# Radar "Angel"

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Radar echoes which are received from regions of the atmosphere in which there are apparently no scattering particles are known as "angels". On the display tubes of search-radars angels are sometimes very similar to aircraft echoes, and as the power of radars is being increased, so angels are becoming more of a nuisance to aircraft controllers.

Some angels have been attributed to clouds of insects, invisible from the ground, but it is clear that the great majority are associated with inhomogeneities of atmospheric refractive index. There are several kinds of angel echo, and their various properties will need more intensive study before any satisfactory theory of their origin is formulated.

Changes in the refractive index of air may be due to variations in temperature or in vapour content. The magnitude of the local variations in the atmosphere is such that they are unlikely to cause radar echoes unless they are concentrated over distances of less than 1 cm. Moreover, even such large gradients of temperature or vapour content cannot produce a distinct and persistent echo unless they occur across a surface which occupies a large part of the radar beam, which at moderate ranges has a width of more than a kilometre. The meteorological problem arises, then, of how a near discontinuity of temperature or vapour content can be formed and maintained in a surface having a linear dimension of about a kilometre.

According to the bubble theory of penetrative convection (Scorer, 1956) the cap of a thermal or cumulus tower represents such a surface. The pattern of flow in and near a rising bubble is considered to generate and sustain a sharply-defined, roughly hemispherical cap, across which the temperature excess of the thermal, or the vapour excess of the cloud tower, is concentrated. It is therefore interesting that angels are frequently, if not predominantly, associated with weather in which convection is active. Ligda has recently described lines of angel echoes which advance 2 or 3 kilometres ahead of thunderstorm echoes, and in the following paragraphs I list some features of other kinds of angels which are often seen in convective weather on the powerful 10 cm radar of the Meteorological Office Radar Unit near Dunstable, England. (They will be discussed more fully in a forthcoming paper prepared jointly with W. G. Harper and P. Saunders.)

At ranges of up to several miles, and on some bearings perhaps even beyond, the display of the radar is confused by echoes from prominent topographical features, such as hills and tall buildings. On the range-height display of a radar whose beam sweeps in a vertical display these ground echoes appear to extend upwards to about 1000 feet. On days of warm sunshine some ground echoes, few of which are identifiable with particular objects, are often much stronger, and extend up to as much as 2000 feet. The echoes are columnar, and frequently have a noticeable slope. They may persist for several hours in particular places. Occasionally small blobs of echo become detached from such columns or appear independently at heights of about 2000 feet, and can be observed for several minutes, apparently moving with the wind. In such a period they may ascend by up to about 1500 feet, but sometimes, especially before disappearing, they descend a little. Often such echoes are grouped into lines, lying more or less in the wind direction, and into parallel lines separated by perhaps 10 kilometres. At the up-wind end of a line the angels may be at low level, but they may be noticeably higher at the down-wind end. Several ascending angels have sometimes been located near or beneath rapidly building large cumulus, and some have then been followed to levels near or even above the cloud base. Lines of angels, 10—20 km in length, can be associated with lines of cumulus which occur in closely corresponding positions.

So many of the properties of these angels are interpretable in terms of the behaviour of thermals that there seems little doubt that thermal caps are the sources of the echoes. However, there are difficulties in the way of a satisfactory theory of the echo production, and further observation and thought are needed. Tentatively it is supposed that the angels signal the presence of strong thermals, with large temperature excesses.

Another kind of angel, called a "mantle echo", is received from cumulus clouds which do not contain any precipitation. It is typically a persistent, but a weak and diffuse echo, in contrast to the angels described above, which are bright, compact "blips" on the radar display. On the range-height display the mantle is seen as an inverted U or V which shows the outline of the cloud in the section swept by the radar beam. Very similar echoes have been seen on a cloudless day when thermals were reaching stable, dry air at a level a little below the condensation level. Evidently this kind of echo is associated with the change of refractive index produced by the difference in the vapour content of cloud (or damp thermal) air and the surrounding clear, and drier air. According to a tentative theory, a part of the radar beam is temporarily trapped inside the cloud, echoing within its walls and becoming bent into the reverse direction, escaping and returning to the receiver.

It is intended to resume the investigation of angel echoes next summer, with the help of a sailplane. If this can be directed into the echoes it should be possible to decide wether thermals are indeed the sources, and the magnitude of the temperature and vapour content excesses within them. If glider pilots are already wondering if a radar would be useful in locating strong thermals, they should consider that a suitable radar costs the equivalent of several hundred sailplanes.

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