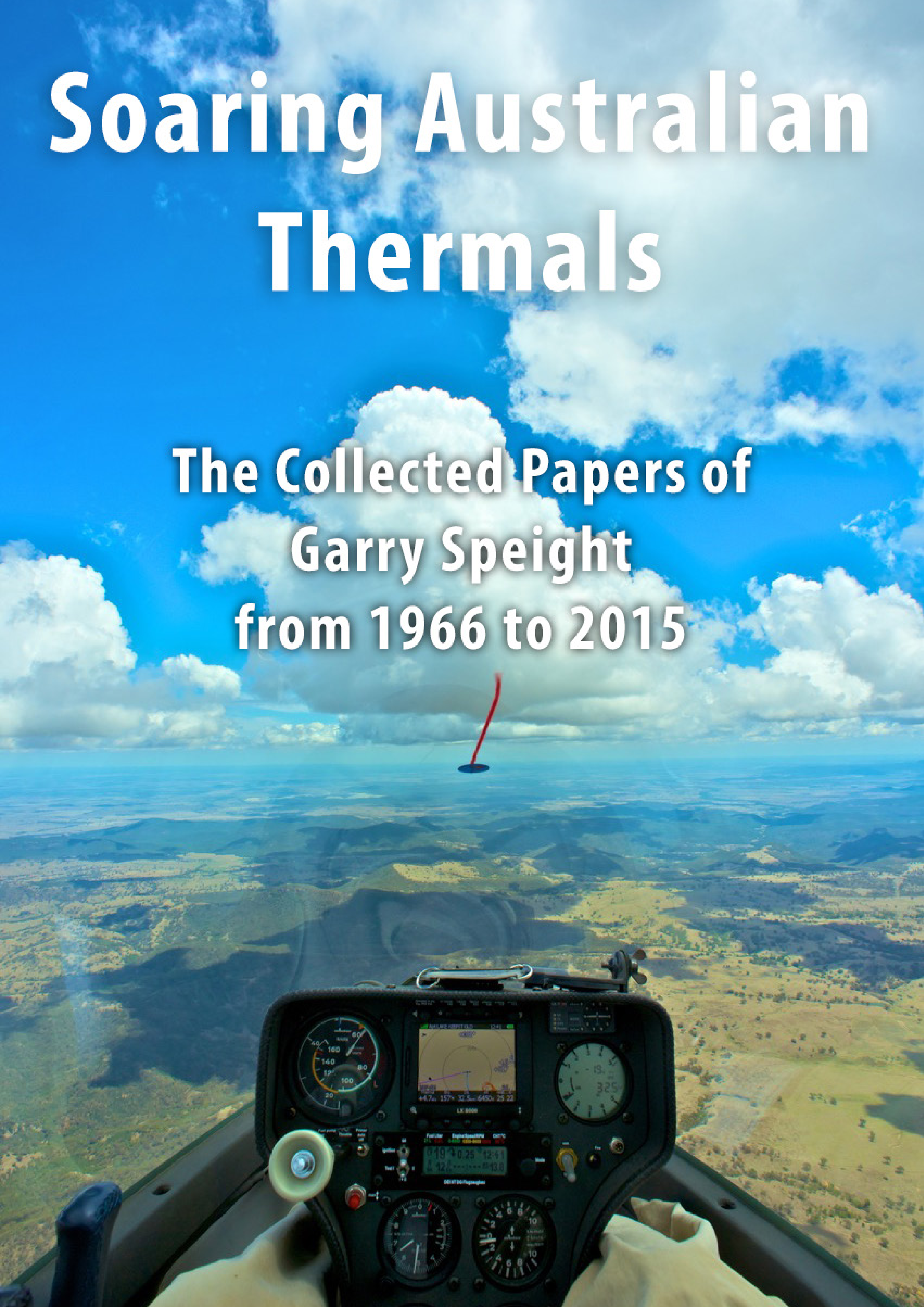
Soaring Australian Thermals

The Collected Papers of Garry Speight from 1966 to 2015



Thermals That Rotate, Part 2

By Garry Speight

Originally published in Soaring Australia, June 2006

Many thermals rotate, and they may be the strongest of the day. You can soar better if you learn to work them. Circling against the rotation is a dream; circling with it. A nightmare!

Part 2: What they are like

Flight In Rotating Air

The glider flies because of its speed through the air. In a thermal, the pilot must keep the airspeed just a few knots above the stall. This airspeed is the same whether flying with or against the thermal rotation, (so long as the air is just as smooth each way). The ground speed is not the same: the ground speed is higher when flying with the rotation than when flying against it.

To keep a turn going, the pilot must bank the glider so part of the lift of the wings pulls the glider towards the centre of the circle. Otherwise, (said Isaac Newton) the glider would fly out of the turn in a straight line. At a chosen speed, a chosen bank angle causes a particular rate of turn.

Is the speed I mention here the same as airspeed? Not if the glider is turning in a rotating thermal. Provided there is no wind, it is the ground speed that decides the rate of turn and the radius of the circle[1].

To see that this is true, think of the path of the shadow of the glider on flat ground on a day with no wind. It is a circle exactly the same as the one the glider makes in the air. It has a certain radius and the distance around the circle is a certain number of metres. The shadow of the glider, travelling at the gliders ground speed (not airspeed), goes around in a given time. From this you can work out the rate of turn, in degrees per second. Thus, rate of turn relates to ground speed rather than airspeed, and so does the radius of turn.

To show how this might affect a pilot flying in a rotating thermal, here is an example.

A pilot circles at 50kt and 45° of bank in a thermal that rotates at 10kt. Flying against the rotation gives a ground speed of 40kt; flying with it gives a ground speed of 60kt.

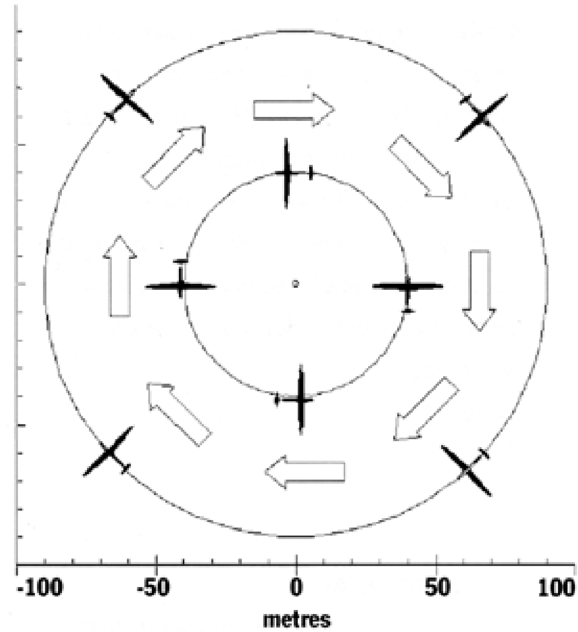


Fig 2.1. Turning radius at 50kt with and against a 10kt thermal rotation

The Technical Note 2 explains how the radius of turn is 40m in the first case and 90m in the second (Figure 2.1).

A thermal rotation of as little as 10kt makes the radius of turn when flying with the rotation more than twice that when flying against it! Added to that, a 90m radius is very large; larger than the radius that Australian pilots normally use for climbing in thermals. The cores of our thermals are seldom wide enough to contain circles that big.

Time Taken To Orbit

The glider takes a certain time to get from a starting point round an orbit back to the starting point. It is not clear whether it will take a longer or shorter time when flying with the rotation rather than against it. Flying with the rotation gives a higher ground speed, but there is more distance to go. In this example, an orbit takes 19 seconds flying with the rotation, and 13 seconds flying against it. The orbit with the rotation takes longer, but not by so much that the pilot will notice[3].

Although skilled pilots notice their rate of turn, and the time taken to get round an orbit, this is little help in deciding the sense of rotation. The circle may be very large or very small without the pilot knowing it.

Winds In A Rotating Thermal

If a thermal rotates, it is like a very weak tornado. Experts have found the pattern of winds in a tornado[4]. I suggest that this pattern also occurs in a rotating thermal, only the winds are not so strong. In Figure 2.2, I have drawn lines to show how much the wind in the rotating thermal has moved the air after certain times. Near the axis the air moves only slowly. Out to the edge of the core it moves faster and faster. Outside the core the air moves slower and slower. Because the air outside the core is moving slower and also has further to go around the circle, it gets left far behind the air in the core.

The flow inside the core is quite different from the flow outside it. The core rotates almost as if it were solid. The air can become calm. Outside the core, each rotating layer of air lags behind the layer nearer the core.

As the layers of air flow past each other, they catch and mix together, curling up to form little willy-willies. The biggest change of speed is in the first few metres outside the core. Here, the air will be very rough.

In a thermal, pilots expect the lift to get less away from the centre, often in a smooth way[5]. In a rotating thermal, every part of the calm core is likely to have the same strong lift (See Figure 2.3). The core will be almost perfectly circular, because the rotation will smooth off any bumps around the edge. In the rough air outside the core there will be wild updrafts and downdrafts. The lift will get very weak not far away from the core.

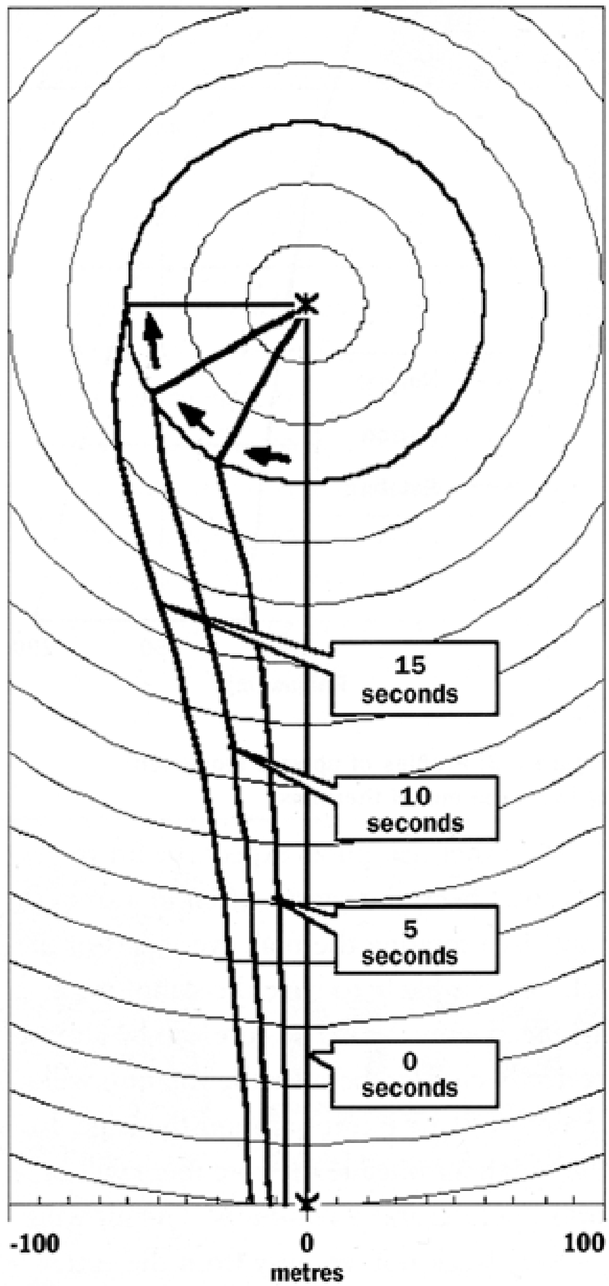


Fig 2.2. Movement of the air around a rotating thermal (as a Rankine vortex)

Features Of Rotating Thermals

In summary, rotating thermals differ from simple thermals in several ways. Clearly, there is a rotating wind that becomes either a headwind or a tailwind for a circling glider. In the core of the thermal, the wind gets faster away from the centre and outside the core it gets slower. The edge of the core is very sharp, and forms a perfect circle. Inside the core the air is smooth, while outside it the air can be very rough.

Thermals That Rotate, Part 2

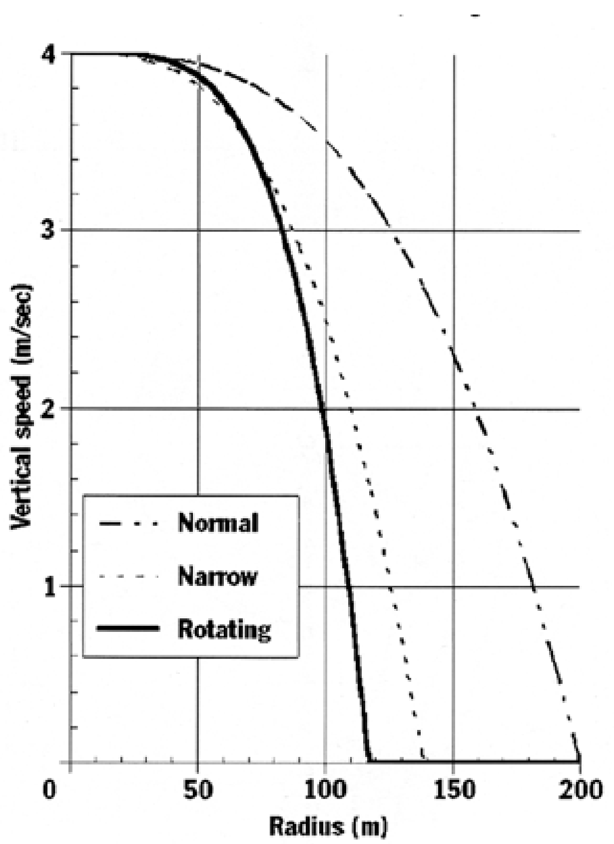


Fig 2.3. Profiles of upward movement of the air in model thermals

In Part 3 of this article I show what happens to the glider in such a thermal.

Technical Notes

1. The pilot must bank the glider to make it fly in a circle. The lift must not only support the glider's weight against the acceleration of gravity, g, but also cause acceleration, f, towards the centre of the circle. The higher the speed, V, and the smaller the radius, R, of the circle, the larger the value of f, and the steeper the bank angle, φ (phi), must be.

The acceleration towards the centre is:
$f= V^2/R$
It is easy to show that:
$\tan \varphi= f/g$
Then:
$\tan \varphi= V^2/gR$
And:
$R = V^2/(g \tan \varphi)$

This shows that the radius of the circle depends on two things the pilot can control: the speed and the bank angle. Unfortunately, "speed" could mean airspeed, or ground-speed, or speed around a circle allowing for the wind. Which is correct?

We can solve this puzzle. Express the acceleration, f, towards the centre of the circle not in terms of speed, but of angular velocity ω (omega). Angular velocity is like rate of turn, but measured in radians per second:
$f = \omega^2 R$
Then:
$\tan \varphi = \omega^2 R/g$
And:
$R = (g \tan \varphi)/\omega^2$

This shows how the radius of turn at a fixed bank angle depends on the angular velocity.

Angular velocity has only one meaning. It is rotation relative to the universe. Since the earth rotates very slowly (only 15° per hour), it is nearly the same as rotation relative to the surface of the earth. On a calm day, the speed that sets the radius of turn of a glider in a rotating thermal is the ground speed. When there is a wind the velocity over the ground must have the wind vector subtracted.

2. Suppose the glider pilot maintains airspeed of 25m/sec (about 50kt) to keep an adequate margin above the stall. Suppose the part of the thermal the pilot is flying in is rotating at 5m/sec (10kt), and there is no wind. Flying against the rotation gives a ground speed, V, of 20m/sec (40kt); flying with it gives a ground speed of 30m/sec (60kt). Also, suppose that the angle of bank φ is 45°, so that $\tan \varphi = 1$. The value of g is about 10.

Find the radius of turn R by:
$R = V^2/(g \tan \varphi)$

In the case of flying against the rotation, R is 40m; in the case of flying with the rotation, R is 90m.

3. Since the angular velocity in a circle is:
$\omega = V/R$

The time for an orbit, T is:
$T = 2\pi R/V$

Thermals That Rotate, Part 2

Substituting for R:
$T = 2 \pi V/(g \tan \varphi)$

This gives the values in the text.

Note that the orbit time varies with the speed, while the radius of turn varies with the square of the speed.

The pilot could still work the thermal if the headwind were equal to, or greater than, the airspeed. When the headwind equals the airspeed exactly, the ground speed is zero, and the orbit could be said to take forever. In this case, no bank is needed. If the headwind is greater than the airspeed, so that the glider is being blown backwards, it must again be banked towards the thermal axis.

4. The pattern of horizontal winds in a tornado is like a Rankine vortex. The Encyclopaedia Britannica reports that, in 1957, meteorologists observed wind speeds of one tornado near Dallas in detail. The rotational speed of the air was very low near the centre, and increased in proportion to the radius, until it was 67m/sec at 60m, then decreased in inverse proportion to the radius, falling below 10m/sec at 400m from the centre. This pattern of linear increase in rotational velocity with radius, followed by decrease inversely with radius (Figure 2.2) is called a Rankine vortex. Others have seen the same pattern in dust devil rotation. Research that is more recent uses other vortex models, but the Rankine vortex model will do.

5. I once proposed two thermal models, “normal” and “narrow” (Figure 2.3) with the lift falling off according to the cube of the radius (“Rate of Climb in Thermals” by Garry Speight, Australian Gliding Vol. 31, No. 2, February 1982, pp 28-39, 47). “Normal” thermals are easy to work; “narrow” thermals need more care and concentration.

I set up these models to put numbers on the profile of Australian thermals as the sailplane pilot sees them. They reflect my experience better than the usual parabolic (square of the radius) ones do, not to mention the very narrow models proposed by Bruce Carmichael in 1954 (“What Price Performance?” Soaring, 18 (May/June), pp 6-10).

Carmichael’s thermals are still cited in textbooks, including “Fundamentals of Sailplane Design” by Fred Thomas (College Park Press, Maryland, 1999). Glider designers use much simpler thermal profiles than those glider pilots fly in. Even the latest ones cited by Thomas, those of K H Horstmann, look like a witch’s hat (but someone has fudged the profiles, by rounding off the sharp peak in the diagram. Bernard Eckey has copied this diagram for his article in January’s “Soaring Australia”). Witch’s hat profiles are “Konovalov Type B” thermals, as discussed by Ian Strachan in Sailplane and Gliding Vol. 25, No, 6 (December 1975), pp 266-271.

In metric units my thermal profile models are:
$V_R = V_{MAX} - R^3.k.10^{-6}$
where
V_R is the vertical velocity of the air at radius R in m/sec
V_{MAX} is the vertical velocity of the air at the thermal axis in m/sec
R is radius from the thermal axis in m
k takes the value 0.5 for a “normal” thermal, and 1.5 for a “narrow” thermal.

Two things are to be understood:

1) negative values of V_R are replaced by zero values;

2) the equations do not allow for a broad zone of more slowly rising air that surrounds the thermal core.

Figure 2.3 shows these model thermals in the case of a central velocity of 4m/sec. They will yield a rate of climb of about 2.5m/sec (5kt).

I believe the lift in a typical rotating thermal is like the “narrow” thermal model, but with a broader zone of nearly constant strong lift near the axis, and a more rapid decrease of lift outside the core. This is better matched by a fourth power curve rather than a cubic:

Thermals That Rotate, Part 2

$V_R = V_{MAX} - R^4.k.10^{-8}$ where k takes the value 2.1.

Figure 2.3 includes this curve.

Such a fourth power profile (not unlike a top-hat) is like the “Konovalov Type A” thermal. Helmut Reichmann, in “Cross-Country Soaring” (Thomson Publications, Santa Monica, 1978, p 92) notes that this type of thermal profile occurred when there was strong surface instability, and that turbulence was greater at the edges than in the centre. One would expect both in the case of rotating thermals. Perhaps the Konovalov Type A thermal profile results from thermal rotation.