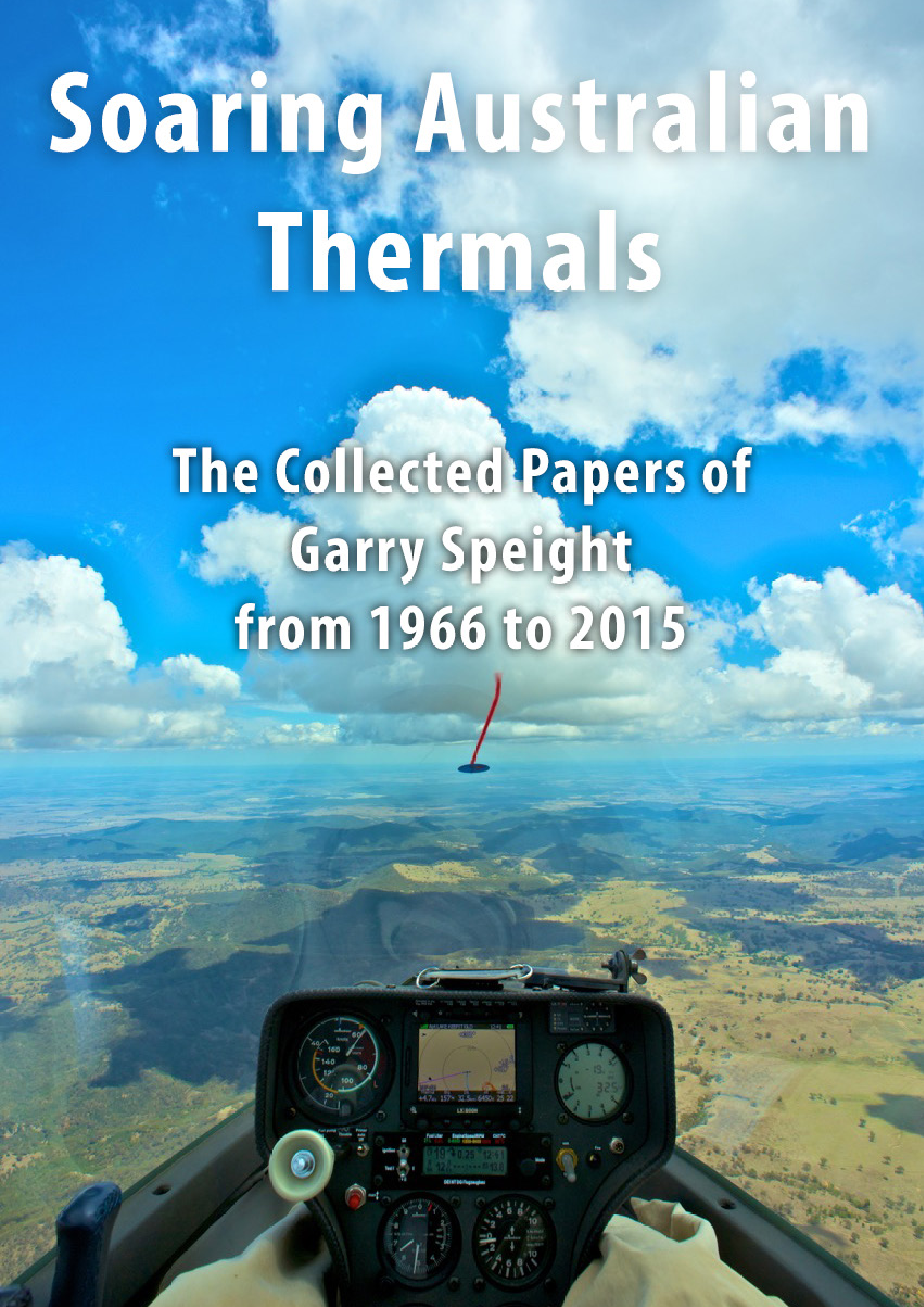
Soaring Australian Thermals

The Collected Papers of Garry Speight from 1966 to 2015



Rate of Climb in Thermals

By Garry Speight

As background to discussing the use of water ballast (the next article) I had to explain details of glider performance at circling speed, the likely lift profile of thermals, and the resulting rate of climb.

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The rate of climb in thermals is one of the most important things to consider when comparing one type of glider with another, as when thinking of buying a new glider, or when choosing one to fly in competition.

Recently, with most gliders having provision, through the use of water ballast, for reducing the wing loading in flight, every competition pilot has a daily need for some information on the relative climbing performance of his glider with and without water ballast.

The published performance polar curve of a sailplane does not yield thermalling performance directly, but it provides the basis for computation of the glider's sink rate in circling flight at various speeds (see Welch et. al., 1968, p. 138-142): I have constructed the nomogram shown in Figure 2 to simplify this task. Most of the rest of the paper is an attempt to construct simple but plausible models of thermals, so that the known rates of sink of circling gliders can be converted to estimates of the rates of climb that can be achieved in the sorts of thermals that they are likely to be flown in. Only then can a pilot get something approaching an objective estimate of relative thermalling performance.

Circling Performance

The basis for estimating the still-air circling performance of a glider is the low- speed end of its performance polar curve, the part within about 10 knots of the stalling speed. Good data for this

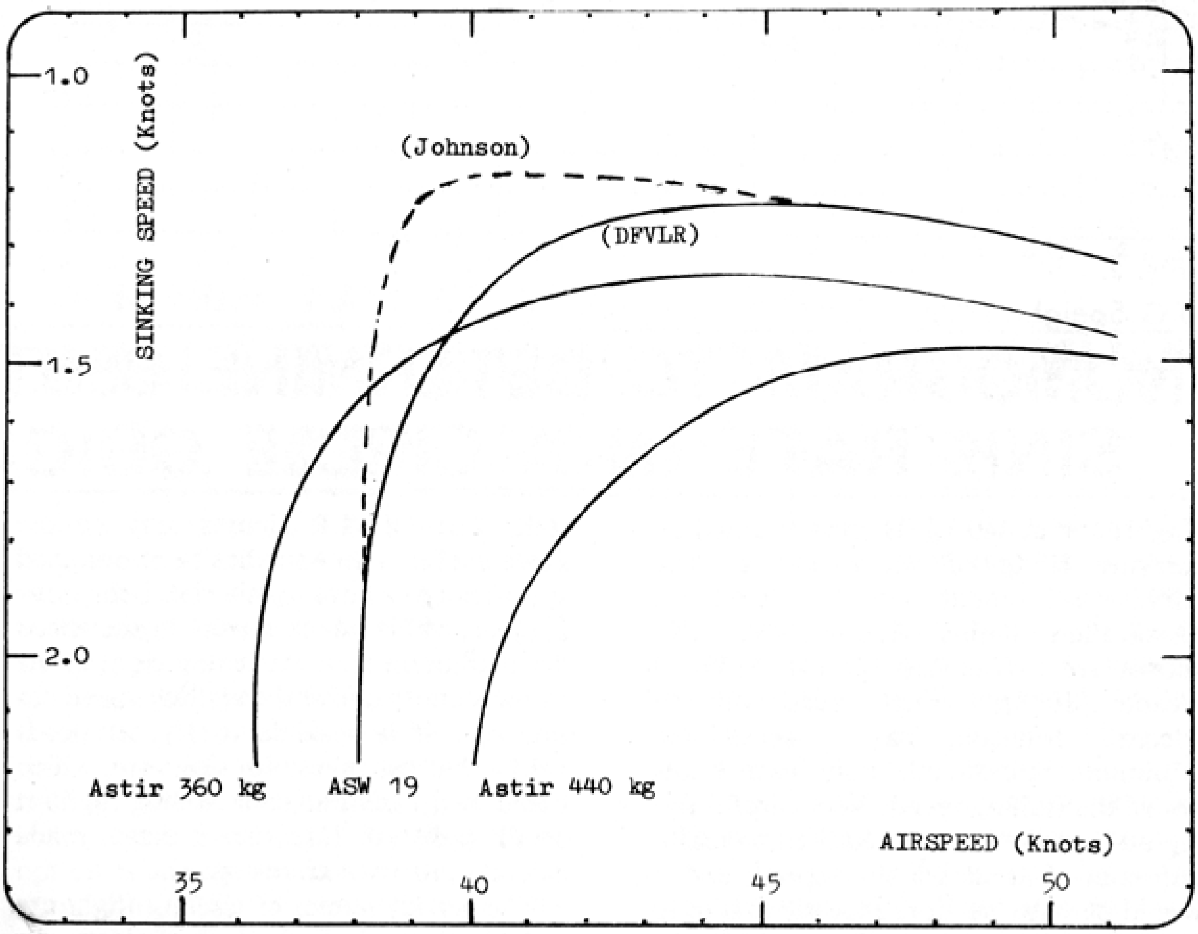

Fig 1. The low-speed end of some glider performance polar curves.

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part of the curve is so difficult and costly to obtain that one should be a little sceptical of the curves published by manufacturers and even those of independent testing authorities. Particular note should be taken of the weight of the glider as tested. The performance curve at any other weight must be estimated by multiplying both the airspeeds and the corresponding sinking speeds by the square root of the ratio of the actual weight to the test weight. The two weights of most interest to a contest pilot are the minimum weight that he can actually achieve with complete contest equipment, and the maximum permitted weight with water ballast.

In Fig. 1 I show relevant parts of the polars of an Astir CS at 360 kg weight (Light) and at 440 kg (Heavy) attained by carrying 80 kg of water ballast. The curves are based on test data in "Australian Gliding (Anon. 1979). Also shown are two curves for the ASW 19 (Anon. 1978), which, according to Richard Johnson, has a speed for minimum rate-of-sink only two knots above the stalling speed. Very careful flying and smooth air are required to maintain control at such a slow speed, and it would perhaps be more realistic to aim to hold a steady speed four knots above the stall. The DFVLR figures may be the more useful. The Astir has been designed specifically to have gentle stall behaviour (Eppler, 1977) which results in the speed for minimum sink rate being eight knots to nine knots above the stalling speed. In this case it is feasible to fly at speeds below that for minimum sink rate, which could be an advantage in circling flight at small radii of turn, so I have made calculations for various speeds.

The aerodynamics of circling flight are well known, but the calculations are tedious. To help pilots to work out the behaviour of their sailplanes I have prepared the nomogram in Fig. 2.

The performance data required are (i) an airspeed value from the polar curve, selected as being a useful basis for calculation, either the speed for minimum rate of sink, or some arbitrary margin above stalling speed, e.g. two knots or eight knots above the stall (N.B. only the first option is mentioned in the titles on the nomogram); (ii) the rate of sink at the selected airspeed, read from the polar curve. Values of (i) and (ii) are represented on the nomogram by sets of curves on the left and right respectively. For each pair of values (i) and (ii), the nomogram is used to obtain a number of values of the rate of sink, angle of bank and actual airspeed, corresponding to a number of selected values for the radius of turn. To use the nomogram, enter it at the top margin at a selected radius of turn. Bring a line down vertically to meet the chosen straight-flight airspeed curve. At this point the actual airspeed required in the turn may be interpolated between the dashed lines, and the required angle of bank may be read on the vertical axis. Then carry the line horizontally to meet the appropriate curve for rate of sink in straight flight, then take it vertically down to the lower margin to read off the rate of sink in circling flight for the selected radius of turn.

Using the nomogram, one or more curves can be constructed, as in Fig. 3, showing rate of sink versus radius of turn. On the figure, curves are drawn for the Astir CS at straight-flight airspeeds that are eight knots, four knots and two knots above the stalling speed in both ballasted and unballasted conditions. For the unballasted glider, it may be seen that, at all radii less than 340 ft, the four knots- above-the-stail speed yields smaller rates of sink than the speed for minimum sink, eight knots above the stall. At two knots above the stall, sink rates are greater again except at very small radii, where adequate speed control would not be possible, so four knots above the stall appears to be a good speed for thermalling. With ballast the curves are steeper, the performance falling off at larger turn radii than in the unballasted state.

Since, in general terms, lift is strongest in the centre of a thermal, good thermalling performance depends on curves that are as high up and as far to the left as possible on this Figure. It is a definite disadvantage to carry water ballast or to have a high stalling speed, whether it is due to a high wing loading or to aerodynamic inefficiency. It is not possible, however, to estimate the **amount** of disadvantage without information about the distribution of lift in thermals.

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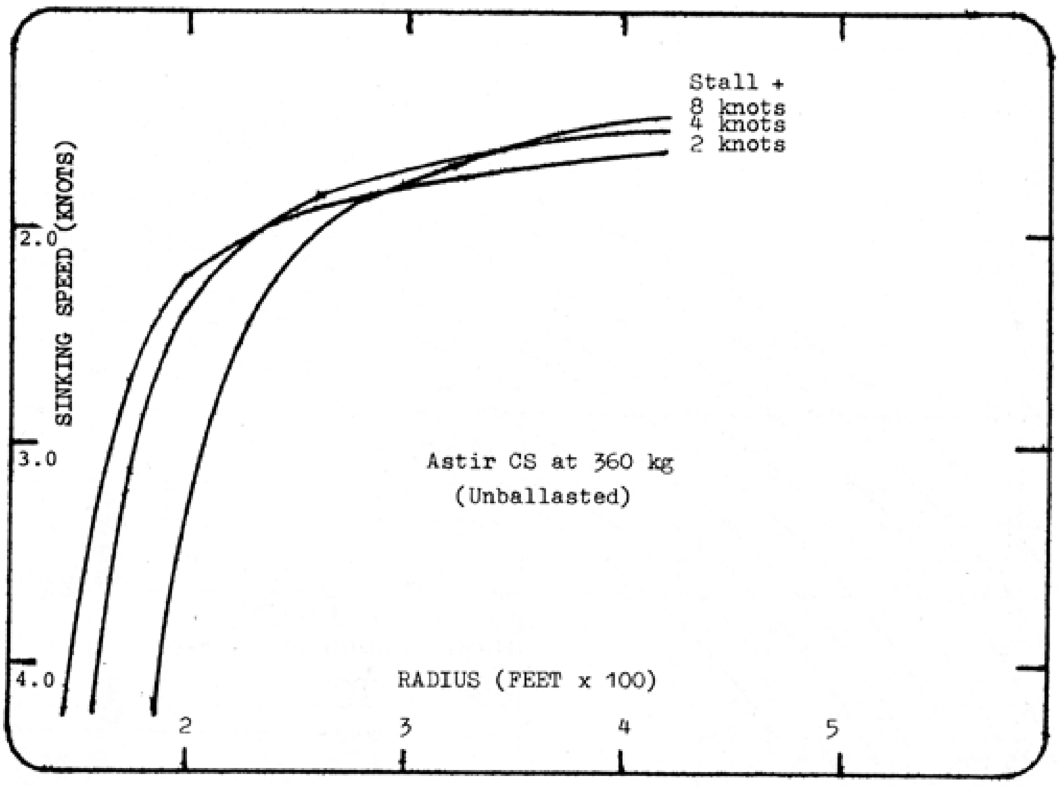

Fig 3a.

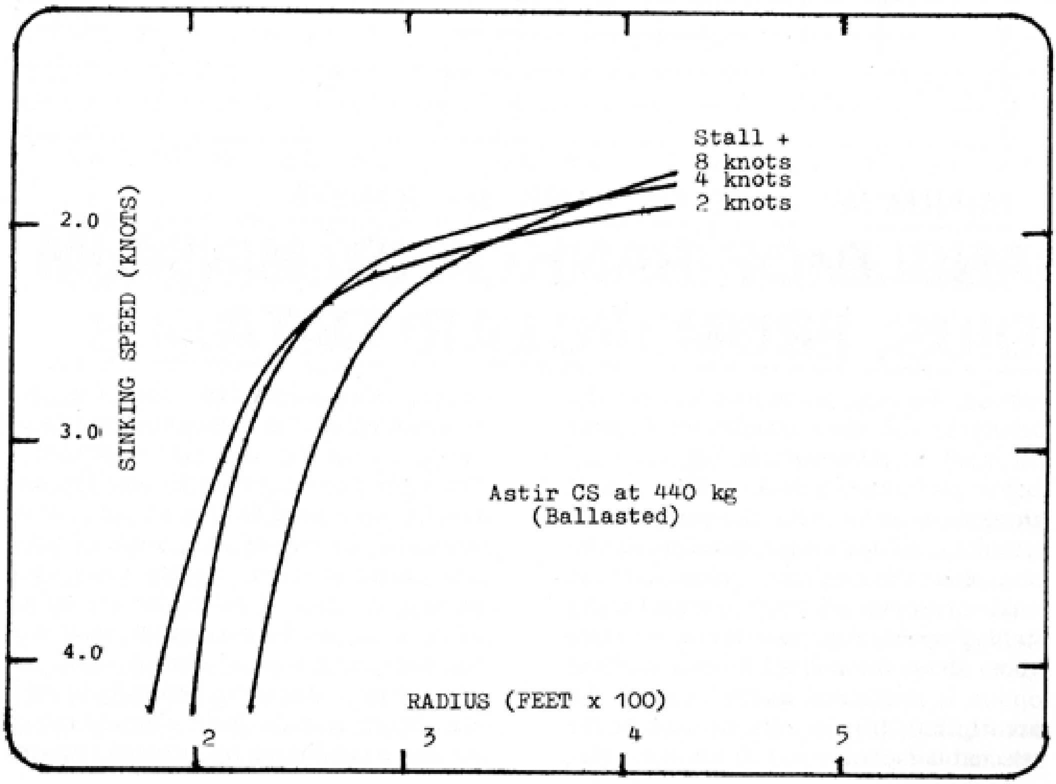

Fig 3b.

Fig 3. Turning rate of sink of the Astir CS plotted against radius of turn for airspeeds 2 knots, 4 knots, and 8 knots above stalling speed in the turn. (a) unballasted (360kg), (b) ballasted (440 kg).

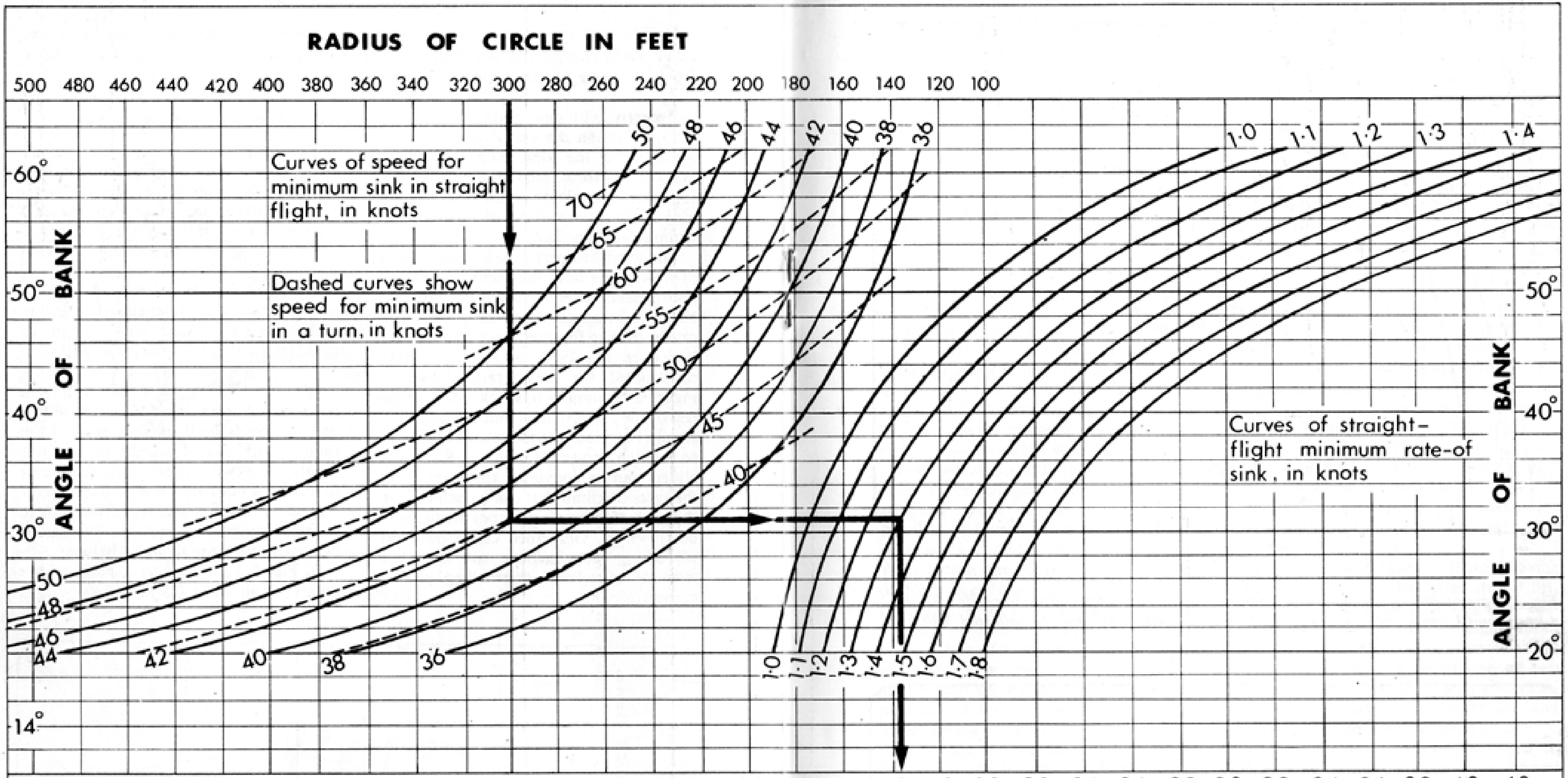

Fig. 2.
J.G.Speight 1980

NOMOGRAM TO DETERMINE BEST SPEED, ANGLE OF BANK AND MINIMUM SINK RATE IN A CIRCLE OF GIVEN RADIUS, FROM POLAR DATA.

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Models of Thermal Lift Distribution

Thermals may be regular or irregular, but there is little point in trying to analyse irregular thermals. Barry Wrenford has jokingly classified them into various types (Wrenford, 1969). I will consider only the regular ones, and presume that irregular ones are much the same on the average, just more difficult to work. The general model I will discuss is an isolated circular patch of lift, strongest in the middle, with lift decreasing equally in all directions away from the central axis. Whether it is a vortex ring, a bubble or a column is not relevant, so long as the lift does not change too rapidly with height in the part of the thermal we are thinking about.

Even such a simple, regular kind of thermal may vary in different ways: in strength, in width, and in the way in which the lift decreases away from the centre.

We have certain clues about thermals from what happens when we try to fly them. Dupont (1974) quotes a survey by Gerhard Waibel indicating that most competition pilots in their efforts to maximise rate-of-climb use between 35° and 45° of bank. Referring to the nomogram. Fig. 2, since the speeds for minimum sink rate of practically all modern gliders fall within the range displayed on the figure, it follows that the pilots must have been flying circles of radius between 150 ft. and 360 ft. Again, from my experience, I would say that circling a Blanik, without flap, at only 20° of bank produces a miserable rate of climb except in very strong thermals. This implies a thermal radius of around 500 ft. to 600 ft.

A further observation is that if, having established a turn that gives steady lift, one happens to blunder through the centre of the thermal without changing speed or bank angle much, the increased lift at the centre is usually about one or two knots above the steady value: it seldom increases as much as three knots, and sometimes there is no increase at all.

These observations may be used to specify the characteristics of a typical thermal:

(i) somewhere in the range from 150 ft. to 360 ft. radius the lift decreases with increasing radius at about the same rate that the glider sinking speed decreases with increasing radius, so that the radius of turn has rather a small effect on rate of climb within these limits

(ii) Beyond 360 ft. radius the lift falls off rapidly until it is practically zero at about 500 ft. or 600 ft.

(iii) Between a useful circling radius and the centre the lift increases by one or two knots.

A number of theoretical models of the size and shape of the zone of lift in a thermal have been constructed over the years. They are illustrated in Figs. 4 and 5. In these and the following figures I have adopted a convention to simplify all comparisons: the centre of the thermal is on the left, and the vertical axis reads downwards, as on a performance polar, showing the decrement of lift relative to the upward velocity of the air in the centre of the thermal called the central velocity. The graphs show how much slower the air at some radius is going up. Later figures also show how much slower than that the glider is going up. If a particular thermal has a central velocity of, say, six knots we can represent the surrounding air by a horizontal line extending to the right at a lift decrement value of six knots.

Fig. 4a shows some British work. In 1967 the British Gliding Association adopted a datum thermal proposed by H.C.N. Goodhart for the purpose of handicapping gliders according to their predicted cross-country speeds in the prevailing weather. This datum thermal had specified strength, radius and lift distribution: a parabola. It fits quite well to all the criteria above, the only problem being how to generalise it for different thermal strengths: should one extend the same curve to make a stronger, wider thermal, or should one change the constant of the parabola to increase the strength without increasing the maximum radius? Later, (Strachan, 1974) the B.G.A. set up a new “1975” datum thermal, also shown on Fig. 4a, which seems far too forgiving! Although it yields climb rates of only two knots to two-and-a-half knots for most gliders, it has the very large radius of 1000 ft, and such a gentle rate of lift decrement with radius that changes in

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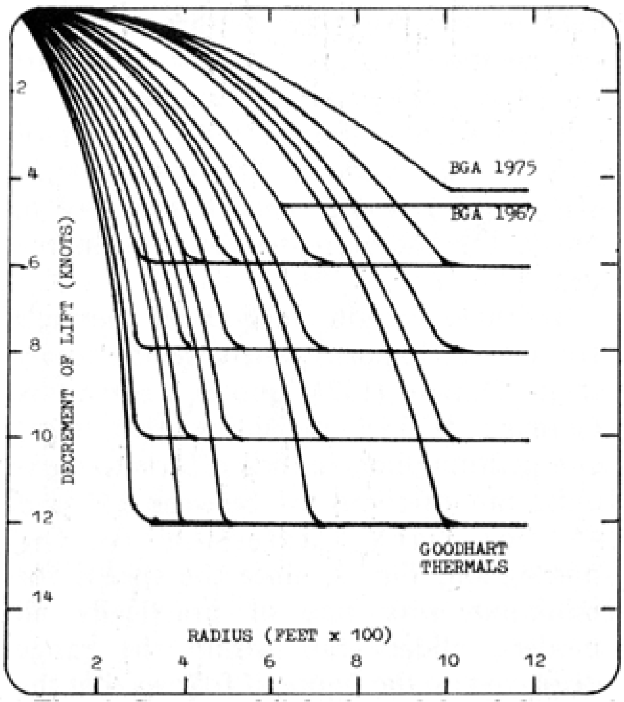

Fig 4. Published models of thermal lift distribution: (a) Goodhart; BGA.

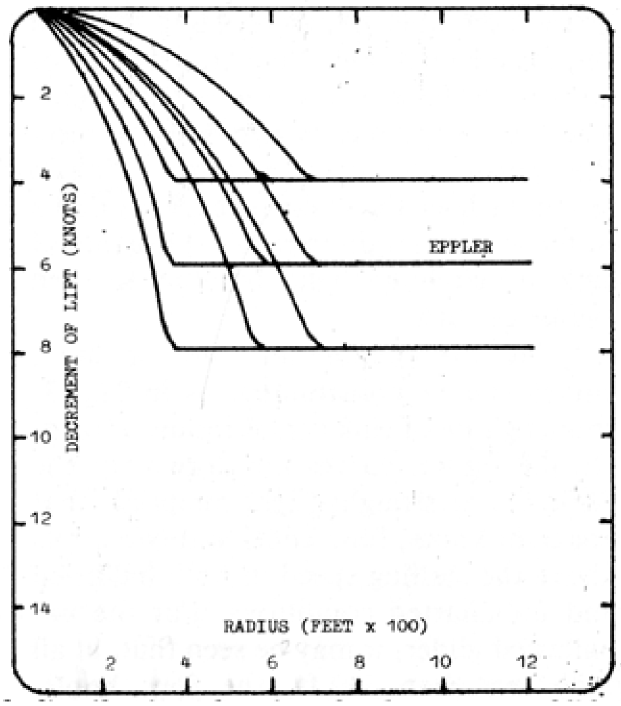

Fig 4. Published models of thermal lift distribution: (b) Eppler.

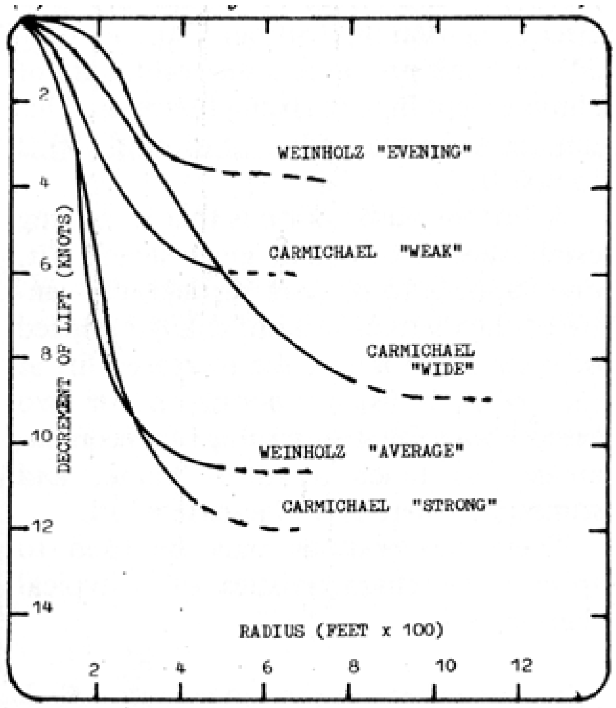

Fig 4. Published models of thermal lift distribution: (c) Carmichael (Reichmann, Holighaus, Weinholz)

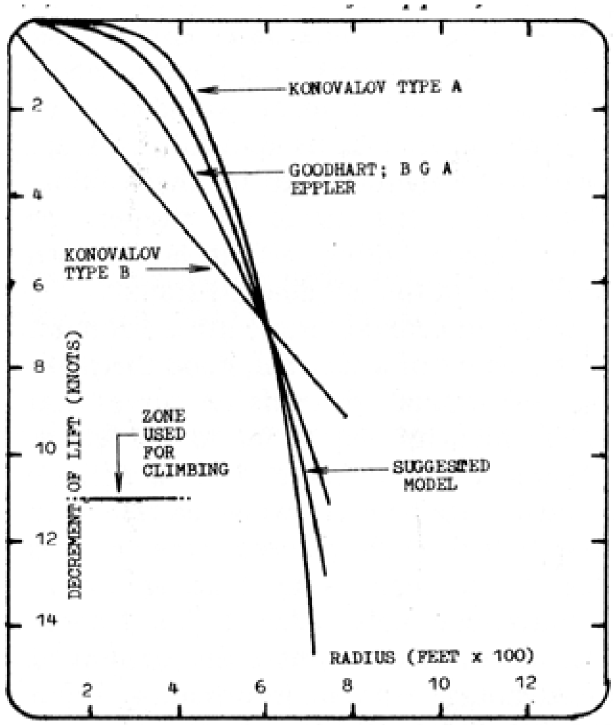

Fig 5. Thermal models with different profiles of lift distribution.

wing loading and angles of bank do not greatly affect the rate of climb. Subsequently, Goodhart produced a whole family of 25 parabolic lift distribution profiles as shown, which have since been used in papers by Frank Irving (1972) and Martin Simons (1976). Dr. Eppler (1977), discussing the Astir design concept, also used a family of parabolic thermals, nine in all, in the central part of the range used by Goodhart (Fig. 4b).

A different tradition of thermal modelling, shown in Fig. 4c, represented by Reichmann (1978), Weinholtz (1969) and Holighaus (1971) is based on a paper in "Soaring" by Carmichael (1954). These thermals, with the exception of the "wide" type which would be classed as "normal" by other authors, are very vicious indeed! In the supposedly typical “strong” thermal an unballasted standard class glider achieves maximum climb at about 50° of bank, and the climb rate will then be only four knots, whereas blunders into the core at the same bank angle will yield nine knots momentarily. A standard class glider carrying ballast will scarcely climb at all. Similarly the major part of the lift in the “weak” thermal can be reached only by extreme angles of bank and low wing loadings. On the basis of his model, Carmichael calculated that optimum aspect ratios would be about 10:1. The fact that such low aspect ratios have not been adopted since does not appear to have caused later authors to question his thermal models. Within the range of circling radius available to sailplanes the Carmichael “strong” and “weak” thermals display the “hyperbolic” lift distribution which, according to Barry Wrenford marks the dreaded “Cowra Corkscrew Thermal.” Such thermals no doubt exist but, fortunately, one is seldom forced to rely on them!

In the Soviet Union D.A. Konovalov (1970) (see Strachan, 1974 and Reichmann, 1978) collected data on a large number of thermals which indicated that, rather than a parabolic lift profile, with the decrement of lift proportional to the square of the radius, thermals have one of two types of lift profile (see Fig. 5): Type A has the decrement of lift proportional to the fourth power of the radius, and Type B has the decrement of lift directly proportional to the radius. The two types were both found to occur with a variety of thermal diameters and thermal strengths. In Fig. 5 I have plotted types of thermal model scaled so that each has a lift decrement of seven knots at 600 ft. radius. Konovalov types A and B are shown, as well as the parabolic type used by Goodhart and Eppler, and the type that I am putting forward.

In the absence of data to the contrary, I propose as a simplified model that “normal” thermals conform to a single equation of lift decrement versus radius, the stronger thermals having larger maximum radius, and the weaker thermals somewhat smaller maximum radius, simply as a consequence of the curve extending a greater or lesser distance before meeting the horizontal line where the lift decrement equals the central velocity of the thermal. This assumption simplifies estimation of glider performance because the best thermalling radius, angle of bank and speed to fly will not vary with thermal strength, and nor will the decrement of the gliders rate of climb compared with the central velocity of the thermal. That is, for a “normal” thermal the maximum climb rate of a given glider (identically loaded) will always be the same amount less than the upward speed of the air in the core of the thermal. For the application of this idea, the Konovalov Type B and the Goodhart and Eppler thermals have radii that vary too rapidly with thermal strength, while the Konovalov Type A not only varies rather too little in radius with different thermal strength, but also has a very small variation in strength across the core. After various trials with graph paper and performance curves, I propose a thermal model, as shown in Fig. 5., in which the decrement of lift varies with the cube of the radius. Specifically, for a “normal” thermal I propose the curve $y = 0.033 (x/100)^3$ where x is radius in feet and y is lift decrement in knots. This thermal matches the three “characteristics of a typical thermal” given earlier.

Such a normal thermal would be rather easy to work. Since quite a few thermals seem to be somewhat more difficult to work because they are not wide enough, I further propose a “narrow”

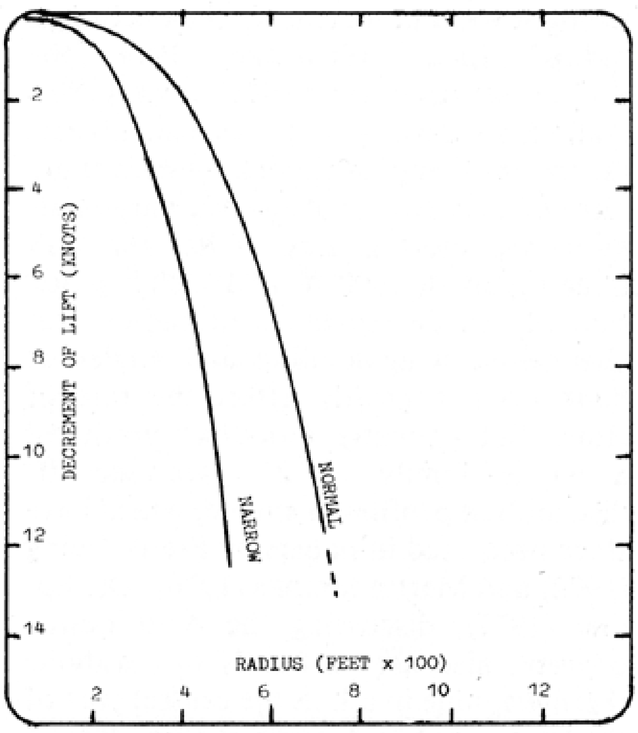

Fig. 6. Proposed “normal” and “narrow” thermals, $y = 0.033 (x/100)^3$ and $y = 0.10 (x/100)^3$ respectively

thermal, also with a cubic velocity distribution and the equation $y = 0.10\,(x/100)^3$.

Profiles of these two types of thermal are plotted in Fig. 6, and their coordinates are listed in Table 1.

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Having settled on a pair of models of thermal lift distribution that will do for the time being, we can study, as an example, the relationship between circling performance of the Astir CS and the lift distribution in the model thermals, to discover the rates of climb, and best airspeeds, turn radii, and angles of bank for thermalling with and without water ballast, as predicted by the thermal models.

Figure 7 refers to the "normal" thermal. The lower curves show the rate of sink of the glider relative to the central velocity of the thermal. Climbing is possible whenever this rate of sink is less than the central velocity. The curves for the glider are plotted by simply dropping below the curve for the thermal itself, by the amount of sink shown in Fig. 3. Six curves are shown, for the ballasted and unballasted condition, and for airspeeds eight knots, four knots and two knots above stalling speed. Best rates of climb are obtained by an airspeed four knots above stalling speed, and selection of this speed also minimises the disadvantage of carrying water ballast when thermalling. Note that the curves are based on speeds selected from the polar curve for straight flight: the speed to fly actually increases with bank angle in each case, although it increases very little relative to stalling speed for the particular angle of Bank.

Figure 8 shows the glider's thermal performance curves, for the " + 4 knot" case with numerical values of speed and angles of bank taken directly from Figure 2. In this "normal" model thermal, the effect of ballasting the Astir CS from 360 kg to 440 kg is that the best thermalling speed rises from 44 knots to 50 knots, the best angle of bank goes from 35° to 38°, and the best rate-of-climb falls by 0.50 knots, the lift decrement increasing from 2.42 knots to 2.92 knots relative to the central velocity of the thermal.

In the case of the "narrow" model thermal, shown in Fig. 9, rates of climb are much

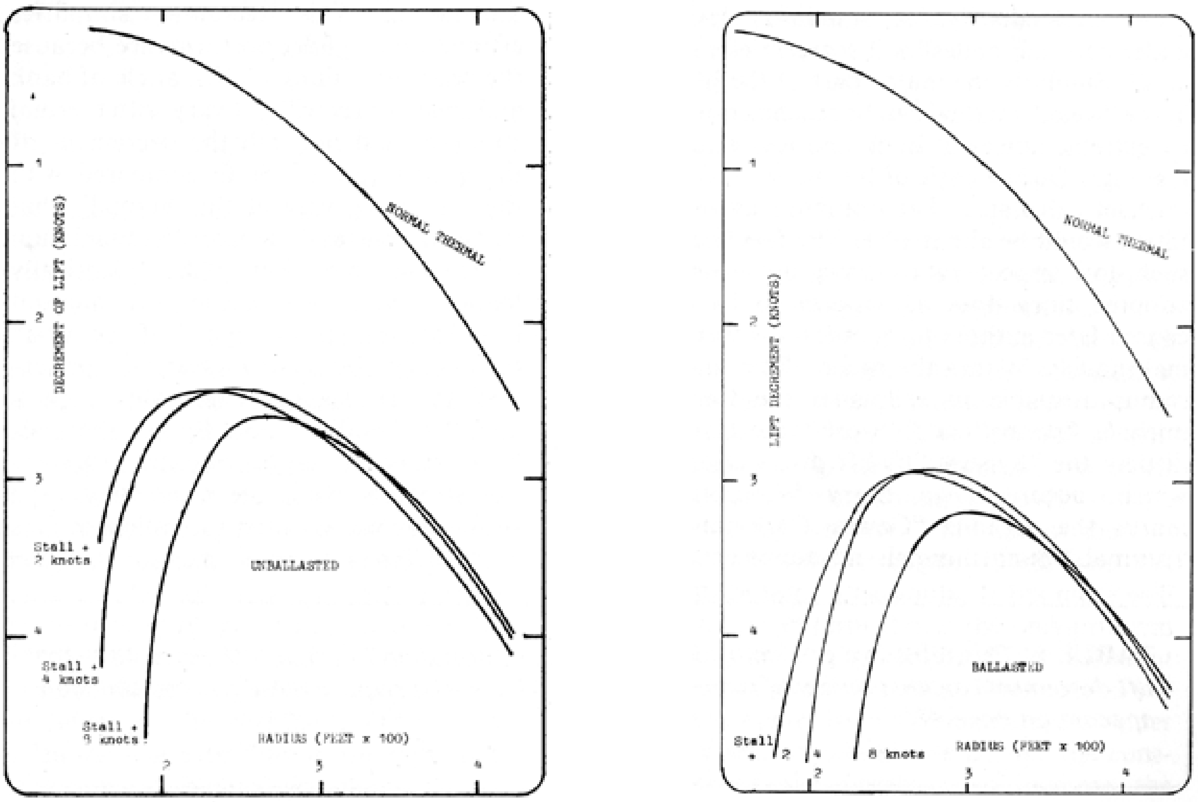

Fig 7. Rates of sink of the Astir CS relative to the central velocity of a "normal" thermal.

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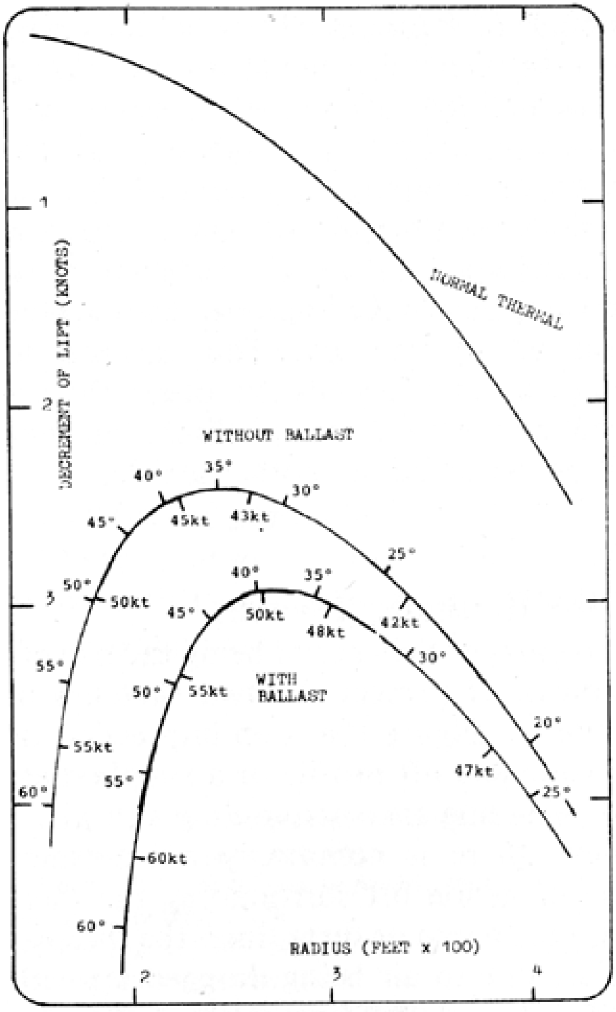

Fig 8. Speeds and angles of bank related to thermal performance of the Astir CS flown 4 knots above the stall in a "normal" thermal

reduced, and the disadvantage of carrying ballast is more pronounced because the practical circling radii are in the zone where the thermal lift is falling off rapidly with radius. Theoretically, maximum rate of climb will be achieved in the narrow thermal by flying within two knots of the stall, but the very narrowness of the thermal will make this impossible in practice because small piloting errors will result in very large fluctuations in thermal lift, that will certainly induce repeated stalls. Stalling in a thermal is foolish from every point of view: loss of height, loss of control, and possibly loss of life!

At four knots above the stall in a "narrow" thermal the minimum lift decrement without ballast is 3.14 knots, attained by flying at 47 knots with 42° of bank. With ballast, it is best to fly at 52 knots with 45° of bank, but this yields a lift decrement of 3.98 knots, a relative decrease in

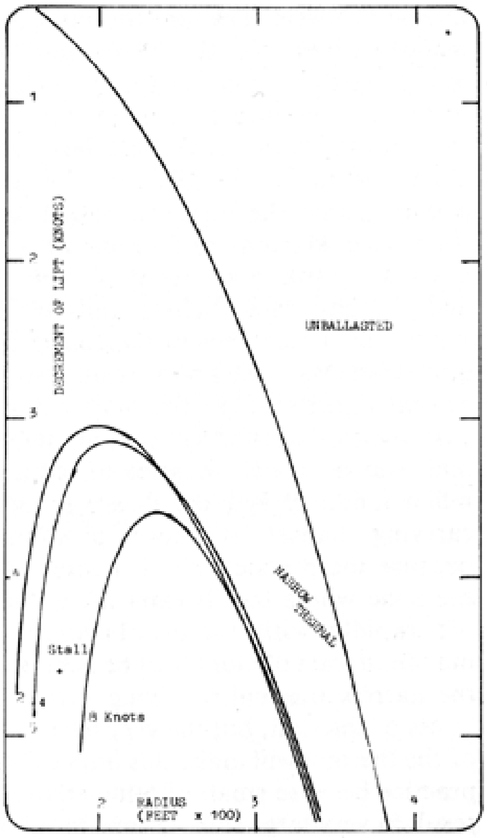

Fig 9a. Rates of sink of the Astir CS relative to the central velocity of a "narrow" thermal

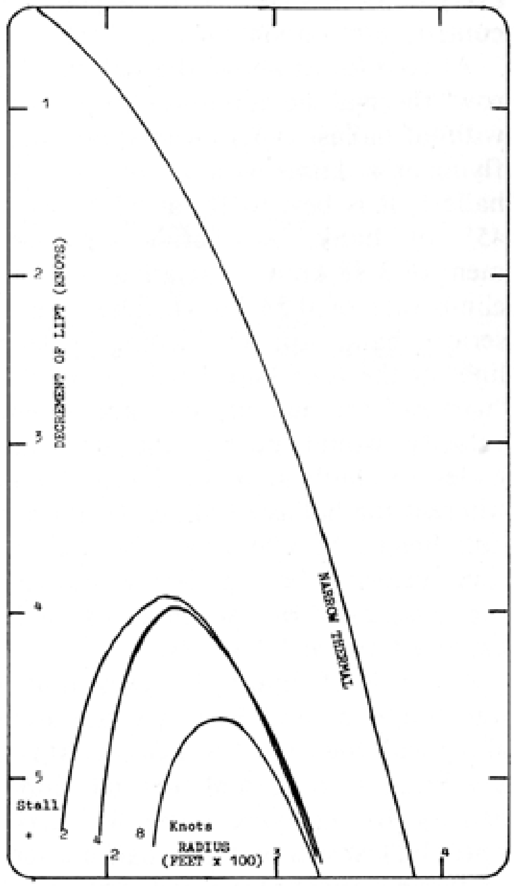

Fig 9b. Rates of sink of the Astir CS relative to the central velocity of a "narrow" thermal

climb rate of 0.84 knots. This is a very serious handicap: by drawing horizontal lines at the four knot level we see that a “narrow” thermal of four knots central velocity would permit the unballasted glider to climb at more than 0.8 knots, whereas the ballasted glider would barely hold height. In a “normal” thermal of the same velocity, both gliders would climb, the unballasted one at 1.6 knots, and the ballasted one at 1.1 knots.

As a rule-of-thumb, I suggest that current Standard and Racing Class gliders, along with the Astir CS, will sink at about 2.5 knots in a normal thermal, and the penalty for carrying some 80 litres of water ballast will be about half a knot. In a “narrow” thermal they will sink at about three knots, and the ballast penalty will be about one knot.

It should be possible to judge whether the thermal is normal or narrow by the amount of bank necessary to maximise the rate of climb (this idea comes from Herbert Pirker (1977)). When one is carrying ballast (and therefore still has the option of dumping it) a normal thermal requires less than 40° of bank; a narrow one requires about 45°. Judgement of these angles may be improved by marking them on the canopy. The decision to dump ballast depends on other factors beside the reduced rate of climb, but they will be discussed in another article.

More Realistic Thermals

To parry the charge of being excessively simplistic, I present the two sketches in Figure 10. Figure 10a is an impression of the complete lift profile of a simple thermal including the surrounding still air. I believe there is commonly a transition zone of gentle lift surrounding the thermal, out to two or three times the thermal radius, due to air being dragged up with the thermal. Any adjacent areas of heavy sink are, I think, usually localised in places where the thermal is tumbling due to wind shear.

I do not think that the circular-cubic model of about 400 to 700 ft radius is invalidated by the typical observation of much larger and less regular areas of lift in experimental traverses by instrumented aircraft, nor by the often puzzling behaviour of gaggles of gliders. It seems to me that larger thermals may have a compound structure, as is seen in actively- growing cumulus clouds. There may be a number of thermals rising as a cluster, Fig. 10b, with a particular individual thermal not necessarily remaining the strongest throughout the ascent. I suggest that each individual thermal of such a cluster often resembles one of the models that I am proposing, so that choice of wing loading and thermal technique remains related to the basic model. The effect of the other thermals in the cluster is to make it necessary to frequently explore the air around the thermal to find if a stronger one has developed adjacent to it.

Conclusion

I suggest that the simple models of “normal” and “narrow” thermals that I have described may be sufficiently realistic to provide the basis for estimating the comparative thermal performance of different gliders and for assessing the effect of water ballast on the rate of climb. The models could be validated, improved, or rejected by pilots willing to experiment in a systematic way, and to record their results. I would like to hear from any pilot who considers that the model should be changed in some specific way.

The table below gives coordinates for Fig. 6 on page 31

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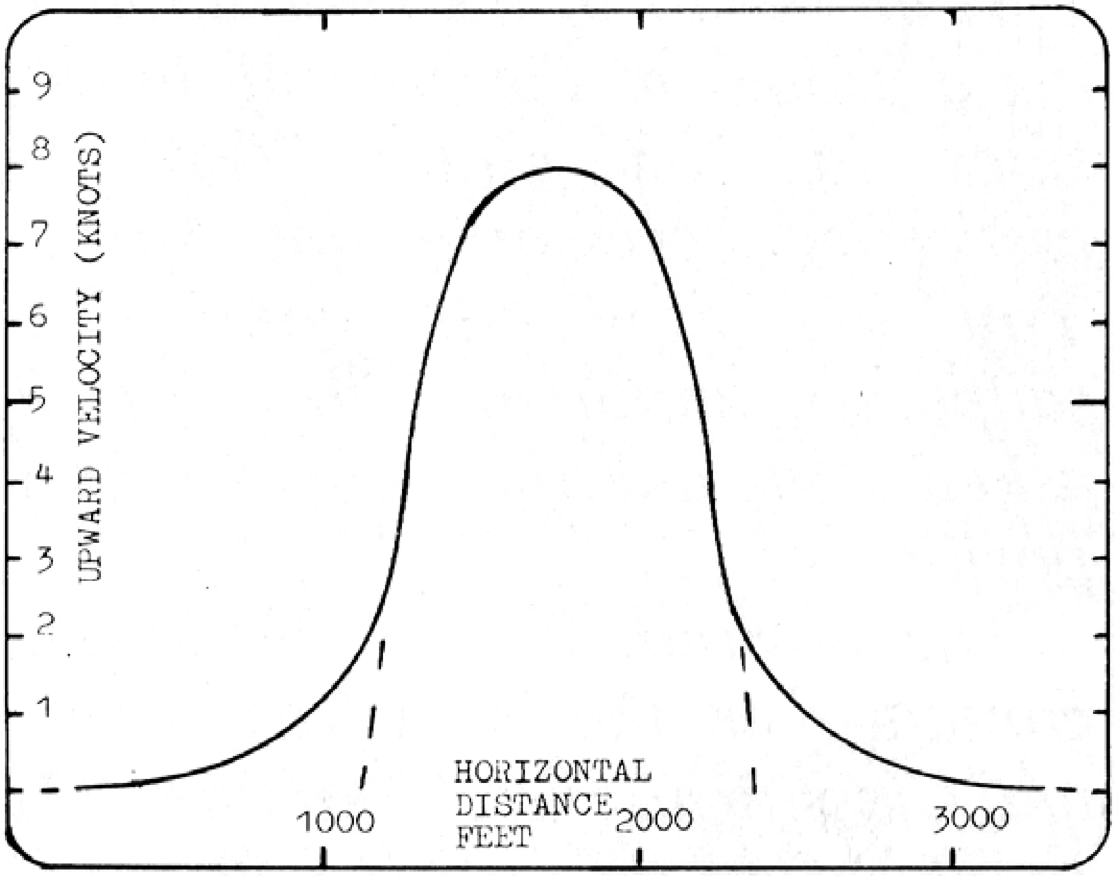

Fig 10a. Sketches of inferred thermal lift profiles: simple thermal

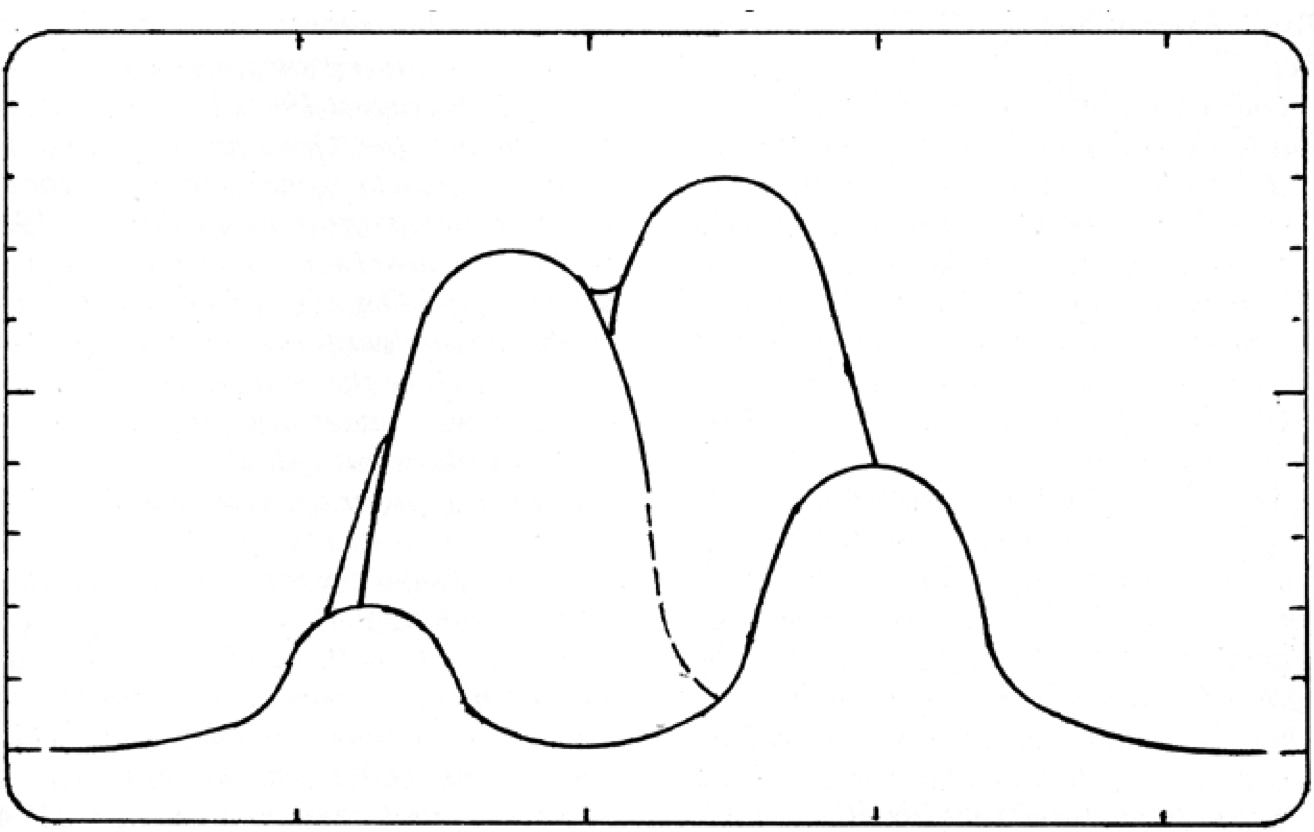

Fig 10b. Sketches of inferred thermal lift profiles: compound thermal

Acknowledgement

Many thanks to Reg Munyard for drawing the nomogram and to Joe Borg for drawing the other figures.

Radius (feet)	Lift Decrement (knots)	
	Normal Thermal	Narrow Thermal
0	0.00	0.00
100	0.03	0.10
160	0.14	0.41
180	0.19	0.58
200	0.27	0.80
220	0.35	1.06
240	0.46	1.38
260	0.59	1.76
280	0.73	2.20
300	0.90	2.70
320	1.09	3.28
340	1.31	3.93
380	1.83	5.49
420	2.47	7.41
500	4.17	-
600	7.20	-

Table 1.

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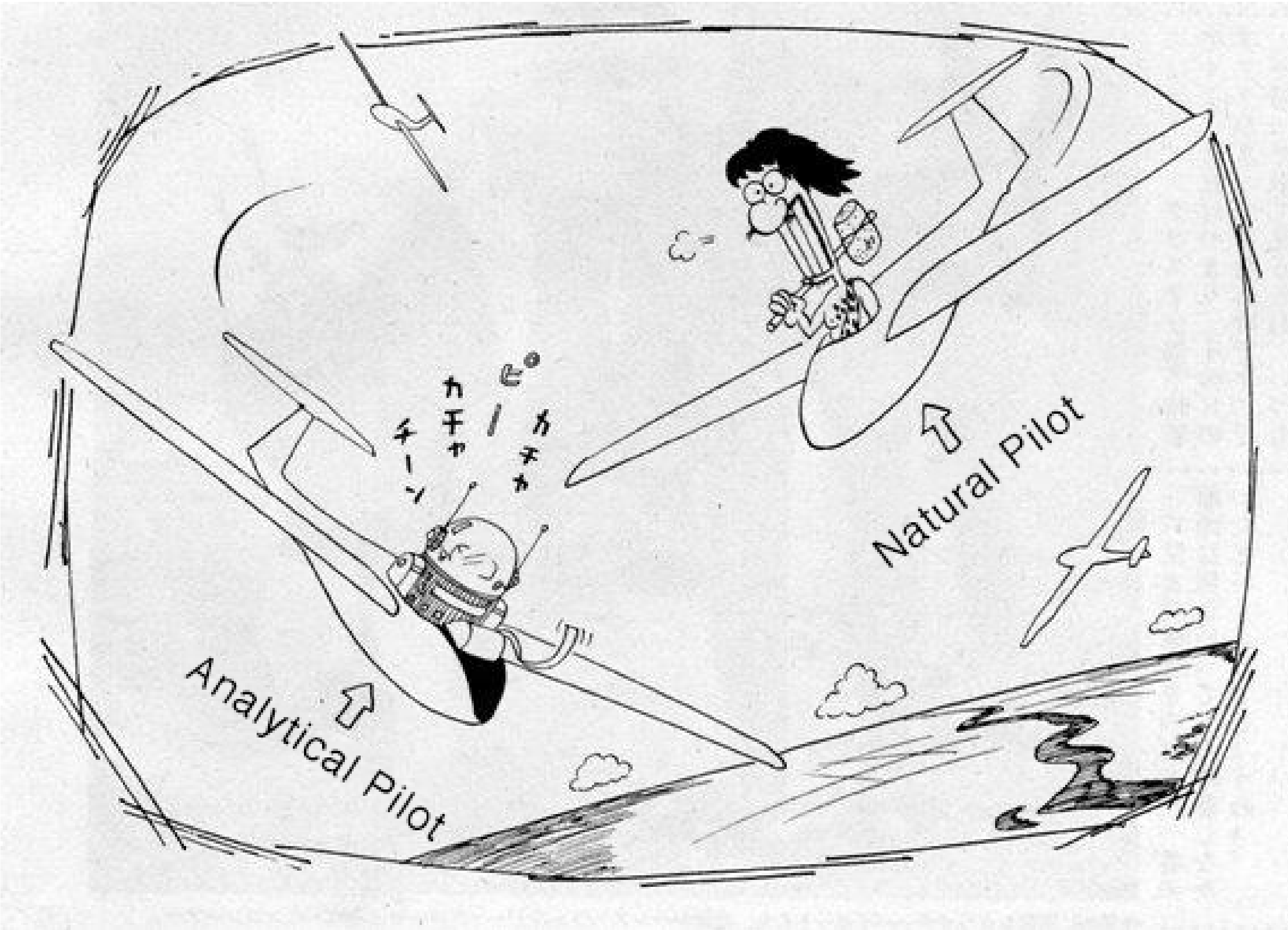

At this time, I was trying various cockpit aids to help me fly efficiently, and I was talking to other pilots about my ideas. A Japanese pilot I spoke to at the 1980-81 Waikerie National Championships was "Hiro" Ichikawa. When Hiro was interviewed by the magazine "Tsubasa" ("Wings"), they published this cartoon. Hiro assured me that the "Analytical pilot" was me, and the "Natural pilot" was John Rowe (who placed second to Shane McCaffrey).