Soaring Australian Thermals

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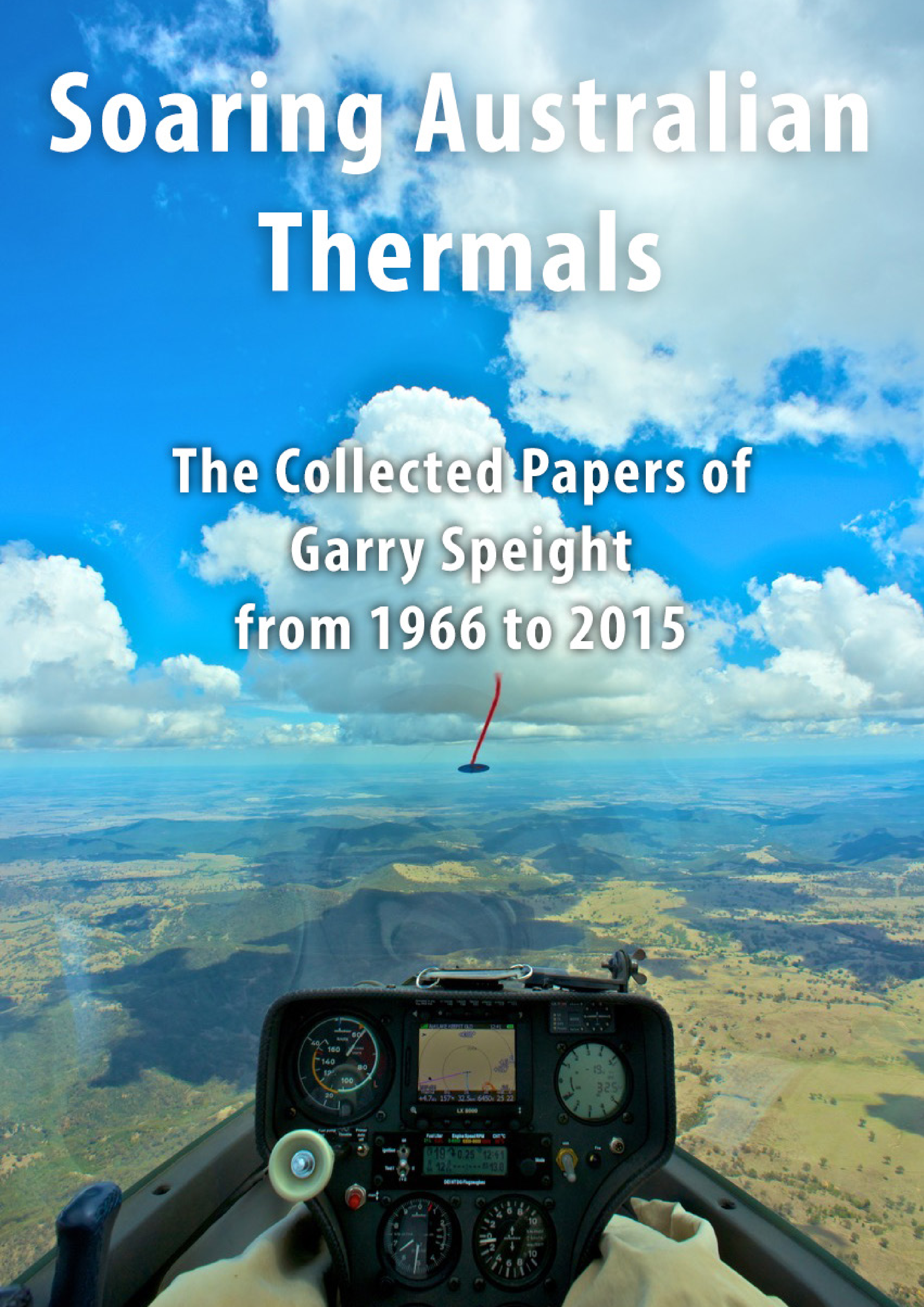

Rotating Thermals

By Martin Simons

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Argument about the possibility of rotating thermals has been going on since at least the 1930s. Letters and articles have appeared at intervals in various gliding magazines ever since. Attempts rave been made to establish whether there is rotation or not by such expedients as throwing out from the glider, quantities of confetti and even toilet roll streamers. None of these trials, so far, has proved anything very convincingly. One reason for inconclusive results is the difficulty of observing the pattern of any such air motions from an aircraft that is, necessarily, itself moving and possibly also circling.

Convergent Flows And Coriolis

When, as we suppose must happen, a quantity of air just above the ground begins to move up to create a thermal, air from the surrounding area moves inwards to take its place (Figure 1).

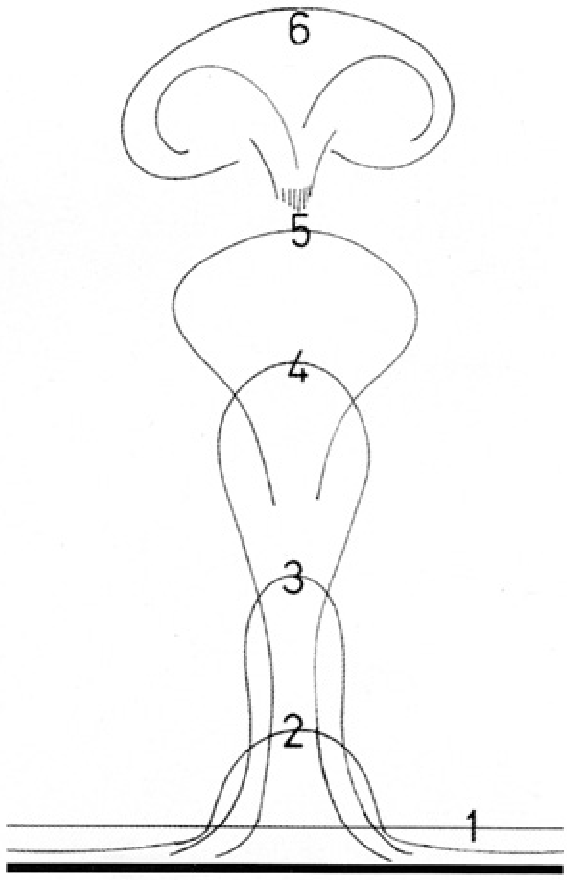

Fig 1. The shape of a rising thermal.
(From Bradbury, Meteorology and Flight, p 47)

1. *A large fairly flat area is heated by the sun and a layer of hot air develops close to the ground.*
2. *A small disturbance or inequality of heating causes a thermal to begin to rise.*
3. *The thermal begins to form a plume, air flows inwards at the base.*
4. *The plume rises further, but the supply of warm air from below begins to diminish.*
5. *The plume is now detached from the source, but continues to rise.*
6. *A vortex ring circulation becomes established as the entire bubble continues to ascend*

It is easy to show that wherever there is a convergent flow there will be rotation. The Coriolis effect is caused by the rotation of the earth. When large scale atmospheric motions are involved, the well known result is that winds round low pressure zones rotate anticlockwise in the northern hemisphere and clockwise in the south.

On the smaller scale of thermals (and plugholes in baths), accidental local disturbances are usually more influential than Coriolis. Irregularities of the surface, clumps of bushes, trees, buildings, even passing vehicles, deflect the inward flow from the most direct radial route. There is invariably some slight diversion, imparting some tendency to rotate as soon as the convergence begins. There may be a slight statistical bias favouring clockwise south of the equator, but it is not much more than a weak tendency. Other things being equal (which they never are), the Coriolis effect ensures that there will always be some rotation but this is not apparent in the initial stages. The inward flow only occurs because some air has already started to rise creating the requirement for replacement.

Any such rotation, whichever direction it may have, becomes intensified. What began as a relatively gentle inward movement of air, but slightly indirect, is transformed into a rapid spin. This is an example of the law of energy conservation. The effect can be demonstrated with a simple rotatable office chair or stool. School children in elementary physics lessons often do this, not only because it is a useful teaching exercise but because it is fun. (If you didn't do this at school, try it now!) A person sitting on the chair with arms and legs stretched out as far as possible horizontally, is given a slight initial rate of spin. If they then bring their limbs inwards, concentrating their mass closer to the axis of rotation, the spin speeds up. A figure skater uses the same effect. Approaching a chosen point at some speed in a long, gently curved path, with arms and one leg stretched out, then reducing the radius of the turn and finally retracting arms and legs to draw the total body mass closely around the point, the rotation becomes very rapid. The kinetic energy of the approach is concentrated close to the centre and a spin is the result.

The result of a strong thermal taking off from dusty ground, is often, though not always, a small whirlwind or dust devil.

The dust rises in a rotating column. It seems there always are strong and turbulent thermals associated with dust devils. It is not uncommon in arid and semi-arid regions to see several such dust columns starting more or less simultaneously at separate places perhaps a few hundred metres apart. As they writhe upwards the general convergence sometimes brings them all together to form one main column that may persist to a considerable height. Entering a dust devil at a low height is an exciting experience: the air is very turbulent, the angle of bank has to be steep to keep within the lift and the airspeed needs to be rather high to ensure adequate control. If well centred, it is even possible to look down the core of the whirlwind and see the 'eye', which is relatively clear of dust.

As the thermal rises further still, however, it is not so obvious that the rate of rotation persists through the whole upcurrent. It seems probable that a rising thermal acquires a rotating tail but this may not always be powerful enough to raise the dust. In the thermal above the spinning tail the air is relatively smooth. Presumably when this happens the glider has entered the original bundle of air whose initial rise caused the convergence in the first place. This mass of air was probably not spinning when it started to rise. Moreover, as the mass of air rises it expands laterally because the general air pressure reduces. The mass as a whole begins to spread out. Such divergence has the opposite effect to convergence. (Figure 2)

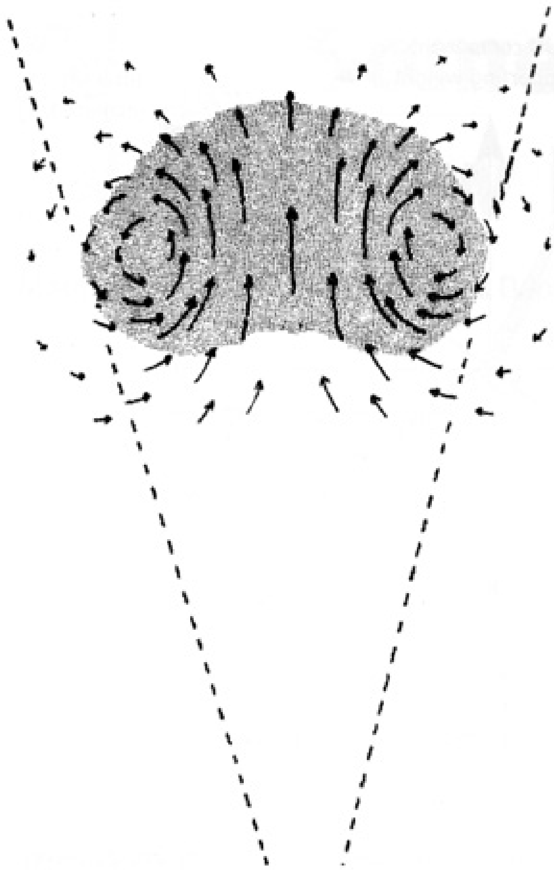

Fig 2. As the thermal rises it expands as a whole. The length of the arrows gives an indication of the speed of the air motion (From Wallington, Meteorology for Glider Pilots, p151)

If there is any rotation round the vertical axis, it tends to fade. (The ice skater can slow the spin down by extending arms and a leg, then skating away on a curved path.) There is also friction and some mixing with the surrounding air, which must slow any rotation down further. So long as air is feeding into the thermal from below the tail continues and spins. It is likely that as the spinning air is drawn into the main thermal, it does carry some of its rotation to the rising core, but dust devils do not persist indefinitely.

The rotating tail itself soon breaks away from the ground. The dust devil is cut off at its base. The main body of the thermal nevertheless continues to rise.

Rotating Thermals

Vortex Rings And Plumes

It is very commonly supposed that thermals are columns rising as more or less vertical currents from the ground up to whatever height is permitted by the environmental temperature lapse rate. Some school textbooks and many of the earliest soaring manuals, show convection currents rising from 'hot spots' on the ground with areas of sinking air over cool lakes, forests etc. Such a crude model suggests that any warm spot on the earth will have a sort of thermal chimney permanently rooted on it. This is clearly inadequate. Thermals begin, develop and take off from their source as Figure 1 showed. If there is any wind, or even a slight general drift of the air at ground level, the thermal must in any case drift away from its original source and then continue independently. Commonplace experience in soaring confirms that even well-known thermal sources produce, at best, intermittent bursts of lift separated by periods of quiescence or even sink. Flying over the so-called 'resident thermal' near a gliding club, does not always produce lift. Even trying to enter a thermal some distance directly below another sailplane or a whole 'gaggle' circling and climbing, does not always succeed. The active part of the thermal, imagined now as a bubble, has risen beyond this point, leaving nothing below but a turbulent wake.

Many other experiences, and some measurements, in soaring support a vortex ring model of the thermal. This was proposed originally by glider pilots but elaborated further by meteorologists such as Richard Scorer in the 1950s and described in the book Meteorology

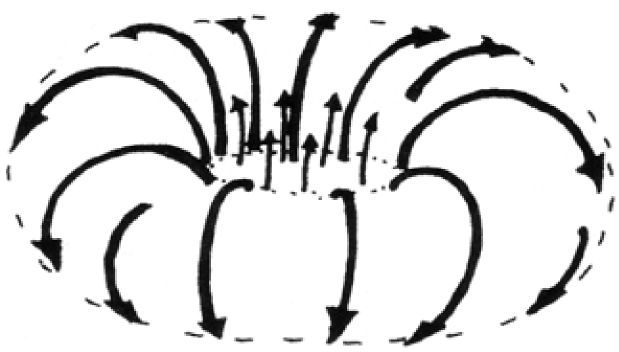

Fig 3. The vortex ring model of a thermal bubble (From Piggott, Understanding Gliding)

for Glider Pilots by C E (Wally) Wallington (1961, p!51), reproduced here as Figure 2. Developed theories appear in Meteorology and Flight by Tom Bradbury (1989, p49) and in Derek Piggott's books, Beginning Gliding and Understanding Gliding (all editions, Figure 3 here).

If it is supposed that the vortex ring has its own circulation as illustrated, and we also believe the thermal is rotating around its centre in the horizontal plane, this rotation must somehow be incorporated into the vortex ring.

As the diagrams show, as the vortex ring ascends, the air converges on the underside and then is drawn up through the centre. The underside convergence, as described above, will tend to encourage rotation in the thermal core. It is very reasonable to suppose that the influence of the spinning tail will introduce sufficient disturbance to initiate the spin, whether or not this accords with the Coriolis influence. The implication is that when circling in a thermal core, there is very probably, if not certainly, some rotation around the vertical axis. This is not likely to be always in accord with the Coriolis effect. In the upper regions of the rising vortex ring, however, in what is called the cap where the bubble is displacing the surrounding air to rise through it, the air begins to diverge and this must weaken the spin.

Does it make any difference?

The effect on the handling of the glider in a rotating thermal is not easy to deduce but one thing must be appreciated. The forces experienced by the glider and its pilot come from the air, not from any supposed influence from elsewhere. It is a mistake to suppose that the thermalling glider is describing circles within some frame of reference provided by the ground, still less relative to some distant star or to the universe as a whole. There is no fixed frame of reference for the glider other than the air in which it happens to be. Hence forces (which may be described as inertia) acting when circling in a rotating thermal arise only from the motion of the glider and the reactions of the air to this motion. Viewed from the ground, or from the distant stars, certainly the glider appears to accelerate and decelerate, but the path over the ground (which is in any case moving rapidly along round the earth's axis of rotation), or relative to distance galaxies, is irrelevant.

Centrifuge Effects

In a rotating thermal the air in which the glider is flying, is itself following a curved path. (We will suppose in what follows that the pilot keeps the angle of bank and airspeed constant throughout, as far as humanly possible.)

When the glider is flying in the same direction as the thermal rotation, it is effectively in a constant tailwind. This does not affect the airspeed of the glider, which we suppose is trimmed correctly. But, with the centre of the thermal as the reference point, the glider is going round somewhat faster than the airspeed would indicate.

Turning against the thermal spin, there is a constant headwind. In angular terms from the centre, the glider is moving slower.

The standard diagram of forces on a correctly trimmed aircraft turning in still air is shown in Figure 4.

The banked wing directs a proportion of the total lift to the side, producing the turn. The reaction, commonly called centrifugal force, is directly opposed and equal to the lift component. The forces balance, so the rate and radius of the turn is steady.

If the glider is turning with the thermal rotation, there is an additional centrifugal reaction, caused by the thermal spin. The thermal, in a sense, is trying to throw the glider out like a centrifuge. To achieve the required balance of forces requires a slightly steeper angle of bank, to direct more of the lift force inwards. Alternatively, if the bank and airspeed are kept the same, the balance is achieved with a slightly larger radius of turn. The thermal spin, so to speak, does in this case move the glider slightly away from the thermal core.

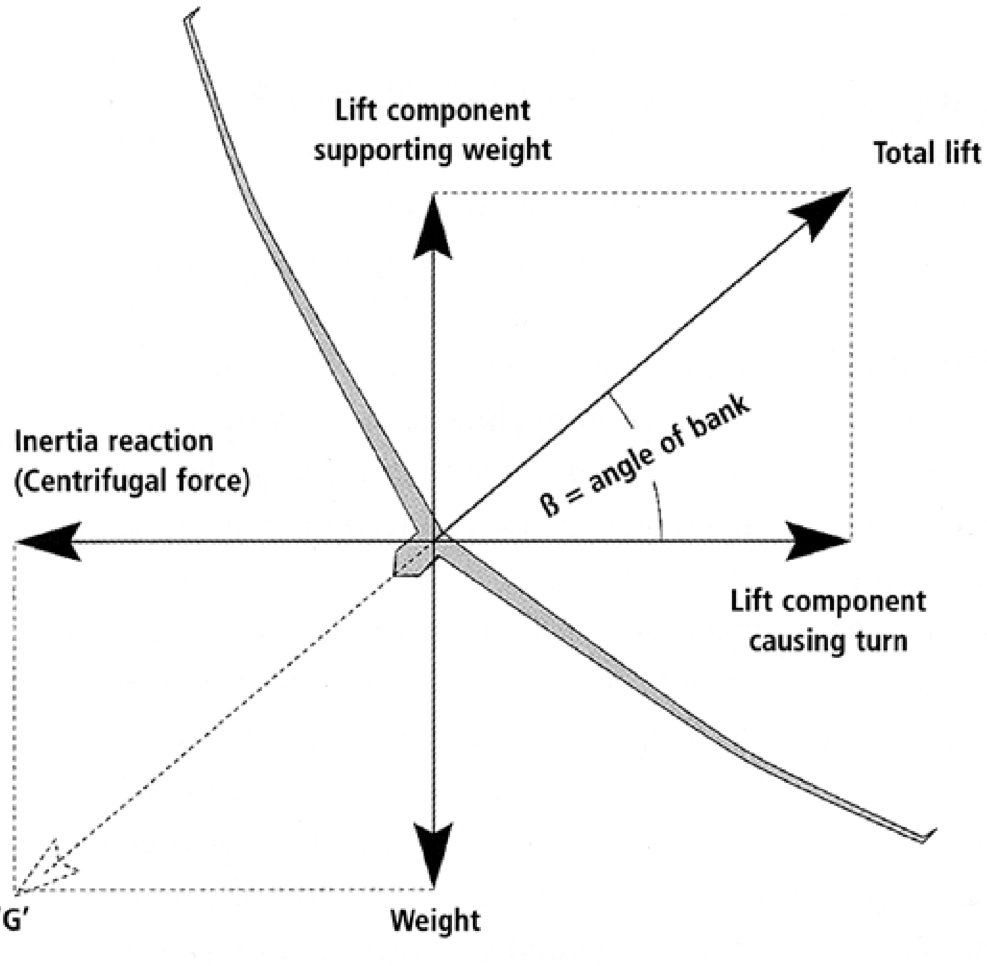

Fig 4. Standard diagram showing turning flight in still air, at constant airspeed and angle of bank

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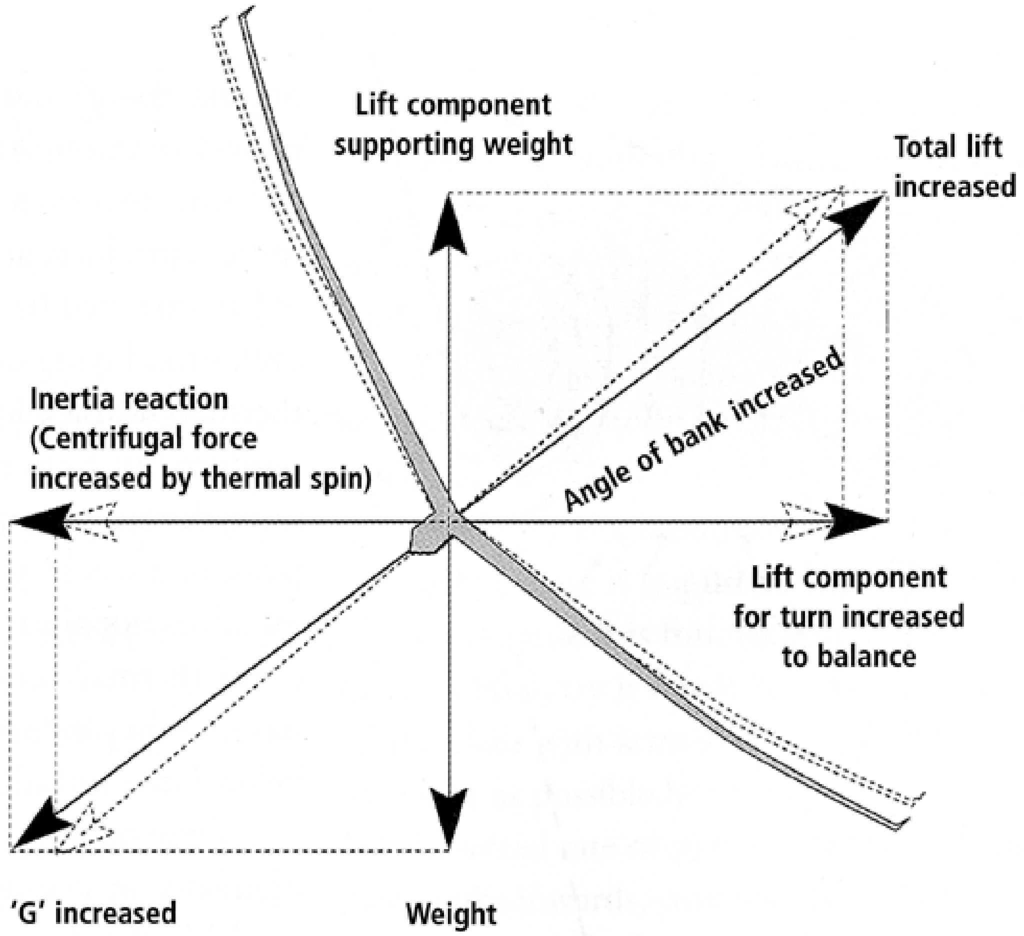

Fig 5. Flying with the thermal spin. Increased angle of bank required. Flying the other way round, reduced angle of bank needed.

Conversely, flying the other way, against the rotation, the balance is achieved with less bank. Or with the same bank, the glider can fly closer in to the core.

And that seems to be all. Unless the thermal spin is very rapid, it seems unlikely that the effect is really going to make a big difference. But if the pilot knows, or believes, that the thermal is rotating one way rather than the other, turning against the rotation will require a little less bank.

The further effects of convergent and divergent flows

There remains another interesting point. An article published in the current issue of Technical Soaring (Vol 29, No 1, January 2007), sets out to show, by measurement and calculation, that the total energy variometer, virtually standard equipment in sailplanes, gives misleading readings when the glider flies into or out of the convergent region below, or the outflowing zone above, the rising vortex ring, or when it circles partly inside and outside the central core. The effect of these more or less horizontal flows is to change the total energy variometer reading in ways that indicate to the pilot that the centre of the thermal is not where it really is.

Possibly, pilots who find that their thermalling is apparently affected by the supposed rotation of the thermal are not quite in the centre even though the variometer assures them otherwise.