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REDUCTION OF PROFILE DRAG BY BLOWING OUT THROUGH PEG HOLES IN AREAS OF STREAMLINE SEPARATION BUBBLES

K.H. Horstmann and A. Quast

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16. Abstract This paper investigates the problem of streamline separation bubbles on aircraft profiles and fuselages. The additional drag is examined in relation to increased angle of incidence and unusually high wall sheer stress. A reduction in the separation bubble and a decrease in drag is obtained with pneumatic turbulators that blow ram air out of 0.6 mm pilot tubes at a distance of 16 mm. The pneumatic models can be implemented at various positions and are also found to be effective after the position of separation.

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REDUCTION OF PROFILE DRAG BY BLOWING OUT THROUGH PEG HOLES IN AREAS OF STREAMLINE SEPARATION BUBBLES

K. H. Horstmann and A. Quast /*2

SUMMARY

For Re numbers below about 5×10^6, laminar separation bubbles can occur on aircraft profiles and aircraft bodies. Figure 1 shows typical pressure distributions along the bottom side of a profile. This is laminar separation and subsequent turbulent reattachment.

Figure 2 gives a preliminary drawing of the flow conditions in a laminar separation bubble. Also Figure 2 shows the paint figure in the region of a separation bubble.

Laminar separation bubbles are undesirable because they can increase the profile drag by means of mechanisms which are not yet sufficiently explained, indicated in Figures 3 and 4.

According to Figure 5, due to the laminar separation bubble, there is an additional underpressure Δc_p, which is perpendicular to the contour and, therefore, has the component $\Delta c_p \cdot \sin(\vartheta + \alpha)$ in the flow direction. Accordingly, the additional drag of a laminar separation bubble would have to increase with angle of attack. An additional explanation for the drag of separation bubbles could be the fact that the turbulent wall shear stress is exceptionally large after reattachment. A combination of both mechanisms is also possible.

It is natural to make the boundary layer turbulent already ahead of the separation point using turbulators. This method is known but has not yet found a practical application. In the case of pneumatic turbulators according to Figure 6, ram air is expelled

*Numbers in margin indicate pagination of foreign text.

from Pitot tubes through 0.6 mm tubes separated by 16 mm*. Already with small amount coefficients c_Q on the order of 10^{-5} +, the laminar-turbulent transition is brought about, the laminar separation bubble vanishes and the drag is reduced. These bubble turbulators, as they will be called in the following, have the following advantages compared with mechanical turbulators:

- Amount coefficient is adjustable or can be turned off. /3

- Blowing can occur at various positions.

- Blowing turbulators are also effective, if air is blown out behind the separation point.

The effect of blowing out on the pressure distribution on the bottom side is shown in Figure 7. The laminar separation bubble is eliminated for the most part. Figure 8 shows that by using the bubble turbulators, the drag of the profile shown here can be reduced up to 15%.

Figure 9 shows the profile polars for various blowing positions. The most favorable location is found to be at $x/l = 0.76$. Figure 10 shows the drag variation for various amount coefficients. Here we have a flat optimum at $c_Q = 7 \times 10^{-6}$. With increase in Re number, this optimum value of c_Q becomes smaller and is about zero for $Re = 3 \times 10^6$. It seems that the required blowing volume flux per wing area has to be constant. Blowing hole separation and diameter have not yet been varied. Up to the present time, blowing was always perpendicular to the contour.

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*For a wing chord of 500 mm.

+The additional drag by momentum loss is therefore $\Delta c_W = 2c_Q = 2 \times 10^{-5}$ but the drag coefficient of a profile is 5×10^{-3}.

Figure 11 shows the drag variation as a function of Re number of a modern profile with destabilization segments by means of dash lines. This touches the envelope of optimally designed profiles at the design point. At Re numbers above the design point, the transition point then migrates forwards along the unsuitable destabilization path and therefore the drag becomes greater because of the unnecessary short and laminar running lengths. For Re numbers below the design point, laminar separation bubbles form because of insufficient destabilization. The separation bubbles are larger, the smaller the Re number. In this range, the blowing turbulators can be used. Figure 12 shows the measured drag variation of a profile designed for Re = 3×60^6 (practically no destabilization path). One can clearly see that by using bubble turbulators, the most favorable working range in terms of drag is substantially enlarged. By using bubble turbulators, one approaches the envelope given in Figure 11 for optimally designed conventional profiles with destabilization paths. /4

Profiles with bubble turbulators require stable pressure distributions, such as for example, that of the underside given in Figure 1. It is important that the destabilization paths which are difficult to calculate become unnecessary. Also, they can only be correct for the design point. In addition, a profile for bubble turbulators is much less sensitive to manufacturing accuracies than one with such destabilization paths. Within certain limits, it could also be insensitive to surface contamination.

Aircraft are easily equipped with bubble turbulators. The glider SB-12 of Akaflieg Braunschweig has flown already for three-quarters of a year with such turbulators. Bubble turbulators are insensitive to rain and do not become noticeably contaminated.

Figure 13 shows the polar of the turbulator curved flap profile for gliders (DFVLR-HQ 17/14,38), compared with the previously known best profiles. The representation is for the prevailing Re numbers which a glider actually uses. One clearly sees the drag reduction which is especially important for low lift coefficients.

Bubble turbulators can always be used where the local Re number is smaller than 3×10^6, which is for profile Re numbers below 5×10^6. The Re numbers could even be greater if nose separations were used as well. Bubble turbulators are especially effective below $Re = 2 \times 10^6$.

Therefore, we have the following applications:
- aircraft for general aviation
- gliders
- helicopter rotors
- propellers
- flow machines
- wind wheels
- model aircraft

Because of the fact that low Re numbers sometimes occur, it seems that the area of flow machines is very promising for this kind of application. For commercial aircraft, bubble turbulators are probably not of interest in the form described. /5

At this point we would like to thank Professor V. Ingen and his coworkers at the TH Delft for his very careful measurements and support.

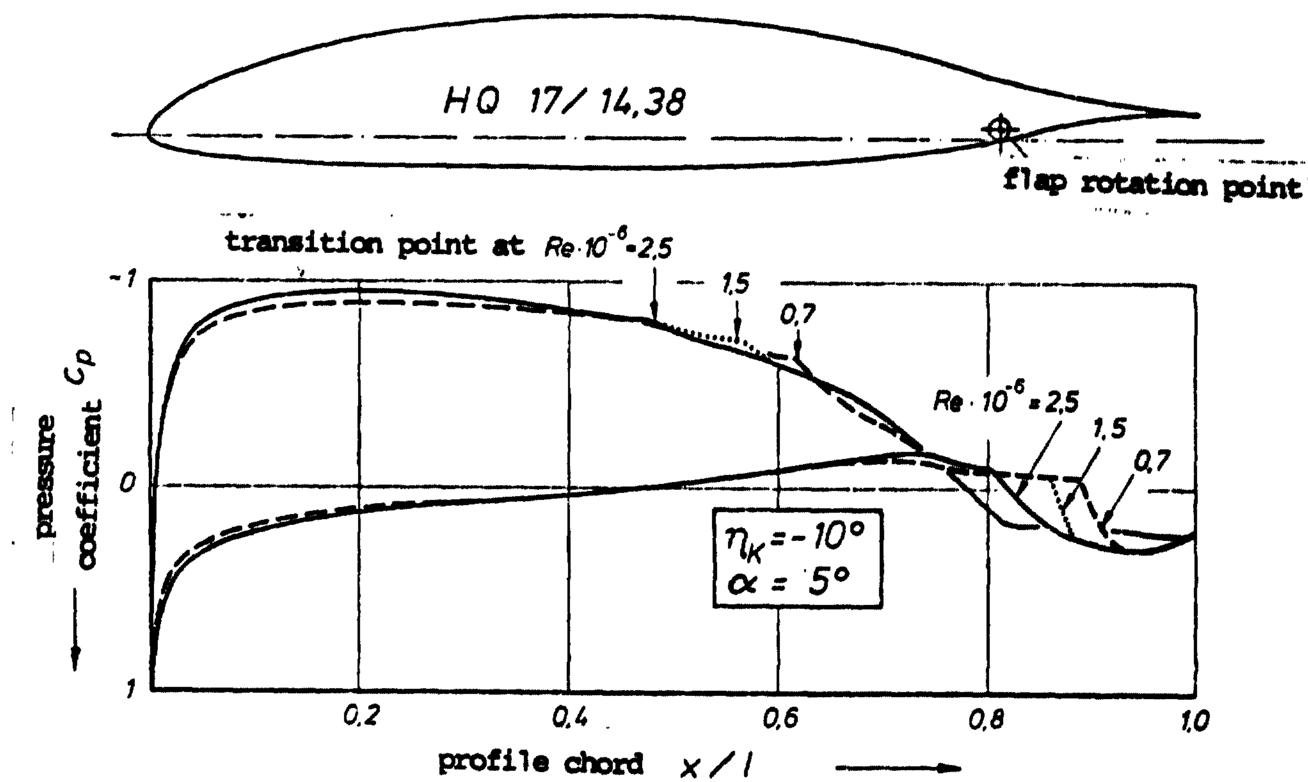

Figure 1. Size of the laminar separation bubble as a function of Re number for the curved flap profile DFVLR HQ 17/14,38 (measurement: TH Delft).

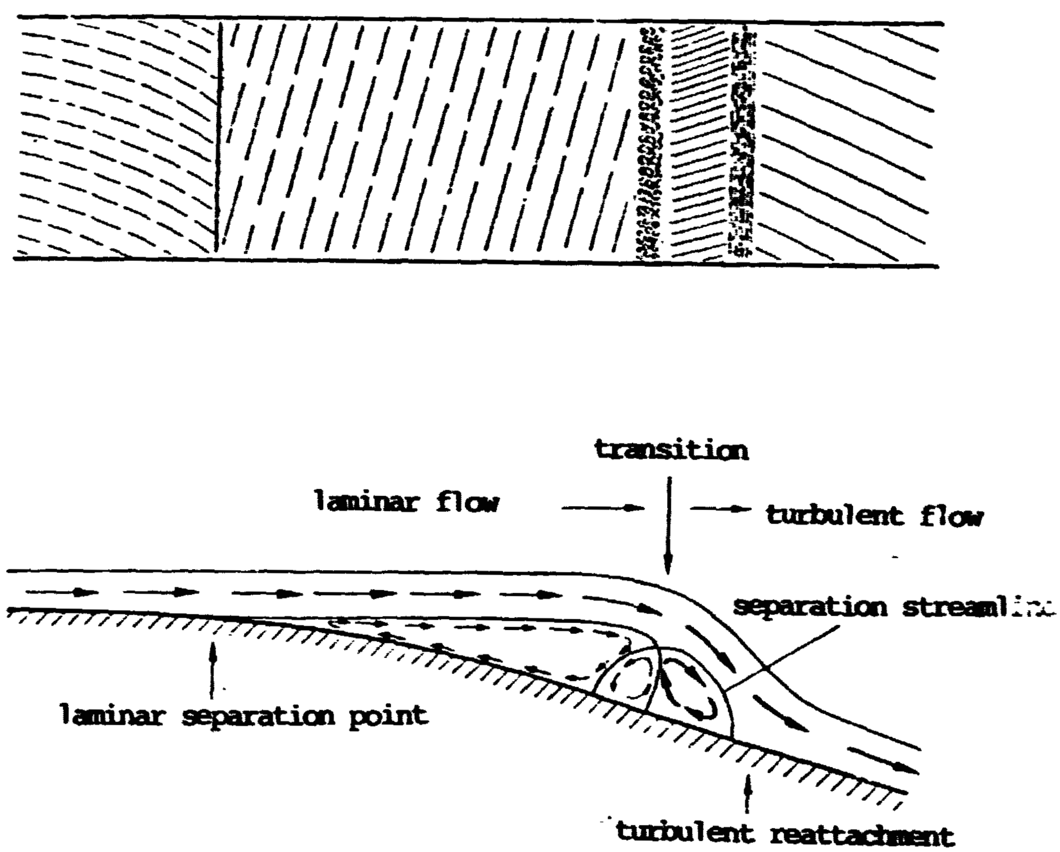

Figure 2. Diagram of the paint image and presumable flow conditions in the region of a laminar separation bubble.

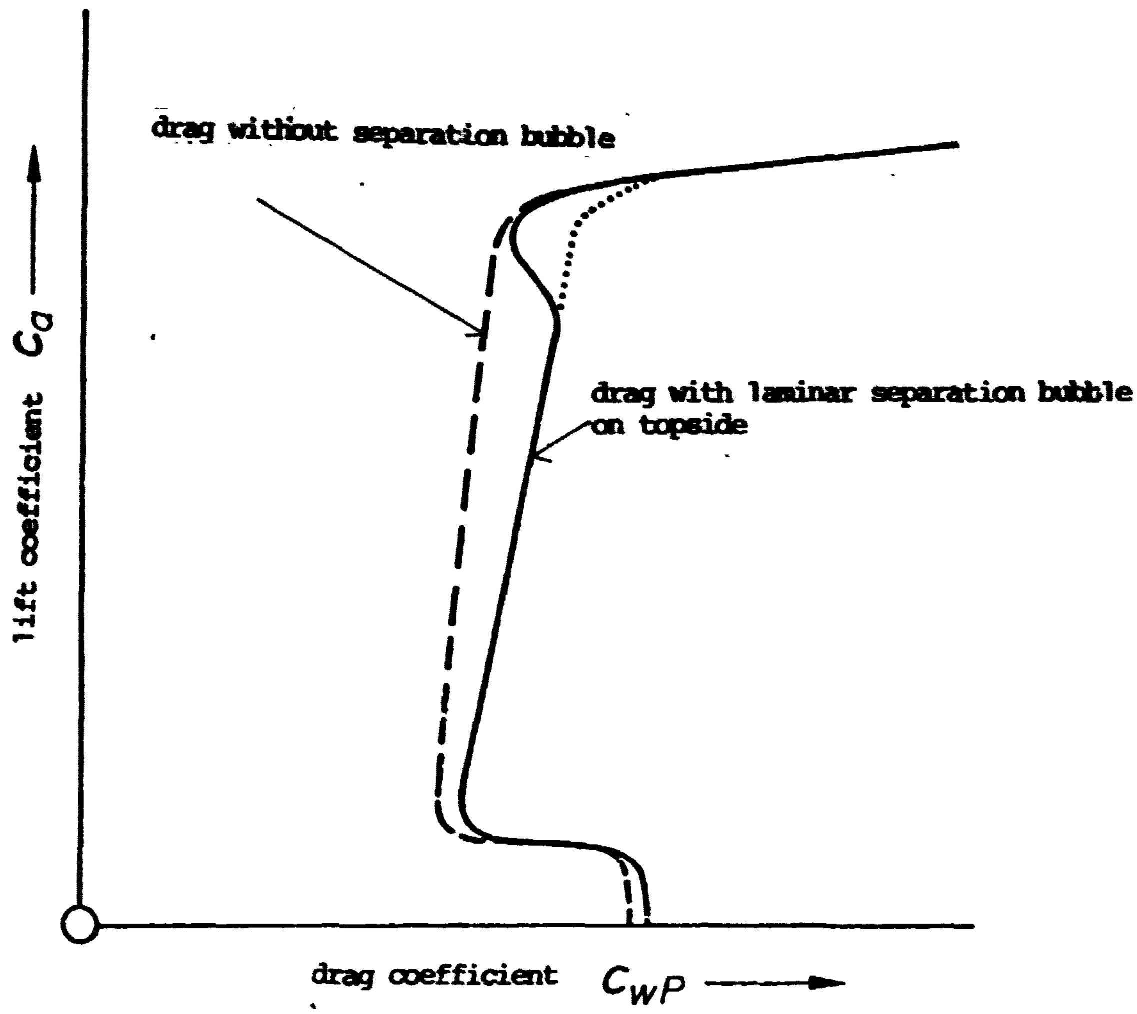

Figure 3. Polar of a profile with laminar separation bubble on the topside.

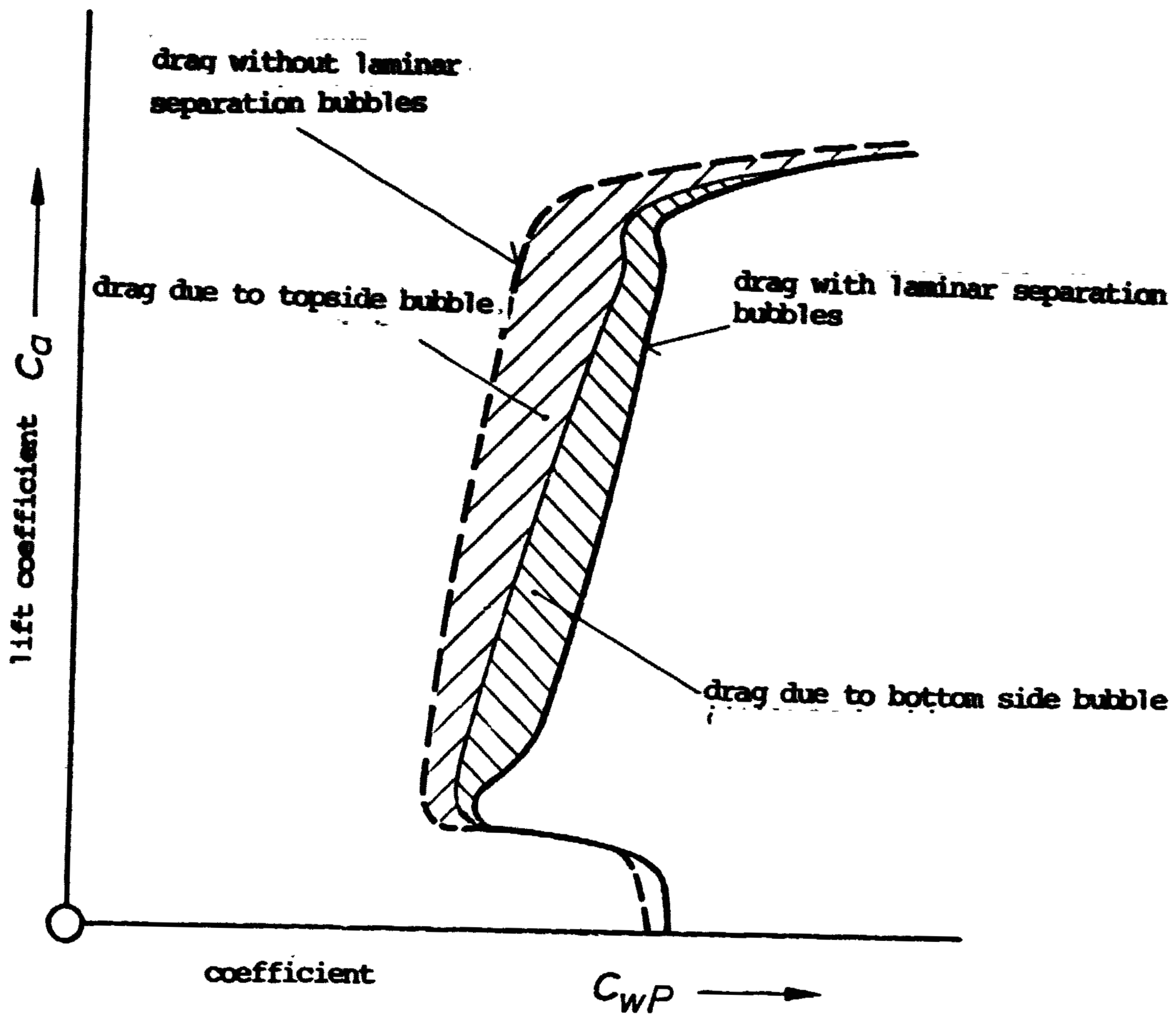

Figure 4. Effects of laminar separation bubbles on the profile pol .

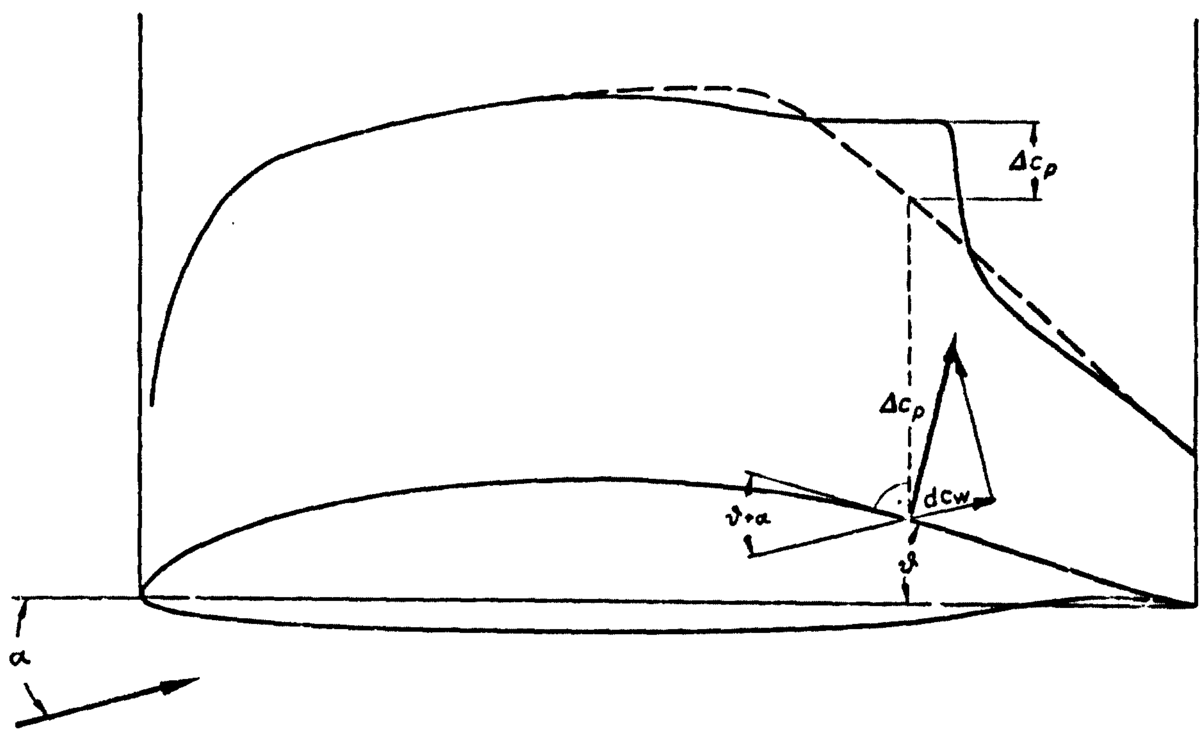

Figure 5. Schematic representation of the applicable additional pressures Δc_p due to laminar separation bubble

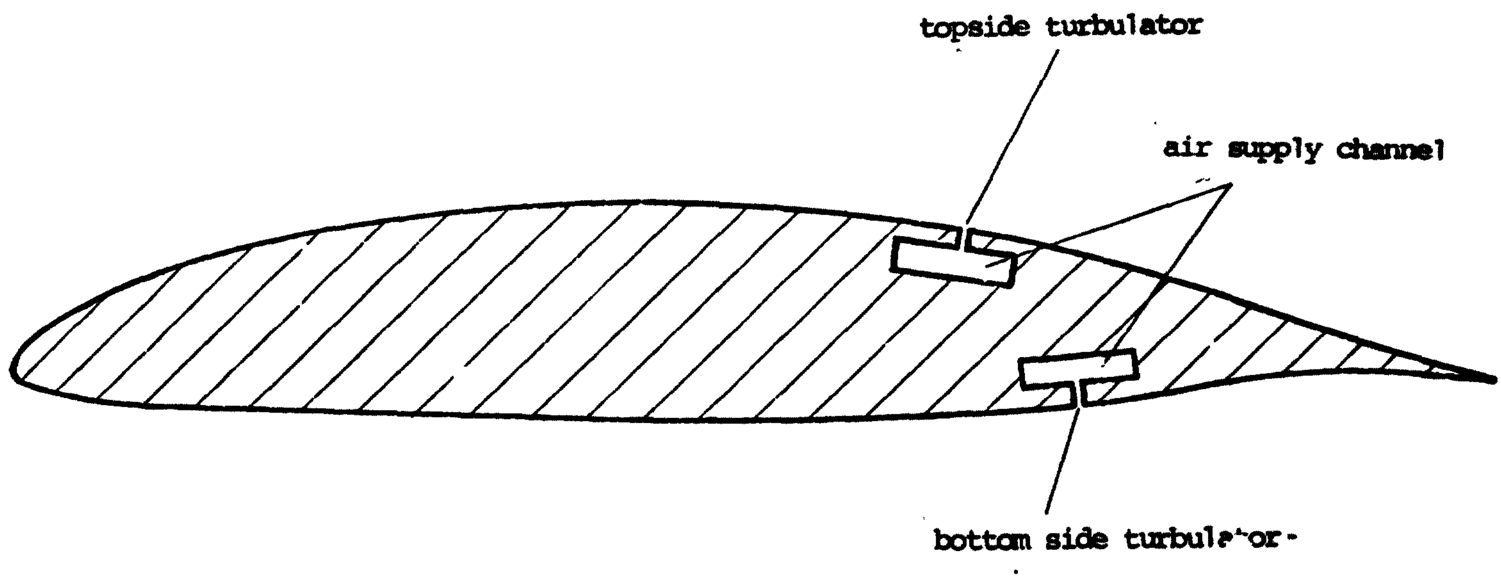

Figure 6. Profile with blowing turbulators

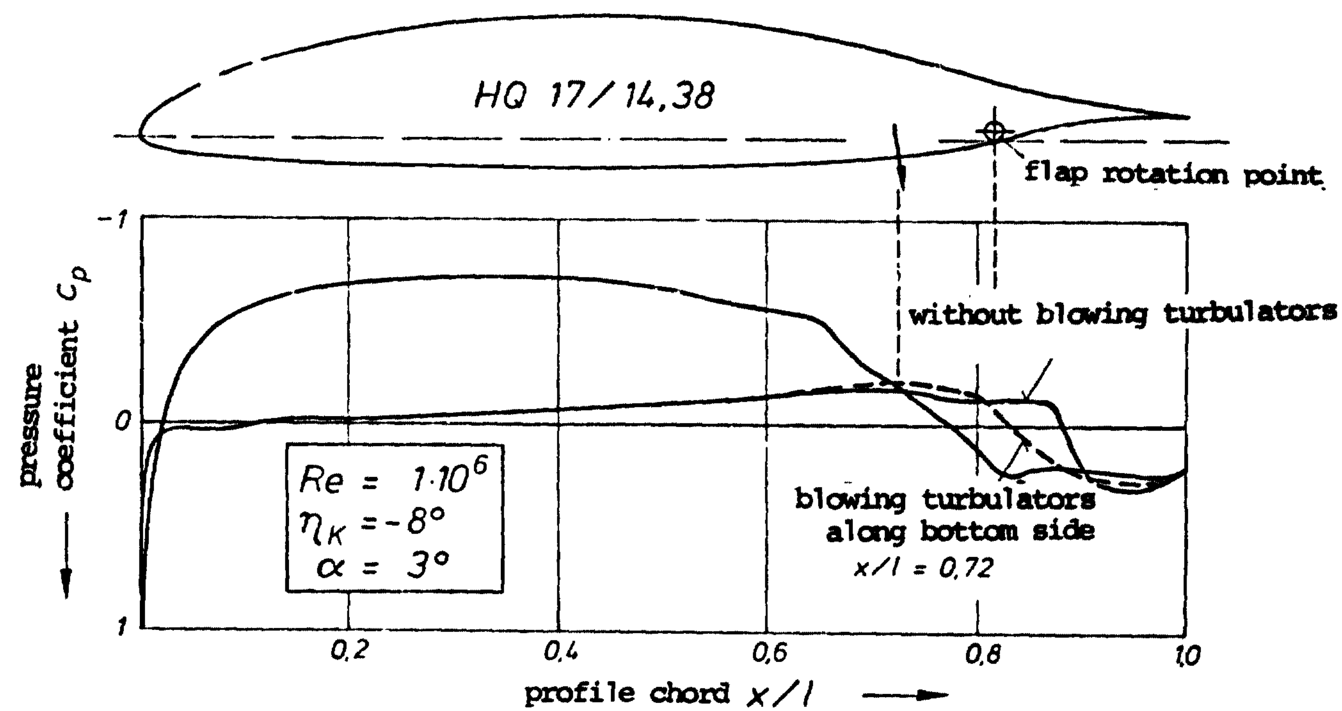

Figure 7, Effect of the blowing turbulators on the pressure distribution of the bottom side of the profile DFVLR-HQ 17/14.38 (Measurement: TH Delft)

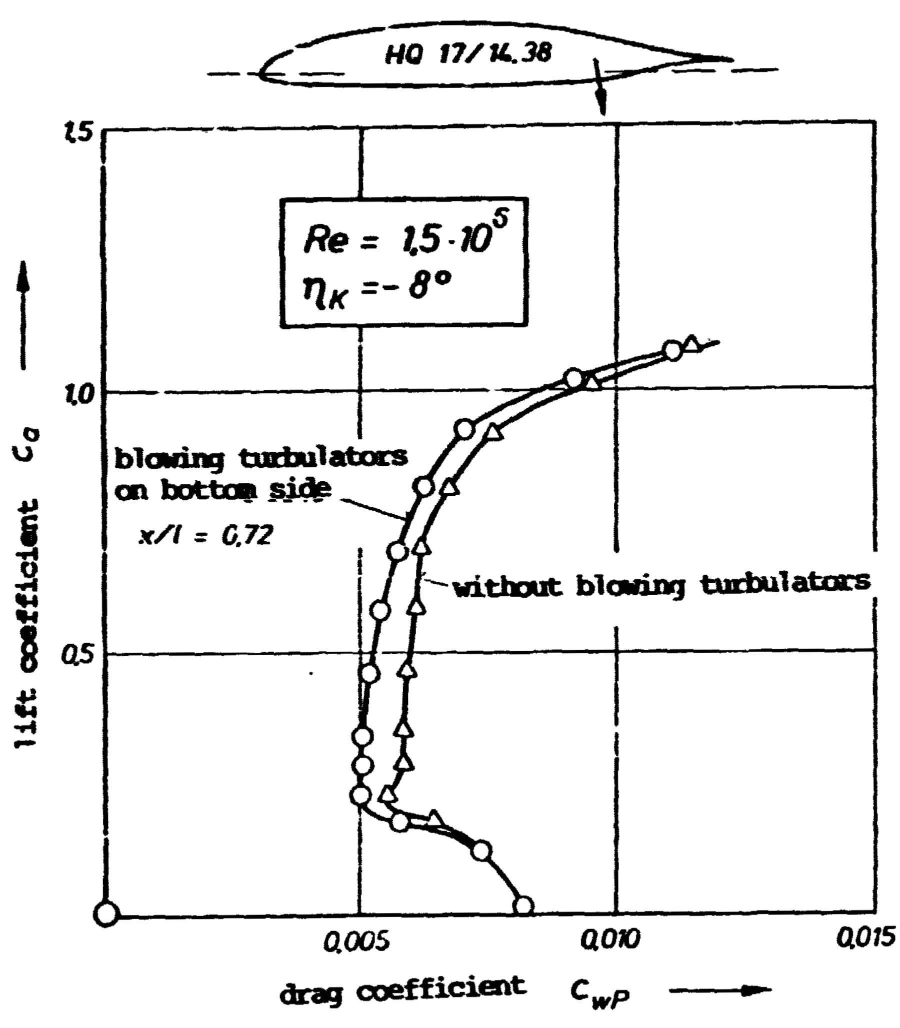

Figure 8. Drag polar of the profile HQ 17/14,38 with and without blowing turbulators (Measurement TH-Delft)

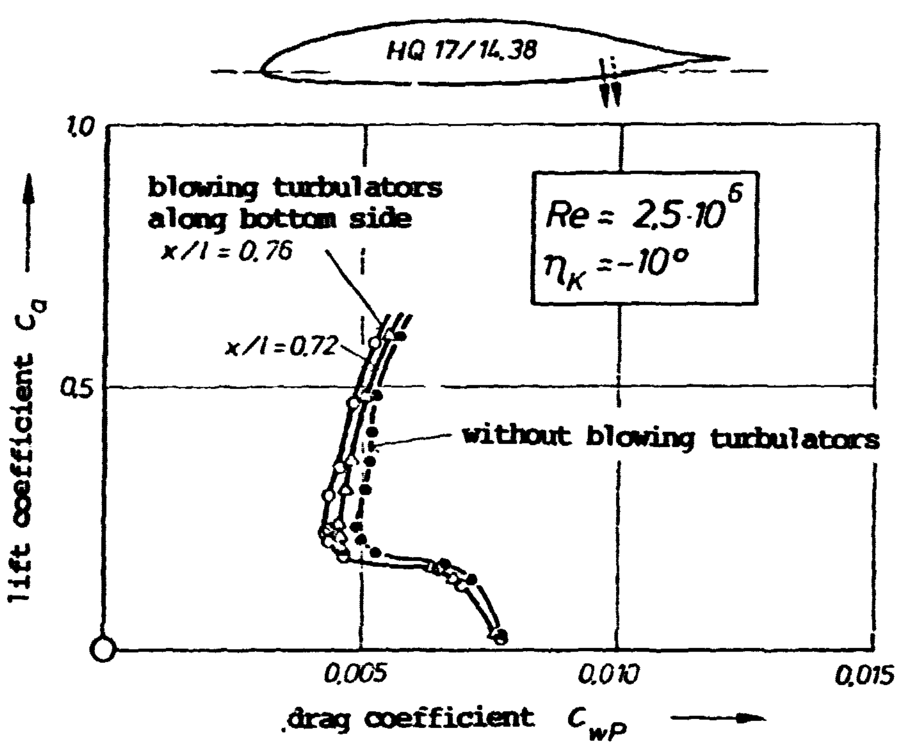

Figure 9. Drag polar of the DFVLR profile (HQ 17/14.38) for a different blowing location along the bottom side (Measurement: TH Delft)

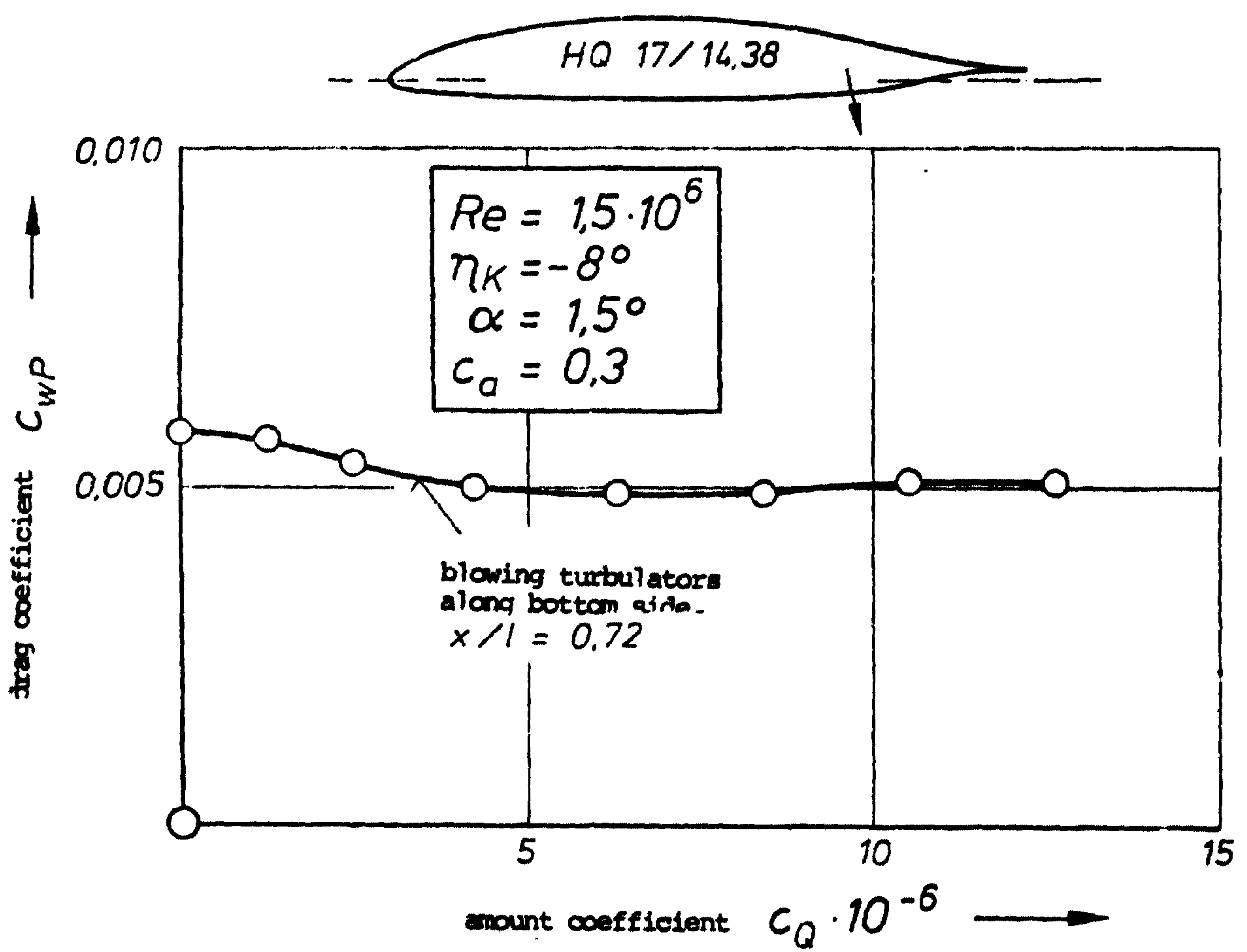

Figure 10. Drag variation of the profile HQ 17/14.38 for various blowing amount coefficients c_Q (Measurement: TH Delft)

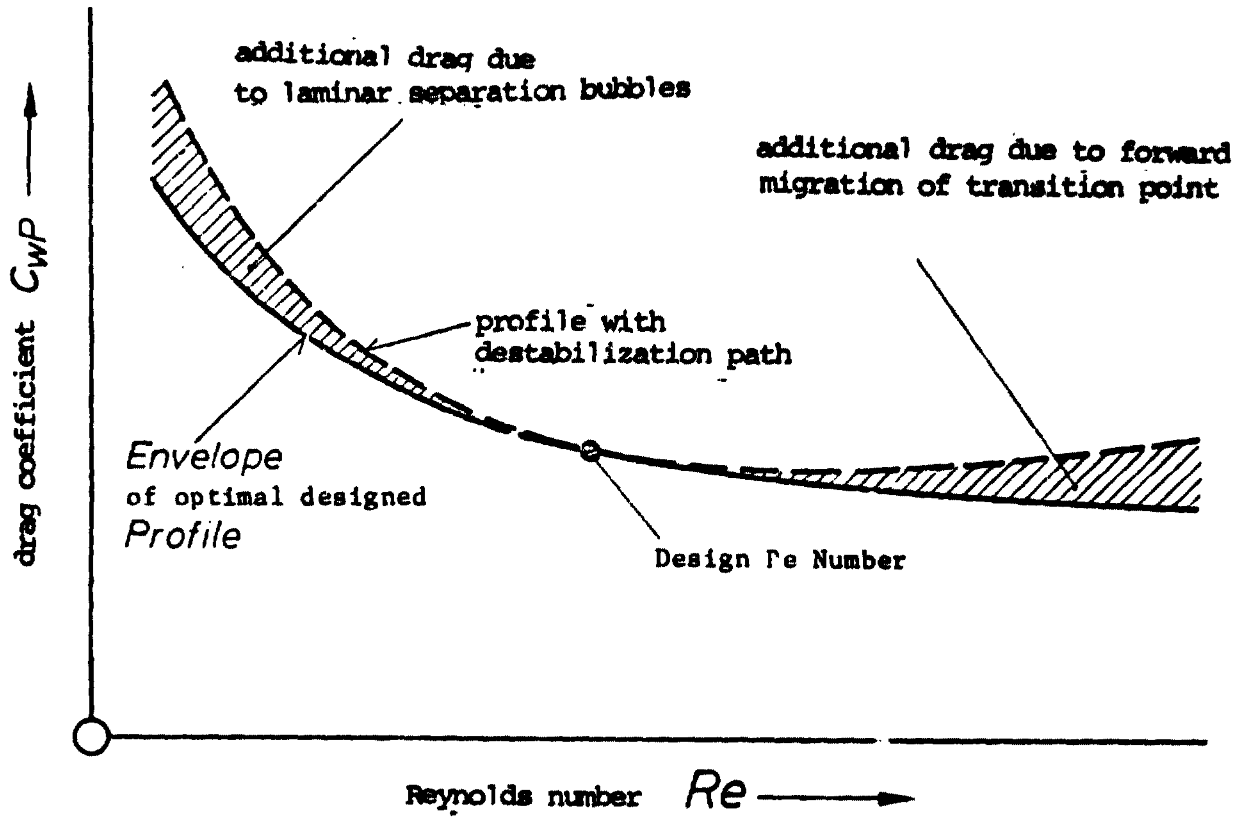

Figure 11, Schematic representation of drag variation as a function of Reynolds number for profile with destabilization path

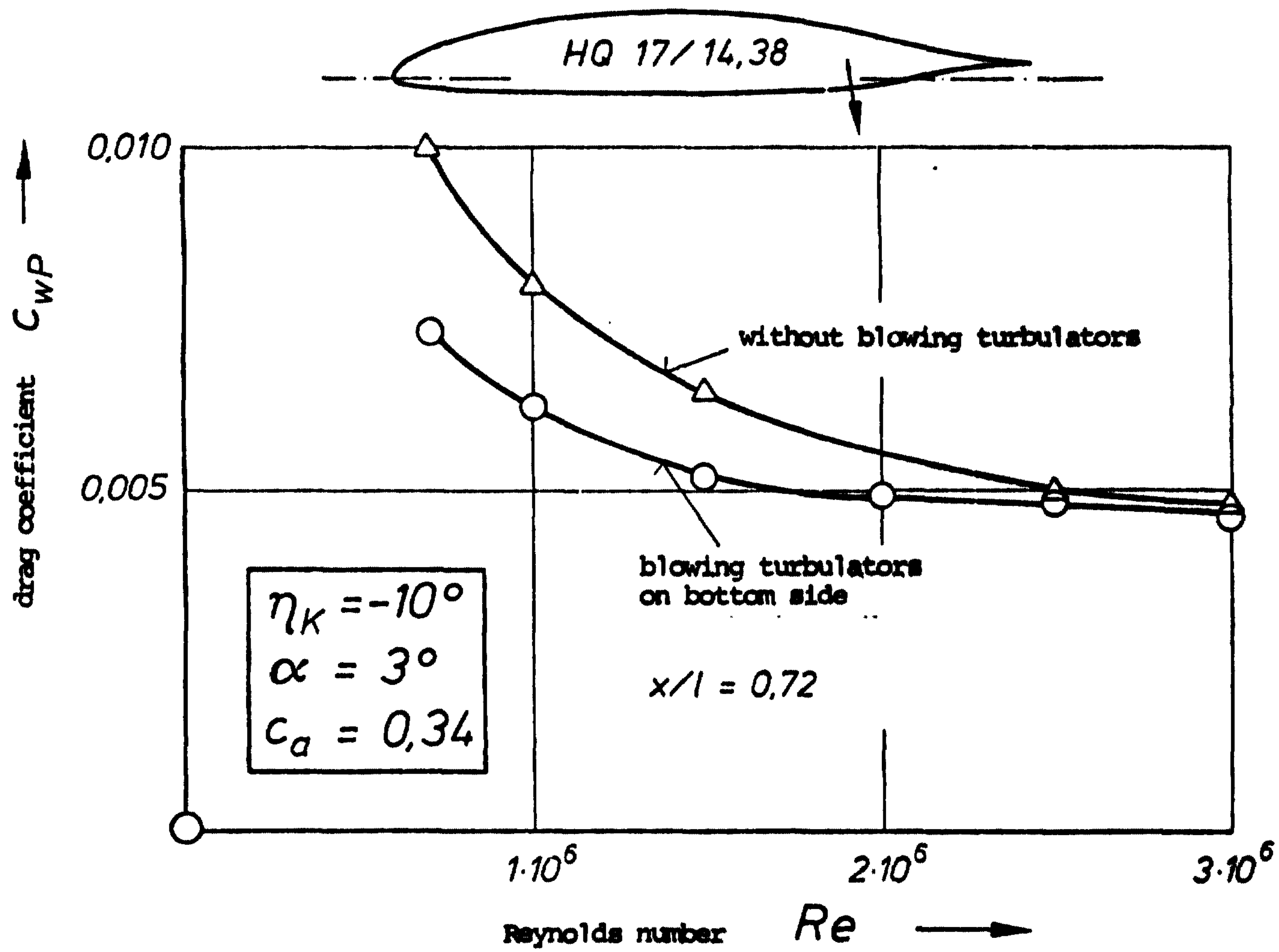

Figure 12. Drag variation of the profile DFVLR HQ 17/14.38 as a function of Re number with and without blowing turbulators (Measurement: TH Delft)

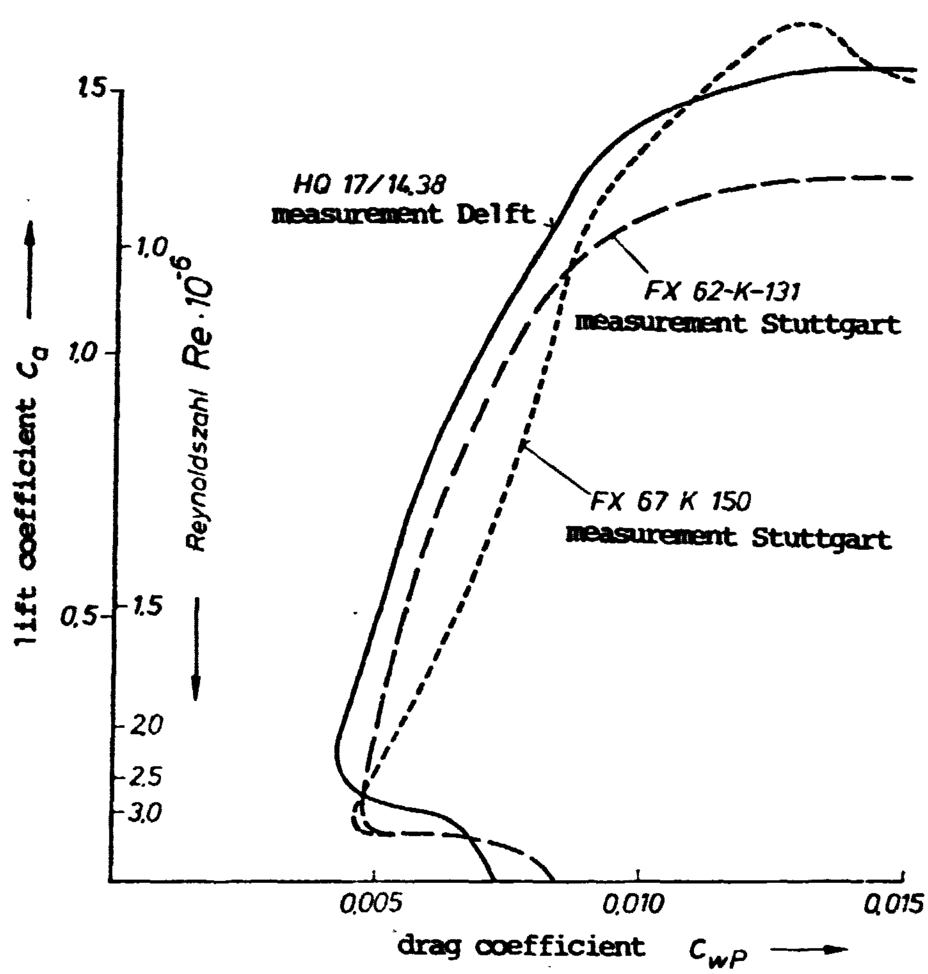

Figure 13, Comparison of drag polars of previous profiles with the profile DFVLR-HQ 17/14,38 with blowing turbulators along the bottom side