highest possible subsonic cruise speed, these aircraft were equipped with swept wings. In this case, there is only a small velocity component perpendicular to the leading edge which specifies the aerodynamic forces and effects. In addition, these profiles were modified so that the pressure distribution along their topside between the profile nose and the largest possible backward position was filled up (see Figure 3). In this way, the underpressure and, therefore, the lift was increased. As a consequence of this, for these rooftop profiles, the angle of attack at the design point was reduced and, therefore, the lower critical Mach number could be increased even more. Low critical Mach numbers on the order of 0.85 were achieved with these swept wings.

The under-pressure variation of the rooftop profiles is achieved by a very flat contour of the profile topside. Another /108 possibility, however, which is only used conditionally, of increaseing the critical Mach number and, therefore, the speed in the subtranssonic range, is to reduce the profile thickness. However, this is associated with the following disadvantages: 1) as a rule, a higher structural weight; 2) a reduced wing fuel tank capacity and 3) a reduction in the desired laminar boundary layer downstream of the profile nose.

With these measures, the lower critical Mach number and the cruise flight Mach number slightly below it were increased. Because of the profiles used at the time and the unfavorable transsonic effects, the transsonic flight range nevertheless remained unusable for most aircraft.

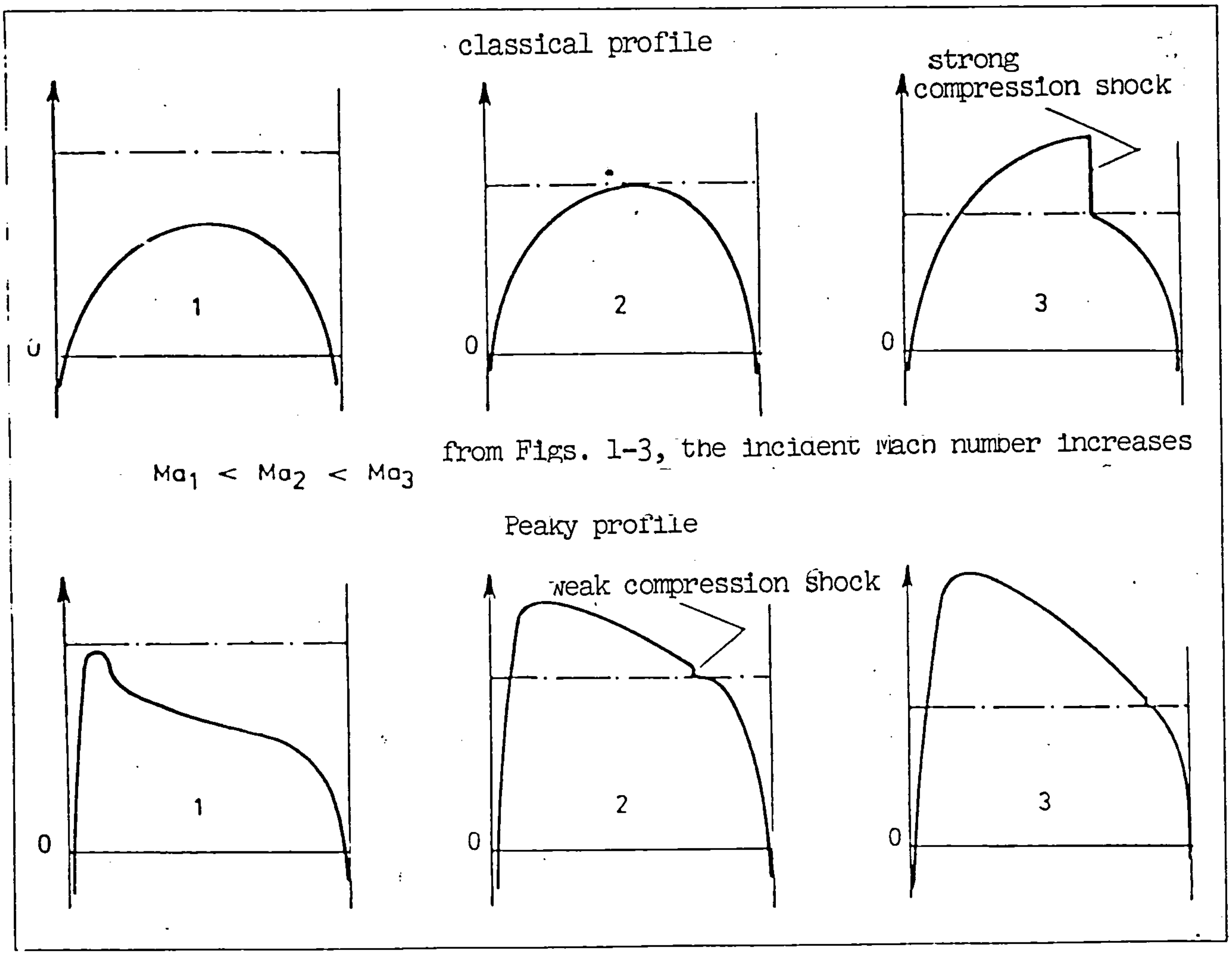

Figure 4. Ordinate: under-pressure along profile topside; abscissa: profile length; — . — . — = critical under-pressure, at which Ma = 1 occurs (for large under-pressures Ma > 1)

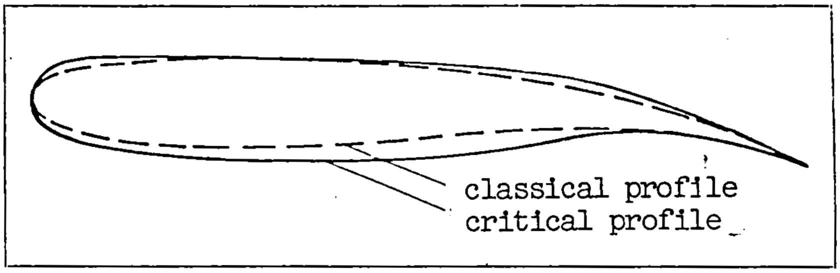

Figure 5. Classical and supercritical profile.

THE SUPERCRITICAL PROFILE

At the end of the 50's, H. H. Pearcey carried out wind tunnel tests at the National Physics Laboratory in England. He found that in his test flights the braking on the profile topside in transsonic flows occurred for the most part without a compression shock. This was in a strong contradiction to the classical thermodynamics, according to which the transition from supersonic flow to subsonic flow was always related with a compression shock which meant drag (which was also confirmed with using conventional profiles).

In addition, he found that for profiles with a very pronounced peak in the subsonic pressure variation in the region of the profile nose (suction peak Δ) so-called Peaky profiles, it was possible to achieve a lower critical Mach number which was about 0.02 larger than for rooftop profiles (under-pressure variation of the topside of a Peaky profile is shown in Figure 3). This under-pressure variation is achieved with a nose radius which is increased compared with the rooftop profiles.

Figure 4 shows the under-pressure variations along the profile topsides for a classical profile and a Peaky profile. As can be seen, in the classical profile there is a strong compression shock when the flow is changed from supersonic flow to subsonic flow. In the case of the Peaky profile, the local supersonic flow is delayed for the most part without losses and is finally brought down to subsonic speeds with a weak compression shock.

Since the main barrier for a transsonic cruise speed, the compression shock at the profile topside with all of its negative accompanying phenomena, was found not to be a necessary evil, design methods were developed which allowed one to design profiles in which the transfer from local supersonic flow to subsonic flow occurs without a compression shock. Profiles having this property are called supercritical profiles.

At the present time it is possible to expand the experimental information using theoretical methods. It is possible for a specified transsonic designed flight state to determine the corresponding supercritical profile (the existence of a transsonic flow without shocks has also been demonstrated).

THE SUPERCRITICAL WING

The knowledge obtained for the supercritical profile (two-dimensional case) has been used for the design of a supercritical wing (on the wing, there is also a transfer from the supersonic range to the subsonic range without a compression shock in the transsonic flight range). This knowledge was expanded to the third dimension. Over the last few years, this problem has been worked on experimentally and theoretically. In the middle of the 70's, R. T. Whitcomb was given the Wright Brothers Memorial Trophy for his wind tunnel tests of the supercritical wing at the Langley Research Center at NASA.

COMPARISON OF PROFILES

In conclusion, we will compare the profile shapes of a classical wing section and a supercritical wing section (see Figure 5).

The important differences include the following:

1) the topside of the supercritical profile is flatter, especially the front part;

2) the nose radius of the supercritical profile is larger, which is a consequence of the under-pressure peak in the region of the profile nose;

3) the supercritical profile can be thicker. This means one can achieve a reduction of the structural weight and an increase in the wing tank capacity;

4) for the underside contour of the supercritical profile shown in Figure 5, the rear part is curved more strongly in a concave manner. In this way, the pressure in this region increases (so-called rear loading) which leads to an increase in the lift for the same speed and the same angle of attack.

SUMMARY

The supercritical profile and the supercritical wing allows one to use incident speeds in a transsonic flight range above the lower critical Mach number, without having compression shocks for the transfer from the supersonic speed to the subsonic speed. In this way, the usual drag increase which occurs in this flight range (increased fuel consumption) and buffeting are for the most part avoided. At the same time, the cruise speed is increased compared with flight close to the lower transsonic flight range.

REFERENCES

[1] Jerry Mayfield: Energy Efficiency Research Growing. Aviation Week & Space Technology, November 12, 1979.

[2] Phased Technological Gains Expected. Aviation Week & Space Technology, November 12, 1979.

[3] Germans to Test Transonic Wing on Modified Dornier Alpha Jet. Aviation Week & Space Technology, April 7, 1980.

[4] New NASA Projects. Flug Revue + Flugwelt, 1/1975.

[5] Klaus Oswahtsch: Wave Propagation over Wings. Zeitschrift fuer Flugwissenschaften und Weltraumforschung. vol. 3, 1979.

[6] J. C. Gibbins. An Empiric Correlation of some Transonic Aerofoil Characteristics.Journal of Aircraft, Sept.-Oct. 1966.

[7] M. S. Cahn, J. R. Garcia. Transonic Airfoil Design. Journal of Aircraft, February 1971.

[8] C. F. Newberry, R. B. Holloway, G. E. Bergmann, M. D. Nelsen. Impact of Advanced Technology on Jet Aircraft. 13th Anglo-American Aeronautical Conference, June 1973.

[9] E. L. Houghton, R. P. Boswell. Further Aerodynamics for Engineering Students. Edward Arnold (Publishers) Ltd. London 1969.

[10] Hermann Schlichting, Erich Truckenbrodt. Aerodynamics of the of the Airplane. McGraw-Hill, New York 1979.