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The following notes are extracted from Air Ministry Publication M.O.M. 393.

"Note for the Guidance of Forecasters on the Subject of Forecasts of Ice Accretion on Aircraft (Revised)", 1942.

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1. General. The following notes are written for the guidance of forecasters, in order that action taken by them should be on uniform and approved lines. It is assumed that, in every case, a recent synoptic chart, properly analysed, is available.

Statistical evidence shows that in the British Isles ice accretion occurs in cloud below 4,000 ft. above M.S.L. practically only during the months November to April inclusive. In abnormal conditions icing may occur below 4,000 ft. in May or October. Cases of ice formation down to about 4,000 ft. may occur at any time of year, and between 10,000 and 15,000 ft. ice formation is more frequent in summer than in winter.

The most dangerous temperatures for ice formation are between 32°F. and 20°F. At temperatures below 15°F. serious ice formation is mainly limited to convectional clouds. In extreme cases, with strong convection, ice formation may occur at much lower temperatures.

In clouds with strong convection, water vapour which has been condensed into droplets at comparatively high temperatures is carried up en masse, and so rapidly that even at temperatures below 20°F. there may still be a large quantity of water which is not frozen, because there have been in it initially no ice crystals to start the freezing process and no ice crystals could descend into it from higher levels. This region is therefore particularly favourable for ice formation on aircraft entering it.

At temperatures above 32°F. (up to 35°F.) ice may form temporarily on a small scale on aircraft entering a layer of air at these temperatures direct (usually by descent) from layers at temperatures below 32°F.

Apart from glazed frost (see section 5) convectional clouds cause the worst ice formation. Aircraft can usually avoid these in daytime though not in the night. They may also be unable to avoid them in daylight at a cold front, or where convergence or orographic influence has resulted in an extensive mass of convectional cloud. It follows that cold fronts (or cold occlusions) are on the average more important than warm fronts for ice formation. Warm fronts during or just after a frost form an exception to this rule. Even when there is no glazed frost, there is sometimes an abnormal thickness of ice-forming cloud. At Mildenhall on January 4, 1939, temperature only fell from 32°F. at the surface to 27°F. at 6,000 ft. and to 15°F. at about 10,500 ft. Clouds were continuous from 800 ft. to a great height and severe icing was reported. Such conditions are more frequent on the continent than in the British Isles.

In hilly or mountainous districts the condensed water vapour may be carried up by convectional currents, due to the hills or mountains, in the same way as it is carried up in convectional clouds originating from purely thermal causes. Thus in these districts conditions will be more favourable for ice formation than they are in flat country, simply because of this increased upward convection which may result in relatively dense supercooled cloud for the reasons given above.

Over the sea conditions may be very different to what they are over the land. This is due partly to the fact that in winter the sea is relatively warm and in summer relatively cold; and partly to the fact that the sea is never dry, but provides a steady source of water vapour, whereas in summer, the warm season over the land, the earth's surface is frequently dry and evaporation from it into the atmosphere may be very smal

One consequence of this difference between sea and land is hat in winter cumulus and cumulonimbus clouds are more common over the sea with the result that icing conditions may be worse over the sea than over tha land. A factor of prime importance is the vertical distribution of temperature. If there is an inversion of temperature at a moderate height, the cloud will be stratocumulus, but if an appreciable gradient of temperature extends to great heights, then after a long sea track the cloud will be cumulus or cumulonimbus. A case of some importance is that a cold northwesterly current across the North Sea. In such a current cumulus and cumulonimbus clouds increase both in quantity and thickness as they travel south-east, and by the time they reach the German coast often form a dense mass of convective and upercooled cloud with general bad weather conditions.

Actual reports of ice may be received from Mildenhall or Aldergrove, or from other places. To what extent the reported conditions are general or local must be judged from the chart. Local variations are most likely to be due to convection, which greatly affects the distribution of cloud and humidity.

2. No recent observations of upper air temperature available.

The lapse rate must be estimated by using all the relevant information on the chart. The primary factors will be the surface air temperature and the origin and history of the air mass. When considering the surface temperature the effect of nocturnal radiation must be allowed for. This is often large at 7 h., but coast stations with a wind off the sea are not appreciably affected.

With regard to the origin of the air mass, polar air has normally a lapse rate close to the dry adiabatic rate up to the cloud base, and a lapse rate about (or slightly above) the saturated adiabatic rate in the layer containing clouds, since heat is usually being applied to the surface layers by the land or sea. The same applies to maritime polar air provided it has not passed too far south. In doubtful cases it is useful to compare the temperature at the coast station with the average sea temperature for the month, and to use any available data from ships. If the air temperature is below that of the sea the lapse rate near the surface is adiabatic (sometimes superadiabatic in a thin layer). If the air temperature is above that of the sea, there is a small lapse rate (often an inversion) in the surface layer.

In currents of tropical or sub-tropical origin there is marked stability in the lowest 2,000 or 3,000 ft. and upper air temperature is well above the normal for the month. The temperature difference betwee tropical air and maritime polar air is much greater up aloft than at sea level.

Continental polar air is usually stable in winter, but it becomes unstable when crossing the North Sea, and if there are clouds an adiabatic lapse rate will prevail at coastal stations up to the cloud level

In maritime polar air the steep lapse rate often extends only to the height of a few thousand feet, above which there is an inversion or stable layer. In estimating whether this is likely on an individual occasion it is important to take account of subsidence. If the isobars are curved anticyclonically, the air has nearly always subsided. Thus, for example, in a wedge there has usually been subsidence. In estimating the level of the inversion the following considerations are important. If there are clouds, i.e. flat-topped cumulus or stratocumulus the inversion is likely to be at their upper surface which will frequently be a practically level surface. The cloud layer is likely to be not more than 2,000 ft. thick (measured from the base of the layer cloud and not from the base of the broken clouds which are frequently found beneath layers of stratocumulus).

Observations of upper air temperature made on the previous day should be used with great caution. This applies not only to temperatures observed over the area under consideration, but also to temperatures observed the previous day over the area from which the air has come and which the air might be assumed to have brought with it. Large non-frontal temperature changes in 24 hours may be due either to subsidence or to advectional changes apparently within an air mass.

3.1 Recent information of upper air temperature available from Mildenhall, Aldergrove, Scilly, Lerwick or elsewhere.

This information should be used in conjunction with the synoptic chart. It is important that the information should be really recent. If the observations refer to the previous day, or even to a time several hours before, they must be used with caution as indicated in the preceding section.

In the event of observations, recently made, not covering the whole of the British Isles, or the region for which the forecast is required extending over an area not covered by available data, the considerations discussed in sections 2 and 4 must still be taken into account, especially if there are frontal conditions in the neighbourhood. Allowance must also be made for latitude effect - temperatures in the north of Scotland may be appreciably below the values at Mildenhall or Aldergrove, and those in the south-west appreciably above, though sometimes the reverse is the case.

The general horizontal temperature gradient within an air mass is not often much in excess of 1°F. per 100 miles. Mildenhall and Aldergrove are 315 miles apart, and in the period January - March 1938, the temperature difference at 800 mb. did not exceed 4°F in 65 per cent. of cases. Of the remaining 35 per cent., 19 per cent. were frontal and 16 per cent. non-frontal. In a few of these cases the temperature difference was due to the variation in height of a subsidence inversion. In most cases there was a wedge of high pressure or newly formed anticyclone over the British Isles. This is the condition which usually gives large horizontal temperature gradients without fronts. In a few cases there was a cold or stationary front not far to the north or north-west of Aldergrove. The temperature gradient in the warm air often steepens near the front.

Variations of temperature over small areas are occasionally important, especially at about the base of inversions or stable layers. Minor fronts, sea breezes or orographic effects may cause an upward protrusion of cold air under an inversion by 1,000 ft. or even more, and undulations with an amplitude of a few hundred feet are quite common. A case is on record when the observations on an aeroplane during the descent were about 7°F. colder than those on the ascent in a layer 2,000 ft. thick. This cannot have been due to lag as there was an inversion above the layer in question, the inversion being higher on the descending flight. The observations are confirmed by an autographic trace. The change was not due to a recognisable front. This was an extreme case, but it is important to realise that local irregularities do occur. Thus if there are clouds at a temperature only just above 32°F. under an inversion there may still be conditions at no great distance favourable for ice formation.

4. Fronts. In the case of an aircraft crossing a front an attempt must be made to estimate the structure of the front as nearly as possible. The angle of slope of a warm front is usually 1 in 100 to 1 in 150, and of a cold front about 1 in 50. The width of the rain belt, though not a reliable guide, gives some idea of the angle of slope. If continuous rain falls some distance behind a cold front the angle is probably below average, perhaps 1 in 100. At the boundary surface there is rarely an inversion, but usually marked stability through a layer some thousands of feet thick, with a lapse rate below the saturated adiabatic. Precipitation in unsaturated air tends to reduce the temperature to the wet-bulb temperature previously existing.

Many fronts over the British Isles have been occluded for a considerable period, so that the original warm air has ascended to a high level and the rain is due to convergence and the difference between the two polar air masses. In such cases the lapse rate in the rain area is roughly the saturated adiabatic. The lapse rate is usually somewhat greater behind than in front of the rain belt. This holds also for rain areas formed by the amalgamation of cumulonimbus clouds at a minor front in unstable air.

5. Glazed frost. Owing to the rarity of true frontal inversions, glazed frost is rare, being largely confined to low levels in winter. In the British Isles true glazed frost (i.e. supercooled rain) is very rare, and is almost entirely confined to cases when very mild air overruns very cold continental air of Arctic or Siberian origin. A case occurred in southern

On the continent and on the eastern side of North America glazed frost is not so rare as in the British Isles. It is most likely at a warm front, but may occur behind a cold front advancing from north-east, as on February 4, 1922 in Europe.

A severe glazed frost occurred over a belt extending from Sussex and Hampshire across the south and west Midlands to north Wales on January 27 to 29, 1940. The meteorological conditions conformed with those mentioned above. The glazed frost occurred behind a cold front which moved slowly south-west against the component of the geostrophic wind at right angles to it.

6. Supplementary notes on icing in cloud and its relation to visibility and size of drops.

(ix) Conclusions. - with these facts in mind the following conclusions may be set down :-

(a) In stratocumulus where drops are small, the ice accumulation will not be rapid even though visibility may be bad. Sometimes there will be cumulus formation in a stratocumulus cloud and there the icing may be rapid. In this cumulus formation the drops will be larger and the visibility worse than in other parts of the stratocumulus layer.

(b) In nimbostratus which has been in existence for a long time the water drops are likely to be large and so icing may be rather more rapid even though visibility is not very bad.

(c) Broadly speaking the rate of ice accumulation will be more rapid in convectional clouds the bases of which reach down far beneath the freezing level than in those with bases only a short way beneath the freezing level. The reason is that in the former case more free water is likely to be available than in the latter. Visibility may be no guide in this case.

(d) In general, the history of the air mass is of great importance in assessing the probable amount of free water available and the drop size.

(e) In a cloud with strong vertical currents, such as cumulus and cumulonimbus, the amount of free water is high because even large drops are supported by the upcurrent. It has often been reported that ice accumulation is heavy in the cumulus and cumulonimbus clouds which are found with very low bases over the North Sea in polar currents. These clouds have travelled long distances over comparatively warm seas, and though the surface temperatures are only, say 45°F., it is quite likely that the amount of free water in these clouds is very high, because they will have grown as they travelled - the water vapour in the clear air, continually going up through the base of the cloud, condenses on reaching the cloud and makes it grow bigger, and owing to the up-current in the cloud the larger cloud drops are kept in it.

(f) In massive cumulus cloud the icing is more likely to be heavy in the heart of the cloud than near the perimeter or the base, particularly if the base is sharply defined.

(g) If the base of a cloud looks woolly and temperature is suitable it is more likely to give heavy icing than a similar type of cloud with a sharply defined base.

Conclusion (g) must be looked on as tentative as it is reached by inference from the physics of clouds.

(x) Icing in Snow Clouds. - There have been reports that icing has occurred during snow. Since, however, dry snow will not stick to the plane and melting snow is of necessity at a temperature above freezing, it might be thought at first sight that the occurrence of icing in snow was a contradiction. It is probable that the explanation is as follows :-

In a cloud of considerable depth and particularly in a precipitating cloud the top of the cloud is snow. Lower down, however, it is likely that there are cloud particles of supercooled water.

The snowflakes from up above will fall with considerable speed relative to the cloud particles and so in some layers with temperature appreciably below 32°F. there will be a mixture of snow and supercooled drops. The snowflakes, it is true, will tend to increase at the expense of the water drops but snow and water will exist for some time together at temperatures below freezing.

The condition is not what is generally understood as wet snow, a term applied to snow in process of melting, but an aeroplane flying into such a cloud will collect a mushy sort of ice rather rapidly, the snow being stuck on by the freezing cloud particles.
