Some Thermal Sections Shown by an Instrumented Glider

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Introduction

At Alpine in 1970, we presented a preliminary report (Milford and Whitfield, 1970) on our work with an instrumented Slingsby T 53B, the Red Queen, which has been provided by the Natural Environment Research Council. The work has continued, and this is a further preliminary report on one aspect of the results. The data come from two data loggers, in the same sequence of devices, one of which is permanently installed in the Red Queen, with the more elaborate sensors, and the other of which is a four channel system which may be strapped quickly onto any light aircraft which is found to be available. The investigation of individual thermal elements has not been a major objective of the research programme to date, so that the reported cases are a rather random selection, and show the capabilities of the system rather than provide definitive results.

Instrumentation

All the sections shown here are from flights with the Red Queen, except for one with a Piper Cub. On the powered flights with the Cub, or with a Scheibe Falke, the record consists of measurements of pressure height, airspeed, temperature, and wet-bulb depression, made every 1.638 sec (Milfords & Whitfield 1970). The resolution is about 1 m in height, 0.1 m s^{-1} in airspeed, and 0.02°C in temperature and wet-bulb depression. The response time of the thermistors used was about 1 sec as was that of the static and dynamic pressure sensors. The response time (τ) for vertical gusting depends on the aircraft used; the expression used (De Tonge 1965) is

$$\tau = \frac{2\,W}{\left(\frac{\partial C_L}{\partial a}\right) \cdot \varrho v}$$

where W is the wing loading, ϱ air density, v the operating speed, and C_L the lift coefficient at an angle of attack, a. At the normal operating speeds the response time of an aircraft such as the Cub is about 1.2 sec, and that of the Falke or the Red Queen about 0.5 sec. In terms of horizontal distance these convert to 36 m, 15 m, and 10 m respectively (Lawson 1972).

On the Red Queen the same set of parameters is recorded as on the powered aircraft, with the addition of the output from an electric variometer, and a second temperature sensor. In this system the time constant used on the main thermometer is lengthened to about 3.5 sec; a thermistor with a time constant of about 0.7 sec records departures from an identical slow thermistor, and by combining the two outputs a temperature record whose detail is limited only by the sampling frequency is obtained. The variometer has a similar response time, but the humidity measurements are slightly lagged.

Accuracy

Each of sensors, with its associated transducer, maintains its sensitivity well between calibrations, but zero drifts have sometimes been troublesome. The variometer output, for example, is not used before its mean has been compared with the overall height change over a period of several minutes, and it is not uncommon to land at a height 20 m above the take-off heigth (with no corresponding pressure change). For purposes of sections such as those shown below, the changes or gradients are important, rather than absolute values, and no correction for the drift has been applied. The most troublesome errors are those involving radiation and the temperature sensors, particularly in a circling glider where the radiation input is changing continuously. Up till now the sensors have been fuselage mounted: a double radiation shield eliminated all the radiation, except for a small leakage when flying the Red Queen down sun in solar altitudes below about 30°, but a modification to the shield led some air from the boundary layer of the fuselage into the housing, and an error of about 0.15°C arose when flying across the sun. This year the sensors are in a new housing under the wing, and those on the powered aircraft have always been well away from the fuselage. The boundary layer error has been corrected for in the flights shown here.
Fig. 1 shows the system installed in the Red Queen, and fig. 2 shows the aircraft with two sets of sensors in place for a comparison flight.

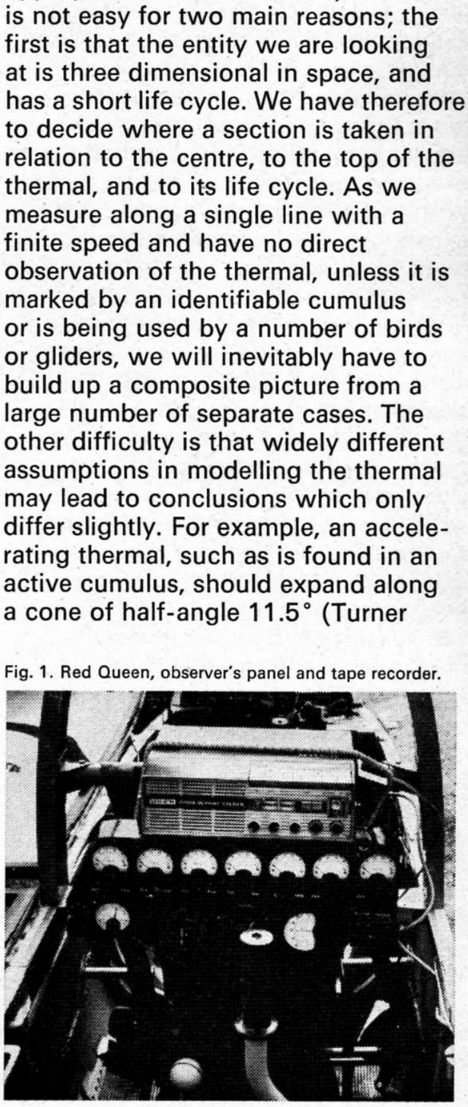
Processed Data

After computer processing the data are available as a printout of each parameter, together with a reference number relating it to the observer's recorded comments on the flight. Potential temperature (Θ°C) and humidity mixing ratio (r g/kg) are also computed, together with vertical velocity derived from differentiating the height, which has poor discrimination, but better long term accuracy than the variometer. A graph of vertical velocity, potential temperature, and humidity mixing ratio against time is also plotted, using a fast line printer, and the sections illustrated below are largely copied direct from this.

Thermal Models

To use the observed sections profitably it is essential to have one or more idealised models to relate them to. The variety of models available in the case of thermals is great, including jets, plumes, puffs and bubbles, with the possibility of entrainment in each case, and combinations of more than one form. The term thermal has been applied to particular models (e. g. Richards 1963) but is here used as a general term for a recognisable continuous mass of predominantly upward moving air without implying anything about its mechanism or its form. This is the pilots' use of the term. A summary by Lilly (1966) lists nine models. Discriminating between the models to find the most appropriate one in an atmospheric case is not easy for two main reasons; the first is that the entity we are looking at is three dimensional in space, and has a short life cycle. We have therefore to decide where a section is taken in relation to the centre, to the top of the thermal, and to its life cycle. As we measure along a single line with a finite speed and have no direct observation of the thermal, unless it is marked by an identifiable cumulus or is being used by a number of birds or gliders, we will inevitably have to build up a composite picture from a large number of separate cases. The other difficulty is that widely different assumptions in modelling the thermal may lead to conclusions which only differ slightly. For example, an accelerating thermal, such as is found in an active cumulus, should expand along a cone of half-angle 11.5° (Turner

Fig. 1. Red Queen, observer's panel and tape recorder.



1963) while a rapidly decelerating puff expands along a 14° cone (Richards 1965). A study of the time development of the thermal could distinguish between the models more easily than any instantaneous picture. Collaboration between aircraft and radar using clear air echoes (e. g. Browning 1972, Hardy and Ottersten 1969) is likely to provide the information required: the limitations of an aircraft appear when quantitative deductions are looked for from such sections as those shown below.

Single Passes
A few samples of passes through isolated thermals are illustrated. Since these are not marked there is no direct evidence as to how close to the centre the aircraft has passed. However, the maximum size is obviously found on a near-central pass, and in this case the aircraft experiences no rolling. Verbal comments are recorded on the data tape and fit well with the subsequent analysis.
Fig. 3 shows a young, low-level thermal with temperature and humidity peaks well correlated with the vertical velocity. This pass, at 250 m above ground, looks slightly asymmetrical, but some of the temperature asymmetry is due to the aircraft emerging from the thermal some 50 m above the entry level. With a potential temperature gradient of about 2°C per km in the environmental air this accounts for about 0.1 °C, or half the observed difference.
With increased height the temperature excess between thermal and environment disappears, typically becoming negligible by the time 70% of the height of cloud base, or of a limiting inversion is reached (see e. g. Grant 1965, Warner & Telford 1963). Fig. 4 shows another chance passage through a thermal, which shows the typically reduced temperature difference, and, in this case, a double structure. The shear observed is limited by the smoothing applied. This pass was made with the Red Queen, flying cross-wind on a day (13 July 1971) with good convection but a wind of about 10 m s^{-1} at these heights to make tracking individual cells difficult.
One isolated case which may be of interest is that of a 'negative' thermal, shown in fig. 5 (b). This was encountered during a run along a line of lift at a convergence zone, reported elsewhere at this conference (Milford & Simpson 1972). It seems unusual to find such a strong isolated downward flow, whose origin must be considerably higher judging from the humidity value found. Fig. 5 (a), from the same flight, is a pass through thermal marked by smoke from a small stubble fire. The correlation of temperature and height variations (and humidity also) is unusually high for this altitude (1550 m).

Cross Sections
18th September 1971
On this day the Red Queen was soaring locally from Lasham, and had made one or two previous attempts to make sections through thermals marked by circling gliders. The usual difficulties were encountered, namely that one glider tended to move before enough passes were made in its particular thermal, and that several gliders would be marking quite different circles. Convection was limited to about 1400 m throughout the day by an inversion, and by the time of

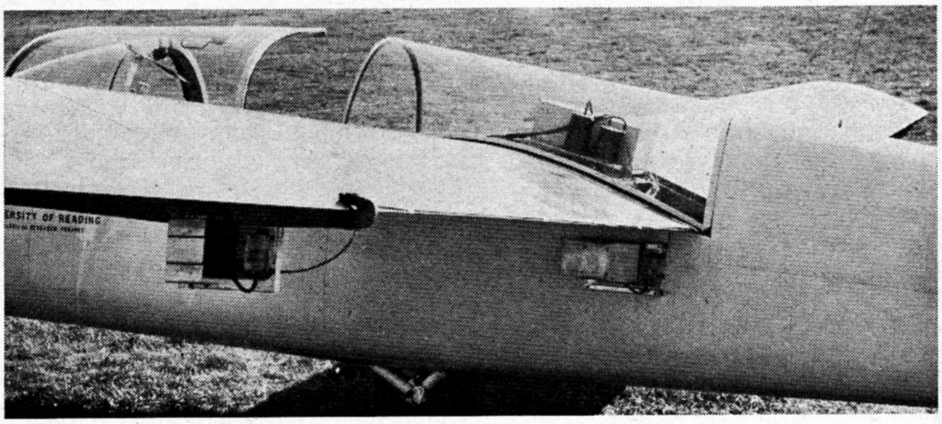


Fig. 2. Red Queen instrumentation. The data logger with pressure and airspeed transducers is behind the observer's seat. Two sets of temperature sensors are fitted for a comparison trial.

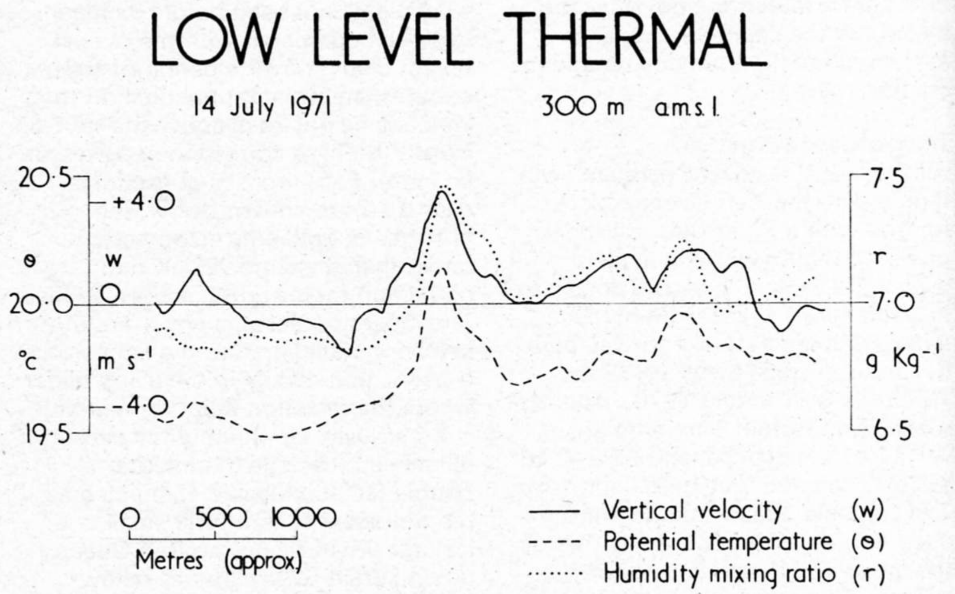


Fig. 3. Low level pass through thermal. The curves show vertical velocity, potential temperature and humidity mixing ratio along the flight path. Piper Cub, 14 July 1971, 1200 GMT, wind about 2 m s^{-1}.

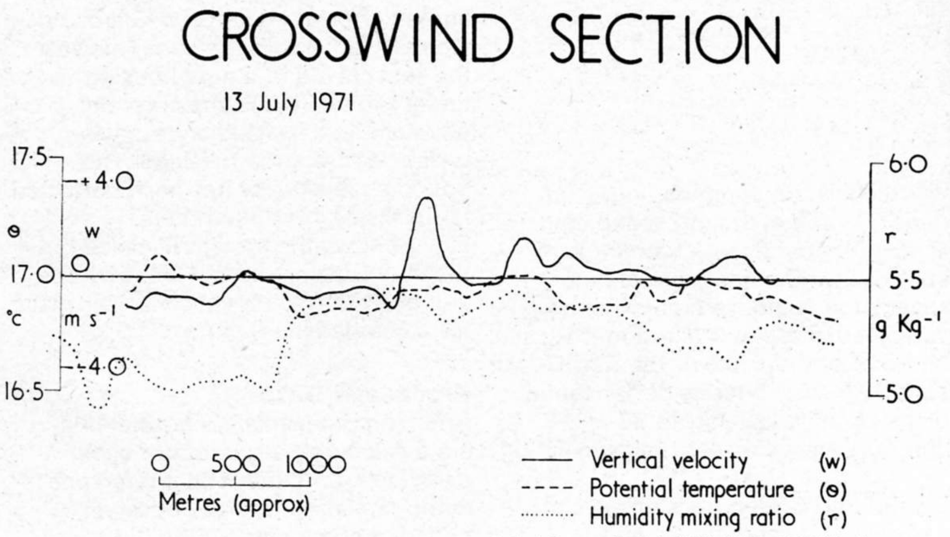


Fig. 4. Crosswind pass through thermal 800 m above ground. Red Queen, 13 July 1971, 1400 GMT. Wind about 10 m s^{-1}, cloud base 1300 m. The lack of temperature variations is typical.

Fig. 5. (a) Pass through a multiple thermal, marked by smoke from a small stubble burn. Red Queen, 11 Sept 1971, 1530 GMT. Cloud base was at about 1650 m, and the region of lift later developed was later included in the convergence zone referred to in (b).
(b) Pass through a negative thermal. Red Queen, 11 Sept. 1971, 1600 GMT. This sharp downdraught was encountered while flying along the line of lift at a local convergence zone.

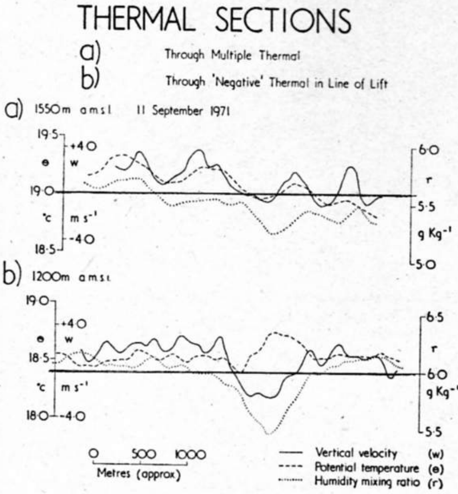


Fig. 6. Section through a thermal. Red Queen, 18 Sept. 1971, 1500 GMT. Wind about 2 m s^{-1} from 270°. The curves show vertical velocity of the air, and potential temperature. The centre is the estimated centre of the circles of 6 gliders using the same thermal. No cloud, but inversion at about 1400 m. No significant variations of humidity were found in the area.

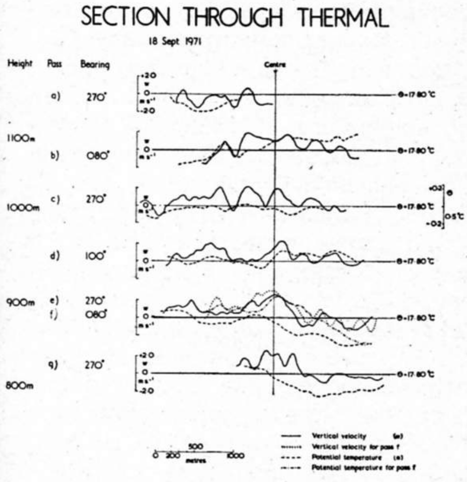


fig. 6 the sky was cloudless. At this time, 1600 BST, six pilots had agreed on one circle and were well spaced from about 1300 m to 750 m. The Red Queen left the thermal near the top, and made the passes shown, finishing in the same thermal, which still showed considerable lift. The core which was in common use was drifting with the mean wind, about 2 m s^{-1}, and was giving useful lift over a period of not less than 45 min.

Fig. 6 shows only Θ and w because humidity showed no variations above the noise level. By this time of day, with a marked inversion, this is not surprising, and it is the reason why radar echoes from convective elements tend to weaken after mid-day. It is clear that the thermal of fig. 6 is in fact a composite entity, containing many smaller cells, which appear on a number of the traverses with clear continuity between levels. Over the whole 2 km diameter of the composite thermal the mean vertical velocity is 0.5 m s^{-1} above 1000 m and 0.9 m s^{-1} between 800 and 1000 m and there are substantial downdraughts only upwind near the top, and in the lower levels on the downwind side. If such a thermal were viewed by radar the larger scale motion, including the downcraft some km away from the centre, would most probably appear, corresponding to the ring echoes which are often seen with diameters typically 5 km (Browning 1972).

On the km scale the correlation between Θ and w is clear in fig. 6 but on the smaller scale it is insignificant, as in pass c. It is not at all obvious that the scientific glider pilot with unlimited resources could benefit himself by any possible temperature or humidity measurements under these conditions.

13th July 1972

Fig. 7 a and 7 b show another two dimensional section through convective activity, again rather late in the day (1700 BST). On this occasion the Red Queen had been soaring, again locally around Lasham, and was returning to land. Downwind from the airfield an active patch was found and fig. 7 is built up from five passes, in this case cross-wind over the same ground track. The total time was under 12 minutes, and mean wind under 2 m s^{-1}.

The existence of several adjacent cells is again obvious, and the continuity suggests reasonably continuous plumes, even at this low level, at least over four or five minutes. The correlation of temperature excess with vertical velocity falls off rapidly with height here, and by 550 m above ground the lift can only be detected as lift, and not by temperature and humidity measurements.

Conclusions

It would be rash to draw general conclusions from these few cases, or even from the others we have gathered. Although Scorer (1958, p. 156) asserted that 'thermals will normally behave like each other except in so far as they are born different', the environmental temperature structure and wind shear have major effects and it seems that no two thermals large enough and long enough lived to be investigated by a single glider are really alike. The temperature excesses found are typically 0.5°C at 300 m above ground falling off with height until they may be zero at 1000 m even in good British conditions. The humidity excesses fall off less rapidly with height, but more markedly as the day goes on.

Our main conclusion is that a more systematic study of thermals will be useful, but that the availability of a powered glider is essential before this can usefully be done.

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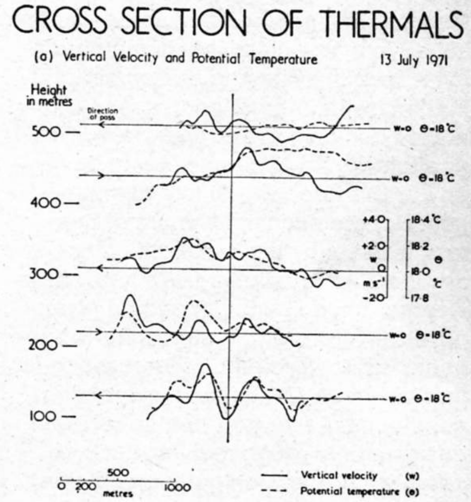
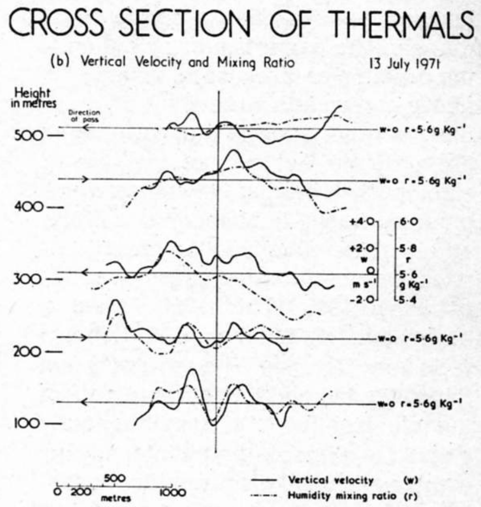


Fig. 7. Section through a thermal. Red Queen, 13 July 1971, 1630 GMT. Crosswind passes, wind about 3 m s^{-1}. This thermal was downwind from the airfield.
(a) Curves show vertical velocity of air and potential temperature.



(b) Curves show vertical velocity of air and humidity mixing ratio.