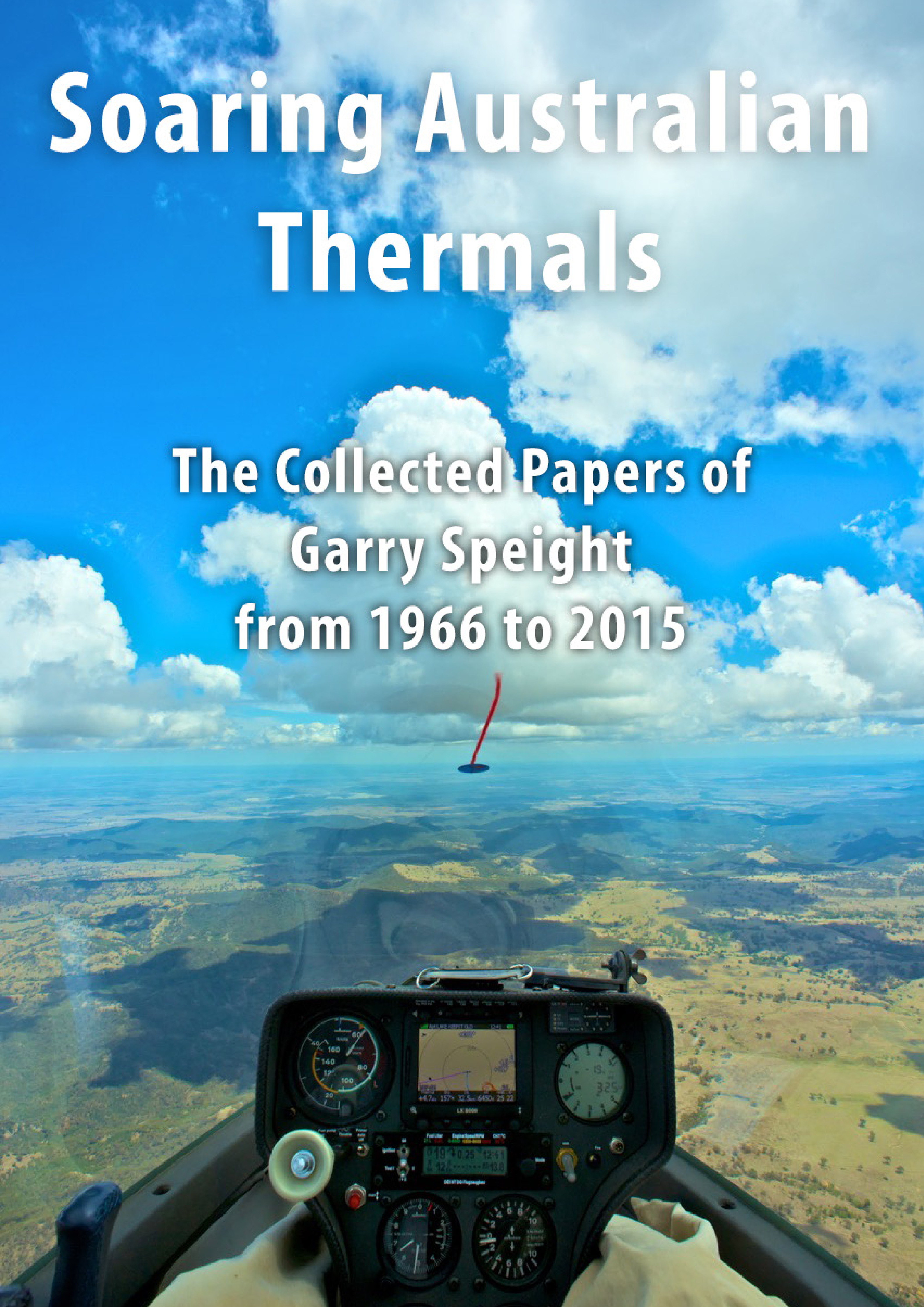
Soaring Australian Thermals

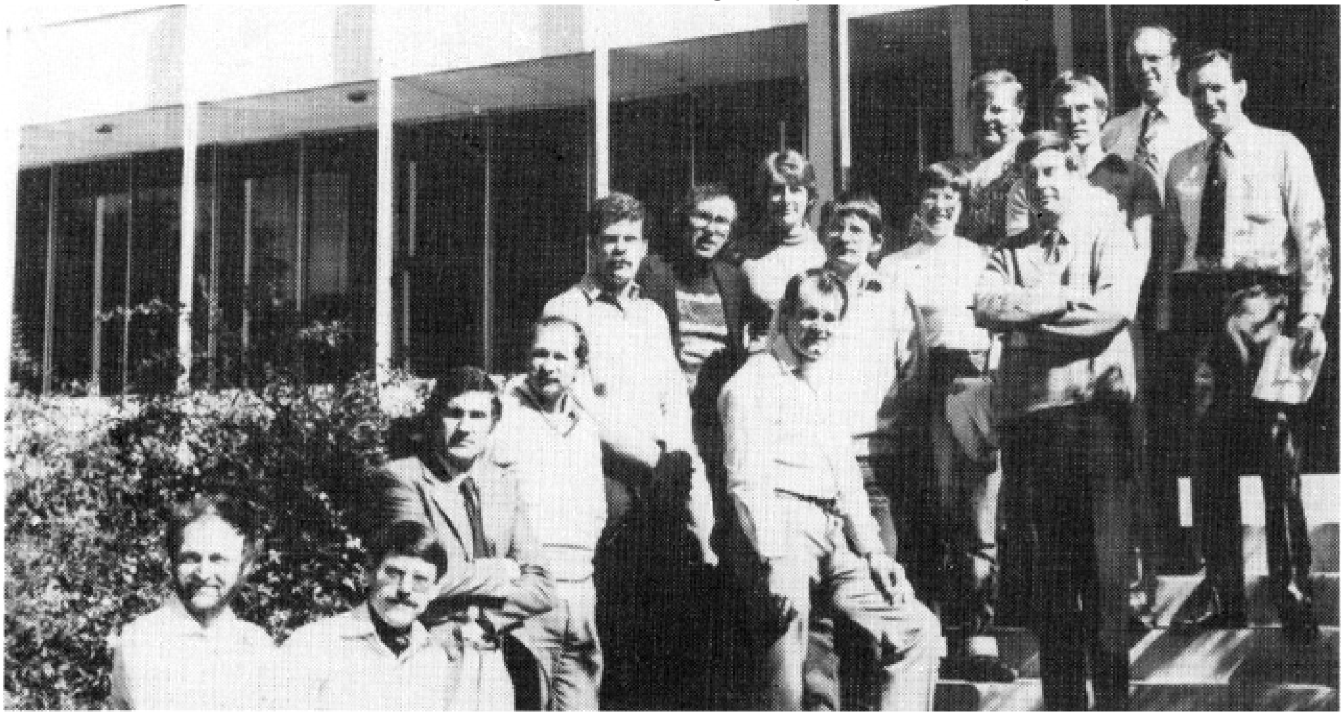
The Collected Papers of Garry Speight from 1966 to 2015



The Use of Water Ballast

By Garry Speight

This material first appeared as a talk I gave to the Second National Soaring Symposium, Canberra, September 1980. The title was "Just what does ballast do for you?"



This photo includes many of those members of the Gliding Federation who were prepared to speak about soaring theory and practice at that time, such as: John Buchanan, Garry Speight, Maurie Bradney, David Pietsch, Mike Giles, Sue Martin, Barry Wrenford, Mike Borgelt, Bob Ward, Dafydd Llewellyn, Harry Walton, and Roger Woods.

It was published in "Australian Gliding" September 1982, and re-published much later in "Keep Soaring", May-June 2011.

The performance of a sailplane is usually expressed by a curve showing the way that the rate of sink varies with forward speed. This is called the performance polar, although it is not nowadays plotted using polar co-ordinates.

The performance polar for the Astir CS (Ref. I) is shown in Figure 1a, plotted in the customary way, with airspeed in knots along the horizontal axis and rate of sink, also in knots, plotted at a much coarser scale on the vertical axis, reading downwards.

There are three key features on this curve. The highest point of it is the point of minimum sink: this corresponds to a minimum sink rate on the vertical axis (1.34 knots) and a speed for minimum sink on the horizontal axis (44 knots).

As the airspeed is reduced below this figure the sink rate increases more and more rapidly until at the stalling speed the curve is going just about straight down.

On the right hand side of the curve, as the airspeed is increased above that for minimum sink, the sink rate increases rather slowly at first so that for a time the glide angle actually gets flatter, down to a point called best glide which corresponds to a best glide speed on the horizontal axis (50 knots).

The ratio of this speed to the corresponding sink rate on the vertical axis (1.43 knots) is called the best glide ratio (35:1) At higher speeds the glide angle become increasingly steep.

The Use of Water Ballast

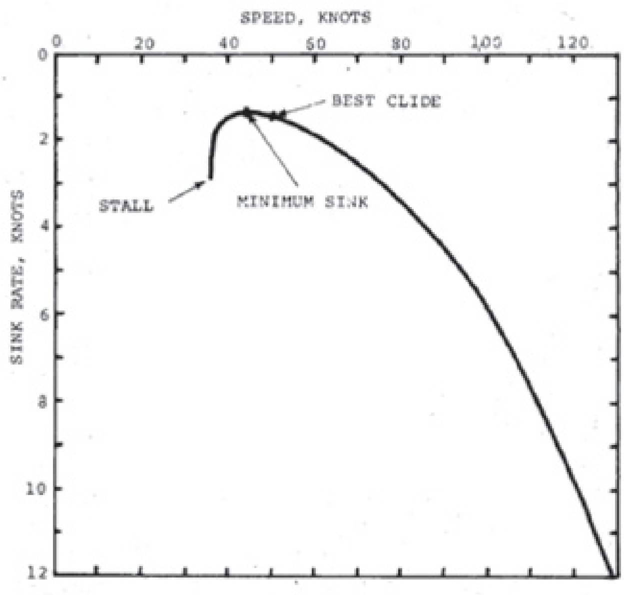


Fig 1a.

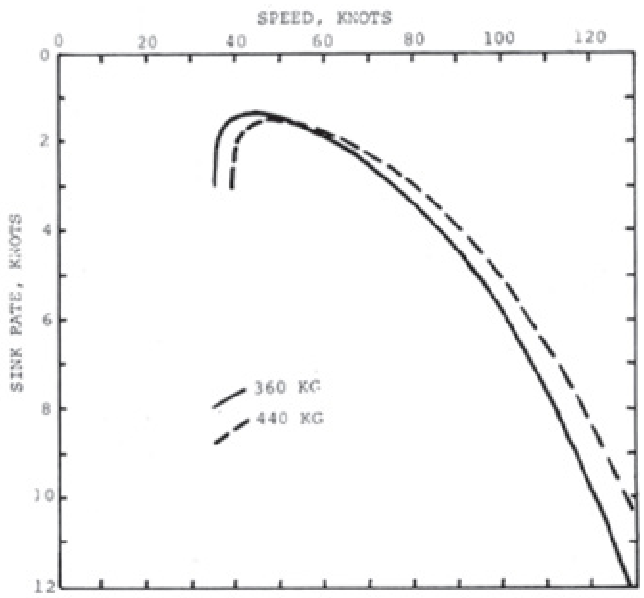


Fig 1b.

By tradition, because lightness of construction used to be highly regarded, test flying for polar curves is done at the minimum practical loading of a sailplane that is, its empty weight plus about 100 kg of pilot, parachute and instruments.

If a glider is more heavily laden as by adding ballast, its performance polar will not the the same: every point on the curve will move both to the right and downwards by the square root of the ratio of the heavier weight to the test weight.

Figure 1b shows the performance polars of the Astir CS at 360 kg weight near its minimum practical loading, and at 440 kg weight, a little below its designed maximum loading.

The ratio of these two weights is 1.22 Since the square root of this ratio is about 1.10, or 110%, each point on the second curve is obtained by adding 10% to both the airspeed and the sink rate of a point on the original curve.

According to this formula (which is little over-simplified) the stalling speed, the speed for minimum sink and the best glide speed will all go up by 10% and so will the minimum sink rate, while the best glide ratio will remain just the same as it was.

By increasing the weight of the glider, we have made it a higher-speed machine. During the sixties many pilots became convinced, whether by "gut-feeling", by comparison flying, or by calculation, that adding weight to their gliders was an advantage in cross-country soaring, particularly when the thermals were strong.

Some carried lead, and the more ingenious began to carry water which could be jettisoned if slow-speed performance became vital.

Some experts were sceptical of the value of water ballast but the idea caught on so well that by 1971 most of the high performance gliders in production had provision for it, and it had even been specifically permitted under the Standard Class rules.

The reason why ballast confers an advantage in cross-country flight is not immediately obvious, and I believe that many pilots rely on a vague idea that a faster best glide speed must somehow produce a faster cross-country speed through MacCready speed- to-fly theory.

Actually, it may be an advantage to carry ballast on a day when simple MacCready theory predicts that unchanged inter- thermal glide speeds and slower average cross-country speeds will result, given the prevailing thermal strength.

The Use of Water Ballast

The key to the problem is that the most important effect of carrying ballast on the performance polar is not that the curve shifts to higher airspeeds, but that the two curves cross each other (at 52 knots) so that the ballasted glider sinks more at the slow airspeeds used for thermalling and sinks less at the high airspeeds used for cruising (Figure 1b).

Ballast and MacCready Speed

The effect of ballast on cross-country performance may be studied using the thermal models developed in the article "Rate of Climb in Thermals" (Ref. 2) and the thermal interception diagram (Ref. 3).

The thermal interception diagram (Figure 2a, 2b, 2c) is constructed from the performance polars (Figure 1) using an arbitrary thermal spacing of 10 nautical miles.

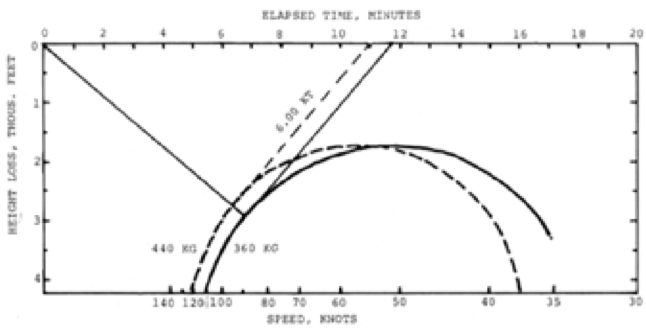


Fig 2a.

Figure 2a (above) shows how, if the pilot flies at the correct MacCready speed to a thermal yielding a particular rate of climb (6 knots), the ballasted glider has both a higher optimum glide speed (as read on the bottom scale below the point of arrival at the thermal) and a higher cross-country speed (as read below the point of return to the starting altitude).

The comparison for equal rates of climb, is, however, quite misleading, as we wish to compare performance in the **same** thermal. The rates of climb will then differ, with the unballasted glider able to climb faster.

In "Rate of Climb in Thermals" it was concluded that, if a ballasted Astir CS were flown in a "normal" thermal (requiring less than 40° of bank), the effect of jettisoning 80 kg of ballast would be to increase the rate of climb by 0.50 knots. In a "narrow" thermal (requiring 45° of bank) the climb rate would go up by 0.84 knots.

In discussing the use of ballast, it seems more sensible to take the case of the ballasted glider as the standard for comparison, using round numbers for its rate of climb. In a ballasted glider one can take a decision whether to dump or not; in an unballasted glider there is no decision to be made!

Figure 2b shows the MacCready construction for a thermal that yields 6 knots climb rate for the ballasted glider and 6.5 knots for the unballasted glider if the thermal is of normal diameter, or 6.84 knots for the unballasted glider if the thermal is narrow.

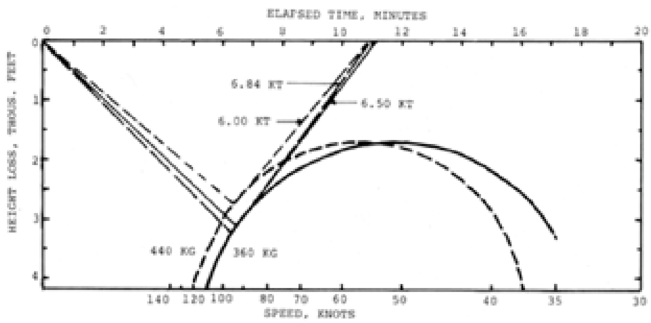


Fig 2b.

It is clear from the reduced gap between the points where the gliders arrive back at their starting altitude that the speed advantage of the ballasted glider is not nearly as large as appeared in Figure 2a, and is particularly small if the thermal is narrow, because of the relatively rapid rate of climb that is possible without ballast.

Figure 2c shows how, in a thermal yielding 2 knots rate of climb (ballasted), the glider's better rate of climb after dumping ballast increases the cross-country speed, especially if the thermal is narrow.

The Use of Water Ballast

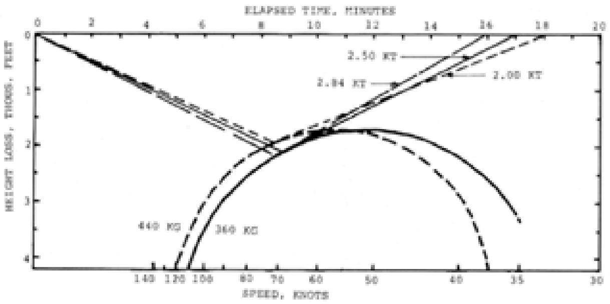


Fig 2c.

By plotting the cross-country speeds in this way for various thermal strengths we can construct Figure 3. This shows that, for normal thermals, dumping ballast will yield a speed advantage if the rate of climb is less than 3.2 knots and this advantage increases rapidly with weaker lift, until at 1 knot it is 20%.

When the rate of climb is greater than 3.2 knots it is better to carry ballast but, even in very strong conditions, the speed advantage does not amount to 5%. If the thermals are narrow the break- even point comes at 5 knots climb rate.

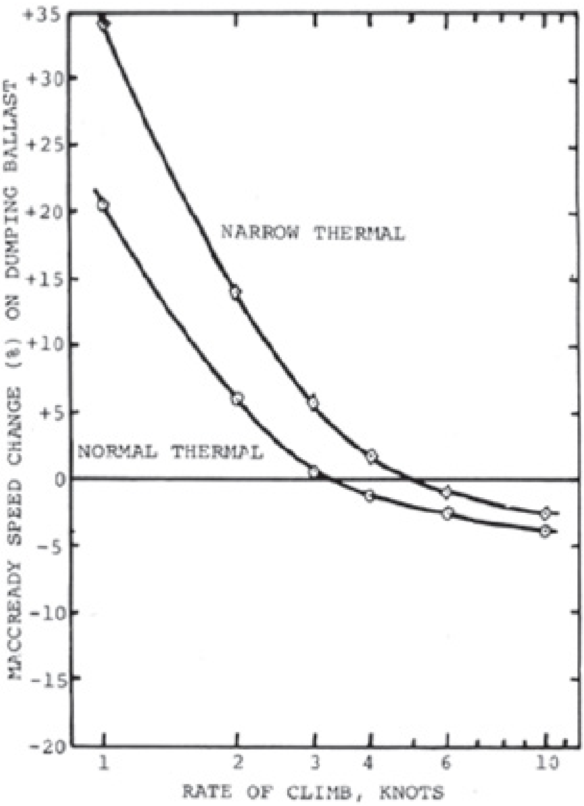


Fig. 3. Change in cross-country speed resulting from dumping ballast versus rate of climb (ballasted) for the Astir CS in normal and narrow thermals according to simple MacCready theory.

The speed advantage of carrying ballast does not exceed 3% even in strong conditions, whereas the advantage of dumping ballast in weak conditions goes as high as 35% for a 1 knot climb rate.

So far, ballast scarcely seems to be worth all the trouble and expense.

Dolphin Soaring

Herbert Pirker of Vienna wrote a paper on this subject which he presented to OSTIV in Finland in 1976 (Ref. 4). His approach was much more comprehensive but, in part, his results agree very well with mine.

He took the case of the DG100 which has a higher wing-loading than the Astir CS so that its performance polars are a little further to the right. However, the ratio of ballasted to unballasted weights is much the same. Unballasted, the Astir CS wing loading is 29 kg/m2 against the DG100's 30 kg/m2 ; ballasted, the figures are 36 kg/m2 and 38 kg/m2 .

Pirker used a Konovalov Type B thermal model to simplify calculations but, of the four thermal sizes that he quoted in his results, the two narrower ones, "Grad 0.015 sec-1," and "Grad 0.03 sec-1, are closely equivalent to my "normal" and "narrow" thermals respectively, requiring 40° and 46° of bank for best climb when ballasted.

The break-even points for dumping ballast were calculated as 3.4 knots and 5 knots respectively.

However, Pirker was concerned with analysing the effect of dolphin soaring on the decision to carry ballast.

To do this he introduced a term called "thermal density" which he defined as "the sum of the gliding paths in the up-drafts, divided by the whole distance" expressed as a percentage. This does not include the thermals used for circling,

The Use of Water Ballast

but only those that are flown through dolphin-fashion on the glides.

The higher the thermal density and the stronger the lift the less circling is required. Pirker found that no circling at all would he necessary if 20% of the sky was going up at 10 knots or if 50% of it was going up at 3 knots.

Figure 4 is re-drawn from the part of Pirker's Figure 19 equivalent to a "normal" thermal, and shows the change in cross-country speed of a DG100 that would result from dumping ballast, not only for the circle-and-glide case, but also for

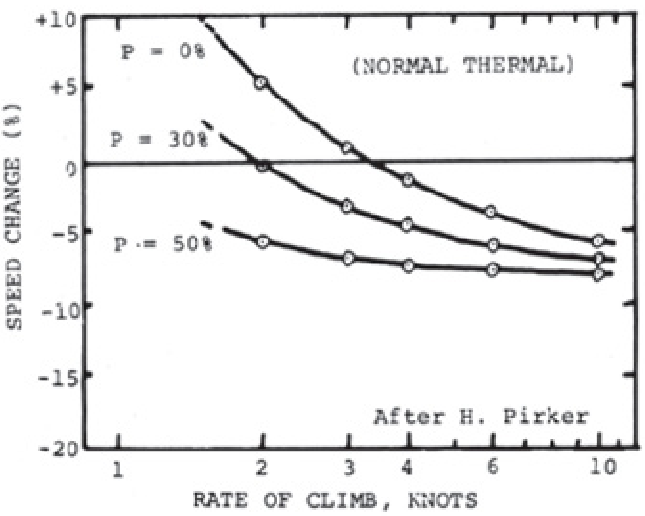


Fig. 4. Change in cross-country speed resulting from dumping ballast versus rate of climb (ballasted) for the DG100 in a normal thermal with varying thermal density (after Herbert Pirker).

mixed circling and dolphin soaring with thermal densities of 30% and 50%.

This shows a substantially greater benefit for the ballasted glider when dolphin soaring is possible amounting to more than 7%, even in rather weak lift conditions, provided that the thermal density is 50% or more.

Unfortunately, I cannot agree that Herbert Pirker's analysis accurately represents the sky. My barograph traces indicate very low thermal densities. I estimate a typical value of 4%.

Perhaps truly skilled pilots can push the figure up to 10%, but I am sure that the influences of thermal density on decisions to load up or dump ballast must be very small.

Thermal search range

I believe the advantages of ballasting to a high wing loading lie in quite a different direction: in increased range as it relates to the varying spacing and varying strength of thermals.

Looking again at Figure 2b, we can see that, whereas the ballasted glider, in this particular ease, loses 2,750' on the way to the thermal, the unballasted glider, also flying at optimum MacCready speed to the same thermal will lose 3,100' or 3,200', depending on whether the thermal is normal or narrow.

(The normal and narrow thermals should perhaps be on separate diagrams: the narrow thermal must actually be a stronger thermal for the ballasted glide to achieve the same rate of climb in each. That is why the unballasted glider loses more height in getting to the narrow thermal.)

Thus the height lost on this glide would be 11% greater after dumping ballast in the case of a normal thermal and 14% greater in the case of a narrow thermal. A lightened glider is very much worse at conserving altitude than a heavy one.

Since we usually do not know where our next thermal is, an 11% increase in height lost over a given distance may more usefully be thought of as an 11% decrease in range for thermal search. To use traditional term, it is a decrease in penetration.

Points plotted on thermal interception diagrams like Figure 2 can be used to produce curves showing how the reduction in thermal search range varies with climb rate: Figure 5.

This figure indicates that the variation is rather small, with an apparent minimum at the figures

The Use of Water Ballast

already given for a 6 knot climb rate.

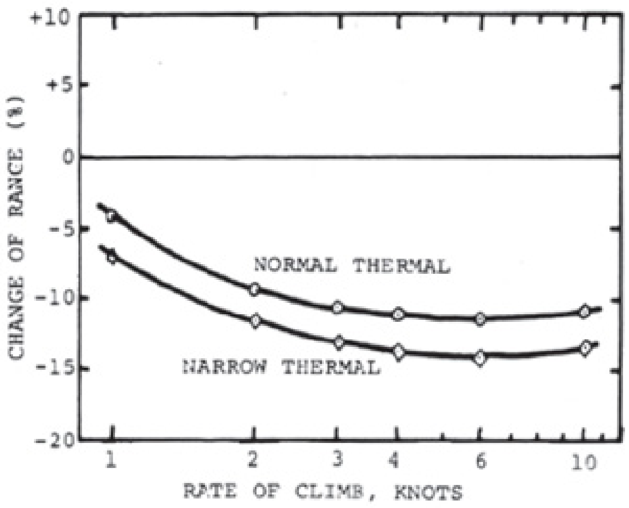


Fig. 5. Change in thermal search range resulting from dumped ballast versus rate of climb (ballasted) for the Astir CS in normal and narrow thermals.

Consequences of reduced range.

How important is this reduction in search range? This depends on some estimates about the way thermals of different strengths are scattered around the sky.

First there is the matter of whether we are going to make it to the next thermal. In a current type of Standard Class glider we will be flying at a glide ratio of about 25:1.

Now the evidence of a number of barograph traces is that the average spacing of thermals encountered on cross-country flights is about seven times the depth of convection. This means that, if we make some allowance for circuit height, a glide from the top of the convective layer will intersect three thermals on the average. But we know that the spacing of thermals commonly varies from half as wide to twice as wide as the average so, on every inter- thermal glide, even one from the top of the convective layer, there is a very real chance of having to land out. An 11% increase in range could prove very useful indeed.

Next, there is the matter of “scratching”: desperately holding height in zero sink at low altitude, waiting and hoping for a useful thermal to break loose. This situation will arise 11% less often for a glider carrying ballast.

The loss of time while scratching can be very large: ten minutes in a 200 minute race is a 5% reduction in speed, equal to the disadvantage already demonstrated by Figure 3.

Finally, there is the variation in thermal strength. Cross-country races are won by the pilot who spends the most time in the strongest lift. Mediocre lift is to be used only to get enough height to resume the search for the very best lift.

When you have dumped your ballast and have lost 11% of your search range you are committed to circling in 11% more thermals. These will not be boomers that the other pilots have missed: they will be the rags that they did not bother to circle in.

This is the answer to the old riddle of how the hotshots of yesteryear, with lead cushions in their Boomerangs, always seemed to find better thermals than anyone else: better penetration allowed them to reject the weak lift and press on with the search for the very best.

Some may argue that you do not have to lose all that height; you can fly at a lower ring setting. Provided that the ring settings mentioned so far have all been realistic settings, this policy will surely slow you down just about as much as if you repeatedly got too low.

Without more information and more detailed analysis, one cannot accurately express the effects of reduced search range as a quantitative reduction in cross-country speed.

However, I believe that the effects are at least in proportion: an 11% range reduction producing at least an 11% reduction in speed. So one can take a stab at the combined effects of MacCready

The Use of Water Ballast

speed ratio and search range ratio by multiplying them together, with the results shown in Figure 6.

According to this estimate, ballast can yield a 15% advantage in achieved cross- country speed in strong thermal conditions. The break-even point comes at about 1.6 knots climb rate,

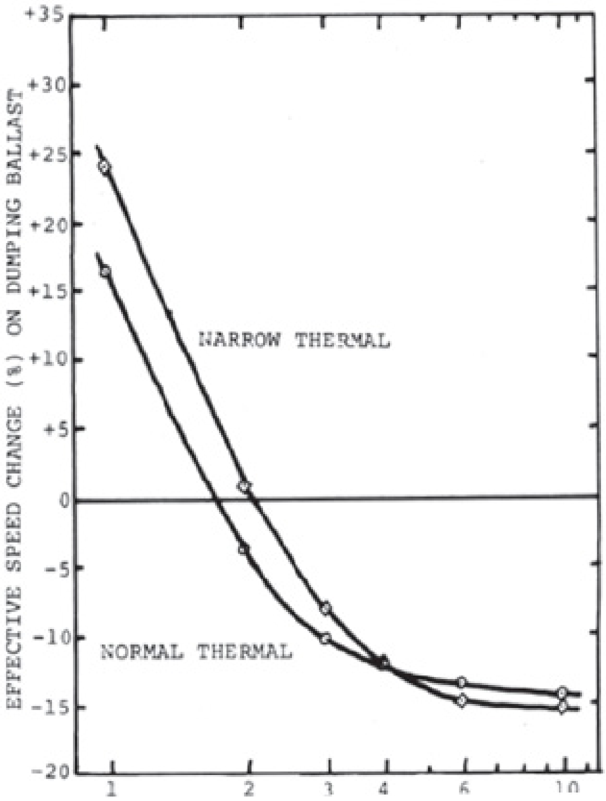


Fig. 6. Estimated total effective change in cross-country speed resulting from dumping ballast versus rate of climb (ballasted) for the Astir CS, combining the effects of MacCready speed and search range.

or 2 knots climb rate for narrow thermals, but it is still much better to be without ballast in 1 knot thermals.

Tactics

If search range is an important feature in the use of ballast, it follows that one should not dump ballast during the thermal search, even at low altitude. You will only reduce your search area, and you may still find a thermal strong enough to justify keeping it on board.

The time to dump it is when the lift that you are working at 800 feet is not much better than zero sink. A social problem may then arise if another glider comes to circle below you(!),

Having once been guilty of dumping water on another, I think I have the answer: either he has already dumped, or he soon will (unless there is someone below him). He should be able to climb through you and it may be possible, with his assistance in finding the centre, for you to climb quite well without dumping the water after all.

Daan Pare mentioned that European pilots have discussed the point as to whether you dump the ballast the first time you have to scratch, or the second, or the third... Clearly it depends on how much value you expect to get out of the ballast after you have struggled up again.

When climbing for final glide, search range is no longer relevant and the simple MacCready argument applies.

If you are climbing for final glide in a 2 1/2 knot thermal, dump the water, change the MacCready ring or speed director to “dry”, set your increased rate of climb on the final glide computer, also on the “dry” scale, and go home in the minimum time.

Other aircraft

The comparative cross-country performance of various types of current Standard Class glider depends largely on their wing-loading. Differences in stalling speed and minimum sink rate when measured at the same wing- loading are scarcely significant.

Advantages in best glide ratio definitely favour certain of the latest types but these can he negated by inappropriate management of water ballast.

The latest models generally have provision for ballasting up to a loading of about 45 kg/m^2, and the Mini-Nimbus is designed to take 51 kg/m^2. Whether the advantages of ballast continue to

The Use of Water Ballast

increase up to that figure I have not attempted to find out.

I am fairly sure that the limitation of the Astir CS and the Standard Libelle to only 36 kg/m^2 is a definite handicap. No manufacturers of competition gliders are now bothering with minimum wing loadings less than 31 kg/m^2: the LS 1f has a minimum of 34 kg/m^2!

The Americans, with their cavalier attitude to loading limits, have apparently found performance benefits in loadings substantially greater than the manufacturers allowed for.

We would do well to find out more about the relationship between performance and wing-loading. We should be analysing championship results, and we should be collecting data on the size, strength and distribution of thermals.

It would also help if glider designers spoke out on what they are trying to achieve and why they think it will work.

References

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4. Some Computer Calculations on the Optimum Waterballast of Sailplanes, by Herbert Pirker, Swiss Aero Revue 3/77 (1977), pp. 173-178.

The Great Man himself...Garry Speight, known internationally as "that Kiwi who can thermal a fart" standing in full regalia in front of the modern equivalent of an Astir CS.

(Photo and caption with the re-published article in "Keep Soaring" May/June 2011)