REDUCTION OF SECTION DRAG BY BLOWING THROUGH ROWS OF HOLES IN AREAS OF LAMINAR SEPARATION BUBBLES

K.H. Horstmann
A. Quast
DFVLR, Braunschweig

Translation by Fred Hermanspann, Seattle, Washington, USA

Presented at the XVIIth OSTIV Congress
Paderborn, Germany
May 1981

Below Reynolds (Re) numbers of about 5×10^6, there may be laminar separation bubbles on wing sections and fuselages. Fig. 1 shows the pressure distributions on the lower surface of a section which involves laminar separation and reattachment.

Fig. 2 shows a preliminary schematic of the flow conditions within a laminar separation bubble. Also shown is a flow visualization sketch in the area of a separation bubble.

Laminar separation bubbles are undesirable because they increase section drag through some not fully understood mechanisms (Figs. 3 & 4).

According to Fig. 5, a laminar separation bubble causes an additional suction pressure $\Delta C_p \cdot \sin(\vartheta + \alpha)$. The additional drag due to a laminar separation bubble should therefore increase with angle of attack. Another explanation for the drag due to separation bubbles could be that the turbulent wall shear stress is unusually high after reattachment. A combination of both mechanisms is also possible. It thus appears desirable to utilize turbulators to make the boundary layer turbulent just ahead of the laminar separation point. This method has found no practical application todate. In Fig. 6, pneumatic turbulators blow ram air from pitot inlets through 0.6 mm tubes with 16 mm spacing (on a section chord of 500 mm). Even at small flow coefficients C_Q of the magnitude 10^{-5}*, laminar-to-turbulent transition is achieved, the laminar separation bubble disappears and the drag is reduced. These blow turbulators, as they shall be called in this context, have the following advantages over mechanical turbulators:

- flow coefficient can be regulated or cut off
- different blowing locations can be used
- blowing turbulators are effective even when they are behind the separation point

The effect of blowing on the pressure distribution of the lower surface is depicted in Fig. 7; the laminar separation bubble has largely disappeared. Fig. 8 shows that the drag of the investigated section is reduced by up to 15%.

Fig. 9 presents the section polars for several blowing locations. The best location appears to be at $x/l = .76$. Fig. 10 shows the drag variation for various flow coefficients; there exists a weak optimum at $C_Q = 7 \times 10^{-6}$. With increasing Reynolds number, the optimum value for C_Q decreases and approaches zero at $Re = 3 \times 10^6$. It appears that the required blowing mass flow referenced to the wing area has to be constant. Blow hole spacing and diameters have so far not been varied, and only blow angles normal to the surface have been evaluated.

In Fig. 11, the drag variation with

*Additional drag due to momentum loss is then $C_d = 2C_Q = 2 \times 10^{-5}$; however, the drag coefficient of the section is 5×10^{-3}.

Reynolds number of a modern section with a destabilization region (transition ramp) is plotted as a dashed line. It touches the envelope of optimum designed sections at the design point. At Reynolds numbers above the design point, the transition point moves forward on the now unsuitable destabilization region and the drag increases because of the unnecessarily short laminar run distance. At Reynolds numbers below the design point, laminar separation bubbles become larger with decreasing Reynolds numbers. In this range, blow turbulators can be used. Fig. 12 shows the measured drag variation of a section designed for Re = 3 x 10^6 (with practically no destabilization region). It can be seen clearly that the low drag range with respect to Reynolds number has been considerably enlarged by blow turbulators. One comes close to the envelope of optimum designed conventional sections with destabilization regions given in Fig. 11.

Sections with blow turbulators require stable pressure distributions such as those shown in Fig. 1 for the lower surface. A basic advantage of use of blow turbulators is that it is no longer necessary to provide laminar instability regions; these are difficult to specify by calculation and are usually correct only for the design point anyway. Furthermore, a section with blow turbulators is considerably less sensitive to production imperfections than one with destabilization regions. Within limits, it could also be less sensitive to surface contamination.

Airplanes can be easily fitted with blow turbulators; the SB 12 sailplane of the Akaflieg Braunschweig has been flying for nearly a year with such turbulators. Blow turbulators are insensitive to rain and do not appear to collect dirt.

In Fig. 13, the drag polar of the turbulataor-camber flap section for sailplanes DFVLR-HQ 17/14.38 is compared with the best sections known so far. This comparison is done at Reynolds numbers applicable to sailplanes. The clear drag reduction, especially important at low lift coefficients, is clearly seen.

Blow turbulators can be used wherever the local Reynolds number is smaller than 3 x 10^6, equivalent to section Reynolds numbers below about 5 x 10^6. In case of nose separation, the Reynolds numbers may even be higher. Blow turbulators are especially advantageous below Re = 2 x 10^6.

Other possible areas for application:

- general aviation airplanes
- sailplanes
- helicopter rotors
- propellers
- turbomachines
- wind turbines
- model airplanes

Because of the sometimes low Reynolds numbers, the application of blow turbulators to turbomachines appears to be particularly promising. For transport airplanes they are probably not of interest in the form described here.

We would like to thank Prof. V. Ingen and his collaborators at the TH Delft for their careful tests and friendly assistance.

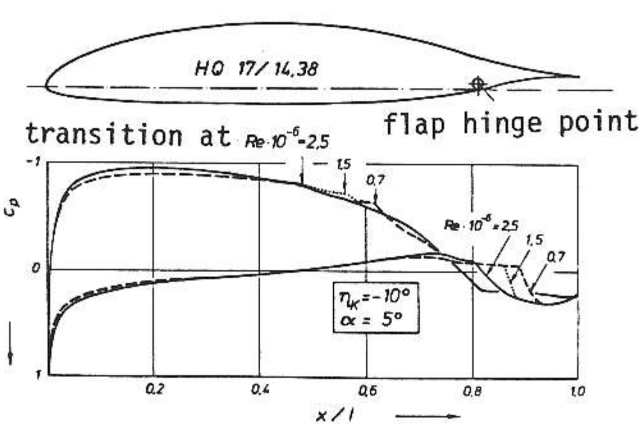

Fig. 1 Extent of laminar separation bubble as a function of Reynolds number for camber flap section DRVLR-HQ 17/14.38. (test: TH Delft)

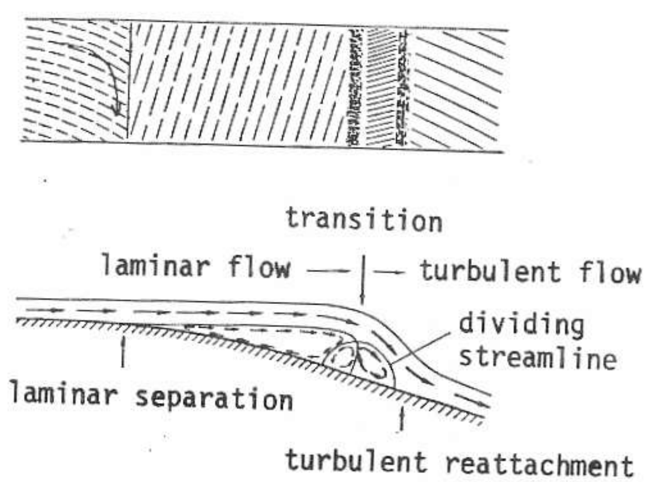

Fig. 2 Sketch of flow visualization picture and presumed flow field in the area of a laminar separation bubble.

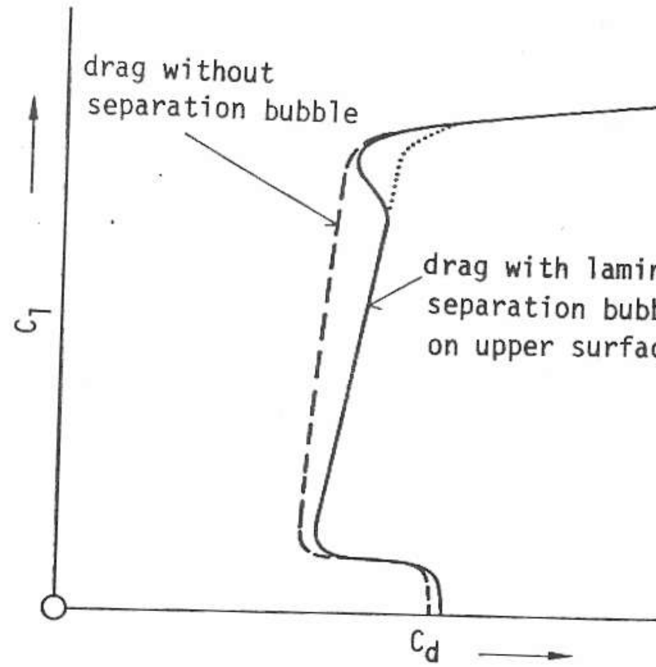

Fig. 3 Polar of a section with laminar separation bubble on the upper surface.

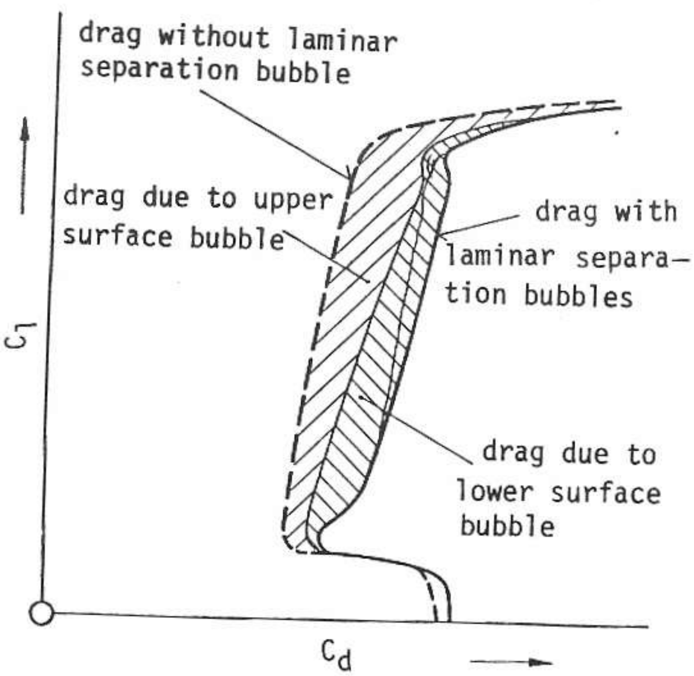

Fig. 4 Effects of laminar separation bubbles on section polar.

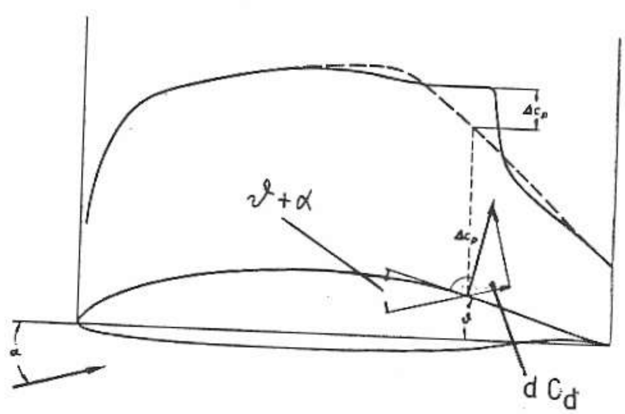

Fig. 5 Schematic presentation of acting incremental pressures ΔC_p due to laminar separation bubble.

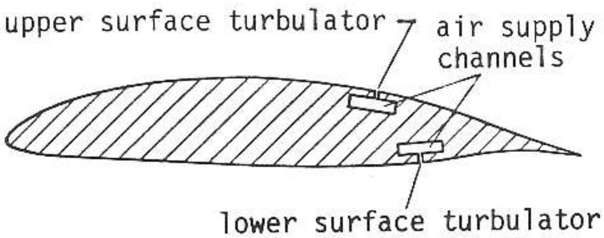

Fig. 6 Section with blow turbulators.

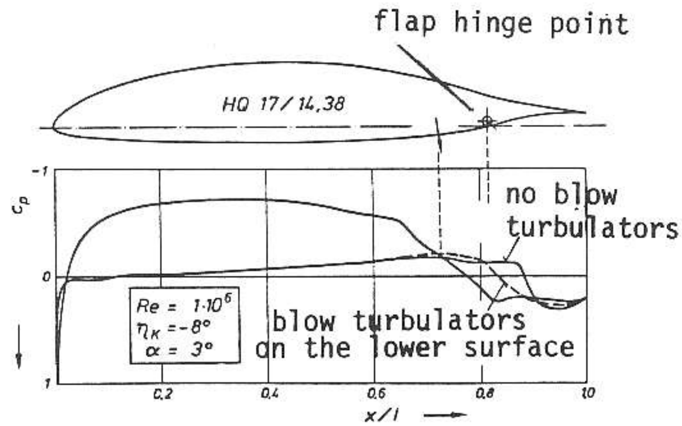

Fig. 7 Effect of blow turbulators on the pressure distribution of the lower surface of the section DRVLR-HQ 17/14.38.
(test: TH Delft)

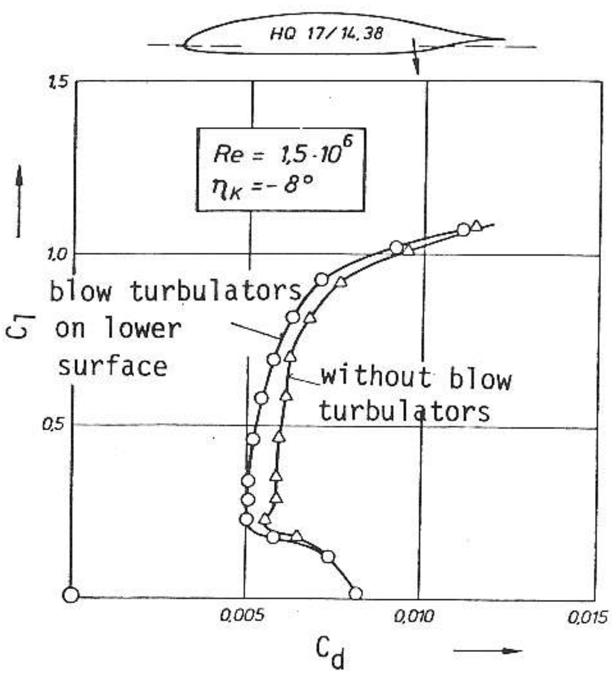

Fig. 8 Drag polar of section HQ 17/14.38 with and without blow turbulators.
(test: TH Dalft)

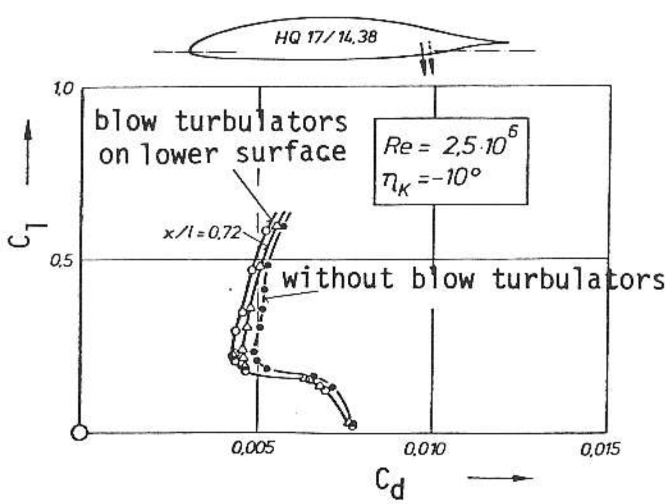

Fig. 9 Drag polar of section DFVLR-HQ 17/14.38 for different blow locations on the lower surface.
(test: TH Delft)

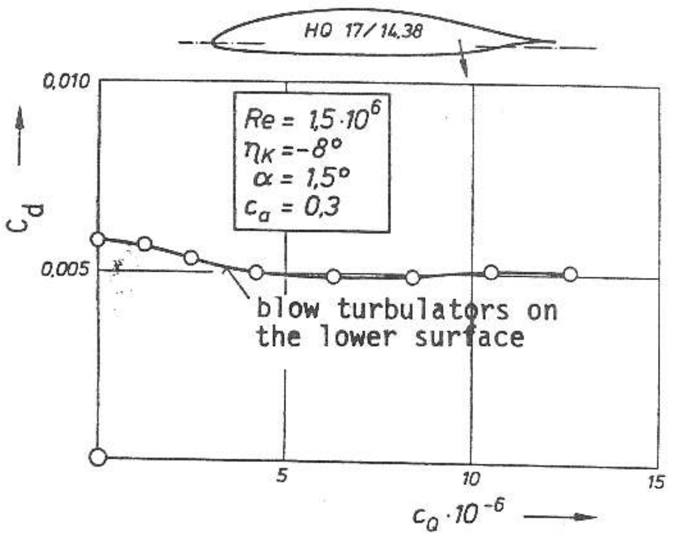

Fig. 10 Drag variation of section HQ 17/14.38 for different blowing flow coefficients C_Q.

(test: TH Delft)

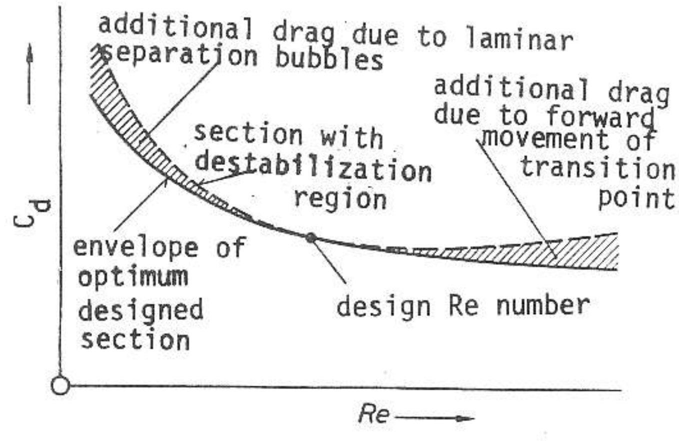

Fig. 11 Schematic presentation of the drag variation with Re number for sections with destabilization region.

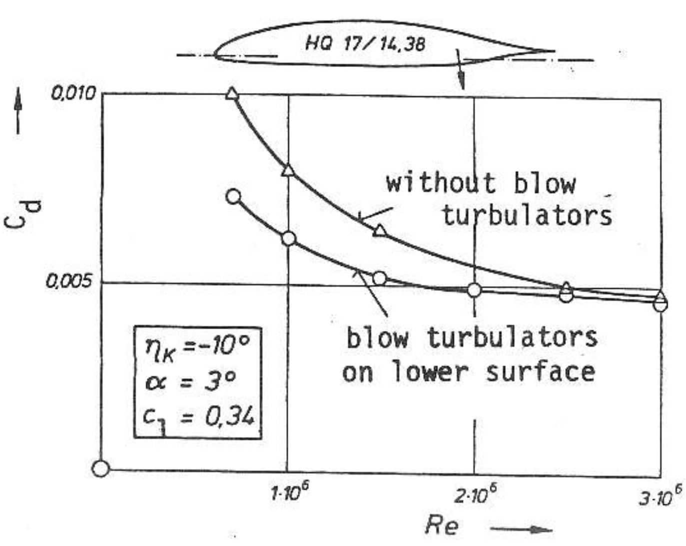

Fig. 12 Drag variation of section DFVLR HQ 17/14.38 with Re number with and without blow turbulators.

(test: TH Delft)

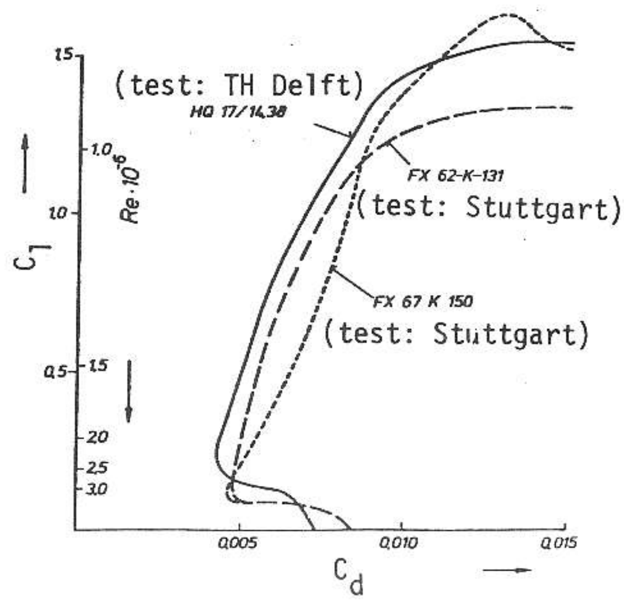

Fig. 13 Comparison of drag polars of currently known sections with section DFVLR-HQ 17/14.38 with blow turbulators on the lower surface. □