Experiments with Convection Bubbles

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The bubble theory of convection, which has received renewed attention in recent years, came into existence because glider pilots felt that it gave the best explanation of their soaring experiences and because cumulus towers often looked like ascending buoyant bubbles. In order to shed new light on the subject a simple convection experiment in the laboratory was set up.

The primary difficulty of having model experiments imitate convection in the atmosphere is to introduce the buoyant fluid into the model in the same way as it is introduced in the atmosphere. There is no trouble about the medium; water is a satisfactory replacement for air since the motion in the experiment is fully turbulent and viscous forces are negligible; in addition all velocities are produced by buoyancy forces.

Instead of having warm, light fluid rising from the bottom, a heavy fluid was put in at the top. The "bubbles" were created by having a spherical cup, which was partly immersed in the surface of the water, pivoted about a horizontal axis through its centre. The cup was filled with a salt solution made visible with a white precipitate, and then quickly overturned. A dome of heavy fluid was thus "created" and its subsequent behaviour was observed.

The maximum excess density of the bubbles was less than 15 %. No matter what the size and density of the original bubble, all the experiments were geometrically similar. The only difference in the results produced is that the greater the excess buoyancy of the original bubble the greater are all the velocities—both the turbulent velocities and the velocity of the "rise" of the "thermal". An experiment with a large (10 %) initial density difference was not distinguishable from one with a small (1 %) initial density difference when both were shown by cine projector so as to appear to be taking place at the same speed.

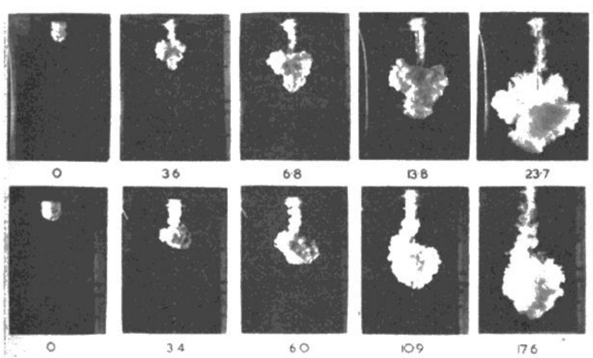

Figure 1. Successive pictures of two separate bubbles which have been released into a tankful of water of uniform density. When viewed from above there was a hollowing out of the top of the bubble giving a vortex ring appearance. Numbers indicate time, in seconds, from release

When the bubbles were released into a tankful of water of uniform density (corresponding to an adiabatic lapse rate in the atmosphere) one of the outstanding features was the absence of any wake. Motions behind the bubble were small and the material in it very tenuous. The bubble became turbulent immediately after release and, as can be seen in figure 1, its appearance at latter stages is a magnified version of an earlier stage. The only difference is that it has become diluted by mixing with the surroundings and consequently the rate of sink has descreased. During its entire history the bubble lies within a cone whose apex is just above the cup from which it was released.

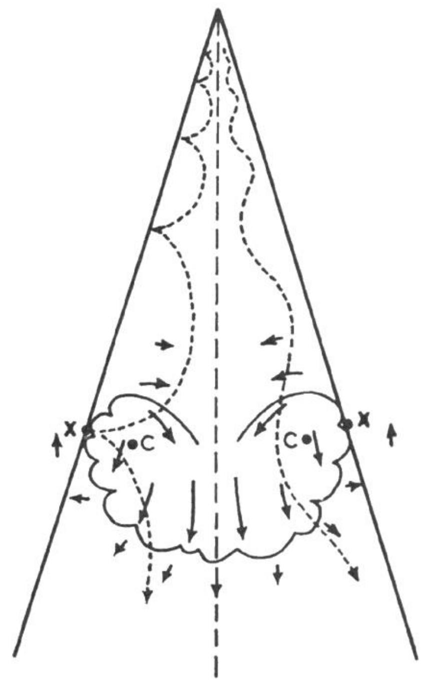

Figure 2. The field of motion in and around a bubble. The arrows show the velocity of the particles not taking the turbulent mixing into account. The particles inside the bubble are moving faster than those outside and are moving into, and mixing with, the fluid in the path of the bubble. The bubble is turned inside out several times, each time being represented by a step in the paths of two average particles shown. The particle on the left appears close to the front and passes round to the rim where it becomes temporarily stationary. The particle on the right remains inside the bubble circulating around the core of the vortex ring (c). The ring grows in proportion to the size of the bubble, and the motion would appear to be circulating round the core to an observer moving with the bubble. To a stationary observer it appears to be circulating round the ring X on the rim of the bubble

Figure 2 shows the field of motion in and around a bubble. The feature which is of primary interest to the glider pilot is that the motion inside the bubble becomes rather like that of a vortex ring; i. e. the vertical velocity in the centre is greater than the rate of sink (the rate of rise in the case of a thermal) of the entire bubble. As long as this difference in velocity is greater than the sinking speed of the glider, the sailplane will rise in relation to the thermal. It will continue to rise in the bubble until the difference in the vertical velocities is equal to the sinking speed and then continue upwards at the rate of rise of the total bubble. Until now laboratory measurements of velocity have been limited to the rate of rise of the entire bubble. In future experiments the velocity of particles in various parts of the bubble will be measured.

As long as the surroundings are neutrally stable the height of the bubble is approximately equal to the width. If one is flying a 30 second circle at 38 knots then the diameter of the circle is approximately 600 feet. As the glider is flying close

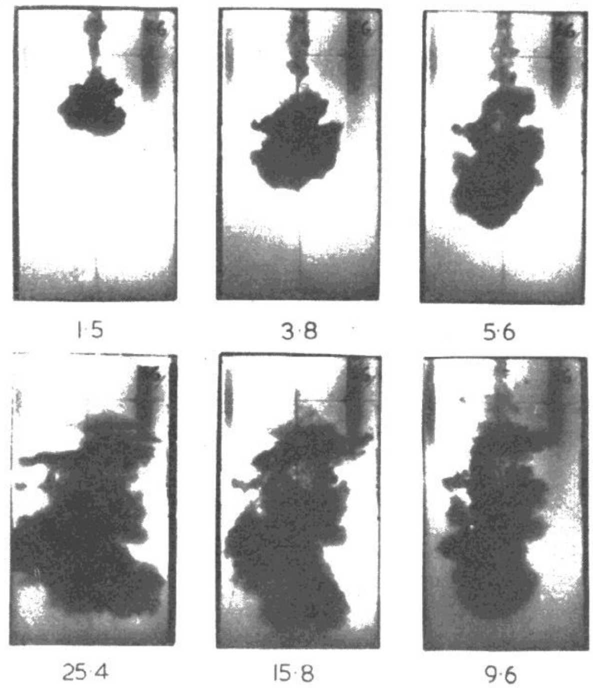

Figure 3. A bubble released into a tank, the top quarter of which has uniform density and below which the density gradually increases. There is a similiarity between this experiment and the rise of a thermal into stably statified surroundings

to the centre of the thermal it can be assumed that the total diameter of the bubble is 800—1200 feet, which appears from observation to be a reasonable height for an isolated thermal bubble.

Because these experiments are dynamically similar to the motion in the atmosphere we may draw certain conclusions. It must however be remembered that assumptions have been made. In the laboratory the bubble has been released as a "blob" the density of which was uniform throughout. In addition it was released as a solitary thermal. The density of the surrounding water in the tank was neutrally stable from the surface to the bottom of the tank. In the atmosphere there is generally a super adiabatic (unstable) layer near the ground. One cannot therefore compare the laboratory thermal bubbles with desert rotating thermals (dust devils).

Additional experiments will be made and observations and results will appear in this journal. Instead of releasing a "blob", a column of dense fluid will be introduced into the tank. It is believed that the "column", once it is cut off from the surface, will eventually compose itself into a shape of the type already observed. The leading edge of the "column" will, by mixing, become more dilute; the tail of the "column", which remains more concentrated since less mixing occurs on the sides, will catch up with the leading edge.

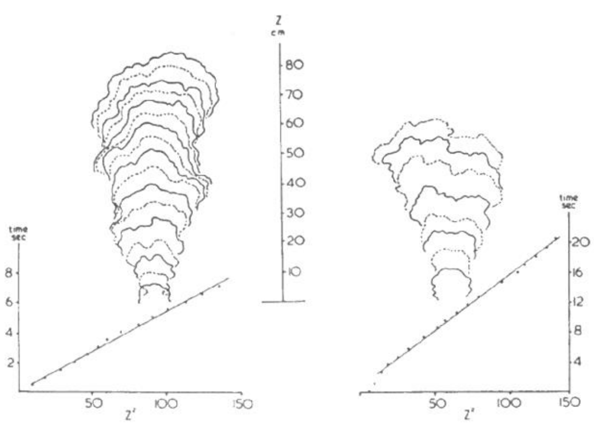

Figure 4. The distance z form the point source vs. time

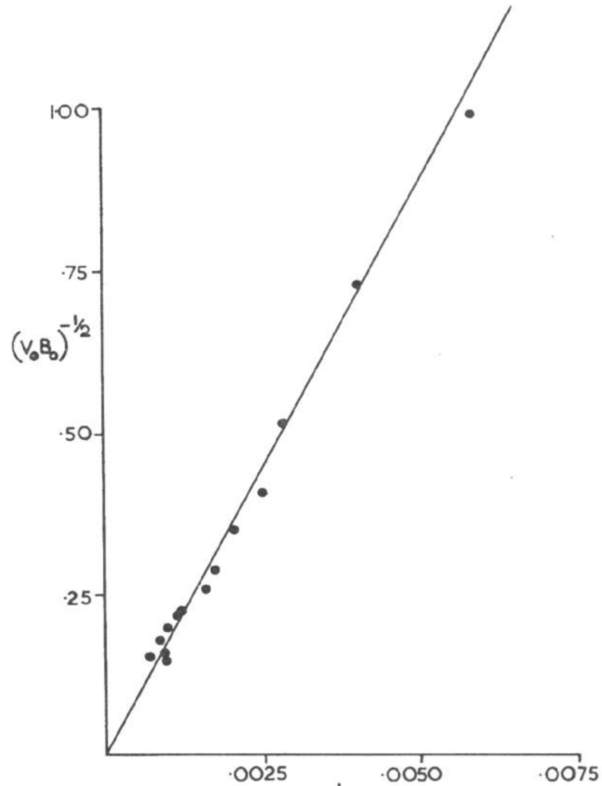

Figure 5. Showing the initial buoyancy $-\frac{1}{2}$ proportional to k, $\frac{\text{time}}{\text{height}}$2, for 14 experiments

Using the normal methods of dimensional analysis it is found that the vertical velocity and the rate of widening of the "cloud" are proportional to each other so that the width $2R$ is proportional to the distance Z of the front of the cloud from a suitable origin above the position or release where the size is finite. The vertical velocity W is also proportional to $(gBZ)^{1/2}$ where B is the mean buoyancy. Since the total buoyancy is constant and the volume is proportional to Z^3 we find that

$$Z^2 = C^{-1}(B_0V_0)^{1/2}t = k^{-1}t \qquad (1)$$

where C is a constant and B_0V_0 is the initial total buoyancy, V_0 being the initial volume. Equation (1) is found to be satisfied for the bubbles separately (fig. 4) and if we measure k for each it is found to be proportional to $(B_0V_0)^{-1/2}$. This is shown in figure 5.

This gives a value of C for all cases equal to 0.006 cgs and since it is based on dimensional analysis and no new process, other than the mechanism of release of thermals, we can apply it to atmospheric thermals. C has dimensions because it contains $g^{1/2}$.

In the experiments it was found that approximately $Z = 4R$ and $V = 3R^3$, and by differentiating equation (1) we have

$$W = \frac{(3R^3\bar{B})^{1/2}}{8CR} \qquad (2)$$