DESIGNING TOWARD A ONE FOOT PER SECOND SINKING SPEED

by Bruce H. Carmichael

Paul MacCready made a comment following the lecture, "New Approaches", by Dr. August Raspet at the 1959 Soaring Conference. Paul said, "If a sailplane could be made with a sinking speed of one foot per second, it should be able to stay up on almost any day." (Ref. 1) This led me to do a study seeking out the parameters required to reach such a goal. (Reference 2) I wrote, "There is no predicting what new information may come to light when we are able to explore a new regime of flight." Now, thanks to the flight experience of Gary Usaba in the Maupin/Culver Carbon Dragon. We are receiving reports of this here-to-fore unexplored regime.

In my 1961 paper, I provided a plot of the required L/D to reach sinking speeds of 2, 1.5 and 1.0 ft/sec. vs. flight speed in m.p.h, shown here as Figure 1. If we could fly at 25 m.p.h., an L/D of 37 would be required to reach 1 ft/sec.. If we were willing to settle for 1.5 ft/sec we could do it with an L/D of 25 at 25 m.p.h. If we assume this L/D is reached at a lift coefficient of 1.15, the wing loading could not exceed 1.8 pounds/sq ft.

From my 1961 study, sinking speed is plotted vertically against flight speed in m.p.h. on the horizontal scale, with lines of constant L/D of 10, 20, 3O and 40 superimposed in Figure 2. Several sailplanes and 2 pre-WWII manpowered aircraft data are plotted on this

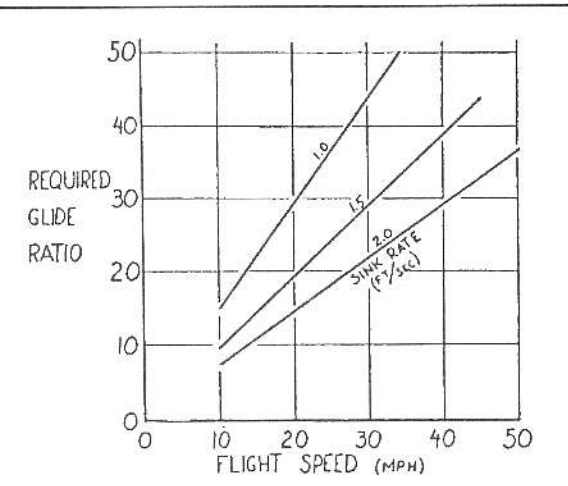
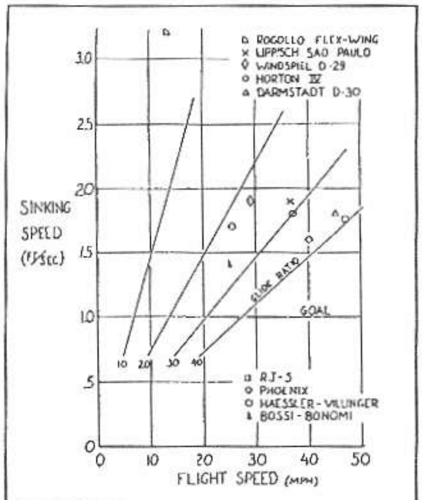


FIGURE 1.



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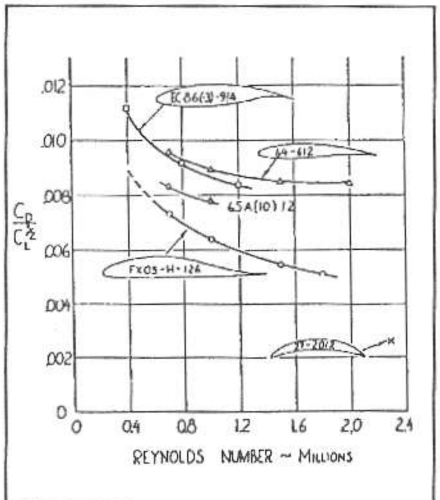

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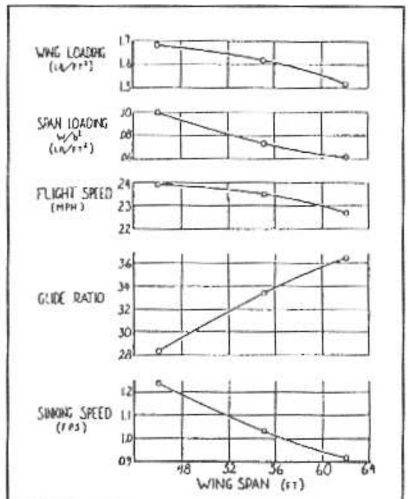


FIGURE 4.

figure. We see the Phoenix sailplane with a sink of 1.6 ft/sec which is remarkable for a practical sailplane. The Bossi-Bonomi man powered would have had a sink of 1.4 ft/sec unpowered. None reach the magical one foot per second.

Very low sinking speeds require a low wing loading and high lift coefficient to produce low flight speed. A very powerful influence on sinking speed is the ratio, gross weight over wingspan squared. It is also necessary to use an airfoil wing section with a high value of lift to the 3/2 power over drag and this should occur at a high lift coefficient. The best practical section I found for my 1961 study was the Wortmann FX 05-H-126. On Figure 3 we observe that I had to extrapolate the data below a RN of 700,000. It is likely that minimum sink sailplanes will operate at RN of 500,000 or less.

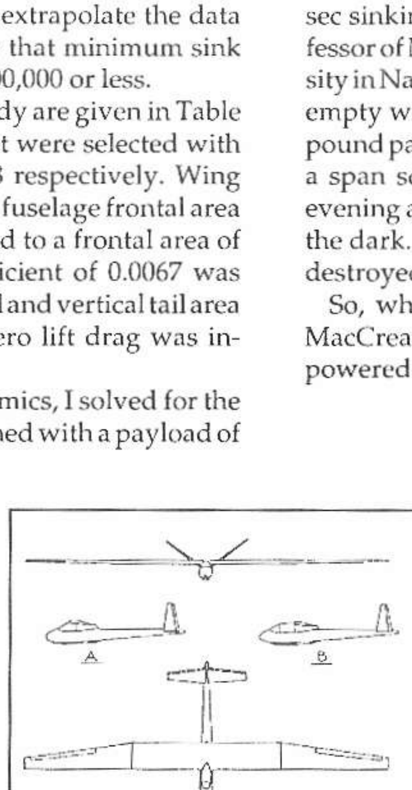
The assumptions of my 1969 study are given in Table 1. Wingspans of 46, 55, and 62 feet were selected with aspect ratios of 16.7, 22, and 24.8 respectively. Wing profile drag data were available. R fuselage frontal area drag coefficient of 0.07 was applied to a frontal area of 3.5 sq. ft.. Tail profile drag coefficient of 0.0067 was applied to the sum of the horizontal and vertical tail area of 15% of wing area. The total zero lift drag was increased 4.5% for the brace wires.

After working out the aerodynamics, I solved for the range of weights that when combined with a payload of 130 pounds would result in sinking speeds near 1 ft/sec. The values appeared unrealistic. Then I found a paper by Haessler (Ref. 3). He had built a 46 ft. span man powered aircraft in 1935 and in his article projected its achieved weight to larger wingspans. He found when he got the structure stiff enough, that he had a 6 g design.

Realizing that low empty weights would require low payload weight, I chose 130 pounds which really limits the test pilot field. I came up with empty weights of 82, 94, and 105 pounds for the 3 wingspans. The results of this 1961 study are given in Figure 4. With increasing span, the wing loading drops from 1.7 to 1.5 p.s.f., span squared loadings drop from 0.1 to 0.06, flight speeds from 24 down to 22 m.p.h., glide ratios from 28 up to 36, and minimum sinks from 1.23 f.p.s. down to 0.42 f.p.s.. A value of 1 ft/sec was reached at a span of 56 feet.

My study did not at that time change the history of soaring flight, but one individual read it, caught fire and built a sailplane with the express goal of reaching 1 ft/sec sinking speed. (See Figure 5). Franklin Farrar, Professor of Mechanical Engineering at Vanderbilt University in Nashville, Tennessee built a 61 ft. span 160 pound empty weight ship of 16 aspect ratio which with a 160 pound payload would have a 1.4 p.s.f. wing loading and a span squared loading of 0.086. He flew it late one evening and it took so long to come down, he landed in the dark. Before it could be investigated further it was destroyed in a storm.

So, what has happened since the 1960's? Dr. Paul MacCready and the M.I.T. group have produced man powered aircraft with wing loadings of a half pound per



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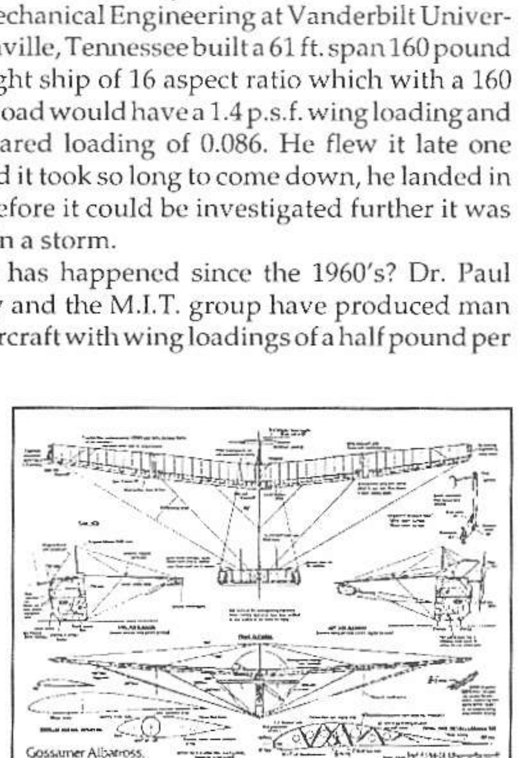

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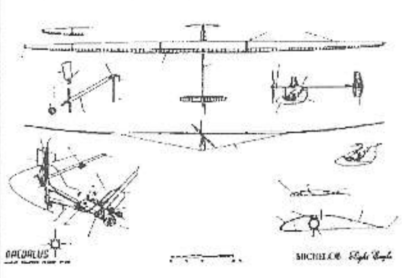

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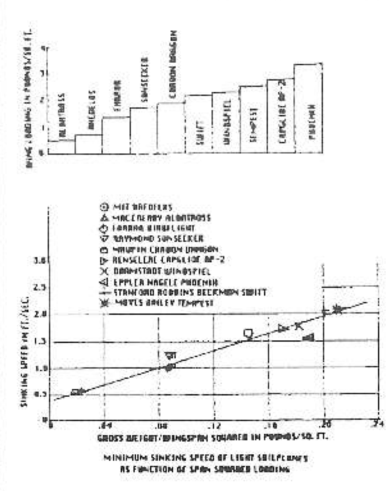

FIGURE 8.

square ft. and sinking speeds on the order of 0.6 ft/sec..(See Figure 6 and 7). While these special purpose machines are not what the soaring pilot desires, the technology will be helpful in developing our dream low sink sailplanes.

Let us examine some light sailplanes from pre-WWII to the present.

The wing loadings appearing in upper Figure 8 range from 0.5 p.s.f. for man powered craft, to 1.4 for Farrar's ship, to 1.75 for Eric Raymond's Sun Seeker with prop, motor, battery, and solar cells removed, to 1.87 for Carbon Dragon. The Swift, pre-war Windspiel, Tempest, and Capglide RP-2 run from 2.2 to 2.8 pound/sq. ft. The landmark sailplane of all time that brought on the composite age. The Eppler-Naugele Phoenix flew at 3.4 p.s.f. All values are with 100 pound payload.

The lower portion of Figure 8 presents sinking speed against span squared loading where the payload has again been set at 160 pounds. We see Sun Seeker at 1.25 f.p.s., Carbon Dragon at 1.65 f.p.s., RP-2 at 1.7 f.p.s. Windspiel al 1.8 f.p.s. and Swift and Tempest at slightly over 2 f.p.s. It appears that practical light sailplanes can obtain minimum sinks of 1.6 to 2.0 f.p.s. Three views of Windspiel and Carbon Dragon appear in Figures 9 and 10.

What might we gain with recently acquired technology? We desire as low a sinking speed as possible but the ship must be practical. The cost cannot be astronomical and it must be producible in quantity. It must be reasonably immune to ground rash as well as meet flight strength requirements. In the aerodynamic line, there have been continued airfoil developments and at last some low turbulence wind tunnel data in the half million Reynolds number range, with much data in the upper model aircraft range of 100,000 to 300,000, seed Reference 4. There are undoubtedly sections developed for high altitude drone aircraft that are not available to me. One section which was available a few years after my 1961 paper is the outstanding Wortmann 63-177 which this genius developed for man powered aircraft. (See Reference 5). Test data were obtained at Reynolds numbers of 280,000, 500,000 and 700,000. (See Figure 11). Very high values of lift to the 3/2 power over drag

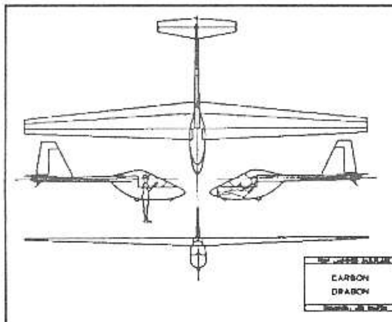

FIGURE 9.

were reached at a lift coefficient of 1.5. The drag was surprisingly low for lift coefficients from 0.5 to 1.6. A full span flaperon would be required to help the penetration of our light sailplane. This would also reduce the high nose down pitching moment at high speed. There is a battle between airfoil designers over whether to go for maximum high lift performance with aft camber, and pitching moment be damned, or settle for slightly lower high lift parameters and design for low pitching moment since the trim drag of aft loaded sections may eat up the gain of these sections. Bob Liebeck has done much work with both types in our RN Range. (See Reference 6).

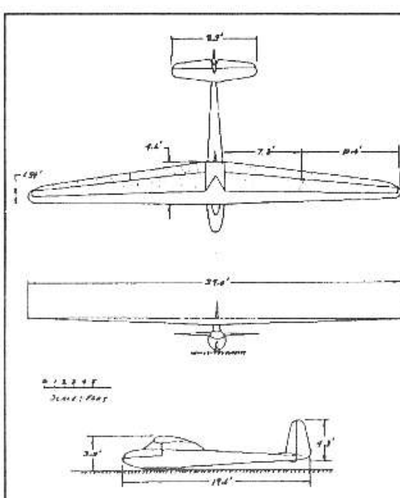

FIGURE 10.

The success of a producible. maintainable, affordable low sink sailplane will be more dependent on materials and processes than on further aerodynamic refinements. The ability to make accurate female molds directly, plus availability of glass and carbon pultrusions and improved sandwich core materials furnish some optimism.

We may write the sinking speed formula as:

$$\text{Sink Speed}_{f.p.s.} = 29\sqrt{\frac{W}{S}}\left[\frac{C_{D_0}}{C_L^{3/2}} + \frac{C_{D_P}}{C_L^{3/2}} + \frac{C_L^{1/2}}{3\,AR}\right]$$

where the first term in the brackets is the wing profile contribution, the second is the parasite contribution, and the third term is the induced contribution. I assumed a fifty foot span sailplane with an empty weight

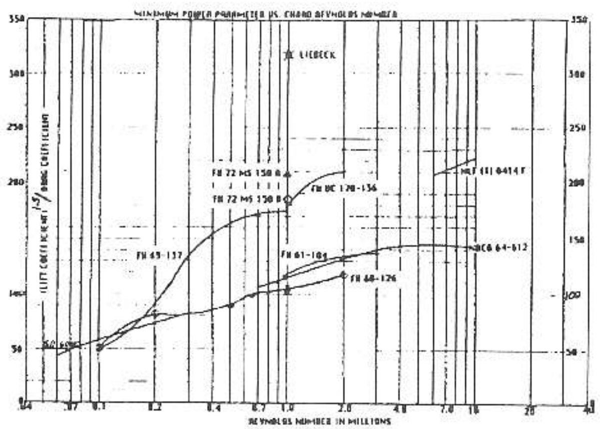

FIGURE 11.

equal to the payload of 160 pounds. A 2 pound/sq. ft. wing loading results in 160 sq. ft. of wing area and an aspect ratio of 15.63. This planform results in a mean chord Reynolds number of about 700,000 near minimum sink. Profile drag data was available from Reference 5. A parasite drag coefficient for fuselage plus tail of 0.002 was assumed.

A sinking speed of 1.3 ft/sec or slightly less was obtained for speeds of 25 to 30 m.p.h. increasing to 2 ft/sec at 45 m.p.h., 3 ft/sec at 54 m.p.h. and 4 ft/sec at 59 m.p.h.. A maximum. L/D of 36 occurs at 36 m.p.h.. If payload is increased to 200 pounds with the same 50 ft. span and if empty weight can still equal payload weight, the minimum sinking speed will increase to 1.6 f.p.s. As shown by recent experience of Gary Osaba in the Carbon Dragon, it is not necessary to fly at 1 ft/sec sink to enter the realm envisioned by Paul MacCready in 1959. While 1 ft/sec is still a desirable goal, the predicted performance of this paper should enhance exploration of this new era in soaring.

The crucial point is whether modern materials and fabrication techniques will result in a practical, producible, maintainable, and affordable low sinking speed sailplane. The elements appear to be available.

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