Parameters of Thermal Convection as Measured by a Powered Glider

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Abstract: Results of hundreds of flight pattern through thermals are presented. Main characteristics as widths, distances of thermals from each other etc. as function of height will be shown, which seem to allow to model a "realistic" thermal. Thermal activity in relation to surface quality is analyzed.

Introduction:

Results of measurements made by means of a powered glider under conditions of thermal convection shall be presented in this report. First some considerations shall evaluate the accuracy of vertical velocity measurements, which have greatest importance for the use of glider pilots. Registrations of data have been done by strip chart recorders and sometimes by a metrodata digital tape-recorder. But there are more analogue data than digital ones, so we have to check to what extent of accuracy especially rough data of vertical velocity can be taken into account. Vertical velocity of the aircraft can be regarded as the vertical velocity of the air, when special corrections by other data can be made, such as aircraft parameters, vertical acceleration, pitch angle, derivation of pitch angle and, of course, air speed. Analogue data cannot be corrected easily, so we had to prove to what extend of accuracy those data could be taken into account. So a comparison between data of rough uncorrected vertical velocity and corrected velocity by the above mentioned parameters was set up. A test flight was made in smooth air to show the effect of the correction method. The pilot made some pitch oscillations of the powered glider by the stick. That induces a change in vertical velocity and speed. Regarding the vertical velocity lines with and without correction we can imagine, that the artificialy induced disturbance is sufficiently damped. During normal measurement flights in thermal conditions the stick corrections by the pilot are very small (constant attitude flight method).

Generally the main effect of correction is to shift the vertical velocity because of the inertia of the whole system of a powered glider and electric variometer.

So it seems to be justified to deal with analogue data of vertical velocity too, which can not easily be corrected.

The next consideration in this connexion deals with the derivation of a medium diameter of thermals out of flight paths through thermals of unknown diameter. The aircraft meets a center of thermal only by chance.

Abel's equation (Vulfsson) is valid to derive a spectrum of diameters out of a spectrum of measured flight path lengths through thermals when the number of measurements is sufficient large. We do not believe, that the whole number of our measurements is large enough for that purpose, so we only intend to get one medium diameter for one height interval and not a whole spectrum. At least we regard two results of Abel's theory, which have been pointed out by Bloem (personal communication). The probability of meeting a thermal increases linearly with the increase of real diameter of thermals. If we assume, that the diameter of all thermals is the same, we have to multiply the mean of all flight paths through thermals by $\pi/4 = 1.27$. That means that the average flight path length is smaller than the average diameter. On the other hand the probability to meet a thermal is the greater the larger the medium diameters of thermals are, because we do not necessarily meet even the smaller thermal.

Taking both results into account it seems to be justified to consider the average of all flight path lengths as the average of all diameters.

Results:

1. Mean parameters of thermals

Most of the evaluated flights were done under conditions of moderate thermal convection for medium latitudes (~50 °N). The stable layers or even inversions, which delay and end the upward thermal movement, differed mostly between 1,000 and 1,600 m above ground in these cases. Figure 1 shows from left to right mean and mean maximum temperature excesses, mean and mean maximum vertical velocities, mean flight path lengths through thermals in relation to height.

The horizontal dashed lines mean the computed standard deviation of the values in that special height, that are of in-

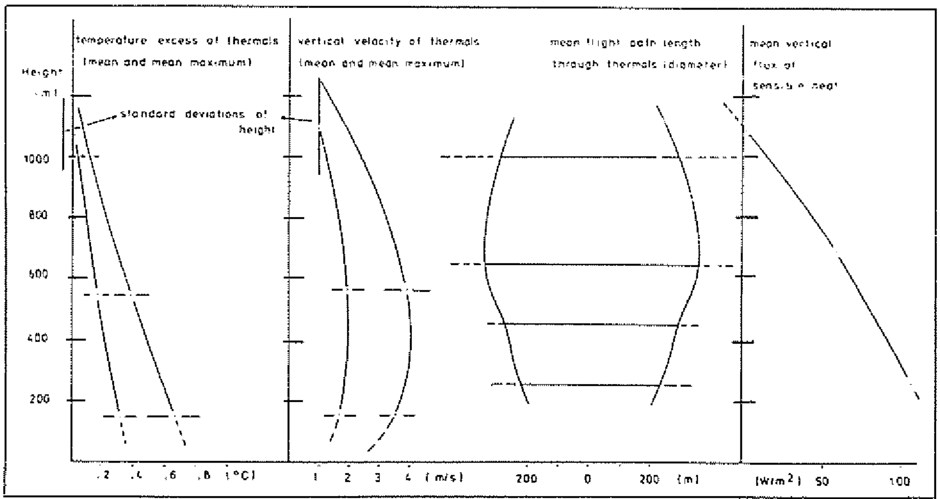

Fig. 1 Mean Properties of Thermal Convection in Relation to Height (standard deviations included).

tense meteorological interest too. The heat which is transported upward by the thermals, because of the vertical flux of sensible heat is presented at the right of that figure. Due to the chosen definition of thermals (vertical velocity has to be more than 1.5 m/s for a length of more than 100 m) we see nearly linear decrease of temperature excess with height, while the vertical velocity has a small maximum in the middle of the convection layer and decreases softly to below and above.

The vertical lines on the left of both parameters represent the standard deviation of that medium height, where zero temperature excess and a vertical velocity of at least 1 m/s was found. The latter was necessary for identification of thermals. As there are no longer positive temperature excesses in greater heights, it is very difficult to localize the thermals, when they disappear in the stable layers. The mean flight path lengths, which can be interpreted as mean diameters (see introduction) increase with height up to about 800 m and then decrease slightly. The standard deviations are represented as horizontal dashed lines outside the shape of thermals. Its maximum is in the upper height, which means very large diameter fluctuations there. The single measurements show that this area partly belongs to the convection layer still being far away from any stable layers above. Then a further growing of magnitude of thermals is most probable. On the other hand this height of measurement is already near stable layers, where the diameters decrease because of loosing of thermal volume having less buoyancy, when penetrating into those stable layers. It would be better to normalize the present measurement heights by inversion heights to avoid difficulties in interpretation in this connexion.

The mean vertical flux of sensible heat decreases linearly with height, which means a constant heating within the whole boundary layer. Standard deviation (not shown) is largest in the uppermost height also proving that the interpretation given before is valid. Penetration of thermals into stable layer means upward transportation of cold air into warmer environment and thus negative heat flux. Enveloping the mean diameters one gets the medium shape of thermals. That does not necessarily mean that only a single thermal body is present. A single thermal (see former definition) can contain more than one thermal body, as radar pictures have proved very often. To identify their numbers (table 1) the intensive peaks of vertical velocity within a thermal flight path were counted.

For that height interval below 300 m (all heights above gnd) there were 1.83 peaks, for 300-600 m 2.37, for 600-900 m 2.81, for 900-1,500 m 2.03 and above 1,500 m 1.57. This gives the idea, that the increase in numbers of thermal peaks up to 900 m is due to catching new neighbouring thermals. The upper decrease will probably mean, that parts of less buoyancy will not penetrate further into the more stable layers regarding the former interpretation.

Table 1 shows more results in computed numbers. The uppermost line gives the total measurement flight path length which points out the statistical limitations. The second line only includes those flight path intervals which at least contain one or more thermals. The area cover with thermals is smallest in the lowest height interval, when the interval above 1,500 m is taken out of consideration because of its partly stable layer behaviour. The distances between thermals are smallest in the lower layer too.

That means that lots of thermals are still below definition limit in the lowest layer. The increase in percentage area cover of thermal and distance between each other with height point out the validity of the collecting behaviour. It is interesting to know what the vertical gradients of vertical velocity and temperature excess are in relation to height. The first gradient is important for steering techniques in thermal climb.

There are lots of different profiles of vertical velocity structure, they cannot be simplified as parabolic or trapezoid ones. That makes the definition of the gradient of vertical velocity difficult. It was decided that the thermal gradient of vertical velocity was chosen as the difference between the last negative value and the first maximum on the inflight side with outflight side vice versa.

Gradients of temperature excess are chosen similarly as the difference between the last environmental value and the first maximum. Environmental values are easily to be identified by their

Table 1 Statistic parameters of thermals in relation to height

Height interval (m) above ground	0-500	500-900	900-1500	› 1500
I total measurement length (km)	981	818	280	161
II length, al intervals with thermals (km)	676	736	172	96
sum of lengths of thermals defined by vertical velocity	132	155	39	19
sum of length of thermals defined by temperature excess	140	162	44	26
number of thermals	263	219	52	28
in mean height (m)	280	658	1116	2038
II total sum of lengths of thermals related to total length with thermals (%)	19.5	21.0	22.9	20.4
II distance of thermals from each other for intervals with thermals (m)	2070	2355	2555	2735
mean number of defined maxima of vertical velocity within a thermal	1.99	2.81	2.03	1.57
Correlation coefficients between standard deviation of temperature (σ_T) and maximum vertical velocity (w_m):				
number of cases	41	33	20	6
$\sigma_T : w_m$	0.41	0.75	−0.03	−0.51
$\sigma_T : w_m; \sigma_T < 0.2$			0.49	
$\sigma_T : w_m; \sigma_T > 0.2$			−0.31	

Correlation coefficients between mean (dT) or mean maximum (dT_m) temperature excess and mean (w) or mean maximum (w_m) vertical velocity:

$dT_{300m} : w_{300m} = 0.48$; $dT_{700m} : w_{700m} = 0.49$;
$dT_{m300} : w_{m300} = 0.07$; $dT_{m700} : w_{m700} = 0.52$;
$dT_{300m} + dT_{700m} : w_{700m} = 0.59$

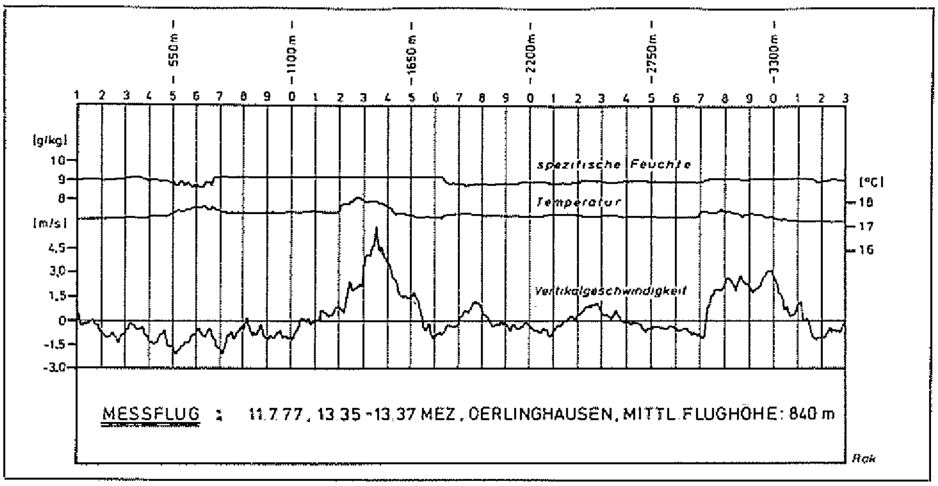

Fig. 2: Typical flight pattern with Motorsegler ASK 16 passing thermal convection recording vertical speed of aircraft, temperature and specific humidity.

very smooth characteristics. As a further result, but not shown here horizontal gradients of temperature excess decrease with height which, however, is a result of disappearing buoyancy by mixing.

Vertical velocity gradients do not change their magnitude very much. It is interesting to compare the length of thermals defined by vertical velocity with those defined by temperature excess, which of course is not possible in the uppermost layers for disappearing excess. The lengths defined by temperature excess are always longer than the others. This consideration will go into the model shown in Figure 3. All thermals flown parallel to the existing wind were checked against those perpendicular to the wind, but there was no significance about a preferred mode of vertical velocity lengths to those of temperature excess. We can believe that the lengths of thermals due to temperature excess are generally larger than those of vertical velocity. That gives a special hint for detrainment and entrainment.

At the bottom of the table we see different correlation coefficients between mean temperature excesses and mean vertical velocities and between their mean maximum values. Except for the mean maximum values in 300 m, the coefficients are about 0.5, which is quite satisfying. The correlation coefficient of 0.07 for the lowest height is very random, which probably points out that in a height of 300 m the turbulent generation process is still existent and/or a balance of forces is not fulfilled. The sum of mean temperature excesses for 300 m and 700 m in relation to mean vertical velocity of 700 m gives a best coefficient of about 0.6, which generally shows that the vertical velocity of thermals in a height is a result of the buoyancy forces due to temperature excesses of all heights below. That means, that acceleration is still present and friction forces are smaller than buoyancy.

Figure 2 shows a horizontal flight of our powered glider ASK 16, which was moved vertically under convection conditions. Specific humidity, temperature and vertical velocity is presented for a summer day with very good thermal convection also in that flight altitude of 840 m overhead Oerlinghausen. There was not much humidity structure near the ground, so that the thermals did rarely transport humidity relative to the environment upward. This can be seen by the smooth parts of humidity connected with both thermals presented here, which can easily be identified by their temperature excess too. Additionally there is another structure of positive temperature fluctuation connected with negative vertical velocity, however, and negative humidity deflection in the neighbourhood of the thermals. These certainly represent the compensating downdrafts, which are well structured as patches of air coming downward from a height of approximately 600 m regarding humidity values mixing neglected. This picture represents the strong mixing of the convective boundary layer not only by thermals coming from below, but also by compensating masses coming from above. Thus vertical heat flux resulting from those downward motion substantially contribute to the warming of the planetary boundary layer. Due to the humidity structure it can be supposed, that the downdrafts are originally from the penetration layer. They move down more than half the way into the convection layer, representing an additional force of friction to the thermals.

These experiences point into a model structure, which is given in figure 3. On the left we regard a starting disturbance of the boundary layer nearly adiabatic structured having a stable layer above. This is expressed by isolines of potential

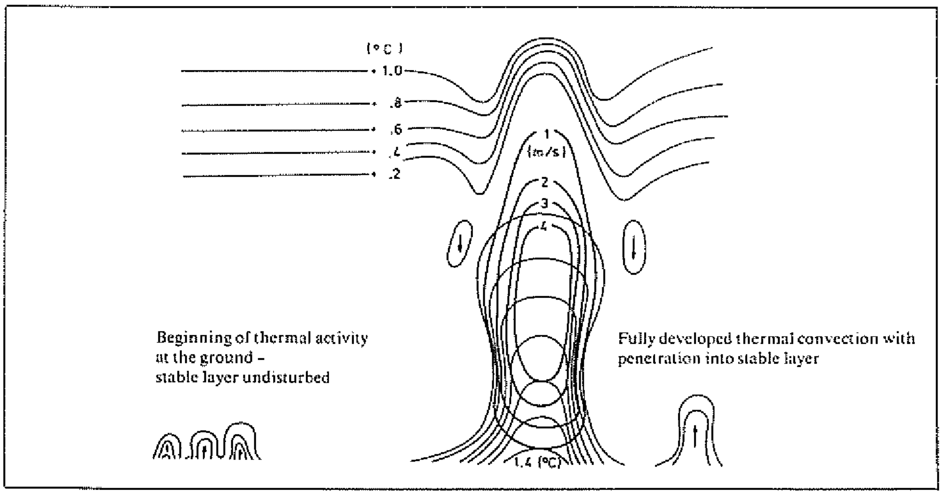

Figure 3: Model of Thermal Convection presented in isolines of potential temperature and vertical velocity (potential temperatures are differences to mean temperature).

temperature difference to the adiabatic layer. Buoyancy forces act in a still unknown way to accelerate warmed air upward until a whole column or bubble of air reaches from the ground up to the stable layer penetrating it, while deforming it substantially. Compensating patches of warm upper air penetrate downward. Statistics above show that thermals being represented by temperature excess are larger than being represented by vertical velocity. This indicates that detrainment acts as the vertical boundaries of the thermals. Entrainment can be expected coming from below, as it is a result of cooling tower measurements too, where thermals are artificially produced having a special formed source. These results are not in contradiction to the Scorer-Woodward model, but our vertical gradients of vertical velocity are much smaller.

2. Thermal activity in relation to surface quality

Again and again glider pilots ask, if there are special criteria how to judge thermal activity in relation to surface quality. Task setting is largely influenced by such considerations. We know that thermals develop quite regularly and quite reliably at special places when conditions are favourable. Conditions are sometimes confusing in nearly flat surfaces, but even there favourable places are well known, but far away from being as reliable as in the mountains.

The question how to quantify qualitative results is difficult to be answered. We tried a certain quantification by using maximum vertical velocities measured by the motorglider as an identifying parameter for the Oerlinghausen area. The mean maximum vertical velocity for the best thermal area, a sandy heath region, was 4.3 m/s, an arable soil region south of it had only 3.0 m/s and a similar arable soil region with more population and therefore more houses north of the sandy one had only 2.7 m/s of mean maximum vertical velocity.

The absolute vertical velocity during a single flight was not always in the sandy region, sometimes it was in the second but never in the worst area. That means that verification of quality of an area by only one single flight path is difficult. But in an average the qualification is valid. These differences in mean maximum vertical velocity do not only mean better and faster thermals for the best region but also earlier development and later finishing up to 1½ hours in those areas. This means sometimes small thermals in the first and no usable ones in the last both regions in autumn and spring.

A further test to try a quantification is given in Figure 4, which shows the results of 17 vertical velocity soundings in 200 up to 400 m above ground for a special flight path pattern between Gauting and Farchant, Bavaria.

We found moderate convective conditions. The curve represents the relative frequency in percent to meet a usable thermal of former definition. It is very small, but not always zero over Lake Starnberg, as it should be expected, because lake temperature normally cannot initiate thermals in May. Thermals measured over the lake drifted in from the countryside. As it was mentioned in my last paper (OSTIV 1976), these thermals had smaller temperature excesses than normal. But we can very well identify areas with a high percentage of thermal frequency up to more than 60 percent at the south side of a small mountain east of Murnau and in the center of a moor near Eschenlohe, while another moor south of the lake has very low values.

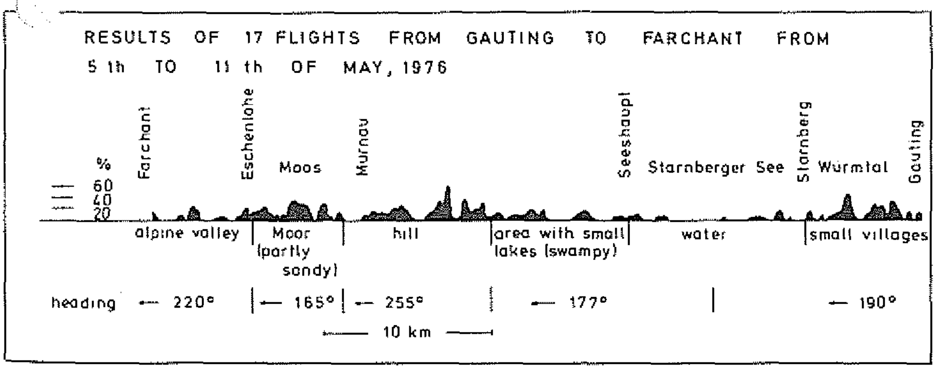

Fig. 4: Percentage of probability of meeting a thermal along a special flight path with different surface conditions.

Taking into account the whole collection of data of both areas we find thermals in 16 out of 17 cases for the small mountain and in 13 out of 17 cases in the moor area of Eschenlohe. The other moor area has very low values of thermal activity. The difference results out of a different amount of surface and subsoil water, making this moor almost to a wet swamp, while the Eschenlohe moor is dry and sandy especially in its centre. This single result only should accentuate that even a geological map alone, which for this region is not as structural as thermal activity for a single interval, is not sufficient for all conditions of thermal activity or even for the mean of it.

Future work must take surface and subsoil water, flora and others into consideration.

Zusammenfassung:

Es werden die Ergebnisse von Hunderten von Flugabschnitten mit Motorseglern durch thermische Konvektion in zusammengefasster Form präsentiert. Die Hauptmerkmale der Konvektion wie Durchmesser der Thermik, Abstand der Thermikschläuche voneinander usw. werden als Funktion der Höhe dargestellt. Die Ergebnisse scheinen als Anhalt für eine realistische Modellierung bzw. für eine spätere Verifikation geeignet zu sein.

Es wird ausserdem versucht, die thermische Aktivität in ihrer Abhängigkeit von unterschiedlichen Bodenoberflächen wie Binnensee, Dorf, Sumpf, Hügel usw. zu analysieren.

Literature

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