Some Statistics of Thermals Observed by a Powered Sailplane

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Introduction

Considering their importance to soaring, and also to meteorologists, thermals have been studied surprisingly little in the atmosphere. Even recent results (Konovalov 1977, Lindemann 1978) are not consistent or detailed enough to discriminate between one model of thermals and another. This paper adds further observations on a random sample of thermals on reasonable soaring days over Southern England, but does not claim to provide definitive anwers. The author's view is that we need to be able to recognise a number of different types of thermal and then to investigate individual specimens before we can claim to know what they are and how to represent them mathematically or physically.

The data discussed here were collected during the powered sailplane programme which is described elsewhere in these proceedings (Milford 1978). The measurements were made in order to determine the heat and water vapour fluxes through the boundary layer capped by an inversion. Cross-wind runs of at least 25 km were made at various heights, with spiral ascents up to the inversion before and after the runs. The pilot flew with constant throttle setting and attitude, and we have shown that the vertical velocity of the air can then be measured to better than 0.2 m s^{-1} every 50 m along the flight path (Mansfield et al. 1974). The potential temperature and the humidity mixing ratio were also measured, together with air-speed. The flights which have been used in the present study are listed in Table 1. All the days were anticyclonic and predominantly free of cloud. The flights took place between 1100 and 1600 GMT, and a total of 37 runs on 9 flights were analysed.

More details of the flights have been published elsewhere (Milford et al. 1979) but Table 1 shows that winds were light on all the days. The vertical velocity variance averages 1 (m s^{-1})^2, typical of the convective boundary layer, with a 3 to 1 range between flights. Humidity variance shows a range of 10 to 1, but temperature little over 3 to 1. Again, the actual values are typical and show the high resolution needed for instrumentation to investigate the temperature and humidity distribution.

Identification of Thermals

In certain other studies temperature characteristics have been used to identify thermals (Warner and Telford 1963), while others have found moisture useful at greater heights (Grant 1965). The only meaningful definition for soaring pilots is that there is an organised updraught, not less than 100 m in diameter. All thermals discussed here had two or more successive points with measured vertical velocity of 0.5 m s^{-1} or greater upwards. This definition corresponds well enough with the pilot's and eliminates random events and small excursions resulting from pilot action. It is not far from Konovalov's criterion (100 m, 1 m s^{-1}). Since our runs were over a predetermined course the intersections with thermals were random, and the "size" used are minimum values.

If thermals are uniform in size and circular the average length of random intersections can be calculated geometrically. If the minimum intersection which is recorded is very small compared to the diameter of the thermal then the average intersection is $\pi/4$ (0.79) times the diameter. In our case we record no intersections of less than 100 m, and the average increases to 0.83 diameters for 250 m diameter thermals, and 0.90 for 150 m thermals.

The caracteristics of thermals under little or no cloud vary with a number of external parameters; among these we should include the height above ground, the inversion height, the wind speed (or the shear across the convective layer) the available radiation and the time of day. In our case we did not have sufficient measurements close to the ground to use the temperature lapse between ground and 300 m (as did Konovalov, 1972): this quantity is in any case greatly influenced by the actual point at which the surface temperature is measured. Because we were interested in the whole depth of the convective layer which is limited by the inversion all heights (z) were referred to the inversion height, (z_i), and variations with z/z_i studied.

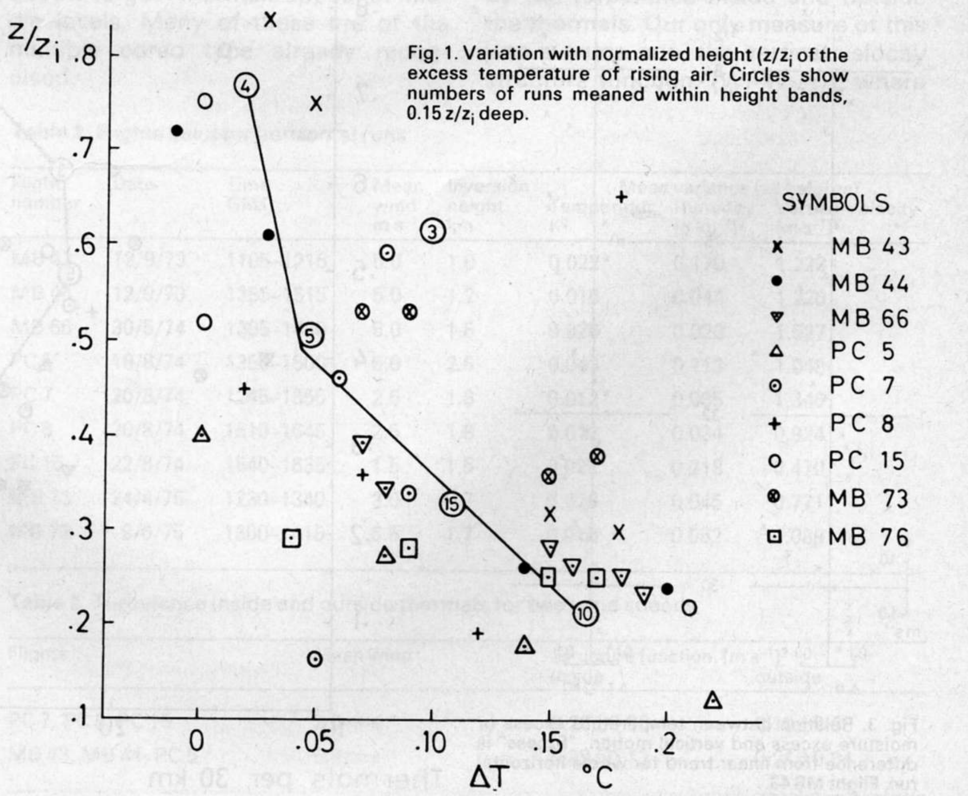

Fig. 1. Variation with normalized height (z/z_i of the excess temperature of rising air. Circles show numbers of runs meaned within height bands, 0.15 z/z_i deep.

Excess temperatures

From many studies of the convective boundary layer it is known that some heat is brought downwards through the inversion so that there is a level at which the net heat transfer is zero. At this height the average excess temperature of thermals over their surroundings will be zero also, and we have found this to be at heights where z/z_i is between about 0.7 and 0.8. The average excess temperature of all thermals is shown in Fig. 1, and the decrease with height can be clearly seen. The buoyancy of the air is affected by the moisture as well as temperature, but the inclusion of this makes no significant change to the pattern.

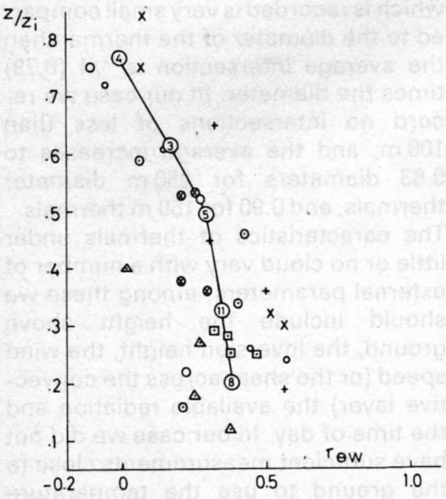

Fig. 2. Variation with normalized height of correlation coefficient between temperature excess and vertical air velocity. Symbols as in Fig. 1.

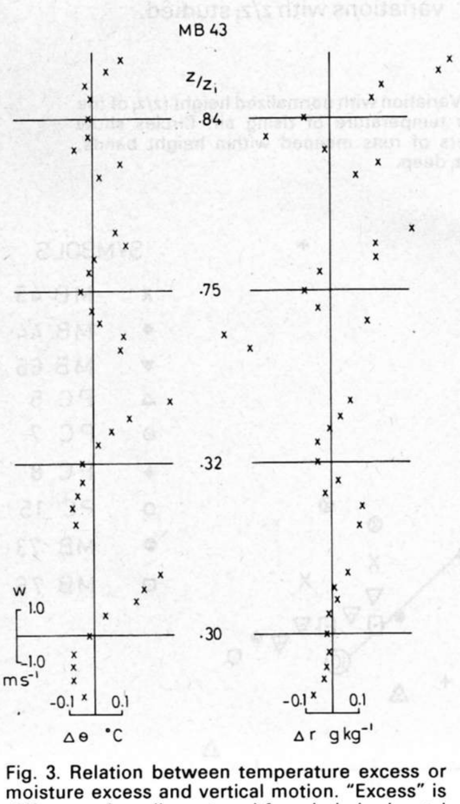

Fig. 3. Relation between temperature excess or moisture excess and vertical motion. "Excess" is difference from linear trend for whole horizontal run. Flight MB 43.

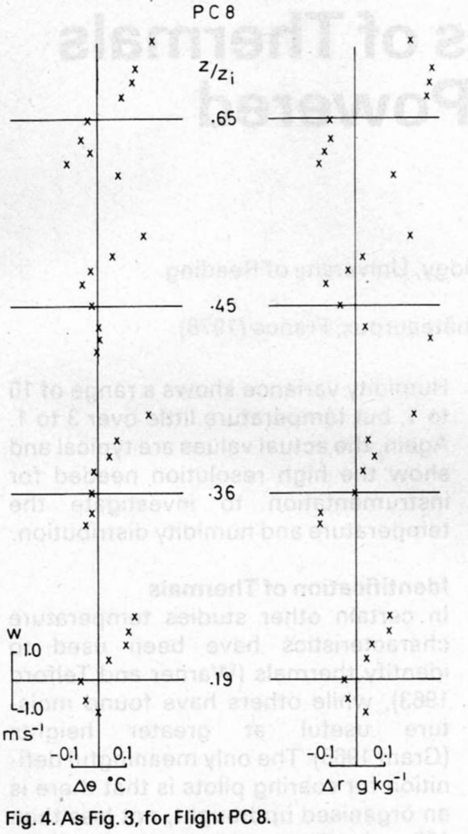

Fig. 4. As Fig. 3, for Flight PC 8.

Another feature which is significant is the degree of correlation between temperature and vertical velocity, and this is shown for all the runs in Fig. 2. It is actually this factor which governs the amount of heat transferred by the upward and downward motions as much as the size of the variances of vertical velocity or temperature found on the runs. Figs. 3 and 4 show two particular flights, with average temperature anomalies (and mixing ratio anomalies) for all points which have vertical velocities in certain ranges. We see that at low levels downward moving air is slightly cool, but that the vigorous thermals are still buoyant, with an excess temperature averaging 0.2 °C. At the uppermost upper levels (Fig. 3) warm air may be found travelling down as often as up: the air in warm down draughts has recently been entrained through the inversion. The humidity relation has a silghtly steadier trend as the entrained air is dry.

A consistent feature observed has been the way in which the boundary layer becomes mixed during the day, so that although a humidity sensor is a useful seeker of updraughts on many mornings it would be useless in the afternoons. This was anticipated by radar studies and appeared in our earlier examples (Milford 1974).

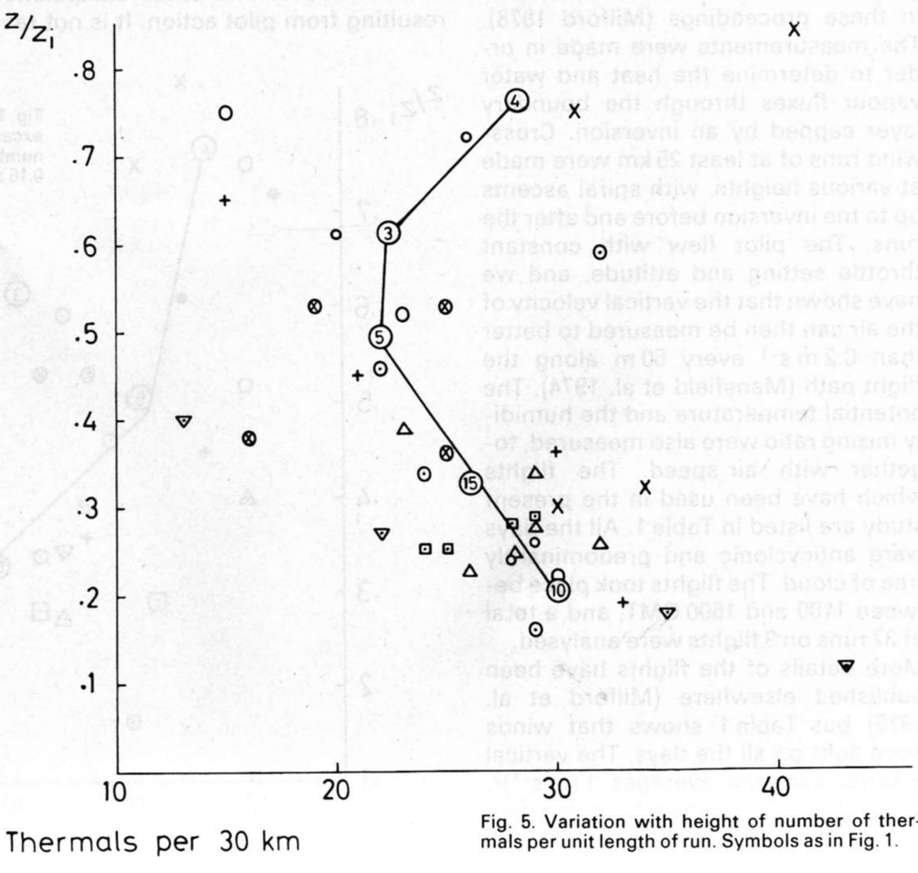

Fig. 5. Variation with height of number of thermals per unit length of run. Symbols as in Fig. 1.

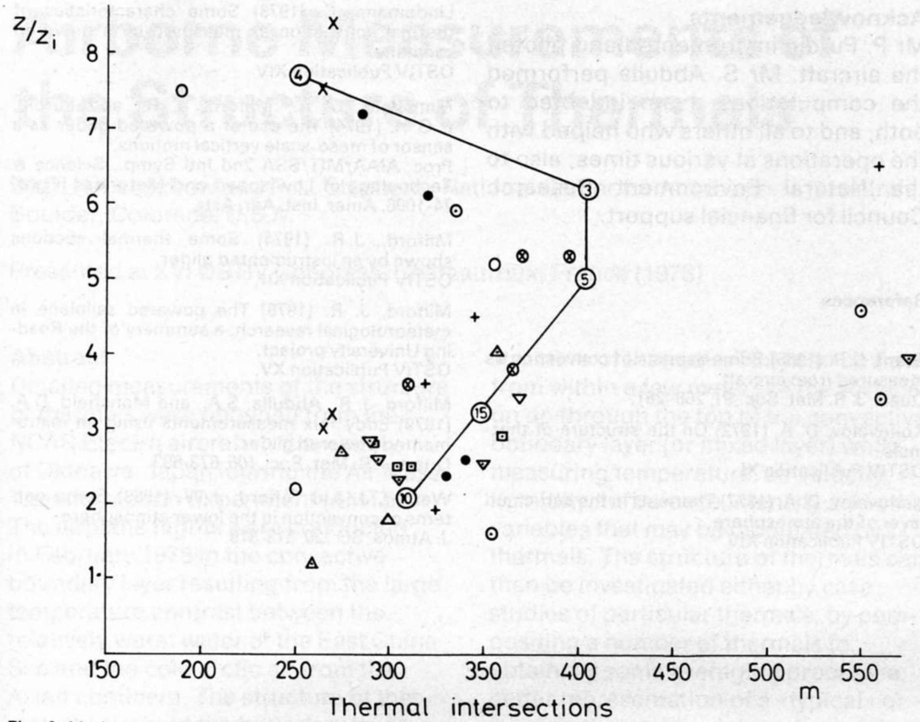

Fig. 6. Variation with height of size of thermals. Symbols as in Fig. 1.

Size Distribution

Figs. 5 and 6 show the number and the average size of thermals encountered on each run, with means. The size varies less with height than expected, perhaps partly due to our definition. The total area moving upwards is calculated from the product of number and size: it is notable that this remains constant through our working range of heights. Thermals occupy 32% (standard deviation 5%) of the total area, with downdraughts occupying a similar fraction.

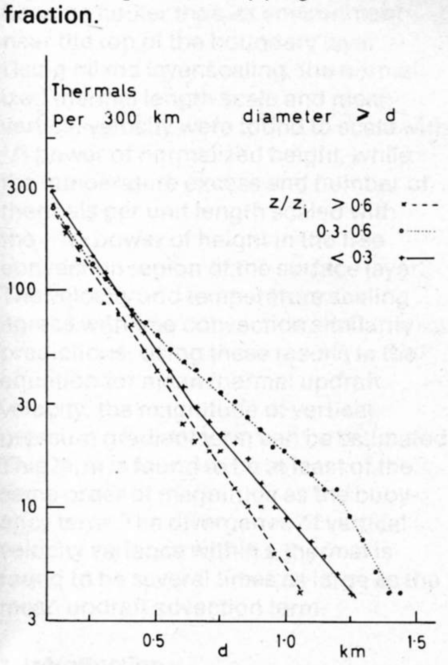

Fig. 7. Cumulative frequency of thermal sizes averaged over three height bands. Average over all runs, all flights.

Finally Fig. 7 shows the total number of thermals of a given size encountered per unit length of run, grouped into three height bands. These are plotted as a cumulative total, on a logarithmic scale, and we see that the total number, not far short of per km, is not very different in the three bands. The largest number appear at low levels, but the largest thermals appear at middle levels. Many of these are of the multiple cored type already recognised.

Table 1 Flights used for horizontal runs

Flight number	Date	Time GMT	Mean wind $m\ s^{-1}$	Inversion height km	Mean variance (all heights) Temperatur K^2	Humidity $(g\ kg^{-1})^2$	Vertical velocity $(m\ s^{-1})^2$
MB 43	12/9/73	1105–1215	5.0	1.0	0.022	0.170	1.223
MB 44	12/9/73	1355–1515	5.0	1.2	0.016	0.044	1.220
MB 66	30/5/74	1305–1430	5.0	1.5	0.026	0.028	1.527
PC 5	19/8/74	1350–1500	5.0	2.5	0.043	0.113	1.048
PC 7	20/8/74	1245–1355	2.5	1.8	0.012	0.085	1.340
PC 8	20/8/74	1510–1645	2.5	1.8	0.013	0.034	0.924
PC 15	22/8/74	1540–1635	1.5	1.5	0.026	0.218	0.470
MB 73	24/4/75	1230–1340	3.0	0.7	0.028	0.045	0.771
MB 76	9/6/75	1300–1415	6.5	1.7	0.019	0.052	1.089

Table 2 Turbulence inside and outside thermals for two wind speeds

Flights	Mean wind	Structure function, $(m\ s^{-1})^2$ inside	outside
PC 7, PC 8, PC 15	2.0 $m\ s^{-1}$	0.26±0.08	0.13±0.05
MB 43, MB 44, PC 5	5.0 $m\ s^{-1}$	0.29±0.13	0.24±0.04

Organisation

One feature which pilots would like to know about, is how far the thermals are randomly distributed at any time, or whether there is a larger scale organisation. On some occasions we can see this in the cloud patterns, whether with streets in strong wind cases, or patches of "overconvection" in lighter winds. Our analysis of the scales transferring the heat energy upwards showed that the fraction carried by thermals (on scales less than about 3 km) decreased in wind less than 2 m s^{-1} and with deep inversions.

Altogether less energy is carried from the surface as heat and more is used for evaporation. This is measured as a water vapour flux at our operating levels and on the days with lightest winds the transfers tended to be on a larger scale than usual. In fact for all runs below 600 m with winds $\geqq 5$ m s^{-1} the average sensible heat flux was 98 W m^{-2} and latent heat flux 118 W m^{-2}. With winds $\leqq 3$ m s^{-1} the respective figures were 54 and 232 W m^{-2}, (see Milford et al. 1979). This may eventually be able to explain why calm days are less satisfactory for soaring than those with some wind, albeit light. It is likely that in this case the effect is controlled at the ground, where active thermals cannot easily be formed without their being carried across the warmed surface. At greater heights the growth of the thermals may be partly controlled by the turbulence inside and outside the thermals. Our only measure of this was a crude one, the vertical velocity structure function, $(W_i - W_{i+1})^2$, where

W_i and W_{i+1} represent vertical velocities at successive observation points. The values are shown in Table 2. We see that the internal turbulence is not affected by wind speed, but the outside value is reduced in light winds.

Conclusion

Because there are so many possible factors affecting the structure of thermals a statistical approach needs a large number of cases. It would be useful if those who take part in such work made sure that their observations were more strictly comparable. In the meantime the difficult task of following the life cycle of an individual thermal needs to be solved so that the physics can be used to illuminate the statistics.

Acknowledgements

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