Improving Sailplane Performance with Suction Boundary Layer Control

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Introduction

Even in the silent flight of a sailplane, man's desire to fly is not completely gratified, mainly because he is a passenger who rides rather than flies in the air. The pilot does perform some physical activity towards keeping the ship aloft but in a two-place sailplane, the observer's main duty is to keep track of where the ship has been. It is the purpose of this paper to present a technique whereby the observer may work to pay for his ride.

By reducing the losses in the boundary layer of air which surrounds a sailplane wing in flight, the lifting capabilities of the wing may be improved while, simultaneously, the profile drag is reduced. With a higher lift coefficient, the ship is thus able to circle tightly at slow speeds and to extract the higher energy at the core of the thermals. This process of reducing the boundary layer losses, boundary layer control, may be accomplished very simply by sucking away the low energy air through rows of small perforations distributed over the surface of the wing. The pump which supplies this suction may be powered by the observer in the sailplane.

Of course, any boundary layer control system which relies upon the human body for its operation must of necessity require only very little power. The power requirement, at low speed, of boundary layer control by suction through distributed perforations does not exceed the power easily available from an average young man.

In the present system, an increase in lift coefficient from 1,40 to 2,40 and a reduction in profile drag coefficient from 0,008 to 0,0065 may be realised with the expenditure of about 0,5 HP. This is equivalent for an 800 pound ship to obtaining more than 600 pounds of lift per horsepower or about 40 times the lift per horsepower of most helicopters.

Design of the BLC system

In order that a maximum economy of power be realized, the rows of holes must be distributed according to the demands of the boundary layer itself. Fortunately, an equation describing the relation of the losses in the boundary layer to the required suction velocity has been written by the renowned Professor Ludwig Prandtl. In a simplified form, this equation is stated below (reference 1).

$$V_o = 3{,}5\ \Theta_i\ U' - 0.5\ C_f\ U$$

where

V_o = local inflow velocity

Θ_i = value of momentum thickness of the boundary layer at the start of suction

U' = local velocity gradient

U = local velocity

C_f = turbulent flat plate skin friction evaluated at local R. N. based on distance run and local velocity.

The local velocities and velocity gradients should be obtained from the potential velocity distribution around the airfoil in question, however, favorable results may be obtained by using measured values of the velocities. The velocities around a sailplane wing are perhaps most easily measured with a pressure tape (figure 1) and a airspeed indicator (reference 2).

The momentum thickness of the boundary layer may be calculated from a measurement of the boundary layer by using a boundary layer "mouse" (figure 2). This measurement should be made at the chordwise point on the wing where the suction is to begin. The third variable in the suction equation may be obtained from published turbulent flat plate skin friction data. The skin friction coefficient should bi calculated at a Reynolds Number based on the local velocity and the distance behind the leading edge. Knowing the suction velocity as a function of the chordwise position on the wing, the surface is then perforated to obtain the required suction. In order to avoid spanwise disturbances the holes in each spanwise row are spaced 10-per inch and the chordwise distance between rows is varied to achieve the required in-flow distribution.

For a sailplane comparable in size and weight to the Schweizer TG-3 A, the spacing between rows near the leading

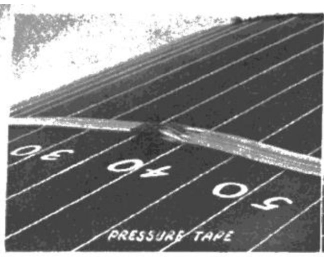

Fig. 1

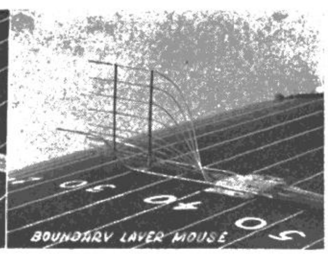

Fig. 2

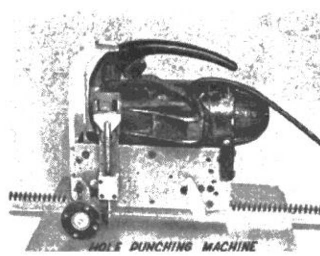

Fig. 3

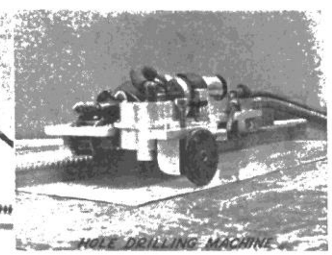

Fig. 4

edge will be about 0,10 inch and near the trailing edge about 1.0 inch.

At the Aerophysics Department at Mississippi State College, two machines have been developed to perforate the wing surfaces. One is used to punch holes in fabric covered wings and utilizes ordinary sewing needles (figure 3). It should be remarked that we are indebted to the fine quality control of the English needle-makers for the uniformity of these needles. The other machine is used to drill holes in metal or plywood covered wings (figure 4). This machine is capable of drilling more than five holes per second in 0,032 inch Alclad. Although these machines are extremely useful and are great time savers, many thousands of holes have been punched and drilled by hand and a wing with an area of about 160 square feet could be perforated by two people in one week.

The pump for the BLC system must be capable of reducing the pressure inside the wing of the sailplane to a value below the minimum pressure on the outer surface of the wing. At this pressure the pump should also be able to move the required amount of air.

Comparison of Performance of BLC Sailplanes

The advantages of applying BLC to the wings of a sailplane may easily be seen by comparing the performance of a typical, clean, two-place ship without BLC to the same ship with BLC.

For this comparison, a ship having the following specifications will be used as the basic sailplane without BLC.

Gross weight–790 pounds
Basic wing aera–160 square feet
Maximum lift coefficient–1.40
Aspect ratio–15,0
Span efficiency–90 %
Profile drag coefficient of wing–0,0080
Profile drag coefficient of fuselage and tail–0,0030

This craft is about the size and weight of the Laister-Kaufman TG-4 A and is almost as clean as the sailplane "Tiny Mite". The performance of this basic ship will be compared to the three boundary layer control sailplanes listed in the table below.

	Basic	1st BLC	2nd BLC	3rd BLC
Gross weight (pounds)	790	840	840	840
Wing area (square feet)	160	160	119	101
Max. lift coefficient	1,40	2,40	2.40	2,40
Span efficiency	90 %	90 %	90 %	90 %
Aspect ratio	15.0	15.0	15,0	15,0
Wing loading (pounds per square feet)	4,93	5,25	7,10	8,30

In each case the weight of the boundary layer control ships has been increased by 50 pounds to allow for the boundary layer control equipment. The wing area of the three boundary layer control ships was changed to adjust the wing loading. The first boundary layer control ship has the same wing area as the basic ship and only a slightly higher wing loading due to the added weight of the boundary layer control equipment. The second boundary layer control ship has a higher wing loading than the basic ship and the third boundary layer

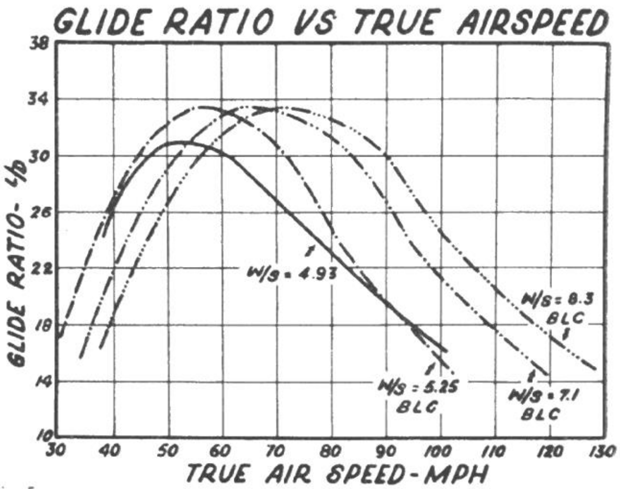

Fig. 5

control ship has such a high wing loading that even at the greater lift coefficient its stall speed is the same as the basic sailplane. Figure 6 compares the sink speeds of all four of these sailplanes and figure 5 shows the glide ratio. As was to be expected, the maximum $L/_D$ and the minimum sink speed occurs at higher speed for the heavier ships.

From the nomograph of Hakkinen (reference 3) the sinking speed as a function of turning radius may be computed.

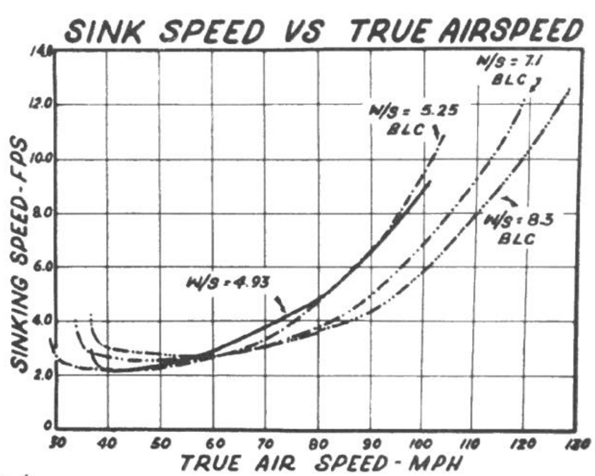

Fig. 6

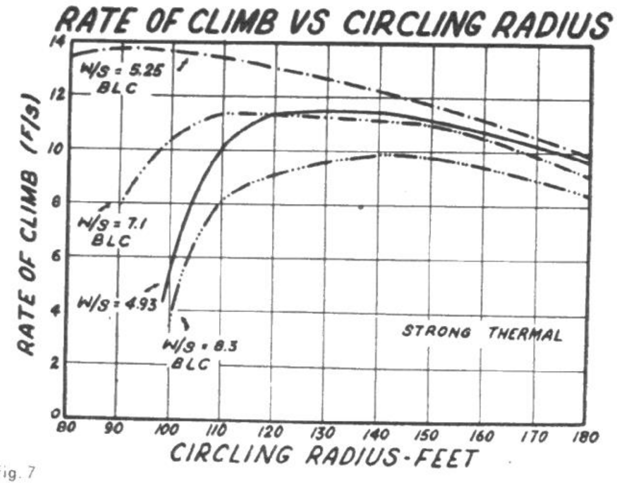

Fig. 7

Knowing the sink speed in circling flight and the thermal strength as a function of radius, the rate of climb in the thermal may be calculated. For this comparison, the thermals described in reference 4 were used with the above sink speeds to determine the rate of climb as a function at circling radius for both a strong and a weak thermal—figures 7 and 8. The ability of the first boundary layer control ship to circle at low speeds well toward the core at the thermal gives it a higher rate of climb than the other ships. The second boundary layer control sailplane is seen to have the same rate of climb in a strong thermal as the basic ship even though its wing loading is higher. This is due to its ability to circle closer to the core of the thermal. However in a weak thermal it is unable to circle tightly enough to make up for its higher sink speed. The third boundary layer control sailplane, which has the heaviest wing loading, has lowest rate of climb of all four ships both in the weak and the strong thermal.

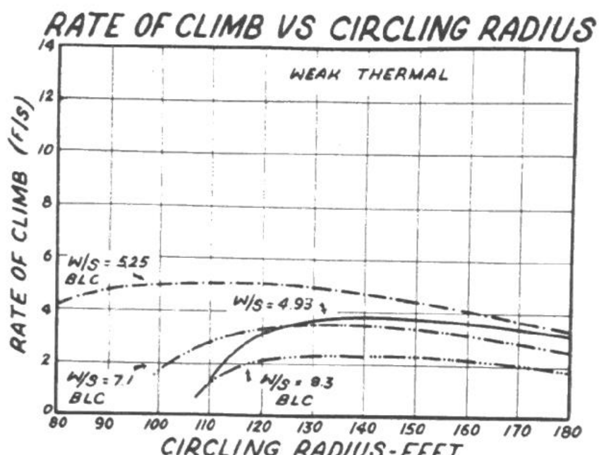

Fig. 8

The influence of the rate of climb in circling flight on the effective cross-country speed is readily calculated from the equation of Temmes (reference 5).

$$V_{eff} = V_g \left(\frac{R/_c}{R/_c + R/_D}\right)$$

V_{eff} = effective cross-country speed

V_g = speed between thermals

$R/_c$ = rate of climb in thermal

$R/_D$ = rate of descent at V_g

When the effective cross-country speeds of the four ships are calculated and compared the powerful effect of the low circling speed is obvious—figures 9 and 10. For the strong thermals where there is a high rate of climb available even for the more highly loaded BLC ships, the higher speed at which these ships fly between thermals gives them a slightly greater effective cross-country speed. However, in the case of the weak thermal where the available rate of climb drops off sharply with distance from the center, the more lightly loaded BLC ship with its better circling ability performs much better. The effect of the BLC is illustrated by the fact that for strong thermals all of the BLC ships show a higher cross-country speed than the basic ship. Even in weak thermals, only the third BLC ship with the highest wing loading shows a drop in performance.

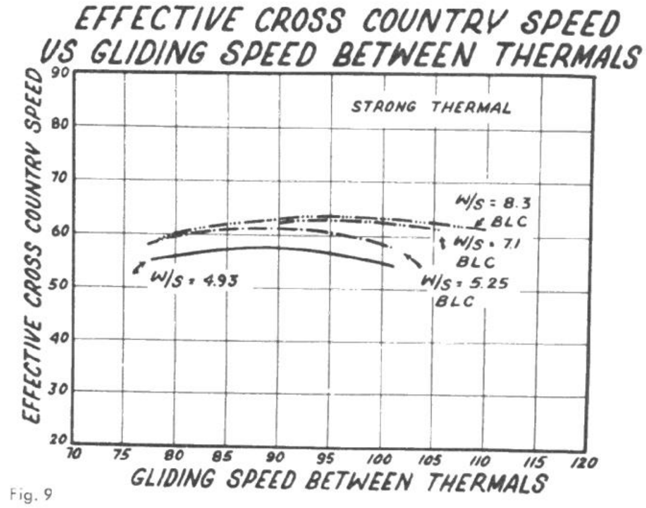

Fig. 9

If it is assumed that there is an equal distribution of strong and weak thermals an average cross-country speed for the ships may be computed. The average cross-country speed for the ships is listed below:

	Basic	1st BLC	2nd BLC	3rd BLC
Avg. $V_{c/l}$	46.4	51.9	50.7	47.2

From this it is seen that the most lightly loaded BLC ship has the highest effective cross-country speed. This indicates that despite its lower speed between thermals its higher rate of climb while in the thermals gives it better cross-country performance.

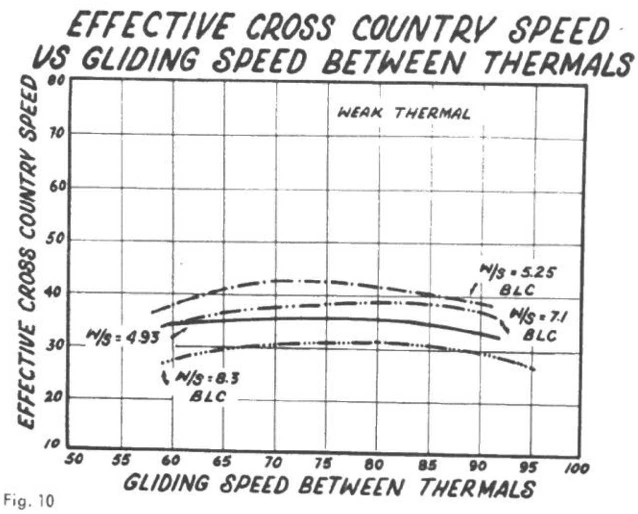

Fig. 10

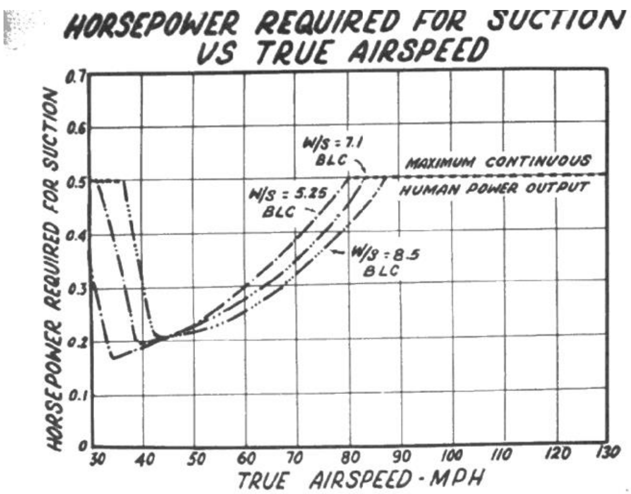

Fig. 11

The power required for this better performance has been calculated for the three BLC sailplanes assuming a 4416 airfoil section and is presented in figure 11. It is of interest to note that the minimum power required for the suction occurs at a speed very close to the minimum sink speed of the sailplane. This would allow the observer to relax in his work and still permit the ship to fly with minimum loss of altitude. Except at the highest speeds, the power requirements could be met by the observer.

Concluding Remarks

While this paper is not intended to present the optimum design for a boundary layer controlled sailplane, it does show the gains to be realized by lowering the stalling speed of a typical contemporary design. By increasing the lift without increasing the profile drag of the wing, as in the case of a flapped airfoil, the rate of climb in the thermals may be considerably improved. The increased cross-country speed to be gained in this manner is seen to exceed that obtained by raising the wing loading and increasing the speed between thermals. The primary object of the paper is to present another parameter to be considered in the design of high performance ships. The use of BLC in contest flying is but one aspect to be considered, the ability to fly very slowly also has other potential. At Mississippi State College, a Schweizer TG-3 A sailplane (figure 12) has been equipped with a boundary layer control system (reference 6). The maximum lift coefficient of the sailplane has been increased from 1,40 to 2,30 with an expenditure of only 0,8 horsepower. The power for this system is provided by an electric storage battery; the entire system including battery weights approximately 160 pounds. The sailplane has been flown in thermals in the company of the buzzards which abound in the vicinity. While circling with the birds with the BLC system turned off, the buzzards exhibited a better rate of climb than the sailplane and they could spiral up past the ship. However, when the BLC system was turned on, the ship soon rose above the birds. This procedure could be repeated over and over until the birds tired of the game and left for another, less crowded, thermal.

It is hoped that this method, BLC through distributed rows of perforations, will allow the design of higher performance sailplanes and perhaps certain special purpose ships with very low speeds. The improvement of the aerodynamics of the sailplane according to the demands of the boundary layer control will produce new applications of the sailplane both as a tool for research and as a vehicle for sheer sport flying.

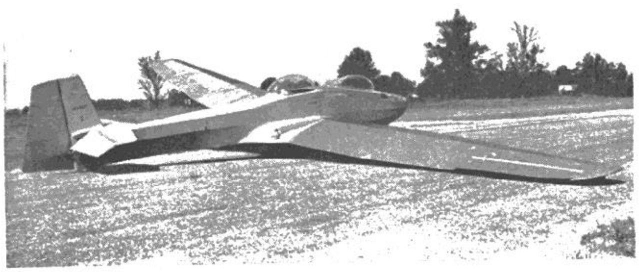
Fig. 12. Schweizer TG-3 A Sailplane

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