# Improving the Constant Chord Wing

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The September 1982 issue of SOARING contained an article that should be of a particular interest to us home builders: IN DEFENSE OF THE RECTANGULAR WING FOR SIMPLE SAILPLANES, in which Stan Hall with his typical sense for clarity showed that the recently much maligned constant chord wing is not all that bad. To sum up his findings:

ADVANTAGES:
* simplicity in construction
* excellent stall characteristics
* excellent high speed behavior

DISADVANTAGES:
* heavy structure at a high aspect ratio
* slightly deficient in roll response
* only fair performance at low speed unless the wing is twisted, in which case the high-speed performance suffers

The remarkable thing about the constant chord wing, of the kind used in sailplanes, is that it can be made aerodynamically almost perfect in slow flight without impairing high speed performance, gaining in the process in the lightness. All this, as we will see, for a price of a few additional working hours only. First, however, before we proceed to "cure" the constant chord wing, we must closely diagnose one of its maladies. In tight banked thermaling flight the constant chord wing experiences difficulties. It climbs much worse than one would expect at a first, superficial look at calculated performances.

When thermaling, the pilot frequently must decrease his speed as far as safely possible. Perhaps only a few mph above the stall. By pulling on the stick he therefore increases the lift coefficient $C_L$ of his wing close to its maximum value. He realizes that by doing so he has forfeited the sailplane's "straight flight" minimum sink rate. In order to remain in the core of the thermal he tries to fly at the best sinking speed his sailplane is capable of when banking 40, 50, 60°. The reader, remembering that in a properly executed 60° turn the wing must generate lift of twice the sailplane weight, will understand that flying at a very high lift coefficient $C_L$ becomes a must in those tight baked turns. (A truly excellent article by Derek Piggott, describing the necessity and benefits of very tight thermaling close to stall, appeared in the July 1980 issue of SOARING. The reader might consider rereading it).

A HIDDEN FLAW

Quite a problem, this tightly banked flight. Forgetting that in circling flight the "inner" wing flies slightly differently than the "outer" wing, and that there are some other details to be considered, we will only try to answer the question: how does the rectangular (constant chord) wing behave close to its maximum lift coefficient, or, in the pilot's language, just before the stall? The buffeting the pilot registers just before the stall is, as we know fromm basic aerodynamics, equivalent to flying close to the maximum wing lift coefficient $C_L$max. Figure 1 shows, approximately, the

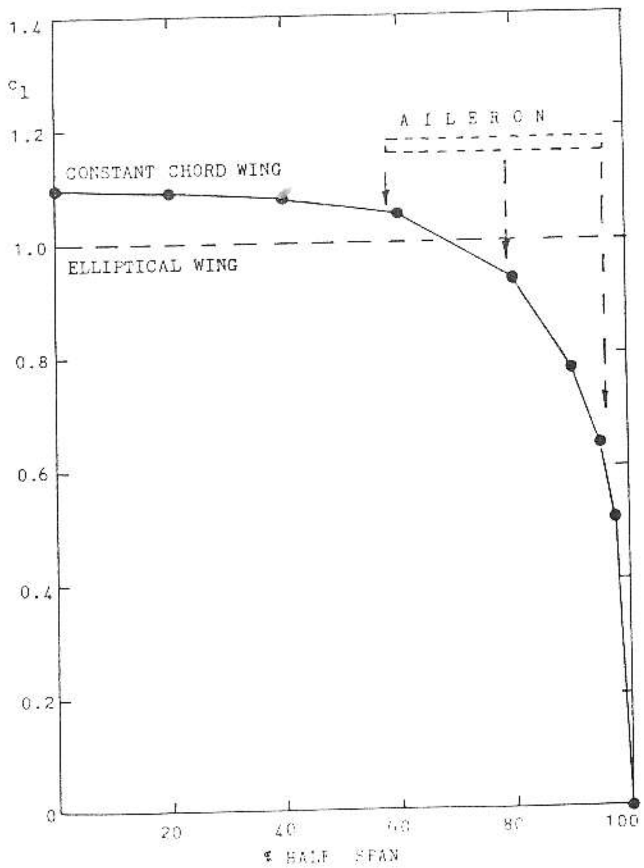


Fig. 1 Lift coefficient distribution for a constant chord wing flying at average lift coefficient $C_L$ = 1.0, aspect ratio = 14 (broken line: elliptical wing)

distribution of the lift coefficient $c_l$ along the wing semi-span for a constant chord wing flying at an overall wing lift coefficient $C_L$ = 1.0. If this untwisted wing had an elliptical planform, "local" lift coefficients $c_l$ would equal 1.0 all along the wing span. In a constant chord wing, however, the "local" lift coefficients vary along the semi-span. The "local" lift coefficient at the wing root is about 10% higher than the overall wing coefficient $C_L$ = 1.0. The local lift coefficients gradually decrease from this highest value at the root, to zero at the wing tip. Ailerons are situated in the quickly falling part of the lift coefficients - a feature that gives the constant chord wing a certain safety at stall as the ailerons remain effective, enjoying a healthy airflow at low lift coefficients.

Most of the modern non-flapped laminar sailplane airfoils stall (at speeds and Reynolds numbers expected in sailplanes) at a section lift coefficient in the vicinity of $c_{l\ max}$ = 1.4, thus permitting flying a wing lift coefficient close to this value, say $C_L$ = 1.35 in a tight thermal. Figure 2 shows the same general shape of the

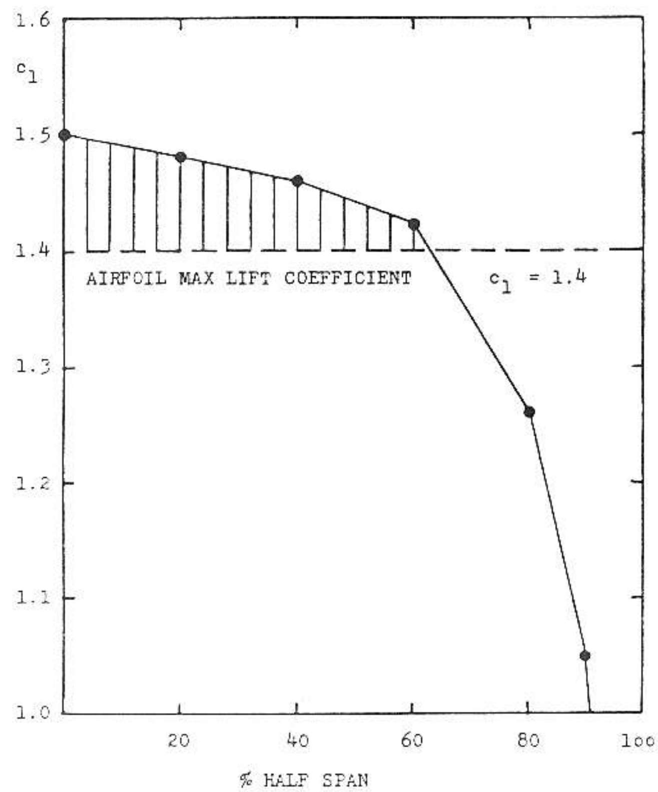


Fig. 2 Theoretical lift coefficient distribution for a constant chord wing trying to fly at an average lift coefficient $C_L$ = 1.35, aspect ratio = 14

lift coefficient distribution along the wing semi-span as Figure 1 did, except that is has been plotted for an overall wing lift coefficient $C_L$ = 1.35. The wing now flies close to stall. The broken line in Figure 2 indicates the maximum lift coefficient = 1.4 this example airfoil is able to obtain. The reader will immediately realize that something is terribly wrong with this diagram: How can the wing fly at an overall wing lift coefficient of $C_L$ = 1.35, as this requires a "local" lift coefficient of approximately 1.5 at the wing root - while the highest lift coefficient the airfoil is able to supply is only 1.4?

As a matter of fact, the entire wing from the root to some 60% of the semi-span flies at or beyond the stall of the chosen airfoil. The expected and desired flight at an overall wing lift coefficient of 1.35 simply never is realized. The best that can happen to the sailplane is that it mushes and buffets while the pilot struggles to keep the stalled machine under control. A practical and disappointing conclusion: this constant chord wing is incapable of flying at a high wing lift coefficient because the inner part of it stalls before $C_L$ is reached for the entire wing.

A more realistic lift coefficient distribution at the desired but not obtainable overall $C_L$ = 1.35 is shown in Figure 3. The central part of the wing has stalled. The higher the theoretically expected "local" lift coefficient $c_l$ above and beyond the $c_{l\ max}$ of the airfoil, the deeper in stall is the part of the wing.

If the designer was ignorant enough to mount the constant chord wing at mid-fuselage ("midwing position"), blindly copying those racing soaring missiles (ASW-20, Ventus.....) the situation will be even worse. The wing-fuselage interference will further contribute to the "killing" of the remainder of the lift at the wing root.

A constant chord wing therefore simply cannot efficiently fly close to the maximum lift coefficient provided by the airfoil used. In the above case, the local stall never allows the total wing lift coefficiet to rise above $C_L$ = 1.29, in spite of flying with an airfoil capable of $c_{l\ max}$ = 1.4.

To make matters worse, the drag of an

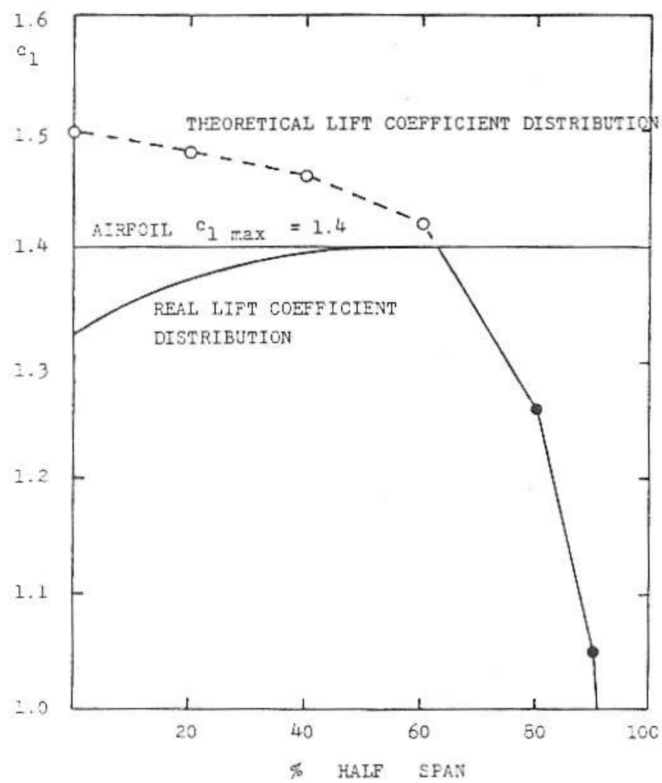


Fig. 3 Constant chord wing expected to fly at an average lift coefficient $C_L$ = 1.35 using an airfoil with a $c_{l\ max}$ = 1.4, aspect ratio = 14

airfoil strongly increases at and beyond the angle of attack corresponding to the stall. And to make matters worse, the drag due to the lift (induced drag) also considerably increases close to and at the stall because the lift distribution is now far from being elliptical. As Stan Hall pointed out in his article, the further away from an elliptical lift distribution, the more the induced drag increases beyond its optimal value. In short: the constant chord wing, when thermaling at low speed, ends up with strongly diminished lift and strongly increased drag. Now the reader will understand Stephen du Ponts concern, as related by Stan Hall, about poor thermaling ability of his constant chord sailplane, and the disappointment of other constant-chord sailplane builders who wonder why their designers did not do the homework.

There is nothing new in what the above Figures tell. About 20 years ago

Professor Wortmann (see Reference 1) warned against this deficiency of the constant chord wing, and diagrams, similar to those above, have appeared in all better sailplane design books for the last 50 years or so.

Twisting the wing does not help. Just the opposite. Wing twist (wash-out) is bad enough at high speed. At a very low thermaling speed - high $C_L$ - it further increases the "local" lift coefficient at the wing root and decreases it at the wing tip, thus accelerating the already adverse situation.

The reader will understand why the designers of good sailplanes opt for at least simply tapered (Libelle, Schweizer 1-35, LS-3, Foka, etc.), but preferably twice and three-times tapered wings.

AND A CURE...

It helps - a little - if the designer choses an airfoil the lift of which does not collapse immediately upon reaching its maximum value. There are several such airfoils known, among them some of the NACA 63, 64, 65 series, Wortmann FX 61-184 and 163, etc. However, the very heavy drag increase at and beyond the stall remains.

It would be a pity to lose the attractive structural simplicy of the constant chord wing. Could we cheat Mother Nature and make the wing just a little bit more "elliptical"? Such a shape would tend to decrease the local lift coefficient where it is too high - at the wing root - and increase it towards the wing tip, exactly what we want. Indeed we can do that and it costs next to nothing. All we have to do is to taper a relatively small outer part of the wing, only 20% or so of the semi-span. In a 15-meter sailplane this amounts to some 5 ft. out at the wing tip. Figure 4 shows, as an example, the "almost constant chord" wing of the S-2 powered sailplane. The photo shows that this kind of wing does not look bad in flight either. It is not an elliptical wing and its lift distribution is not really elliptical in shape; the lift coefficient is not constant all along the semi-span as in an elliptical case. But, as an inexpensive and simple modification, this shape approaches the "elliptical" wing surprisingly well, as Figure 5 shows. The reader recognizes the desired decrease of the root lift coefficient as compared to the crude constant chord wing. The longer the tapered part, the closer will be the root lift coefficient to that of an ellipse. The degree of tapering (2/1, 3/1) plays a relatively minor role. As a fringe benefit, the new lift distribution results in a nice decrease of the induced drag coefficient because the shape approaches that of an ellipse (Figure 5 shows only the central, more critical part of the wing semi-span). Now the designer can also slightly increase the "constant" chord to keep the same aspect ratio the original wing

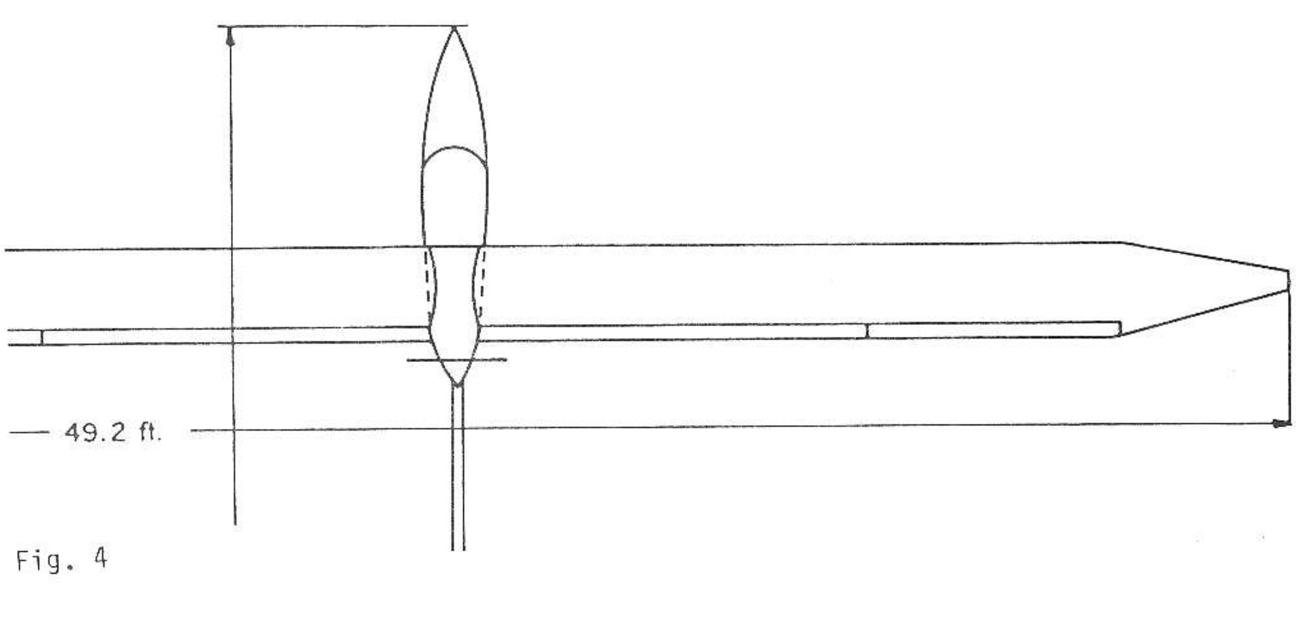


Fig. 4

had, ending up with a spar several % deeper and therefore lighter - another fringe benefit.

Calculation of the lift and the lift coefficient distribution of the wing of the new shape is a little more complex than for a constant chord or a straight tapered wing where the references in Stan Hall's article are a great help. There exists, however, an interesting and simple method proposed by O. Schrenk (Reference 2) which enables us to calculate and plot the lift and lift coefficient distribution along the semi-span of any reasonably shaped wing planform. The Schrenk Method states that the lift distribution consists by 50% of the general elliptical shape contribution and by 50% of the actual wing planform contribution - all all we have to do is add up the two. The method does a little injustice to the constant chord wing, presenting too high a lift at the wing root (in Figure 5 this has been taken care of). For the example wing (Figure 4)

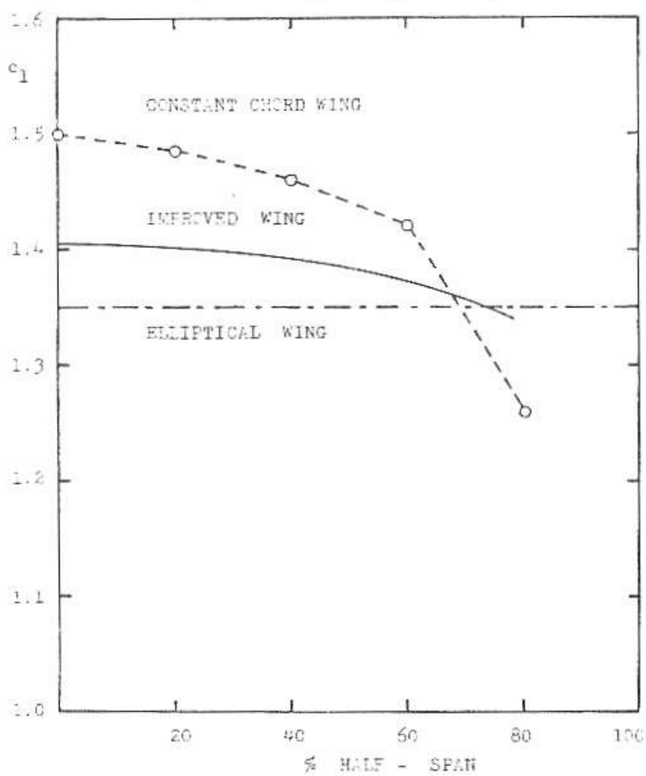


Fig. 5 Lift coefficient distribution for a constant chord elliptical & "improved" wing flying at an average lift coefficient $C_L$ = 1.35, as aspect ratio = 14

Reference 3 gives a complete calculation together with a simple introduction to the Schrenk Method. This Schrenk Method should be quite attractive to the homebuilder as it is easy to understand and quickly produces results. It is only moderately accurate (I would estimate around + 5%), but in most aerodynamic calculations this accuracy should suffice, and it is definitely accurate enough for the determination of the lift distribution in the wing stress analysis.

Again, the little, simple, and economical change at the tip of an originally constant chord wing is nothing really new. For years it has been known that a wing having a constant chord up to, say, 50 or 60% of the semi-span, and tapered from here to the tip, produces, if untwisted, for all practical purposes an elliptical lift distribution. We simply carry this "elliptical" idea a little further, engaging only the tip of the wing, while retaining good aileron efficiency. The modification of the wing, for example, with foam and glass - no spar is necessary - although a little heavy, may turn out to be the simplest part of the building the sailplane. Finally, one more benefit: the lift distribution of this kind of a semi-tapered wing produces smaller bending moments than a constant chord wing of the same span and same aspect ratio. This "almost constant chord" wing is not a perfect solution, obviously. It does represent, however, a substantial improvement in both increased lift and decreased drag in slow flight, and pays no penalty at high speed.

REFERENCES


1. F. X. Wortmann, "Drag Reduction in Sailplanes," Paper presented at OSTIV 1965 and published in OSTIV Publication VIII (available from SSA). A translation in two parts appeared in SOARING, June 1966).

2. O. Schrenk, "A Simple Approximation Method for Obtaining the Span-wise Lift Distribution," NACA T.M. 948, 1940).

3. A. Strojnik, "Low Power LAMINAR AIRCRAFT DESIGN," 1983.