Cooling tower thermal

After the last issue dealt with the migration of thermals in the wind,
this issue takes a special look at thermals above cooling towers.
Because although industrial thermals are generated in a very different way to natural thermals, it behaves in exactly the same way in the end.

TEXT AND ILLUSTRATIONES OLIVER PREDELLI PHOTO THOMAS GERLACH

In the previous articles, it was shown that thermals do not break off at a fixed location, such as the edge of a forest, and then rise diagonally in the wind. Instead, it behaves more like a "scarf" of warm, moist air lying on the ground, which is lifted at one end and then peels off upwards in the direction of the wind. The thermal always rises vertically, with the thermal moving at the horizontal speed at which it detached from the ground (***Fig. 1***). Consequently, this is no longer referred to as a detachment point, but as a detachment path. Why this is the case is described in detail in a publication in Technical Soaring, the link to which can be found at the end of this article.
The question now is whether this is also the case with "industrial thermics". This is because there is a quasi point-shaped and fixed energy source at the cooling tower outlet. You are clearly displaced when circling in this updraft. So could it be that cooling tower thermals behave differently from thermals over fields, forests and meadows? No, of course not. After all, an ascending air parcel does not "know" how it was created and will therefore not behave one way or the other. To understand this, you have to delve deep into the mechanisms involved in the formation and dissipation of cooling tower clouds.

"Industrial thermals" are a special treat for glider pilots around Aachen. At the end of a long day of cross-country flying, they often make an extra loop to enjoy one last good climb over the lignite-fired power stations in Weisweiler, Grevenbroich or Niederaussem, when the natural thermals are already dying down. On WeGlide, some pilots even jokingly label these flights "coal exit is thermal exit".
Fig. 2 shows two flights over one of the 173 m high natural draught cooling towers of the Grevenbroich-Neurath power station. Thomas Gerlach, one of the pilots, is photographing the cooling tower. It is the cover photo of this article. He and his companion head for the power stations to extend their flight path and are happy to have found a powerful thermal source here, as the other power stations on the route are not currently in operation.

During the entire three minutes in which the pilots circle in the industrial thermal, they fly directly above each other (purple lines). The horizontal drift speed of the parcel of rising air is v = 9.3 kt (4.8 m/s) above ground, which corresponds to the wind speed measured at cooling tower height on that day. The climb speeds of the gliders result in an updraft of w = ~8 kt (4 m/s). The graphical analysis in ***Fig. 2*** suggests that there must also be a "separation path" here, as is known from natural thermals. Along this detachment path, the parcel rising air initially gains height while it is fed out of the cooling tower cloud. After some time, it breaks off and continues to rise while maintaining its horizontal speed. The break-off can be recognized, among other things, by the fact that the gliders stop climbing when the lower end of the parcel has passed them.
Embedded in ***Fig. 2*** is the "vertical projection" presented in the first article. If the drift speed of the updraft is subtracted from the local offset of the gliders, you can see how the pilots first try to center themselves and then circle in the center of the (drifting) parcel. Here, too, you can see that both gliders are on top of each other and turn together within a circle diameter of about 1,300 to 2,000' (~400 to 600 m).

The cloud of a cooling tower naturally tilts in the wind. Unlike thermals, which only consist of moist air, a cooling tower cloud is full of countless water droplets. And these have an air resistance, which is why the wind can push them along. Scientific studies have measured typical droplet diameters of 8 to 24 thousandths of an inch (~200 to 600 μm) one hundred meters behind a cooling tower outlet. The droplets begin to evaporate as soon as drier ambient air swirls into the cloud. The swirling and mixing is called "entrainment". It has been found that tiny droplets with a diameter of 4 thousandths of an inch (100 μm) at 20 °C in 80 % humidity take around 12 minutes to dissolve. A 4 thousandths of an inch (100 μm) droplet could therefore rise to 11,500' (3,500 m) in ***Fig 2***. Larger droplets dissolve more slowly, and evaporation is also delayed with increasing humidity, while it is faster with entrainment. The detachment path shown in the picture extends 3,300' (1,000 m), so the order of magnitude is initially correct.
However, the thermal that is released from the cloud and in which the pilots are circling is no longer inclined in the wind. The thermal column is always vertical. This is because, just as with natural thermals, it is not possible for the ambient wind to exert a force on the thermal and incline it. The many WeGlide flights confirm that aircraft in the same thermal always circle directly above each other, no matter how many meters apart they are.
The relationship between droplet evaporation and thermal development is shown in ***Fig 3***. The water droplets in the cooling tower cloud dissolve. Entrainment swirls drier ambient air into the cloud, which absorbs the moisture from the evaporating droplets. The turbulence causes this more humid air to return to the environment outside the cloud, where it begins to rise due to its lower density (humid air is lighter than dry air). The rising air forces an inflow of ambient air, which increases entrainment and evaporation and forms a thermal tube.
This reinforcing effect ensures that the thermal tube can exist for many minutes and that not only individual small bubbles are released from the cooling tower cloud. Gliders would not be able to circle in individual bubbles, especially not for mi-

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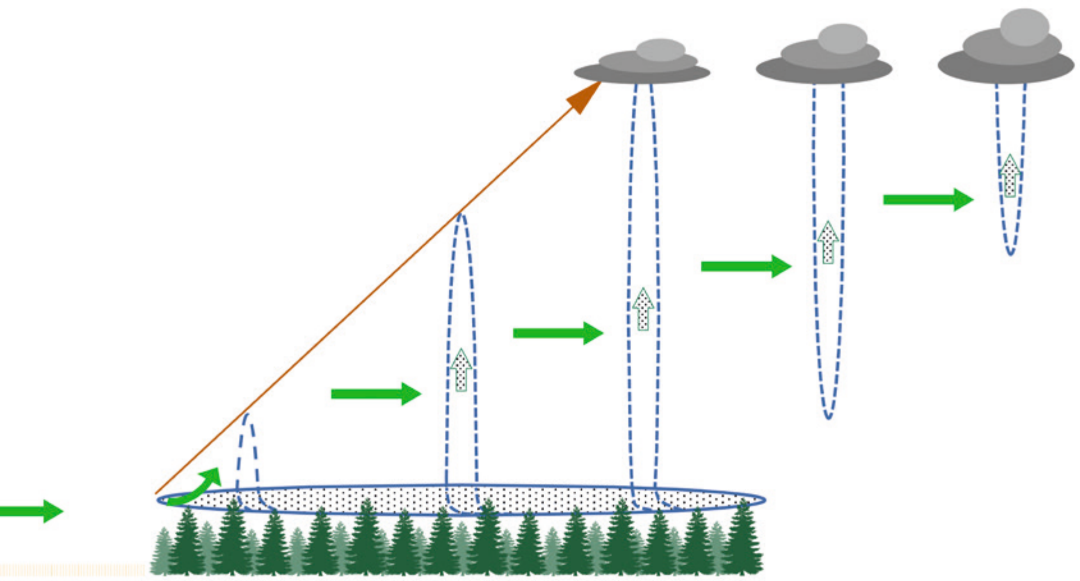

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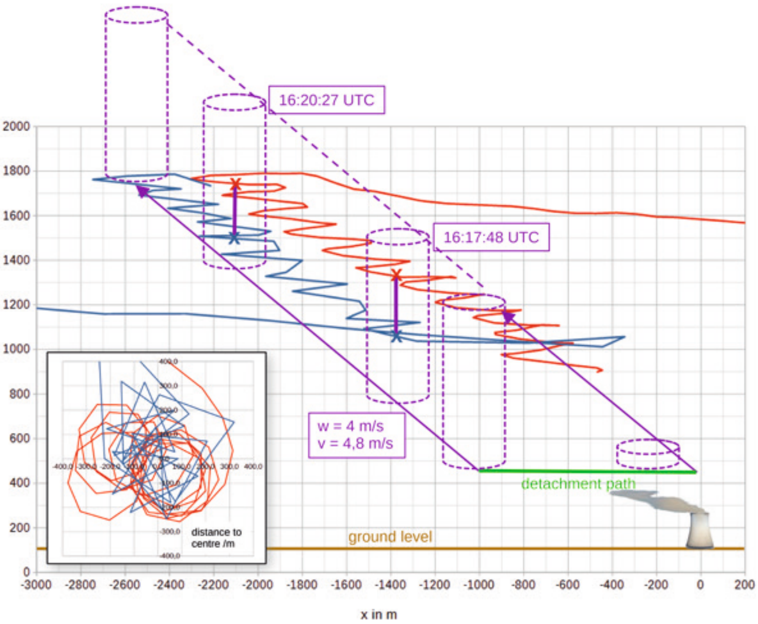
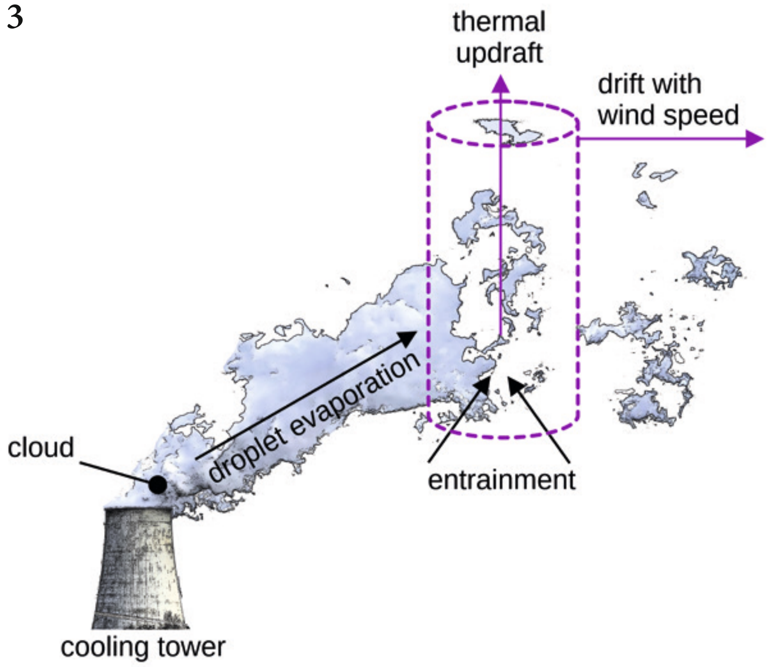


1 Detachment and ascent of a warm, moist air parcel. A detachment path forms above the treetops. A glider pilot might mistakenly think that he is in a sloping beard that has formed at the edge of the forest (yellow arrow).
2 Two gliders circling directly above each other between 16:17 UTC and 16:20 UTC in the same updraft of a cooling tower cloud; the updraft detaches from a separation path (WeGlide No. 180635 and 180696). Embedded image: vertical projection with v = 4.8 m/s.
3 Formation of a vertical updraft from a cooling tower cloud by vaporization of the water droplets and entrainment.

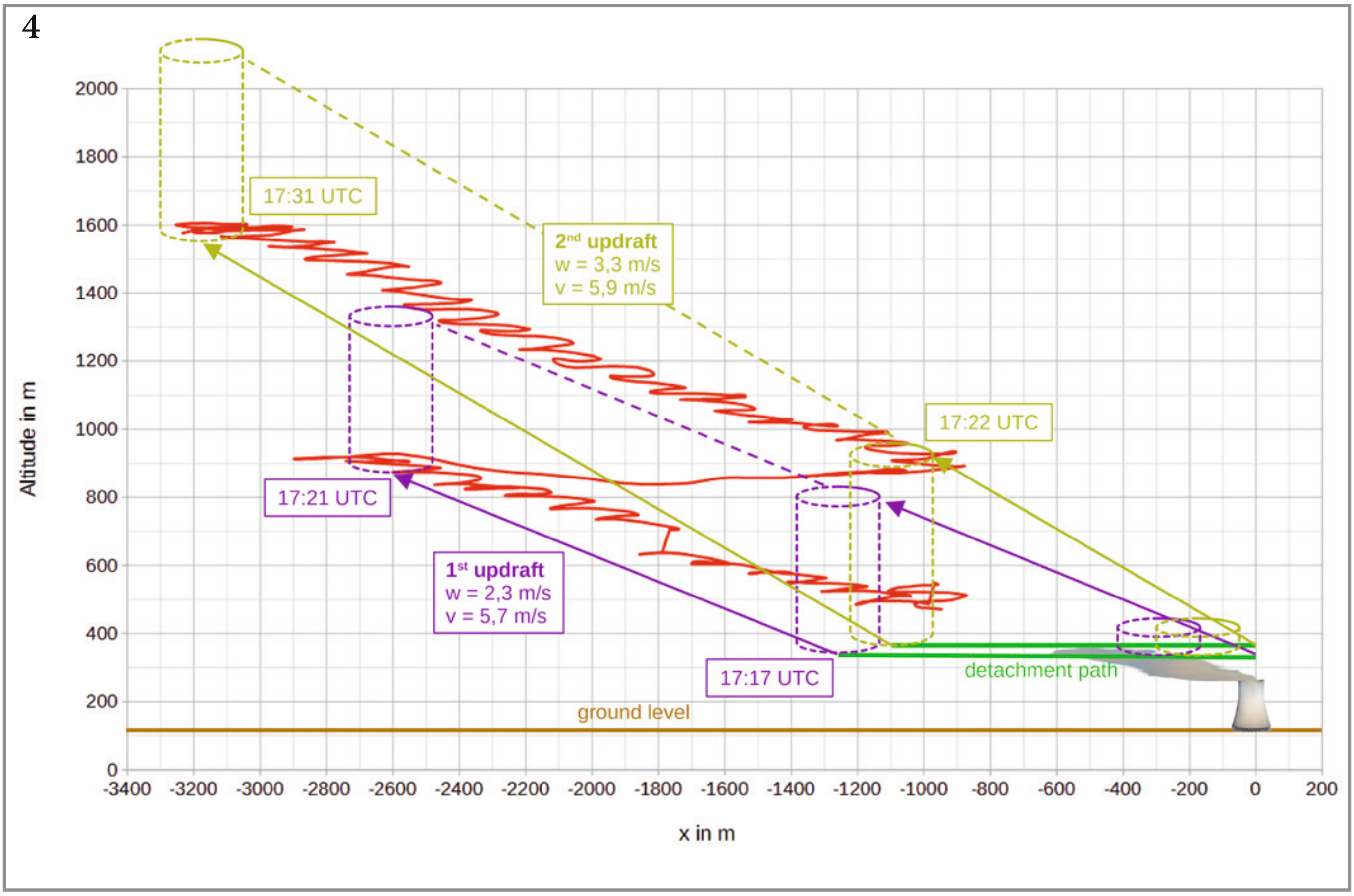
3



nutes at different altitudes on top of each other.
Sometimes the detachments become visible as wisps of cloud rise above the actual cooling tower cloud. The thermal tube moves over the ground at the speed it had when it detached, i.e. at the horizontal wind speed at the cooling tower exit. The whole process is constantly repeated, so that new parcels of rising air are formed again and again. As a result, gliders sometimes circle in an "older" thermal, while others use a "younger" thermal closer to the cooling tower.
This can be seen in ***Fig. 4***, where a pilot is initially circling in a first bit, which, however, disappears upwards past him at around 17:21 UTC. After he is no longer able to use this bit, he "picks up" the next bit at the cooling tower exit. This then takes him to ~5,000' (1,600 m) until the lower end of the parcel has also passed by here. Both parcels move at approximately the same horizontal speed. However, the climb rates differ and the second parcel is significantly stronger. This succession of parcels and the flying out of a small "yo-yo" is reminiscent of the mountain thermals presented in the last article.

A Mollier diagram can be used to explain what happens above the cooling tower (***Fig. 5***). On July 4, 2022, the day of the flights in Figure 2, weather data on the Internet shows that the air pressure at the cooling tower outlet altitude was approx. 30.06 in Hg (1 018 hPa) at 16:00 UTC and the ambient temperature was approx. 72°F (22.4 °C) with a mixing ratio of approx. 6.3 g/kg (point ①).
The water used in the working area of the cooling tower evaporates at approx. 95°F (35 °C). At 100 % relative humidity, this air contains 36 g/kg of water (②).
During its humid adiabatic ascent within the cooling tower with a temperature gradient of approx. 3.3°F/1,000' (~0.6 °C/100 m), some of this water condenses so that the cooling tower air cools down by approx. 2°F (~1 °C) by the time it reaches the outlet opening and the wet bulb temperature there is approx. 93°F (34 °C) (③).
Point ④ shows the condition within the wet vapor region of the cloud above the cooling tower. The air still carries 36 g/kg of water, with ④ at the intersection of the enthalpy line that runs through the associated wet bulb temperature in ③. The liquid

4 A glider circling in various updrafts between 17:17 and 17:31 UTC, that detach from the cooling tower cloud (WeGlide No. 411968).



water content (LWC) of the cloud is approx. 2 g/m3, which results from the difference in the mixing ratio between ② and ③. During the evaporation and mixing by entrainment described in Figure 3, the state in the wet vapor region of the cloud moves towards the ambient conditions at point ①. At approx. 77°F (25 °C), the droplets are dissolved to such an extent that the water they contain is in gaseous form and the relative humidity is 100 %. In this air, should it rise thermally, condensation would immediately occur again due to the cooling caused by the atmospheric temperature gradient. Sometimes these processes can be seen as small cloud-like "eruptions" that swell upwards out of the cooling tower cloud.

As the gliders are circling in clear air, it can be assumed (and the wispy clouds in ***Fig. 3*** indicate this) that the cooling tower air mixes a little more with the surrounding air before it rises as thermals at point ⑤.

Rising thermal air no longer has a relevant temperature advantage over the ambient air after just a few hundred meters of altitude. The decisive factor for the strength of the updraft is rather the moisture content of the thermal air compared to the surrounding air.

Calculate the associated dew point temperatures for the points ① and ⑤ (τ_A = 8°C, τ_P = 19°C at ϑ_A = 22.4°C) and use them in the (SI unit) "thermal formula":

$$w = 5{,}6\,\frac{m}{s} \cdot \sqrt{\frac{1.1^{(\tau_P-\tau_A)}-1}{1.1^{(\vartheta_A-\tau_A)}}},$$

results in a thermal strength of w = 3.8 m/s (7.4 kt), which is a good approximation of the value determined in ***Fig 2***.

In summary, it can be said that thermals also rise vertically above cooling towers. This is because gliders do not circle in the cooling tower cloud itself, but in updrafts that arise as the cloud evaporates. These updrafts move horizontally at the speed of the wind at the height of the cooling tower exit. Cooling tower clouds therefore follow the same physical laws as natural thermals. The relationships shown in ***Fig. 1*** also apply to them.

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5 Mollier diagram with the weather data for Fig. 2 and the resulting thermal strength.