Research on Sailplane Aerodynamics at Delft University of Technology.
Boundary layer suction.

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Boundary layer suction

The goal of boundary layer suction is:

- to reduce drag by keeping the boundary layer laminar and attached up to the trailing edge, and/or
- to increase lift by keeping the turbulent boundary layer attached.

As illustrated in fig. 1 the drag of an airfoil with boundary layer suction - in the present case on the rear upper surface - is composed of wake drag, sink drag and equivalent suction drag. Wake drag is due to the boundary layer development on upper and lower surfaces 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 the flight speed. The equivalent suction drag implies the power needed to bring the sucked air Q in the wing back to ambient pressure p_∞ and flight speed V_∞.

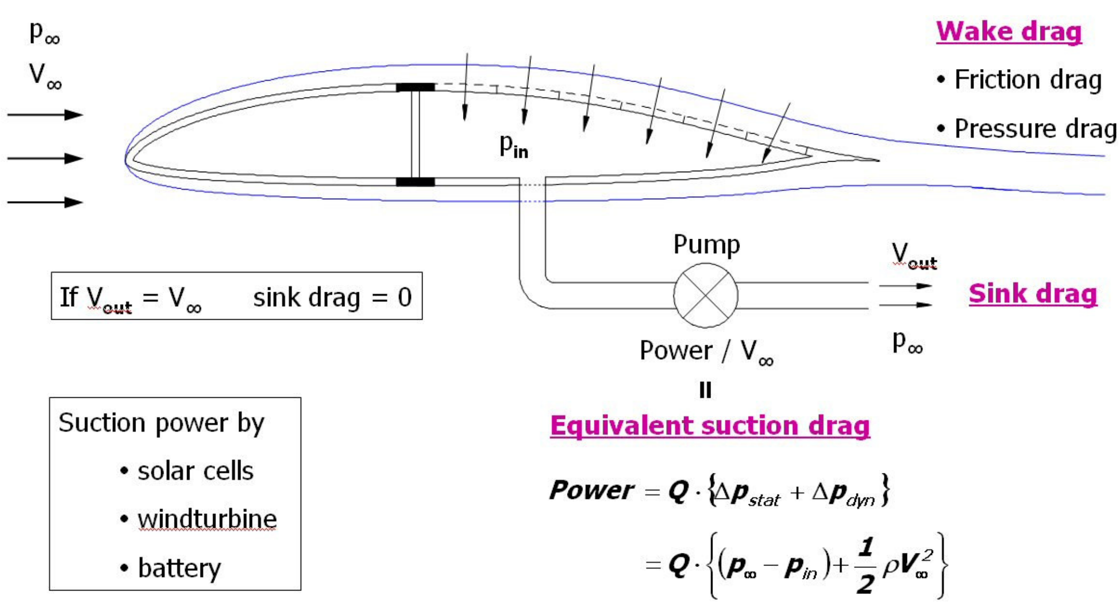

Fig. 1. Drag contributions in case of boundary layer suction.

The principle of blowing the sucked air out backwards in order to reduce the sink drag, no matter the power source (solar cells, 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 existing classes. Hence a new class has to be defined, and in doing so the International Gliding Commission of the 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 (0.1mm diameter, every 1mm) in carbon fibre laminate by micro abrasive air jetting, an adapted version of sandblasting. This new and cheap technology, developed at Delft University of Technology, is based on the erosion of a mask-protected carbon laminate 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. A blasting cabinet with a computer controlled traversing system has been built, fig. 2, and research is going on to further optimize this technology for use on a large scale.

Fig. 2. The blasting cabinet for micro abrasive air jetting, with traversing system on top.

While a minimum amount of suction is required to keep the boundary layer laminar and attached, there is an upper limit as well, because strong suction produces vortices that originate at each hole and become unstable, acting like a turbulator. In order to determine this suction limit as well as the pressure loss of the suction holes, windtunnel tests have been carried out with a model especially designed for this purpose and equipped with a suction sandwich skin as shown by the dark area in fig. 3.

Fig. 3. Windtunnel model for boundary layer experiments in the interchangeable test section of the Low Speed Low Turbulence Windtunnel of TU Delft.

As shown by the expression for the suction power, minimum suction power is realized when the required minimum suction flow rate Q is brought back to ambient pressure p_∞ and flight speed V_∞. The required minimum suction flow rate is determined by the suction distribution in chordwise direction required to keep the boundary layer laminar and attached. This suction distribution is realized with a specific pressure difference between the outer and inner sides of the porous outer skin, and since the outer pressure varies in chordwise direction, the inner pressure should vary too. When this suction air is

finally brought back to ambient pressure and flight speed, the ideal minimum suction power is obtained.
In practice, the minimum suction distribution can be realized by a special layout of the suction sandwich on top of the structural sandwich, fig. 4. The air is sucked through the perforated outer skin, flows in forward direction through a perforated folded core and finally through throttling holes into the inner space of the wing, where the pressure is controlled by a pump. The suction sandwich is divided in buffers and an imperforated wall of the folded core separates the buffers.

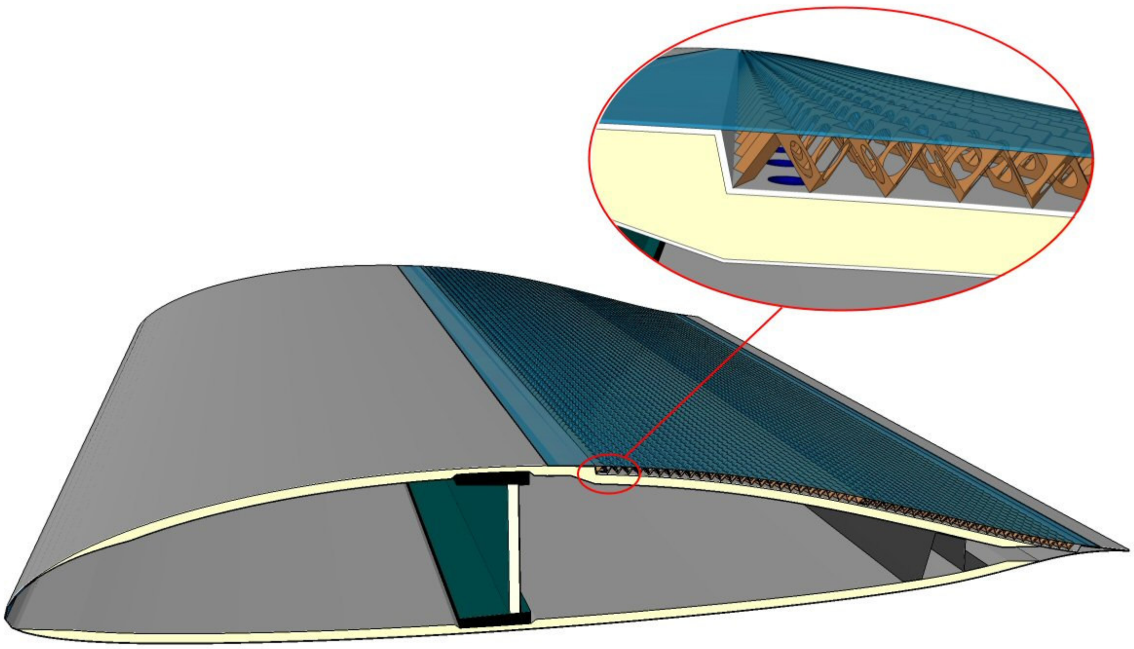

Fig. 4. Layout of the suction sandwich on top of the structural sandwich. The air is sucked through the porous outer skin, flows forward through perforated folded core and finally through throttling holes into the wing.

The suction sandwich can be compared with corrugated cardboard with many tiny holes in the upper skin, larger and fewer holes in the folded core and even larger and fewer holes in the lower skin. The folded core is a new core material developed at the Institut für Flugzeugbau of the TU Stuttgart. The channel type structure enables cleaning the inner structure when pollen and dirt are sucked into the suction sandwich.

While the minimum suction distribution at a particular flight speed can be realized in practice, the ideal minimum suction power cannot be realized because all the suction air has to be brought back from a certain inner pressure - and not an inner pressure that varies in chordwise direction – to ambient pressure. This inner pressure has to be slightly lower than the lowest outer pressure on the airfoil. In addition, the layout of the perforations in the suction sandwich can be optimized for one flight speed only.

When suction would be applied on the rear upper surface of a Standard Class sailplane wing, fig. 5 shows the ideal minimum suction power and the real suction power (per square metre wing area) for the best suction sandwich layout with 2 buffers. Although the 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. Fig. 6 shows the dramatic reduction in profile drag and the increase in lift due to suction. At lift coefficients below 0.9 suction keeps the boundary layer laminar, thus reducing pressure drag and friction drag. At lift coefficients above 0.9 natural transition occurs in front of the suction area and the same suction distribution needed for laminarization is applied to postpone separation of the turbulent boundary layer, thus increasing the lift. Finally, fig. 7 shows the corresponding enormous improvement of the speed polar and glide ratio.

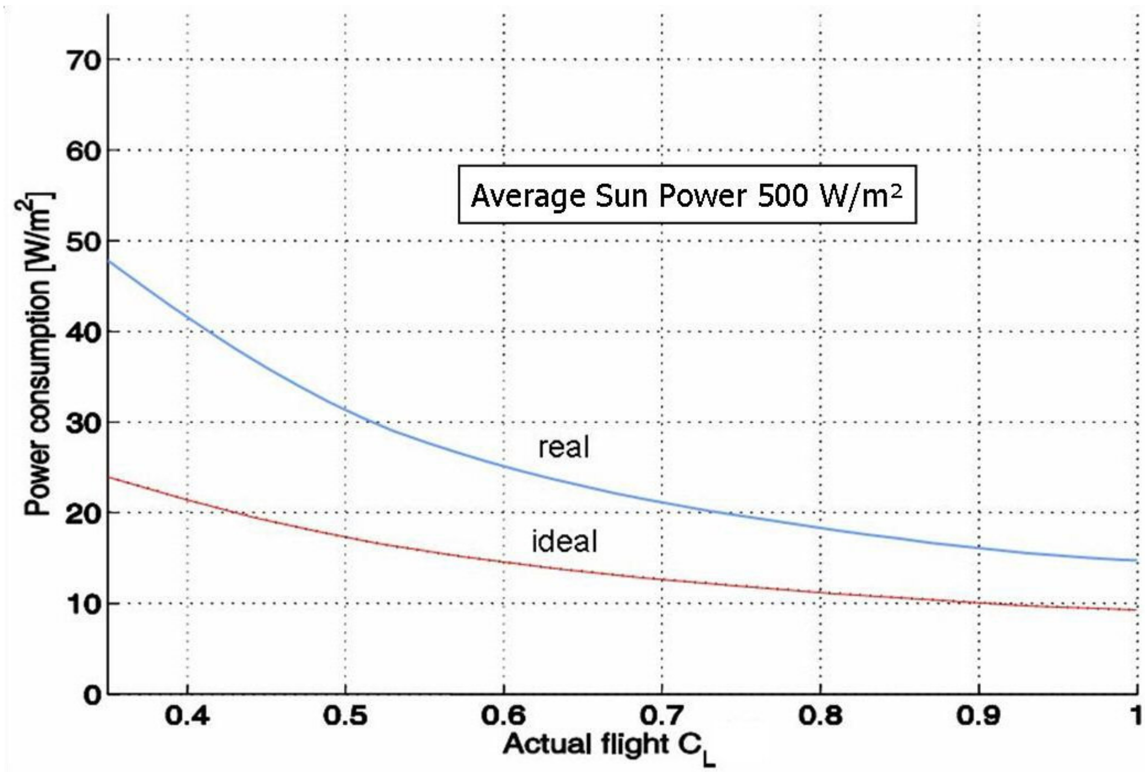

Fig. 5. Ideal minimum suction power and the real suction power.

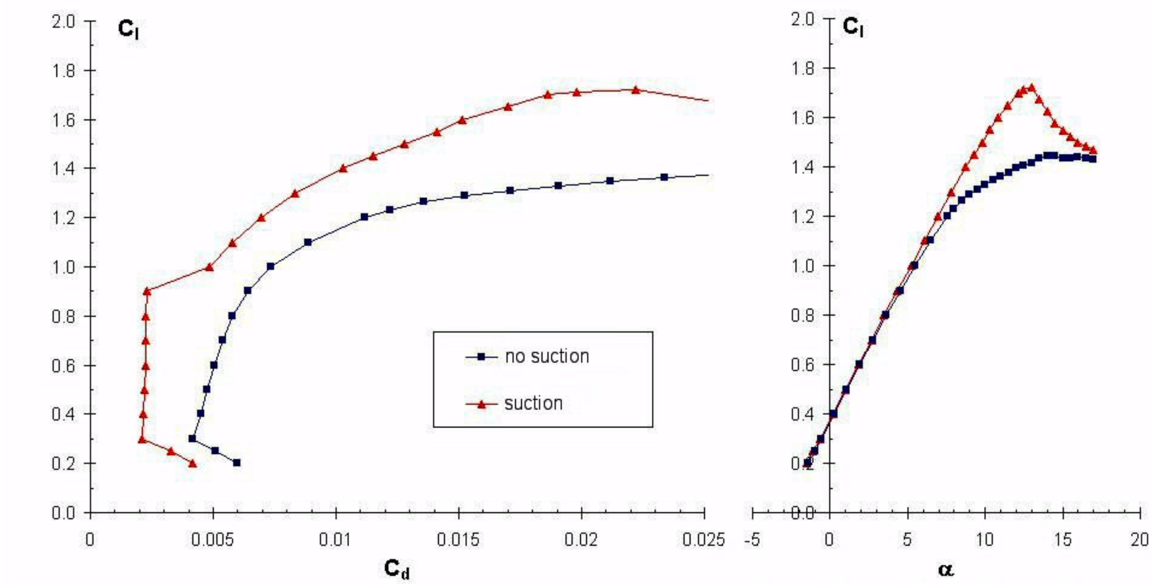

Fig. 6. Calculated aerodynamic characteristics without and with boundary layer suction.

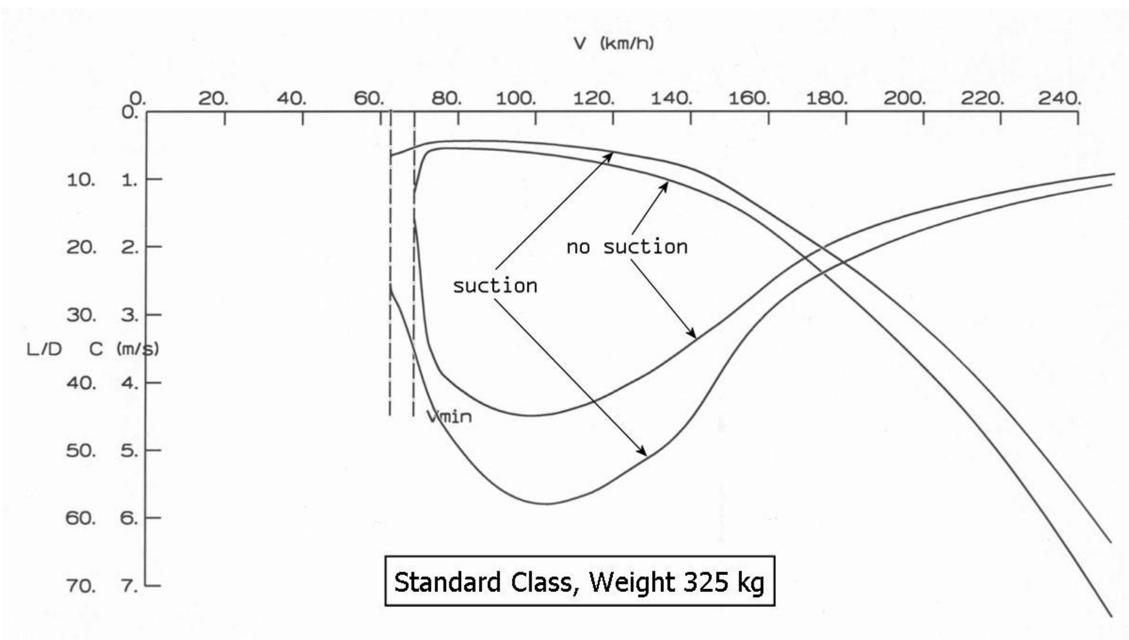

Fig. 7. Improvement of the speedpolar of a Standard Class sailplane by boundary layer suction.

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