Thermal structure and behav

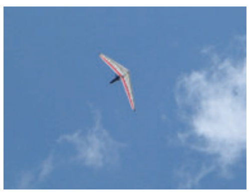

PHOTO: TONY WEBB

I recently came across an excellent article, by Wayne Angevine of the University of Colorado, Boulder, USA , titled Thermal Structure and Behaviour. The content immediately hit home and I must have read it at least three times. Wayne flies model sailplanes and does research in boundary-layer meteorology. Here I will pick out key points from his article and align them with my own learning experiences. Statements from the original article are italicised and numbered.

The basics

1. *The sun warms the ground, and the ground in turn warms the layer of air nearest to it. As soon as a parcel of air is warmer than its surroundings, it starts trying to rise. Air has mass and momentum and it's immersed in other air, so it can't just go to its desired level instantly. Furthermore, the ground is not uniform, some parts are darker and/or drier and heat up faster, and some parts are moister or lighter in colour. The result is that there are blobs (parcels) of air forming, rising, and pushing other parcels out of the way. Some of those parcels end up at the ground, get warmed up, and want to rise themselves. All of this turbulent motion leads to small plumes of varying shapes and sizes of rising and sinking air.*

2. *Thermals are like fat trees, with small, chaotic roots near the surface and large trunks above. The trees tilt and sway with the wind and change with time, and sometimes they let go of their roots and drift. Between the trees is sinking air.*

3. *Where thermals form, their exact shape, and how fast they change is hard to predict, since it depends on details of the interaction between the ground and the air. Key principles to remember are:*

- *Thermals are driven by temperature contrast between the ground and the air.*
- *Air exists in parcels (blobs) that have mass and momentum as well as temperature and humidity.*
- *Plumes near the surface look and act different from thermals well above the surface.*

None of the above will be new to experienced pilots, but it's worth repeating for newcomers to our sport. Wayne also dispels the myth that thermals are shaped like donuts and re-circulate; I have to confess to believing this myth for years! The assertion that thermals are like fat trees with small chaotic roots is a key principle in this article.

The boundary layer

4. *The part of the atmosphere in which we fly is the atmospheric boundary layer (BL for short). In the kind of conditions we're talking about, it's the lowest 500 - 2000 meters (1500 - 6000 feet) of the atmosphere.*

5. *The BL is shallow (100-200 m) at night, builds up in the daytime as the sun heats the ground, and collapses again in the evening.*

A key point is that the depth of the boundary layer changes with time. Fig. 1 (produced using radar imagery) illustrates how the depth of unstable part of the BL changes during a typical day.

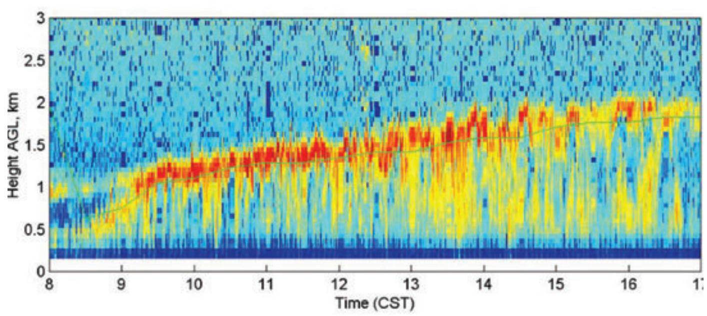

Fig. 1: Reflectivity, BL height, and cloudbase

Note that this is a 'typical' day and assumes nice, uniform, consistent heating from the sun and no external influences/changes like sea breezes or unforeseen cloud cover. Using a less typical and contrasting example, during the Saturday of the recent Cambridge aerotow comp it was overcast until around 12:30, after which the sky rapidly cleared and we consequently had an accelerated rate of heating. Base rapidly went from 3000ft to 5000ft, which (on the same diagram) would give a sudden and steeper gradient when this change occurred, and is possibly an explanation for the extremely turbulent thermals that pilots unanimously reported for around an hour or so.

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Nev Almond examines a reliable model of thermal organisation

Sub-layers within the boundary layer

6. *The boundary layer has three important sub-layers; the surface layer, mixed layer, and entrainment zone.*

7. *The surface layer is the lowest 100-200 m.*

8. *The mixed layer extends from the top of the surface layer to near the BL top.*

9. *The entrainment zone is the interface between the BL and the free atmosphere above, and is where clouds form. The surface layer is unstable, the mixed layer is neutral, and the entrainment zone and the atmosphere above are stable.*

The key point for me is the distinction between the surface layer and the mixed layer. During the 80s and 90s I became increasingly aware that there was something very different about the first (say) 500 - 600ft of air above the ground, a layer I would have described as having an abundance of regular and small, high frequency and chaotic thermals. This nicely correlates with point (2) earlier which describes a thermal column in the mixed layer having a chaotic root structure in the surface layer.

Thermal behaviour in the surface layer

Having moved to rigid wings during the last decade (and benefiting from flaps and a 30%+ improvement in sink rate), I have had the opportunity to explore the surface layer more extensively. Figures 2 and 3 help visualise the perceived surface layer activity. Fig. 2 is a top view of the surface layer, with periphery thermals being drawn into a central plume. Fig. 3 is a side view of the thermal roots showing chaotic surface layer plumes drawn towards a more central plume that will converge and progress into the mixed layer above. The vertical extent is 100 - 200m.

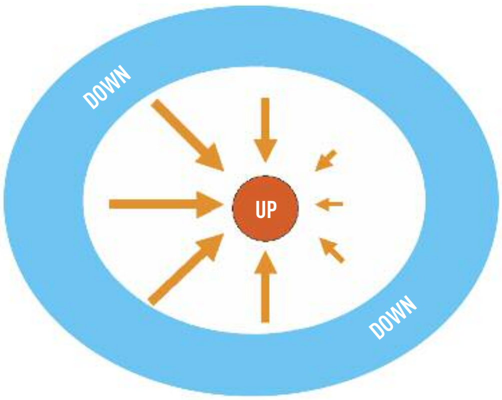

Fig. 2: Top view of surface layer while standing still (wind blowing left to right)

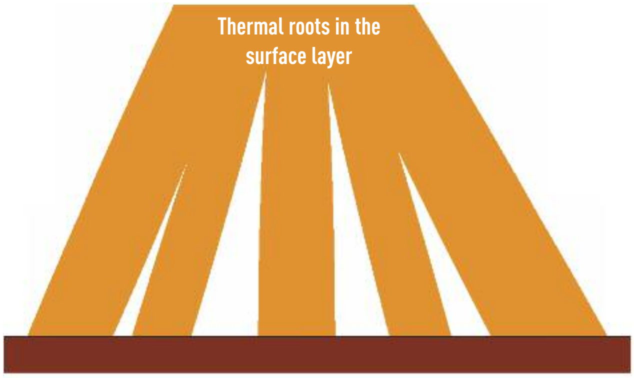

Fig. 3: Side view of thermal roots (plumes) in the surface layer. The vertical extent of this figure is 100- 200 m. Real plumes are much more ragged and chaotic than this schematic drawing.

Let's now look at some more of Wayne's assertions:

10. *All of this turbulent motion leads to small plumes of varying shapes and sizes of rising and sinking air.*

11. *Some of the rising parcels meet up with others and form larger blobs; others get torn apart by turbulence and lose their identity.*

12. *The size of parcels in the surface layer is roughly proportional to their distance from the surface.*

13. *The air within a plume is rising, but it is also turning in all three dimensions, its motion depending in a completely unpredictable way on the small-scale shape, colour, and moisture of the ground and the motion of all the other parcels in its vicinity.*

Sounds familiar? I'm sure many pilots have flown through air movement as described above perhaps wondering what is going on. 'Small' and 'turbulent' are key descriptors, and to use such lift often requires the ability to thermal exceptionally tightly. In good thermic conditions you need to be prepared to be spat out in any dimension of pitch, yaw, roll, or even all three!

To use such air will require confidence in your aircraft given the proximity to the ground, and indeed may be a step too far for some types of paraglider. Using such air requires a wide range of aircraft characteristics, namely agility, low sink rate and speed range. Speed range may be a further impediment for paragliders; any extended time in sinking air at low altitude and you are on the ground quickly. In this scenario on my Rigid I would dump the flaps and accelerate from 20 to 40mph back to the last known lift.

Such conditions are very workable by both conventional flex-wings and rigids, with rigids having a sink rate advantage which is so critical when working with minimal height. An essential skill, if embarking on this sort of flying, is to be able to multi-task and plan ahead for a variety of potential landing alternatives in case you don't connect with the lift.

Most of my experience of the surface layer has been on UK days in good soaring/XC weather with light (or non-existent) wind, making ridge soaring difficult. Pilots who are prepared to watch, learn, interpret and attempt to use such marginal air will significantly increase their understanding of thermal behaviour, and for me this is one of the most satisfying aspects of our sport.

Flying at Piedrahita (Central Spain) in high pressure and high temperature conditions early in the day shows, I believe, a good 'model' surface layer. I have had many days flying from the cool, shaded north-west facing mountain slopes, launching too early only to descend to an active surface layer (say 1,000ft agl), and then fly for up to an hour or so in the turbulent surface layer mixing, before the plumes in the mixed layer above become properly established.

If you are ever in the (London) Science Museum, go down to the kiddies section, and near the entrance there is a 4ft wide and ceiling-high cylinder filled with a coloured viscous liquid. A large pump creates chaotic small bubbles at the bottom, and these are very quickly drawn together into larger more coherent bubbles as they rise. I can't remember the point of the apparatus, but it's a great simulation of how I would envisage chaotic roots converging into a more significant central plume.

Thermal behaviour in the mixed layer

14. *The plumes converge as they rise (Figs 2 and 3).*

15. *By the time they reach the top of the surface layer, 100 - 200 m above the ground, they have joined into relatively large columns of rising air.*

16. *The size of thermals in the mixed layer is roughly proportional to the BL height, so the columns are a few hundred meters to as much as a couple of kilometers in diameter.*

17. *We could think of the thermal as a tree with a trunk in the mixed layer and roots in the surface layer.*

The four quotes above describe the characteristics of thermals found in the mixed layer, the type of lift typically sought and frequented by pilots flying XC. The computer model in Fig. 4 helps us visualise the combined surface and mixed layers: the area is 5km x 5km, and the height approximately 4,000ft.

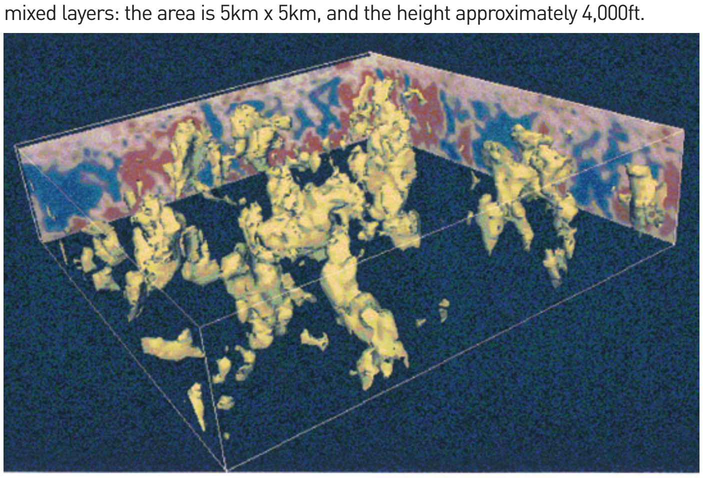

Fig. 4 © 1998 Peter Sullivan/US National Center for Atmospheric Research

The resolution (sampling) used to produce this diagram is 52m in the horizontal and 21m in the vertical. Wayne says that the surface level plumes are not resolved by the model. I would concur with this; my experience would suggest the existence of a wide distribution of small, random and chaotic parcels close to the ground.

Thermal movement and relationship to the ground

18. *Pilots standing still on the ground have a different perspective than pilots who are immersed in the moving air.*

19. *The local wind at the surface is the vector sum of the background wind and the flow into the thermal.*

20. *A thermal upwind will reduce the local wind speed, or even reverse the direction if the background wind is light enough.*

21. *A thermal downwind will increase the wind speed.*

These are key indicators that skilled XC-hungry pilots will use when deciding when to hill launch on a marginal, light-wind day. It is not just a change of wind you should look for, but also a conjunction with cloud positioning, as other newly-triggered thermals will be drawn towards existing plumes. Scan the sky, visualising where those plumes (up above in the mixed layer) may be in relation to you, and wait for changes of wind direction that correlates with your own visualisation. Now add in other indicators (e.g. a bird going up, some thistledown, a pilot going down where you expect the bad air to be). It's not an amazing sixth sense that some consistently lucky pilots have – such skill is achieved through using your imagination and stacking the balance of probability in your favour.

These same rules apply while XC of course. For example, if you have a northerly drift, ground sources emitting smoke should normally drift south. If it is being drawn any other direction, search for the reason - extrapolate where the smoke is going and there is probably a nice Cu at the top of it.

Conclusion

Of all the hints and tips I've read over the years, understanding thermal structure and behaviour must be the single most important skill set for getting the most out of our foot-launched flying, irrespective of whether your aspiration is XC or not. The subject will require some imagination and cannot be applied as a clinical set of rules: some pilots will take to it readily, and some will take years to learn through frustrating experience. To acquire it is important if you want to master the air, and (assuming reasonable conditions) want to stay up as a result of sound, rational decisions and not leaving it to luck.

Reflecting on key points from this article to improve your flying:

- When flying between (say) 600ft and cloudbase in the mixed layer, fly underneath clouds to connect with established plumes.
- As you drop under (say) 800ft and are nearing the surface layer, still follow the same general advice in the previous point – the most active areas within the surface layer will be under established plumes.
- When in the surface layer under an established plume, widen your search to connect with more chaotic 'roots', paying some attention to good thermal sources, but remembering that thermals also move laterally (i.e. not necessarily directly upwards) from likely good sources.
- When in the surface layer, a small thermal is likely to be moving towards the strongest plume, which could be any direction and not necessarily drifting with the wind. Converging and mixing with other small thermals in the surface layer is typical – monitor nearby pilots and birds to build a mental map.
- The surface layer is a great place to find thermals – they are there in abundance, albeit often quite small and difficult to use, so practise the skill of staying in tight, isolated lift to improve your ability to use the surface layer.
- Developing your field selection and landing skills will enable you to make more effective use of the surface layer. You need to be able to plan a series of just-in-case landing options, and be adaptable to use one at short notice.
- Practise ground-based visualisation of what you think is going on in an area of sky (this is also known as daydreaming); this will train your thought process for when you actually need it.
- You can practise encountering 'fat trees and chaotic roots' at your local ridge without going XC. Do this by gaining height and (i) defining a rationale for where you believe a thermal's plume may be, and (ii) analyse what actually happened each time. This will build confidence in your decision.

With thanks to Wayne M. Angevine, University of Colorado Boulder, USA. His original article can be found at www.rcsoaring.com/docs/thermals_2006.pdf.