# A Homebuilt Two-Seater Powered Sailplane: Some Design Considerations

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## ABSTRACT

An attempt is described to combine a reasonable soaring performance (L/D 35, sink rate 120 ft/min) with good cross-country power-on performance, comparable to that of the Cessna 150/152. It is found that with a 15-meter, very high aspect ratio wing, a low-weight structure can be built and that less than 30 bhp are required for more than 100 mph in level fight or more than 500 ft/min climb in the two-seater configuration.

## INTRODUCTION

By the time a prospective homebuilder is financially in a position to consider building his own sailplane he is likely to be old enough to realize the importance of sharing the magic of flight with his wife or family member or a friend. Unfortunately there are no kits on the market that would fit the average would-be builder's checkbook and his wishes. If fact, there are no more than a handful of homebuilt two-seaters of any description flying at this time.

Ever since the plans for the author's S-2 powered sailplane became available, a surprisingly large percentage of enquiries concentrated on the future S-3 two-seater. This could be based partly on the subconscious wish of some would-be ("theoretical") builders to postpone making a costly and perhaps binding decision and to begin working; partly, however, it had to do with the fact that many letters came from power pilots, spoiled by flying side-by-side two-seater power planes.

The S-3 has been designed to be—lacking a better description—a "family motorglider." For the designer this meant that there would be no pressure for the best possible, "racing" performance. The goal has been set, however, to match, in powered flight, the known performance of the Cessna 105/152, with perhaps a bit less baggage, and in soaring flight to give a pilot a good chance to fly his FAI Badges. While the superior aerodynamic cleanliness of a sailplane almost automatically guarantees a high speed on low power, a satisfactory rate of climb under power requires a lightweight structure.

Distance flying for FAI Badges requires a reasonably fast design, a glide ratio L/D of 30 or better and a low sink rate of around 2 ft/sec, obtainable at *low speed.* The term *low speed* should be emphasized here in order to separate powered sailplanes from some modern light planes, which sport strong, mostly VW-derived engines in the fuselage nose, huge tail-dragger landing gear and low-wing configurations, while still satisfying the FAA definition of a motorglider. While these light planes can soar in strong conditions—as can the Cessna 150—and can reach high altitudes in clouds (a bold pilot in the 150 can do the same), they are predominantly used for power-on cross-country flying. Claims have been made for their usefulness as soaring trainers; however, it is easy to overlook that neither towing nor outlandings, two very important parts of "glider" training, can be taught in them.

At the beginning of the development of the S-3 two-seater a decision had to be made whether to proceed in the direction of a "light plane" as described above or in the direction of a soarable "sailplane." To clarify the situation it should be remembered that the soaring performance of a sailplane depends upon two "outside" parameters, each easily measurable by using only a yardstick and a scale. To be efficient in narrow thermals a sailplane must have a high aspect ratio $b^2/S$ (b wingspan, S wing area) and a low wing loading W/S (W gross weight). Each of these parameters may, of course, vary within certain limits, but the ratio wing loading/wing aspect ratio $W/b^2$ must be low if the sailplane is to soar well.

Using the data in the Nov. 1983 issue of *SOARING*, gross weight (W) has been plotted against wing span (b) in **Figure 1** and a very simple means found to separate "motorgliders" (light planes?) from powered sailplanes. The separation parabola has been computed as $W/b^2 = 0.45$, and it appears as a heavy curve in Fig. 1. If the data in *SOARING* are correct not a single "motorglider" to the left of the separation curve climbs in thermals as efficiently as *any* powered sailplane to the right of the $W/b^2 = 0.45$ separation line.

This method of presenting "soarability" is not new. It has been used by H. Zacher (Ref. 1) in his presentation at the 14th Congress OSTIV in Waikerie in 1974. FAA could use this easily measurable $W/b^2 = 0.45$ dividing line to get out of the mess it created with Advisory Circular AC 61-94.

The following report presents the considerations along both "power" and "soaring" lines that led to developing the design of the S-3.

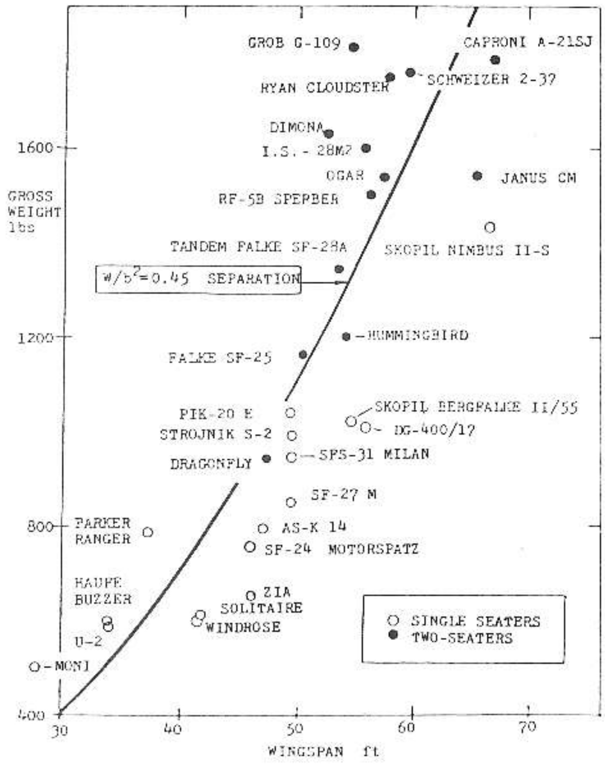

Figure 1: Gross weight vs. wingspan for motorgliders

### AERODYNAMIC CONSIDERATIONS

At the beginning of the development of the S-2 single-seater (Ref. 2, 3, 4) we did not know to what extent our then-new technology in the production of fiberglass wing skins would withstand the pressures of time. After five years the wing is as good as new. In fact, the torsional rigidity seems to have increased slightly over the years. No "step" above the spar, as noticed on some commercial fiberglass sailplanes, has been observed. Because of uncertainty regarding the stability of the skins, a rather conservative Wortmann airfoil was selected for the S-2. Today we feel confident that the skin technology introduced in the S-2 satisfies stringent requirements regarding airfoil accuracy and waviness of the surface. As the control surfaces seem to have been computed relatively well, it was decided to introduce no essential external dimensional changes in the S-3 as compared to the S-2. The wingspan (15 m) and fuselage length therefore remain unchanged for the two-seater.

The side-by-side seating required some modifications in the fuselage pod. The S-2 had a slenderness ratio $l/\sqrt{A}$ (l length of the pod, A maximum cross section) of approxi-

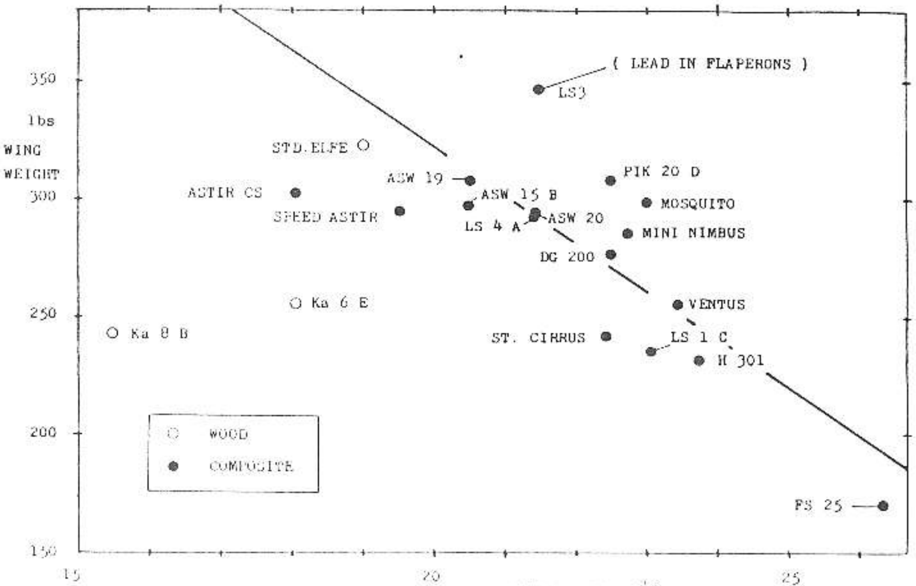

Figure 2: Wing weight vs. wingspan in 15 sailplanes

mately 4.5. In the S-3 it is approximately 2.9. During the search for an optimum aerodynamic shape we found that extensive work has already been done (Ref. 5), and on contacting the author of the above source, B. Carmichael, we were able to shape the fuselage for minimum wetted area and for a hoped-for amount of laminar flow along the pod. A practical amount of laminar flow depends, as is generally known, on the execution of the fuselage/canopy gap, on the placement of the yaw string and on the position and treatment of the landing gear.

Parametric performance analysis indicates that some overall performance gain in a 15-meter two-seater can be expected with a wing of very high aspect ratio, using a relatively high-lift airfoil. The choice of an aspect ratio of 25 (in the S-2 it is 19) is further supported by the experimental fact that the wing weight in composite wings slightly decreases with decreasing wing area, as indicated in **Figure 2**. Smaller aileron/flap forces can be expected, along with smaller horizontal tail volume and perhaps a little smaller vertical tail—all of which contribute to a lower empty weight. The wing loading with 400 pounds of pilot and passenger increases as the aspect ratio (span constant) increases, so a compromise is necessary. In the present case an aspect ratio of about 25 results in a spar only four inches deep when using a modified Wortmann FX 67-170/17 airfoil.

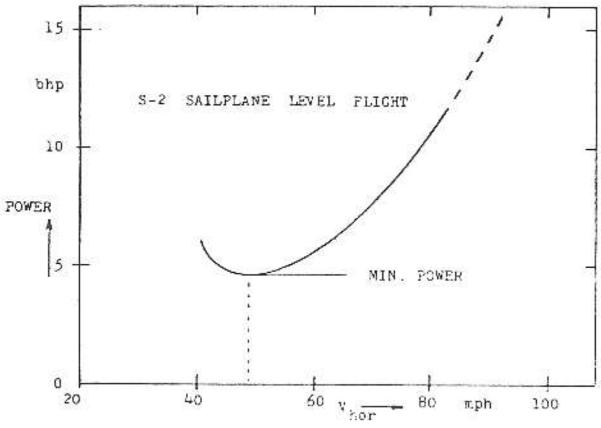

Figure 3: Power required in level flight, sailplane S-2

**Figure 3** shows the approximate power required in unaccelerated level flight as measured on the S-2. The minimum power of slightly less than 5 bhp occurs at 50 mph. For a preliminary calculation 5 hp can be assumed for the two-seater as well at the "economy cruise." Inserting this power into the simplified general climb diagram (**Figure 4**), one notices the expected very strong dependence of the climb rate on the gross weight. Empty weight of the S-3 has been estimated at 500 pounds. With two aboard and some fuel, etc., the gross weight may amount to 1000 pounds. According to Fig. 4 a climb rate of 500 ft/min will require 20-25 bhp, assuming a 75% propeller efficiency. While the expected empty weight of only 500 pounds seems rather low, the weighing of the spar, the skins, aux spar, etc., on the unfinished wing provides us with some information. The total weight of the wing should be less than 200 pounds and therefore *under* the straight line indicating the trend in wing weights in Fig. 2.

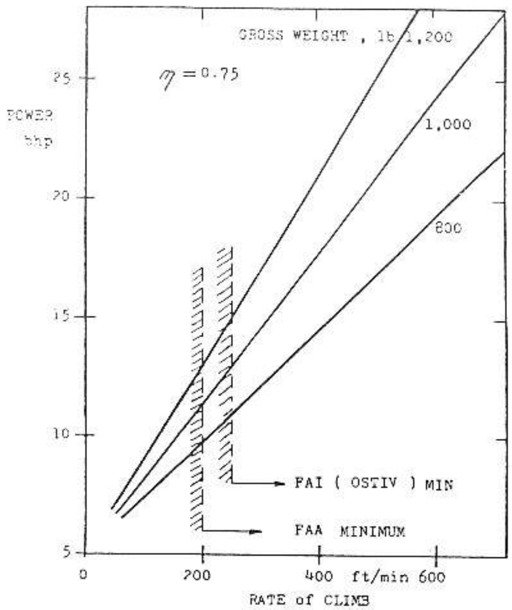

Figure 4: Power required in climb, sea level

Calculated speed polar for the S-3 is presented in **Figure 5** for both cases of a single-pilot (7.5 $lb/ft^2$) and pilot/passenger (10 $lb/ft^2$) flight. In spite of its excellent performance as a two-seater the S-3 clearly belongs to sailplanes and not light planes, as indicated by its $W/b^2 = 0.4$ value. Flown as a single-seater the S-3 can change its wing loading from 6.8 $lb/ft^2$ to 10 $lb/ft^2$ if fully ballasted. It must be remembered that the S-3 has not been designed as a racing aircraft. This is best manifest at high speeds, where its performance deteri-

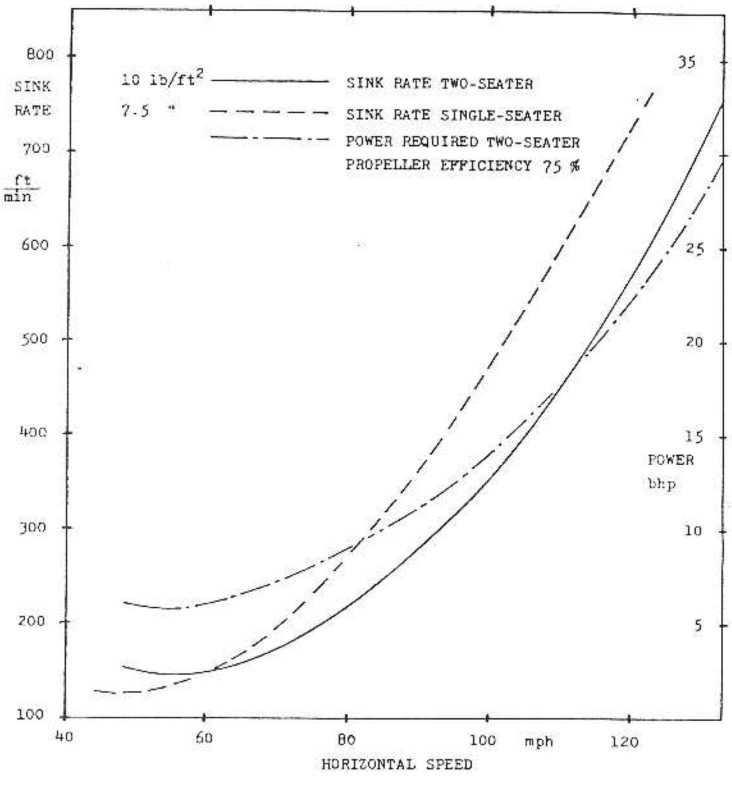

Figure 5: Speed polar and power required for the S-3

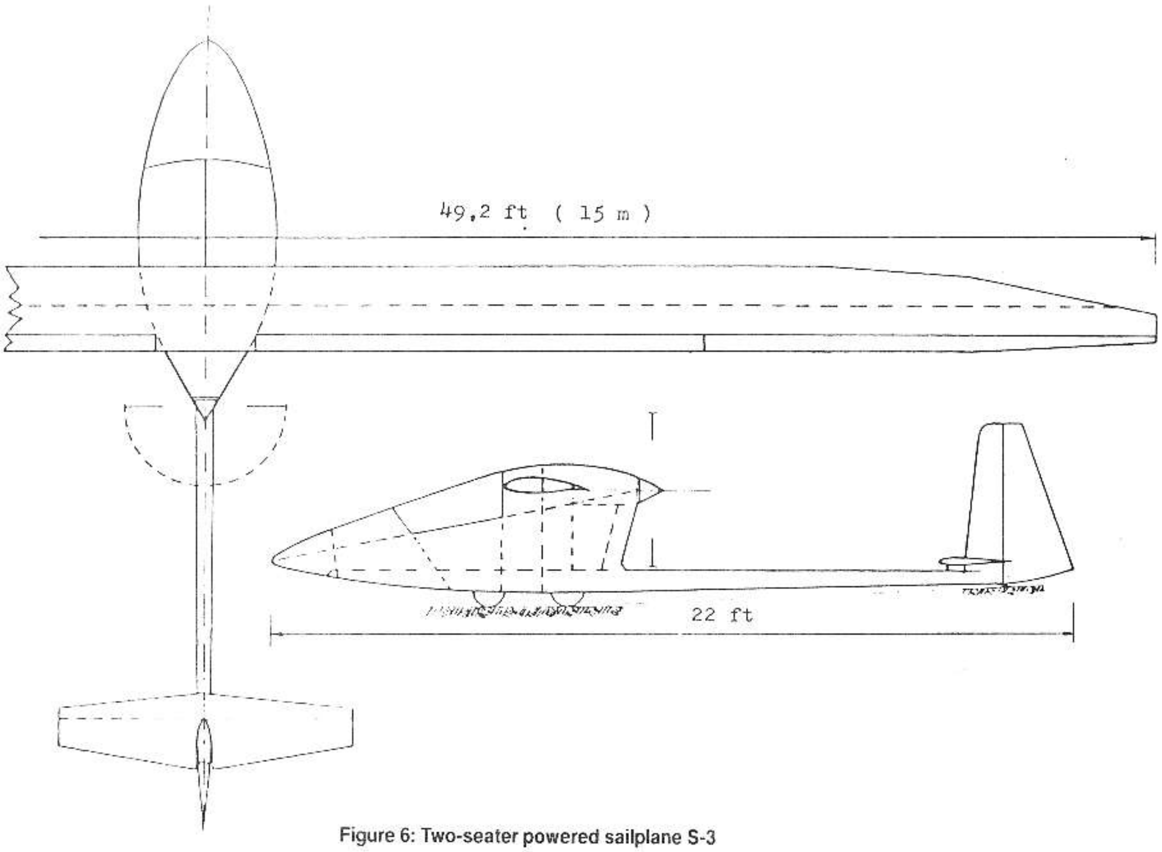

Figure 6: Two-seater powered sailplane S-3

orates. As a cross-country powered aircraft, flying at 120 mph, the S-3 needs less than 25 hp, if pushed by a 75% efficient propeller, as shown by Fig. 5. (That figure is slightly misleading in the sense that it assumes a constant 75% propeller efficiency throughout the speed range. Within a certain range, selected by the designer, the efficiency of a well-designed wooden propeller should be in excess of 80%.)

The best glide ratio $L/D \approx 35$ is poor for a 15-meter sailplane by today's standards. It should be realized that certain sacrifices had to be made in the design for the S-3 to be "homebuildable."

All data in the above section are calculated and will have to be verified experimentally.

## STRUCTURAL CONSIDERATIONS

While the S-3 is structurally based on the S-2 (aluminum spar, fiberglass skins on the wing and control surfaces, fiberglass-covered fuselage with plywood bulkheads, aluminum boom), some minor refinements have been found necessary to guarantee (a) sufficient stiffness of the higher aspect ratio wing and (b) a low empty weight. After extensive (and expensive!) tests with a carbon fiber spar the decision was made to use aluminum for the main wing spar.

Theoretically, carbon fibers represent by far the best building material for spar flanges. In practice, however, manufacturing uncertainties (mixing of epoxies, changing temperatures, local misalignment of fibers) often force the manufacturer to over-dimension highly stressed parts. If one tries to determine the strength of the carbon composite on the basis of the dimensions found on executed sailplanes, one finds that only a small part of the theoretically expected strength has been assumed by the designers. The consequence is, of course, that carbon in practical applications tends to lose its structural/weight superiority. Finally, for a homebuilder who has no means to organize a series production of carbon spars, the "manufacture" is a messy procedure at best. Should anything go wrong, which is quite likely but sometimes difficult to discover, the entire process of building the spar becomes very costly. The above statements are based on the experience of this author, and may not be confirmed by other workers.

The S-3 wing spar is a built-up box spar (parts of an HP-18 spar have been used) made of multi-laminated 7075-T6 flanges and partly aluminum, partly plywood webs. The entire spar is bonded with HYSOL epoxy and glass spheres. It is about four inches deep, and the entire spar for one wing weighs only 50 pounds.

**Figure 6** shows the position of the main wing spar, of the bulkheads and the fuselage boom. The landing gear is in principle the same as that of the S-2. The idea of the constant-chord wing had to be modified slightly in order for the wing to have a more elliptical planform. Breaking the leading edge of the wing became necessary in order for the axes of rotation of the flap and the aileron to remain in one line.

## REFERENCES

1. H. Zacher, "The 'Definition' of a Motorglider," Aero Revue 8/1974, p. 479.
2. A. Strojnik, "Development of a Homebuilt Powered Sailplane," Proc. 1981 SSA National Soaring Convention, p. 77
3. A. Strojnik, "Building the S-2 Powered Sailplane," *SOARING*, Feb, 1982, p. 22.
4. A. Strojnik, "The S-2," Sport Aviation, Apr. 1982, p. 24.
5. B. H. Carmichael, "Underwater Vehicle Drag Reduction Through Choice of Shape," AIAA Paper 66-657, June 1966.