# Experiments on the Suppression of Thermals by an Inversion

By J. M. Richards Dept. of Meteorology, Imperial College, London

*Presented at the 8th OSTIV Congress, Cologne, Germany, June 1960*

*Summary*

*Model experiments are described which simulate the motion of thermals through a neutral medium containing an inversion. The results are expressed in simple mathematical relations. A thermal tends to flatten out at the inversion, but a certain portion of it, drawn from an internal region, may proceed as a new, smaller thermal into the upper layer. The size of this thermal is a function of the inversion. If the inversion exceeds a certain treshold value (depending on the excess density of the thermal) it will prevent any thermal from rising into the upper layer.*

*The results if applied to the atmosphere suggest that, for an average thermal, this treshold is given by a sharp inversion of more than 1 °C.*

*Introduction*

At Imperial College, thermal convection in unstratified surroundings has been imitated in a water-tank model. The warmer air inside the thermal was represented in the model by salty water, while the atmosphere through which the thermal rises was represented by fresh water. Since all the water in the tank was at the same temperature, this represented a neutral atmosphere, which is one in which the temperature decreases with height so that a small volume, or parcel, of air at any level would have the same density as its surroundings when moved adiabatically to any other level.

Full details of this type of experiment are given in papers by Scorer (1957) and Woodward (1959) so that only a short summary will be presented here.

The salty water representing the thermal was coloured with a white precipitate, and measurements of the size and rate of descent of the whitened region gave the following results

$$z = n\,r, \tag{1}$$

$$z^2 = \sqrt{\frac{g\,M}{\rho\,C}}\cdot t, \tag{2}$$

$$V = m\,r^3 \tag{3}$$

where n, m and C are constants for any one thermal.

M is the mass excess of the thermal, which is the difference between the mass of the thermal and the mass of an equal volume of the external fluid.

ρ is the density of the external fluid.

2 r is the greatest horizontal dimension of the thermal.

z is the position of the extremity of the thermal in the direction of its motion, which is called the front.

Equation (1) states that, if z is measured from the position where r would equal 0, that is from a virtual origin, z and r are proportional.

t is the elapsed time, also measured from the moment of virtual release.

V is the volume of the thermal cloud.

The shape of the thermal cloud did not alter as the motion proceeded, and this shape, with z and r, is illustrated in figure 1.

Recently, the experiments have been modified so as to imitate thermals moving upwards through a stably stratified environment. (This case is not described here.) Furthermore because such cases frequently arise in the atmosphere, the effect of a sharp discontinuity of density at a certain height, with neutral stratification above and below, was investigated. The results are as follows.

Fig. 2

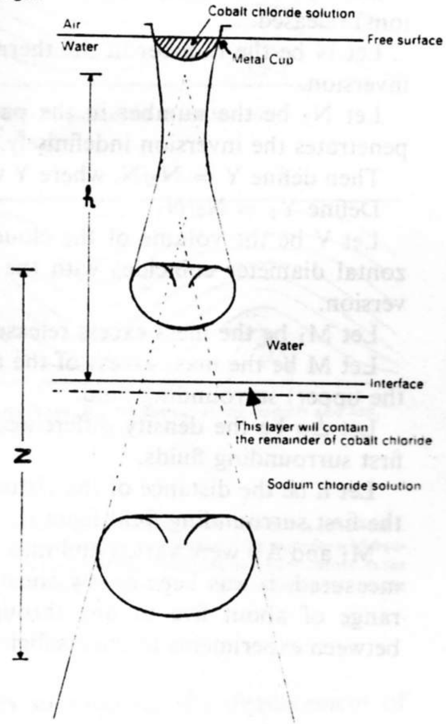
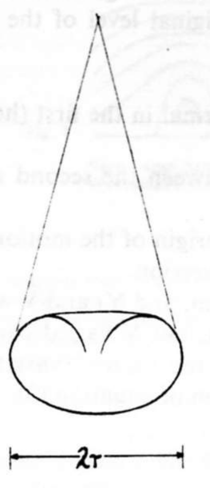



Fig. 1




*Experimental Procedure*

The arrangement of the tank at the beginning of an experiment is shown in figure 2. The hemispherical metal cup was pivoted about a diameter which lay in, or just above, the free surface of the water. It contained an aqueous solution of cobalt chloride, which is strongly coloured and so was easily seen in the clear surroundings. The fluid surface in the cup was initially adjusted to the same level as the outside water.

When the cup was inverted by a rapid rotation about its pivots, the resulting immediate motion was negligible. However, the mass of cobalt chloride solution accelerated under the influence of gravity on its relatively greater density, and after the lowest part had descended through a short distance the motion was that described by equations (1) to (3). This type of motion continued until the influence of the interface became appreciable, which was observed to be the case when the cloud front was closer than about r to the interface. At this stage, the cloud flattened considerably unless the density change across the interface was relatively slight.

When the leading portion of the cobalt chloride cloud had entered the lower layer, the deceleration and flattening became more pronounced until, depending upon the relative change of density at the interface,

*either* (a) the whole of the cloud returned to near the level of the interface,

*or* (b) a part of the cloud, drawn from an internal region, proceeded downwards. This part soon assumed the motion described by equations (1) to (3), but the constants in these equations did not necessarily have their original values. The remainder of the cloud returned to the interfacial region.

At the end of an experiment, therefore, most of the cobalt chloride originally contained in the cup had been divided into two layers, the first near the bottom of the tank and the other near the interface. A small part of the coloured fluid remained outside the cloud throughout the experiment, and none of this material penetrated the interface.

Let $N_1$ be the total number of marked particles (e.g. Cobalt ions) released.

Let N be the number in the thermal before it reaches the inversion.

Let $N_2$ be the number in the part of the thermal which penetrates the inversion indefinitely.

Then define $Y = N_2/N$, where Y will be called the yield.

Define $Y_1 = N_2/N_1$.

Let V be the volume of the cloud when its greatest horizontal diameter coincides with the original level of the inversion.

Let $M_1$ be the mass excess released.

Let M be the mass excess of the thermal in the first (here, the upper) surrounding fluid.

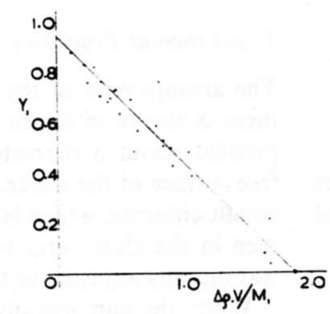
Let $\Delta\rho$ be the density difference between the second and first surrounding fluids.

Let h be the distance of the virtual origin of the motion in the first surrounding fluid from the inversion.

$M_1$ and $\Delta\rho$ were varied and measured, and $Y_1$ and V were measured. h was kept nearly constant, but V varied over a range of about five to one through the natural variation between experiments in the coefficient m of equation (3).

## Results

Fig. 3




In figure 3, $Y_1$ has been plotted on a graph against $\frac{\Delta\rho \cdot V}{M_1}$.

It will be seen that $Y_1$ decreases linearly with $\frac{\Delta\rho\, V}{M_1}$. The graph suggests the relationship

$$Y_1 = k\left(1 - \frac{\Delta\rho\, V}{K_1 M_1}\right), \quad \frac{\Delta\rho\, V}{K_1 M_1} \leqslant 1$$
$$Y_1 = 0, \quad \frac{\Delta\rho\, V}{K_1 M_1} > 1 \qquad (4)$$

where k is a constant, approximately equal to 0.94, (5)

and $K_1$ is a constant, approximately equal to 1.9. (6)

Let $p = \frac{N}{N_1}$. It seems reasonable to assume that each thermal contained a constant fraction of the material released from the cup, and therefore that p is a constant.

$$\text{Then} \qquad Y_1 = \frac{N_2}{N_1} = \frac{N_2}{N}\, p = Y\, p.$$

$$\text{And} \qquad \frac{M_1}{M} = \frac{N_1}{N} = \frac{1}{p}.$$

$$\text{Therefore} \qquad \frac{Y}{Y_1} = \frac{M_1}{M} = \frac{1}{p}. \qquad (7)$$

The case $\frac{\Delta\rho\, V}{M_1} = 0$ corresponds to a thermal moving through uniformly neutral surroundings. Since the number of marked particles in such a thermal is constant, Y must equal 1 for $\frac{\Delta\rho\, V}{M_1} = 0$. (8)

From (4), when $\frac{\Delta\rho\, V}{M_1} = 0, \quad Y_1 = k.$ (9)

From (7), (8), (9), $p = k.$ (10)

$$\text{From (4), (7), and (10),}\quad Y = 1 - \frac{\Delta\rho\, V}{M}, \quad \frac{\Delta\rho\, V}{M} \leqslant 1$$
$$Y = 0, \quad \frac{\Delta\rho\, V}{M} > 1. \qquad (11)$$
$$\text{where} \quad K = \frac{K_1}{k}.$$

From (5), (6) $\quad K \Omega 2.$

### Application to gliding

Equations (11) indicate that if a sharp atmospheric inversion is such that $\frac{\Delta\rho\, V}{M} > 2$ approximately, no part of any such thermal which began below the inversion level is to be expected far above that level. On the other hand, we may expect that some fraction of any thermal for which $\frac{\Delta\rho\, V}{M} < 2$ will proceed upwards indefinitely.

As a numerical example, measurements of atmospheric thermals by Miss Woodward (Woodward, 1956) lead to $\frac{M}{\rho\, V} = -\frac{1}{540}$ for a particular thermal. If a sharp inversion existed at the same height, we may calculate the temperature change there which would just prevent the continual progress of any part of such a thermal.

Thus $\frac{\Delta\rho\, V}{M} = 2$, and so $\frac{\Delta\rho}{\rho} = -\frac{2}{540} = -\frac{\Delta T}{T}$,

where $\rho$ is the air density and T the absolute temperature at the level of the inversion. $\Delta T$ is the required temperature change.

If T = 290 °K say, then $\Delta T \, \Omega + 1$ °C.


**References**

Scorer, R.S. 1957 Experiments on convection of isolated masses of buoyant fluid, J. Fl. Mech. 2, 583.

Woodward, B. 1956 Exploration by sailplanes of the structure of thermals, O.S.T.I.V. News, Supplement to Swiss Aero Revue, Sept., 1956.

Woodward, B. 1959 The motion in and around isolated thermals. Quart. J. Roy. Met. Soc. 85, 144.