# Maximum Sailplane Speed

Just what it will take to extend the World Sailplane speed record/**Richard Weber**

Interest in the FAI R/C sailplane speed record has been renewed by the recent Austrian claim of 303 km/hr (188 mi/hr). The present official record is 183 km/hr set in 1971 in the USSR. In order to find out what maximum speeds are possible, as well as how to go about reaching them, a detailed mathematical analysis of the problem has been carried out.

Important FAI rules for sailplane speed include maximum weight 5 kg, maximum surface loading (wing + stab) 75 g/dm², maximum launch line length 300 m, and timed course length of 50m, flown both directions on the same flight. Complete FAI record rules are contained in the FAI Sporting Code, available from AMA for $2.50.

It is no surprise that a sailplane designed for speed will be different from those normally seen at the flying field. The speed model must be heavier and stronger Also we know that diving from higher altitudes should result in higher speeds through the timed course. But these common-sense notions are not enough to earn a world record. Just how should a speed model be designed, how should it be flown, and how important is a longer dive? We will take a careful look at these questions, aided by plots made from computer solutions of the relevant second order differential equations of motion. This analysis shows what is needed to have a sporting chance at breaking the record.

The excellence of a speed sailplane design ultimately depends on just two things —its weight and drag. There is a single number which tells everything about its aerodynamic potential. This quantity is the terminal velocity, the highest speed it could reach in a very long dive. At terminal velocity the aircraft weight and drag are balanced. Terminal velocity $v_T$, is given by

$$v_T = \sqrt{\frac{2mg}{\rho S C_D}}$$

where m = mass of aircraft (kg)
g = acceleration of gravity (9.8 m/sec²)
$\rho$ = air density (1 225 kg/m³ at sea level)
S = wing area (m²)
$C_D$ = overall drag coefficient referred to wing area

Terminal velocity increases as the square root of weight (mg), but decreases as the square root of drag (SC ) and density (P). For the highest possible terminal velocity, use the heaviest allowable surface loading (75 g/dm²), the skinniest wing and fuselage you can produce, and maybe fly at Pike's Peak where the air is thinner A maximum sized model will weigh 5 kg and have a total surface area of 66.66 dm². The better visibility of a large model will help the pilot fly a good course.

Terminal velocity is used on the horizontal scale of Figures 2-6, ranging from values of 0 to 125 m/sec. At the maximum allowable surface loading a terminal velocity of 125 m/sec corresponds to an overall minimum drag coefficient of about 0.008 at sea level. With great care it may be possible to achieve this, and have a terminal velocity of 125 m/sec (279 mi/hr).

The best flight path for a speed run is shown in Figure 1. It consists of a long vertical dive, a pullout near the ground, horizontal flight through the timing traps, a quick pullup, and a vertical zoom climb to trade the leftover speed for some of the altitude needed for the next dive. We will examine exactly what happens to the speed during each phase of the speed run.

The speed reached at the end of a vertical dive is plotted in Figure 2 for several starting altitudes. The higher you start the faster you finish. But there is, of course, a speed limit, at the terminal velocity The left side of each altitude curve merges into the same line, equal to the terminal velocity. An airplane having a terminal velocity of 25 m/sec (Antic?) will reach that velocity in a dive of less than 300 m. Our super swift record breaker with a terminal velocity of 125 m/sec will be going 91 m/sec after a 600 m dive. Start higher and go even faster, but it will never exceed terminal velocity

Figure 3 shows the speed change during a 10 g pullout from vertical dive to horizontal flight. The speed ratio found in the figure is multiplied by the speed at the start of the pullout (entry speed) to get the horizontal speed after the pullout exit speed). This ratio and the 10 g pullout radius are plotted for two entry speeds. Values for different entry speeds can be estimated from the two shown. The most important fact found here is that the speed does not change much in the pullout, since the speed ratio is near unity for practical cases. This means that altitude used up in the pullout does little to help accelerate the model. Consequently the highest timed speeds will be reached by pulling out from the dive at the last possible moment, and at the highest g loading which the wing can take without breaking or stalling. A 5 kg model times 10 g works out to 110 lb. Can your wife stand on your model without damage? (Would she like to anyway?) A tapered wing and moderate aspect ratio will help reduce the stress on the wing root, but severe taper might lead to tip stall. A tip chord of 60% of the wing root and an aspect ratio of near 8 should be reasonable choices.

The speed loss in horizontal flight is given in Figure 4 for three horizontal path lengths. Similar to the procedure for Figure 3, multiply the starting horizontal speed by the velocity ratio found on the plots to get the final speed. These curves

DRAWINGS: RICHARD WEBER

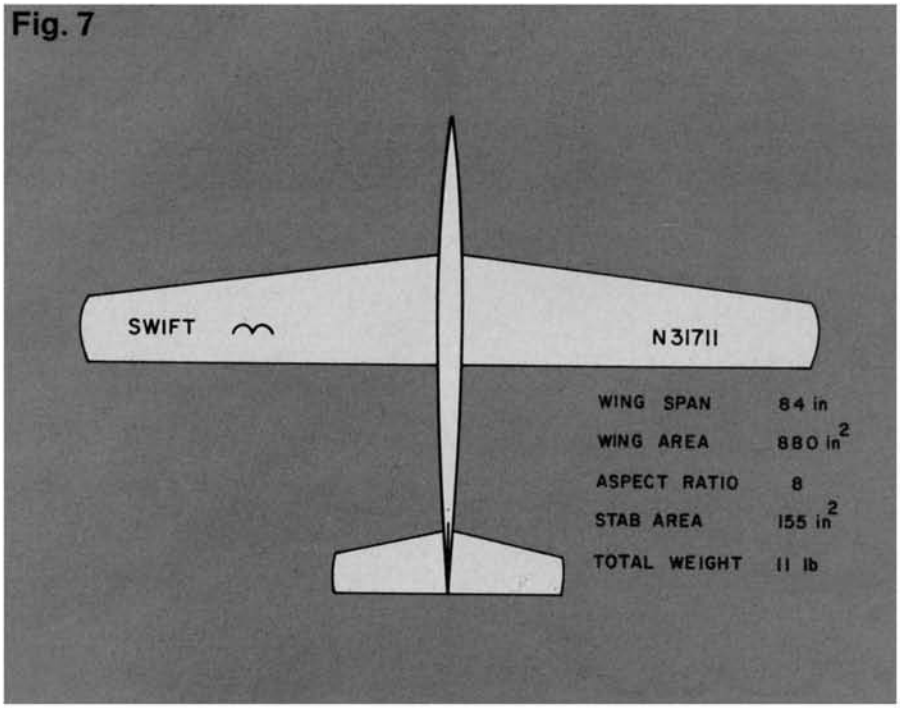


Fig. 7

Fig. 1

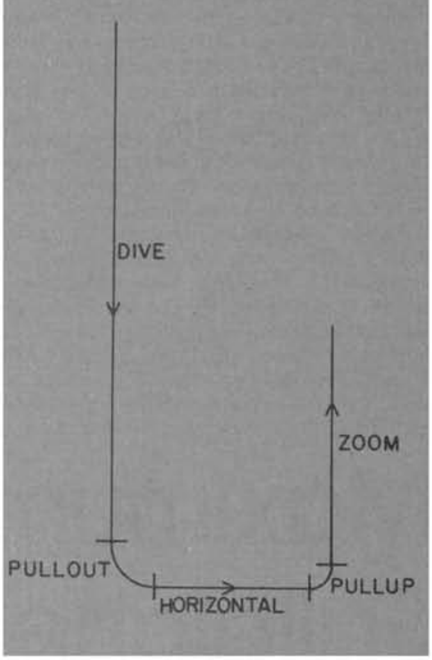



Fig. 2

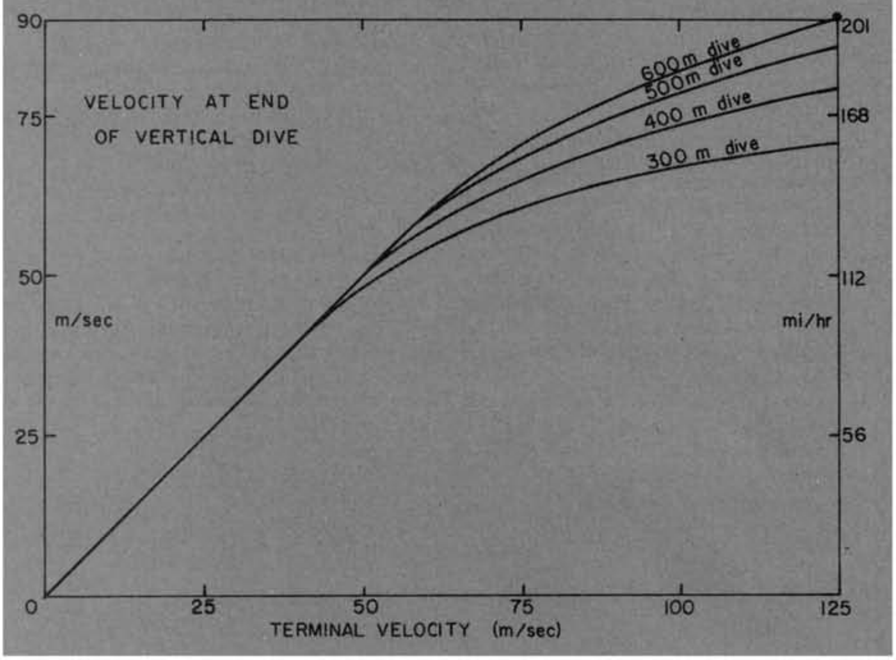



Fig. 3

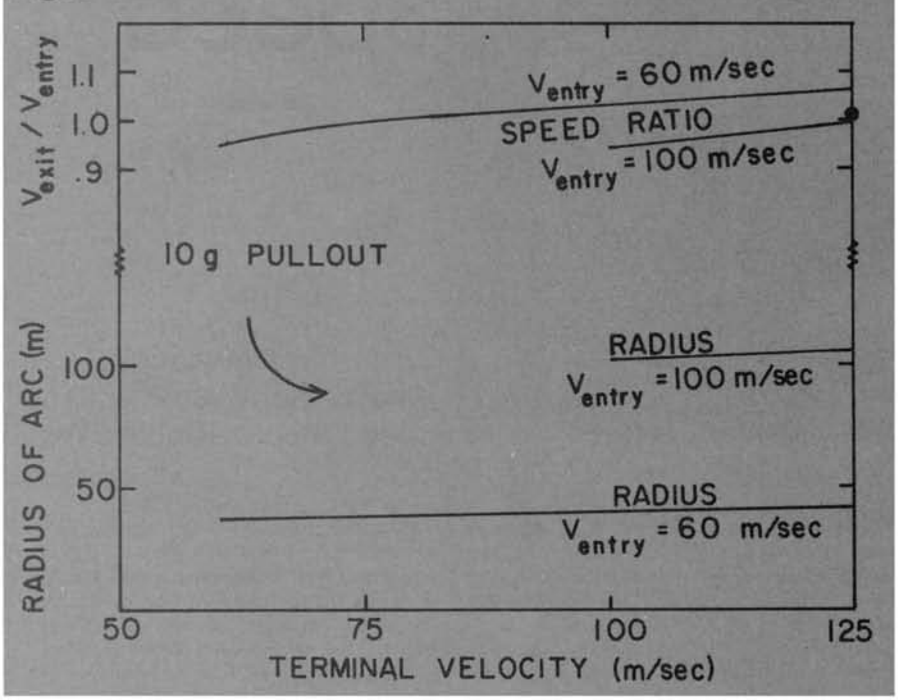
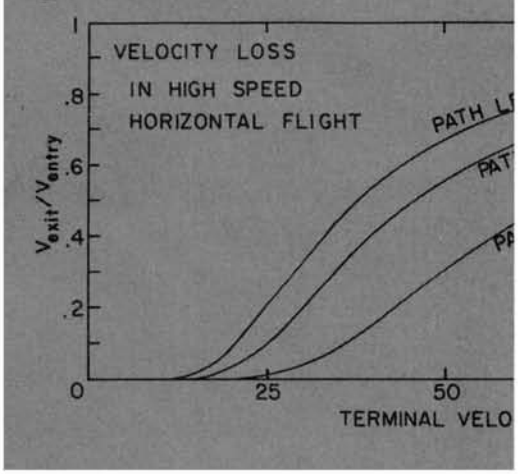



Fig. 4




### Metric Conversion Table

| | |
|---|---|
| 1 meter (m) | = 3.28 ft |
| 1 kilogram (kg) | = 2.205 lb |
| 1 gram (g) | = 0.0353 oz |
| 1 kilometer (km) | = 0.621 mi |
| 1 m/sec | = 2.236 mi/hr |
| 1 square decimeter ($dm^2$) | = 15.5 $in^2$ |
| 66.66 $dm^2$ | = 7.176 $ft^2$ |
| 75 $g/dm^2$ | = 24.57 $oz/ft^2$ |
| 300 m | = 984 ft |

### A Decade of Sailplane Speed Records

| | | km/hr | mi/hr |
|---|---|---|---|
| Austria | 1976 Tentative | 303 | 188 |
| Russia | 1971 | 182.3 | 113.2 |
| Germany | 1970 | 149.7 | 93.0 |
| USA (Willoughby) | 1969 | 139.3 | 86.5 |
| Germany | 1967 | 125.5 | 77.9 |

neglect lift-induced drag. Near stall speeds induced drag becomes important, but at high speed it decreases drastically and may be ignored. For record attempts, 100 m level flight is required, consisting of 25 m before the timers, 50 m timed, and another 25 m before pullup.

Figure 5 shows speed loss during the pullup from horizontal flight to vertical climb. It is used just like Figures 3 and 4.

The most efficient way to regain altitude after a high-speed pass is a vertical zoom climb until most of the speed has been converted to altitude. The curves in Figure 6 show how high the model can climb for three different initial vertical velocities. Curves for other initial velocities can be estimated.

Now let's put it all together by working through an example of a flight profile for an ultimate model having a terminal velocity of 125 m/sec, and starting the dive 700 m (2300 feet) above the ground. Dots on the figures show the valued used in this example.

Fig. 6

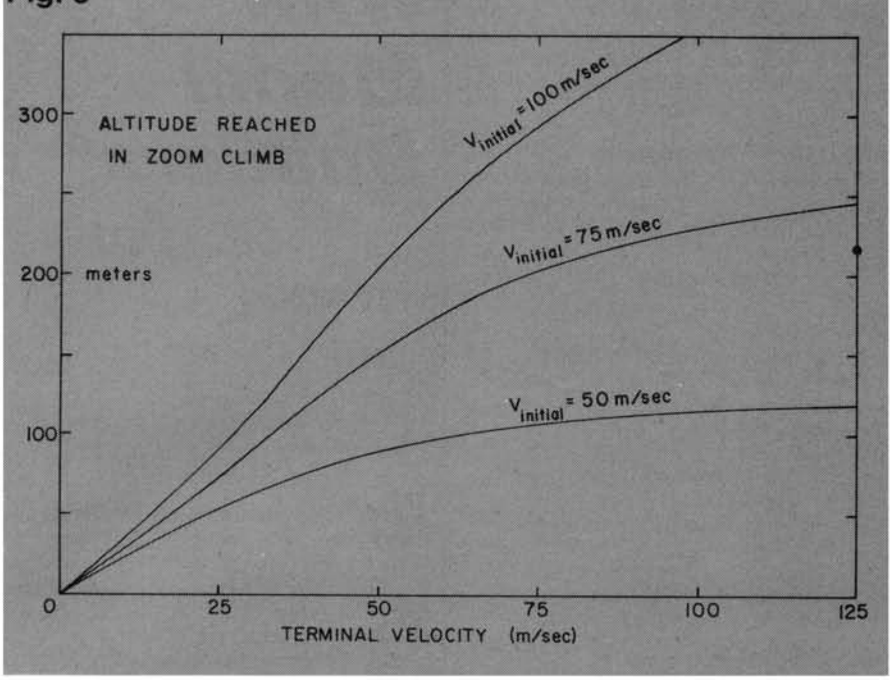
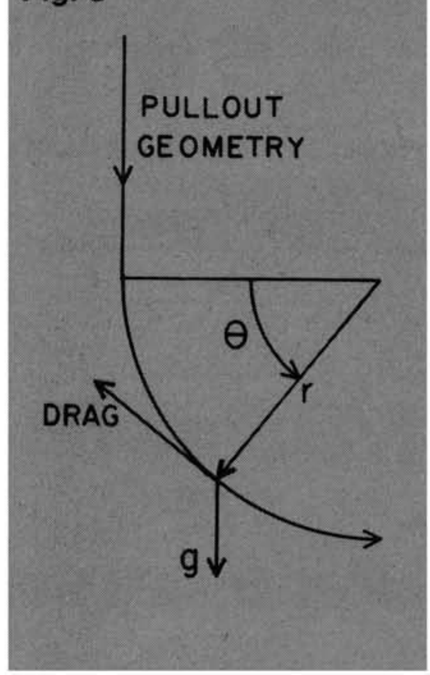



Fig. 8



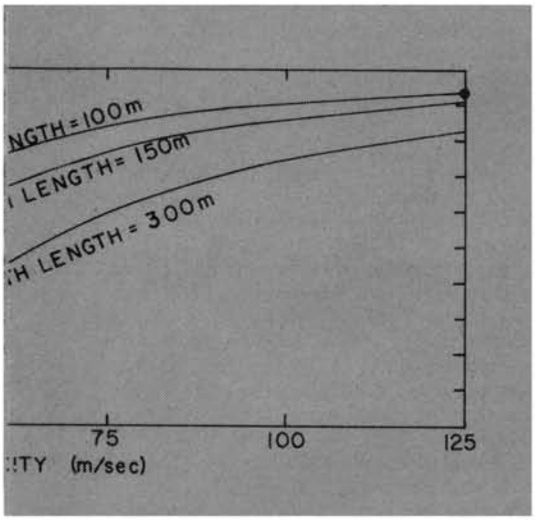




Fig. 5

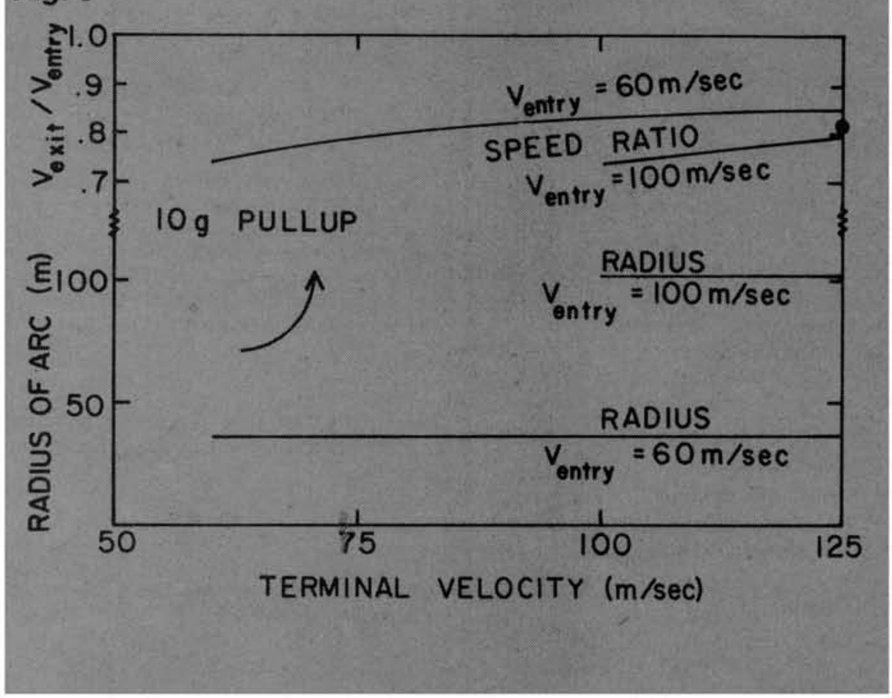



Fig 2) A vertical dive of 600 m ends with 91 m/sec
Fig 3) The 10 g pullout has a radius of 90 m and an exit velocity of:
1.01 x 91 m/sec = 92 m/sec
The model is now flying 10 m above the ground.
Fig 4) a 100 m horizontal flight beginning at 92 m/sec ends at 0.94 x 92 m/sec = 86 m/sec
Fig 5) The 10 g pullup has a radius of 80 m and an exit velocity of 0.82 x 86 m/sec = 71 m/sec
Fig 6) A vertical zoom climb starting at 71 m/sec reaches 220 m, for a total altutude of 220 m + 80 m + 10 m = 310 m
The timed horizontal velocity is approximately equal to the average of the horizontal entry and exit velocities.
$V_{ave}$ = (92 + 86)/2 = 89 m/sec = 320 km/hr = 199 mi/hr

So how might a good design look? Swept leading edges will help discourage flutter during the dive. We might dispense with ailerons to reduce drag, but will that make it too difficult to fly a good course? Heavier models fall faster (Galileo didn't have a sailplane), so use the maximum permissible surface loading. Invest weight in structural rigidity, not lead. Study Formula 1 construction and surpass it. Formula 1 builders are trying to hold down weight, you need more

The Austrian design, shown in the March '77 issue of *Model Airplane News* is good. It has one major shortcoming, which is insufficient weight. Its surface loading is 34.6 g/dm$^2$, less than half of the ideal maximum allowable 75 g/dm$^2$. That is equivalent to using a .19 engine in Formula 1.

Flying an ideal course will not be easy. The dive should be vertical, since that is the only way to gain full advantage of the gravity "motor." Pullout must be low and tight, to allow for maximum dive. A minimum of guidance corrections should be used, since a control surface has more drag when it is deflected. Keeping the model in the groove will take practice and skill.

All of the foregoing discussion may have looked fine. Build a large, heavy, clean model and fly the curve in Figure 1. There is, of course, a hitch to separate the men from the boys: how to gain enough altitude with such a heavy ship. A thermal sniffer may help. The high wing loading will require a flying site with healthy updrafts extending to great altitudes. If you know where to find a good site, get started on your design today

## Appendix

For interested readers this section shows the equations used to generate the plots in Figures 2-6. In a dive there is a net force F

$$F = ma = \text{weight} - \text{drag}$$
$$= mg - \tfrac{1}{2}\rho S C_D v^2$$

where a = acceleration of aircraft (m/sec$^2$) and the other quantities were defined earlier. When the aircraft reaches terminal velocity the net force is zero

$$0 = mg - \tfrac{1}{2}\rho S C \ \ v^2$$

Solving for this terminal velocity gives

$$v_T = \sqrt{\frac{2mg}{\rho S C_D}}$$

This can be rewritten as

$$\tfrac{1}{2}\rho S C \ \ = mg/v_T^2$$

Substituting this equation into the first equation gives

$$F = ma = mg - mg(v/v_T)^2$$

or

$$a = (1 - v/v_T)^2)g \quad \text{Dive Equation}$$

The pullout from the dive is calculated using an arc of constant radius. This is not the ideal pullout arc, which would have a variable radius, but the difference in the resulting horizontal velocity is small. Figure 8 shows the geometry which leads to the acceleration equation for pullout

$$a = (\cos\Theta - (v/v_T)^2)g \quad \text{Pullout Equation}$$

The total g load, Q, in the pullout includes the centrifugal force and a component of gravity

$$Q = v^2/r + g \sin\Theta$$

The velocity change in horizontal flight is just a loss due to drag. The acceleration is always negative.

$$a = -(v/v_T)^2 g \quad \text{Horizontal Equation}$$

Next, the pullup from horizontal flight to vertical climb uses the pullout equation again, beginning the calculations at $\Theta = 90°$, the bottom of the arc.

Finally, the vertical zoom climb to maximum altitude has both gravity and drag opposing the velocity, so

$$a = -(1 + (v/v_T)^2)g \quad \text{Climb Equation}$$

The acceleration equations for each part of the flight are all second order differential equations. The velocity change (accelerated) depends on the velocity squared. This cannot be untangled by simple algebraic manipulation, so if you are not familiar with differential equations, ask a friend for help or just use the plots. They should contain everything you need. Good Luck!

Fig. 4