Research on Sailplane Aerodynamics at Delft University of Technology

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Introduction

The lecture dealt with results of recent aerodynamic developments at DUT applied in high-performance sailplanes, followed by results of ongoing research on boundary layer control by suction.

Recent developments

The speed polar of a high-performance sailplane, subdivided in contributions to the sink rate of the wing, fuselage and tailplanes (Fig.1) illustrates that the largest contribution is due to the wing, at low speed due to induced drag and at high speed due to profile drag.

The following examples, focused on drag reduction, were presented:

Induced drag has been minimized by optimizing the wing planform with integrated winglets of the Advantage wing as shown in Fig. 2. Strictly, winglets can be optimized for one lift coefficient only, but the figure shows that the absolute minimum induced drag according to Munk's third theorem can be realized within 1%. The Advantage is a new Standard Class high-performance sailplane with shoulder wing (Fig.3) to be built by Sailplanes, Inc. in New Zealand.

Profile drag has been minimized by increasing the laminar flow extend on the upper and lower surface and by reducing airfoil thickness. The recent 12.7 % thick airfoil with camber changing flap applied in the Antares wing has laminar flow up to 95% of the chord on the lower surface at high speed, and up to 75% of the chord on the upper surface at low speed. Full laminar flow on the lower surface cannot be realized at low lift coefficients and high Reynolds numbers, and more laminar flow on the upper surface leads to a steeper pressure gradient thereafter which in turn promotes flow separation and causes unfavorable flying qualities in thermals. This example shows that further improvement of airfoil characteristics by conventional means is hampered, being the reason for present research on boundary layer suction.

Fuselage drag depends mainly on fuselage thickness and contraction behind the cockpit. Fuselage thickness has to be minimized, contraction is limited by flow separation in turbulent boundary layer conditions, for instance flying in rain. A remarkable finding is that the cockpit length can be increased without any drag increase, thus improving crashworthiness by enabling a longer crumbling nose cone. This feature has been applied in the fuselages of the Antares and Advantage.

Wing-fuselage combination is aerodynamically complicated. Main interference effects are an increase (or decrease) in angle of attack of the wing root region due to cross-flow of the fuselage named α-flow, resulting in viscous flow effects as the forward shift of the transition position on the wing and possibly separated flow at the wing root, shown in Fig.4. Another viscous flow problem is separation of the turbulent boundary layer on the fuselage in front of the wing root due to the stagnation pressure on the wing root leading edge, leading to a vortical flow system around the wing root.

Examples of wing-fuselage combinations of the Stemme S2/S6/S8/S9 family, the Mü–31 and Advantage illustrate how these problems have been encountered. A new theoretical concept for the design of a leading edge fairing that avoids flow separation and causes the turbulent boundary layer to relaminarize rapidly on the fairing, has been developed and validated in the wind tunnel. This method has been applied for the first time at the wing root junction (Fig.5) and vertical tail-tailboom junction of the Advantage.

A new tailplane airfoil with laminar flow and artificial transition by zigzag tape at the hinge position has been presented.

Boundary layer suction

The goal of boundary layer suction is (1) to reduce drag by keeping the boundary layer laminar and attached up to the trailing edge, and/or (2) to increase lift by keeping the turbulent boundary layer attached.

As illustrated in Fig. 6 the drag of an airfoil with boundary layer suction (on the rear upper surface in the present case) is composed of wake drag, sink drag and equivalent suction drag. Wake drag is due to the boundary layer development on upper and lower surface forming the wake, and is composed of friction drag and pressure drag. Sink drag is created by the momentum loss of the sucked air brought to rest in the wing, and can be reduced to zero again by blowing this air out backwards with a velocity equal to flight speed. The equivalent suction drag expresses the power needed to bring the sucked air back to ambient pressure and flight speed.

The principle of blowing the sucked air out backwards to reduce the sink drag, no matter the power source (solar, wind turbine, batteries), can be interpreted as thrust, which is not allowed according to the present FAI definition of a sailplane. However, as will be shown, the improvement in sailplane performance due to boundary layer suction is so large that it would be unfair to compete with such a sailplane in the present classes. Hence a new class has to be defined, and in doing so FAI should take new technological possibilities into consideration.

A breakthrough for the application of boundary layer suction is the possibility to produce many tiny holes (about 0.1mm with interspace 1mm) in carbon fibre material by micro abrasive air jetting, an adapted version of sandblasting. This new and cheap technology, developed at Delft University of Technology (PTO), is based on the erosion of a mask-protected carbon fibre skin by a high-velocity beam of abrasive powder (bulk material), blown by pressurized air through a nozzle. The geometry of the mask, easily produced of photosensitive polymeric film, determines the hole pattern. Research is going on to further optimize this technology for use on a large scale.

While there is a minimum amount of suction needed to keep the boundary layer laminar, there is an upper limit as well, because too strong suction produces vortices at each hole that become unstable and act like a turbulator. In order to determine this suction limit as well as the pressure loss of the suction holes, wind tunnel tests have been performed with an airfoil specially designed for this purpose and equipped with a suction skin, as shown by the dark area on the wind tunnel model in Fig. 7.

The suction volume flow rate and corresponding suction power depend on the difference between the outside pressure, that varies in chordwise direction, and the constant inside suction pressure. In order to approximate the ideal pressure difference required for the optimal suction distribution, the suction skin has to be divided in several sections (Fig. 6) and their internal pressure is adjusted by throttling orifices. Nevertheless, due to the stepwise approximation of the ideal pressure difference, the ideal suction flow distribution and suction power cannot be realized. A study on different airfoils designed for boundary layer suction, in combination with different suction skin designs, yielded the power curves (per square meter wing area) for the best compromise with 3 skin sections shown in Fig. 8. Although the maximum actual power is about twice the ideal one, the power required is still very low, as indicated by the solar power datum used for the design of the solar powered glider Icare-2.

Finally, Fig. 9 shows the dramatic improvement of the speed polar and glide ratio of a modern Standard Class sailplane, where suction is used to decrease the drag coefficient as well as increase the lift coefficient.

Research on boundary layer suction is going on in an effort to solve the remaining problems step by step, because the improvement in performance is a very beckoning perspective.

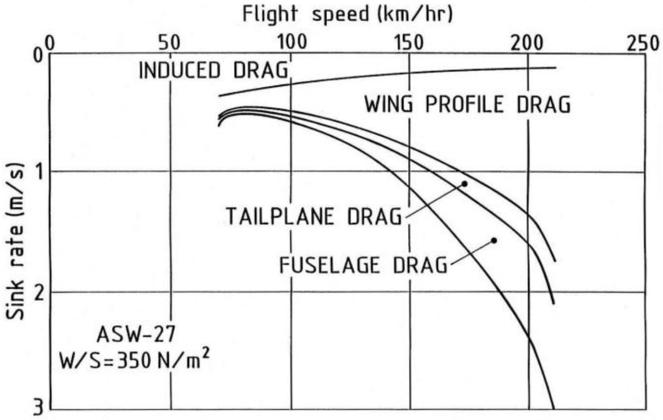


Figure 1 The speed-polar of the ASW-27 built up by several drag contributions.

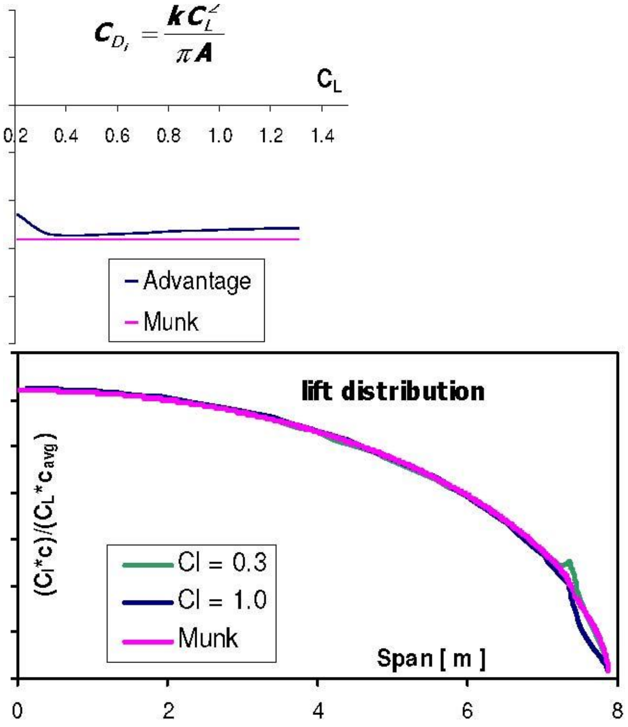


Figure 2 Planform, lift distribution and induced drag of the Advantage wing with winglet in comparison with Munk's lift distribution and absolute minimum induced drag.

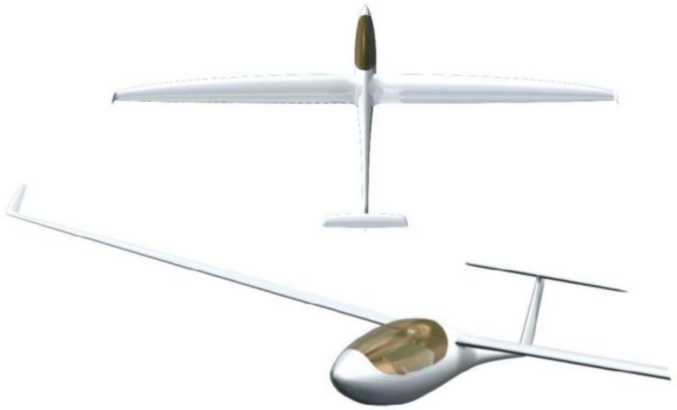


Figure 3 The new Standard Class high-performance sailplane Advantage of Sailplane Inc., New Zealand

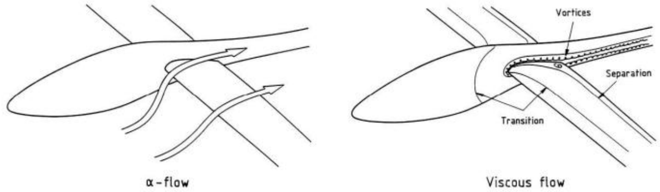


Figure 4 Wing-fuselage interference effects.

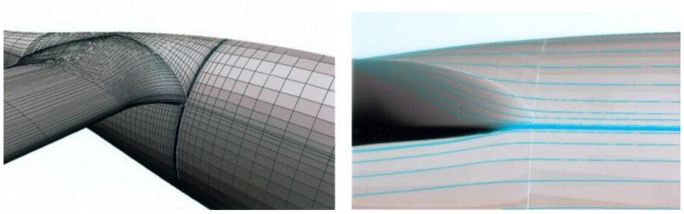
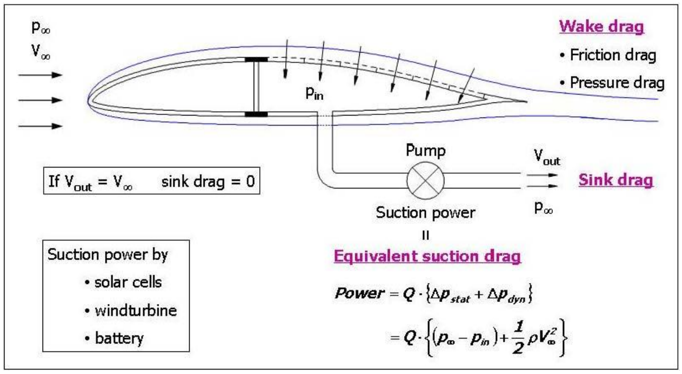


Figure 5 Wing root leading edge fairing design of the Advantage and streamline pattern.



$$Power = Q \cdot \{\Delta p_{stat} + \Delta p_{dyn}\}$$
$$= Q \cdot \left\{(p_\infty - p_{in}) + \frac{1}{2}\rho V_\infty^2\right\}$$

Figure 6 Drag contributions in case of boundary layer suction.

Figure 7 Wind tunnel model for boundary layer suction experiments.

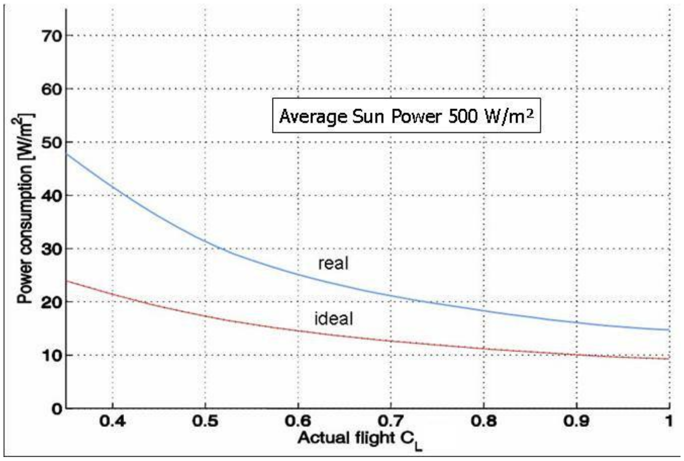


Figure 8 Ideal and actual power curves for boundary layer suction.

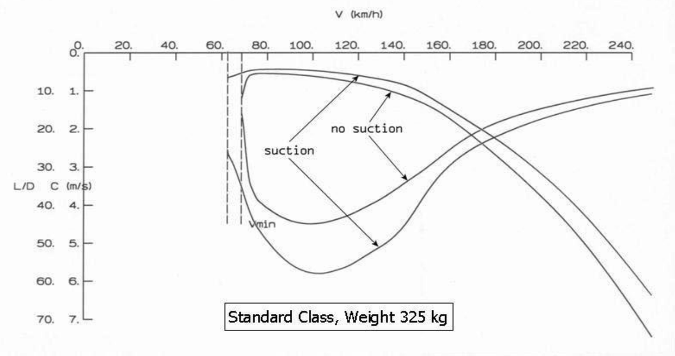


Figure 9 Improvement of the speed-polar of a Standard Class sailplane by boundary layer suction.