AVIATION SERIES

AVIATION SERIES NO. 1

FLYING WEATHER FORECASTS . . .

How USEFUL Are They ?

●

U. S. WEATHER BUREAU

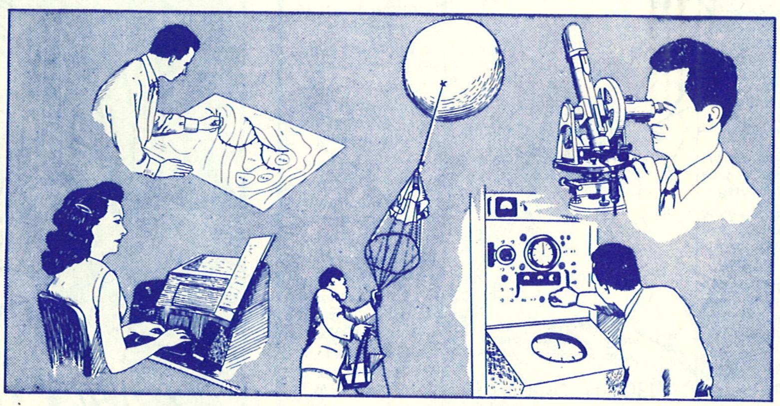
Flying Weather Forecasts...

There is a lot of speculation, conjecture and misinformation about what weather forecasters CAN and CANNOT do about forecasting flying weather.

This article is to tell you, the PILOT, what you can expect in the way of forecast ACCURACY and something of how far in advance the meteorologist can forecast.

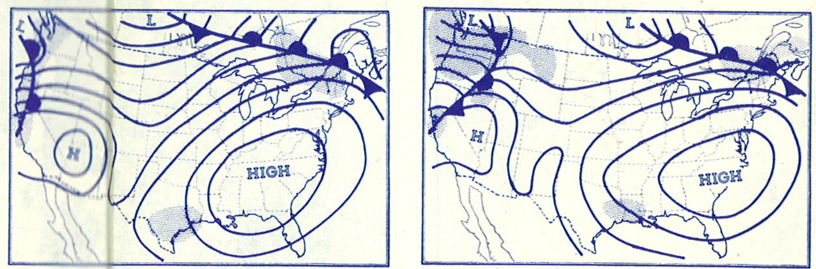
The meteorologist can give the pilot the answers to many of his weather problems. He has at his fingertips more weather information than anyone else, placing him in a position where he can be of considerable help to the pilot.

There continues to be speculation that weather tends to follow definite cycles and that once the cycle is known it should be possible to forecast ceilings and visibilities for several days in advance. There is NO accepted scientific foundation for such ideas, nor are there any known methods whereby it is possible to accurately forecast what the flying-weather will be for several days ahead. On the other hand, man's knowledge of the behavior of the invisible atmosphere continues to increase. Modern weather instruments are used to make precise weather observations, not only to determine conditions at the earth's surface, but to sample the wind, temperature, and moisture conditions of the atmosphere to heights in excess of 50,000 feet as an aid to forecasting.

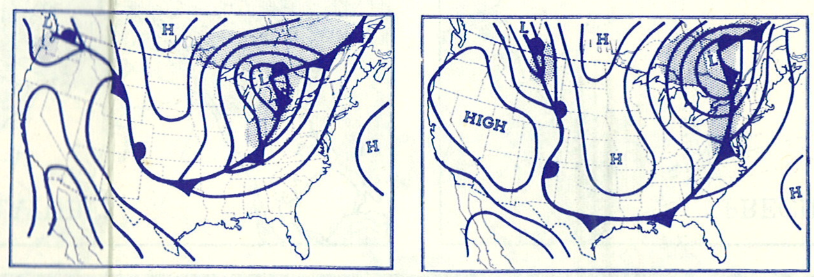


MODERN INSTRUMENTS AND TECHNIQUES HELP THE METEOROLOGIST TO CHART THE WEATHER

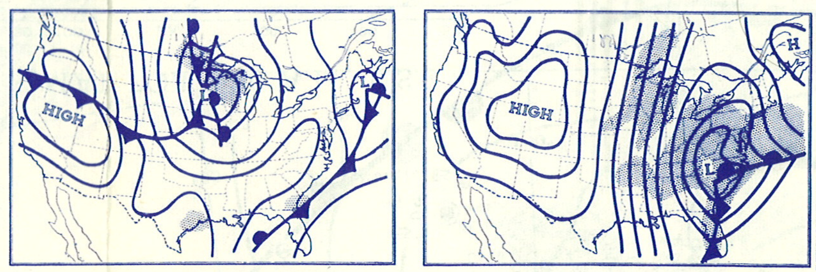
Flying Weather Forecasts...



WEATHER MAPS FOR TWO SUCCESSIVE DAYS SHOWING VERY LITTLE CHANGE IN 24 HOURS



WEATHER MAPS FOR TWO SUCCESSIVE DAYS SHOWING EXAMPLE OF CONSIDERABLE CHANGE IN 24 HOURS

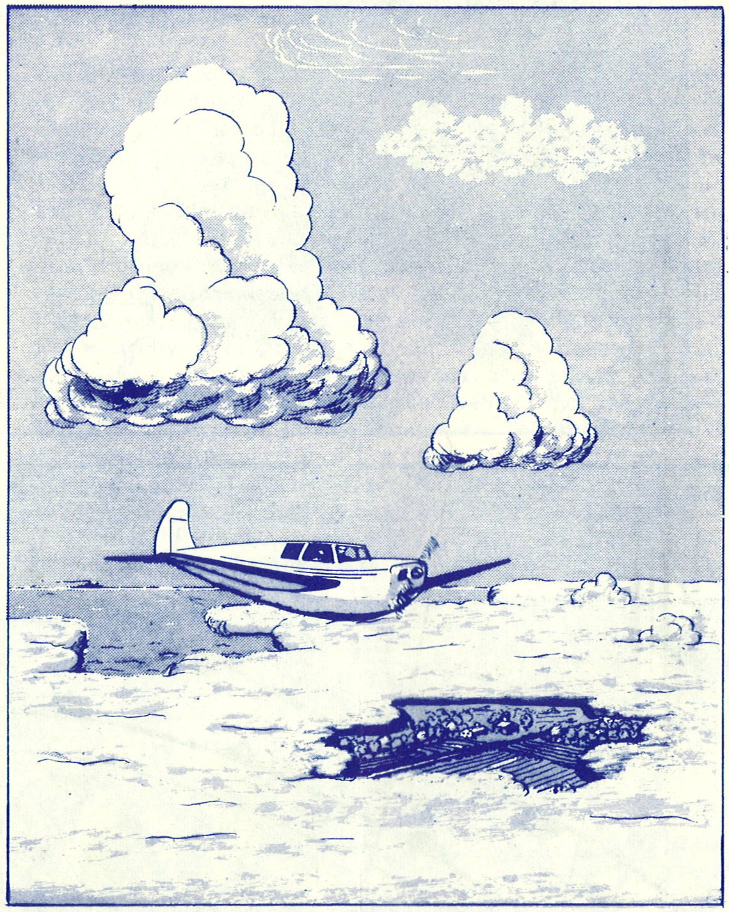


WEATHER MAPS FOR TWO SUCCESSIVE DAYS SHOWING EXAMPLE OF VERY GREAT WEATHER CHANGES

Pilots, through their own experience, know that flying weather manifests itself in very complex, irregular, and ever-changing forms that sometimes defy complete description. The futility of trying to classify these variations into definite cycles in the weather should be evident

Flying Weather Forecasts. . .

to anyone who has flown through a widespread weather disturbance and noted the extreme variations in clouds, visibility and weather over short distances and in relatively short times.



CLOUD AND WEATHER CONDITIONS CAN CHANGE CONSIDERABLY WITHIN SHORT DISTANCES AND IN RELATIVELY SHORT TIMES

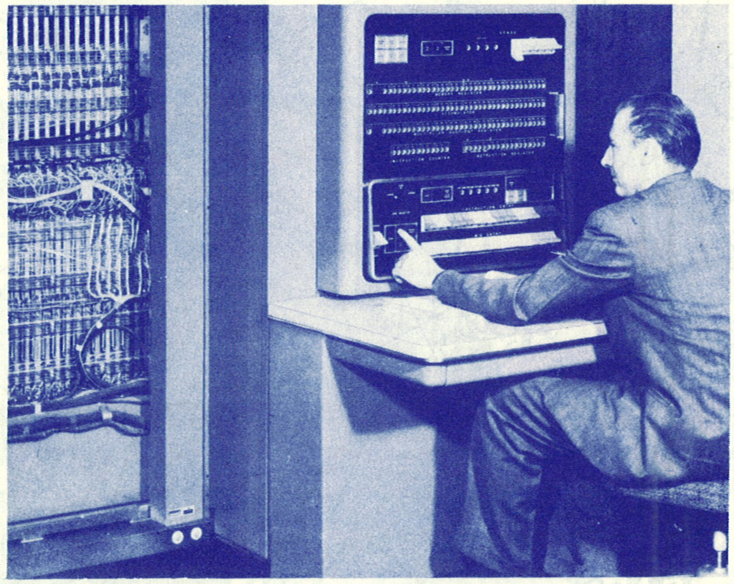
WHAT, THEN, CAN THE FORECASTER DO ?

It is usually possible to make satisfactory flying weather forecasts for periods of 12 to 24 hours in advance. For shorter periods forecasters have about 85% success in forecasting the lower ranges of cloud heights within a few hundred feet and in forecasting the lower ranges of visibility within a mile or so.

For periods of a day or two in advance, the forecasters usually can give general indications of the expected weather conditions and cloud heights. But they cannot be as specific as in the case of the short term forecasts. Thus it is necessary that pilots accept these preliminary indications of cloud heights, visibilities, winds and other weather elements as advance planning forecasts -- OUTLOOKS that represent the forecasters' best views of the probable weather conditions for that far in advance.

As the time of the proposed departure approaches, there will very likely be need for amending the information given in the outlooks and for giving more specific information on ceilings, visibilities, winds, and other elements. Therefore, for operational use it is better that pilots seek the latest available information shortly before take-off even though they may have made some earlier preliminary checks on the expected weather.

Forecasting is not yet an exact science, but meteorologists are doing all they can to improve their product. Comprehensive research programs have been and continue to be carried out within the Government itself and in cooperation with universities, aeronautical foundations, and other research organizations. Within months, an electronic computer will be in daily use to forecast large-scale wind circulation patterns -- a fundamental step that must precede the making of detailed flying-weather forecasts. The fact that many thousands of pilots continue to come to the Weather Bureau each day for information and guidance on flying weather problems is an indication that despite the present day limitations of forecasting, the services offered by the meteorologist are of real value.



Courtesy International Business Machines

PART OF AN ELECTRONIC COMPUTER FOR WEATHER FORECASTING

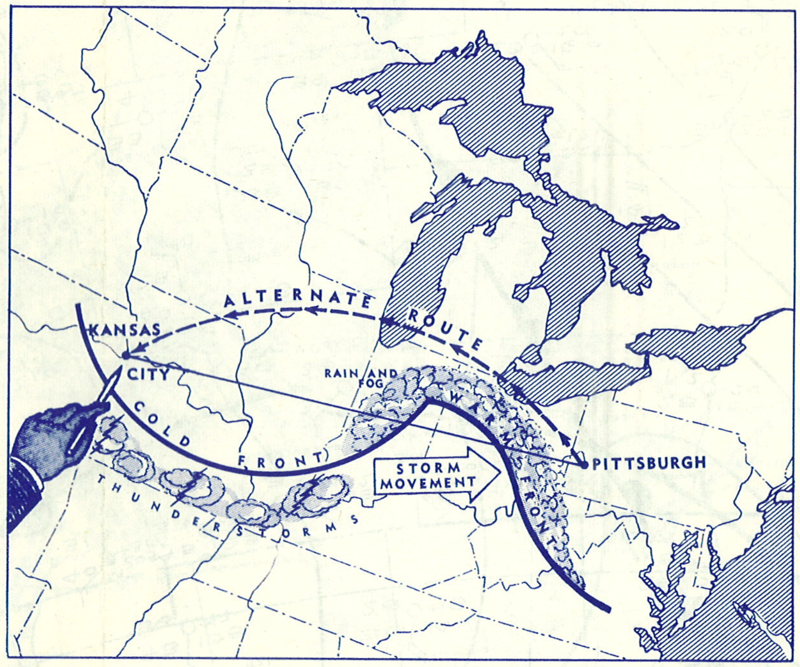
In summary, THESE ARE THE FACTS ABOUT FLYING-WEATHER FORECASTING:

1. The forecaster CAN usually do a good job of forecasting ceilings and visibilities up to about 12 hours in advance. He usually CANNOT tell you with much confidence what kind of flying weather to expect for several days in advance.

Flying Weather Forecasts...

2. The forecaster CAN give you a general OUTLOOK of flying weather conditions for one or two days in advance. He CANNOT make satisfactory flying weather forecasts for longer periods.

3. The forecaster CAN do a good job of telling you some hours in advance when, and the general area where, thunderstorms are likely to occur. He CAN NOT tell you exactly where thunderstorms will be, the exact time they will occur, or precisely forecast their intensity.



WEATHER REPORTS AND FORECASTS HELP PILOT TO PLAN AN ALTERNATE COURSE AROUND BAD WEATHER

4. The forecaster CAN often give you an "out" -- an alternate course of action to take -- in case your weather turns out worse than expected. He CAN NOT do this however, when the weather is doubtful in all areas..

5. The forecaster CAN often tell you some hours in advance when conditions are favorable for tornadoes and the general areas in which they may be expected. He CANNOT tell you precisely when and where a tornado will occur.

6. The forecaster CAN and is anxious to help pilots with their weather problems. He CANNOT make the decision "to fly" or "not to fly" for the pilot.

This is the first of a series of special articles on flying weather that will appear on the back of the Daily Weather Map at approximately one month intervals. Each article will discuss a phase of aviation weather directly from the pilots' point of view. Each one will be aimed at helping pilots to apply weather knowledge to practical flight problems.

The next issue will discuss Aircraft Icing and how to avoid it. Subsequent articles will discuss such subjects as Turbulence, how Radar helps to pin-point thunderstorms, and tips on VFR flying weather. Still others will explain what goes on inside a thunderstorm, and will present charts (by seasons) showing the average number of thunderstorms in various parts of the country and the percent of time the weather is below "1000 feet and 3 miles."

All the articles will be laid out in a form similar to this one so that persons wishing to keep a file of them for future reference have only to punch holes as marked and assemble the material in a note book. A minimum of 12 articles is planned. Additional ones may be issued if there is sufficient reader interest.

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AVIATION SERIES NO. 2

ICE ON AIRCRAFT...

Its CAUSES and EFFECTS

U. S. WEATHER BUREAU

Ice on Aircraft...

It is important that the pilot be informed about icing because of the serious effects it has on his aircraft's performance. When ice forms on the wings, it changes the shape of the airfoil and thereby decreases the lifting capacity of the wing and increases its stalling speed. At the same time, the change of the airfoil shape causes the drag to increase, and this calls for more power to keep the aircraft flying at the same speed. If ice begins to form on the blades of the propeller, the propeller's efficiency is decreased and still further power is demanded of the engine to maintain flight. Thus, the effects of icing are cumulative; sometimes to the extent of forcing the pilot to make an emergency descent unless there are adequate means for disposing of the ice formation on the wings and the propeller. Some of the effects of ice on an aircraft are illustrated in Figure 1.

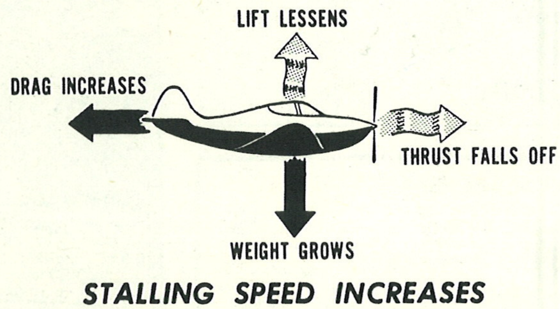
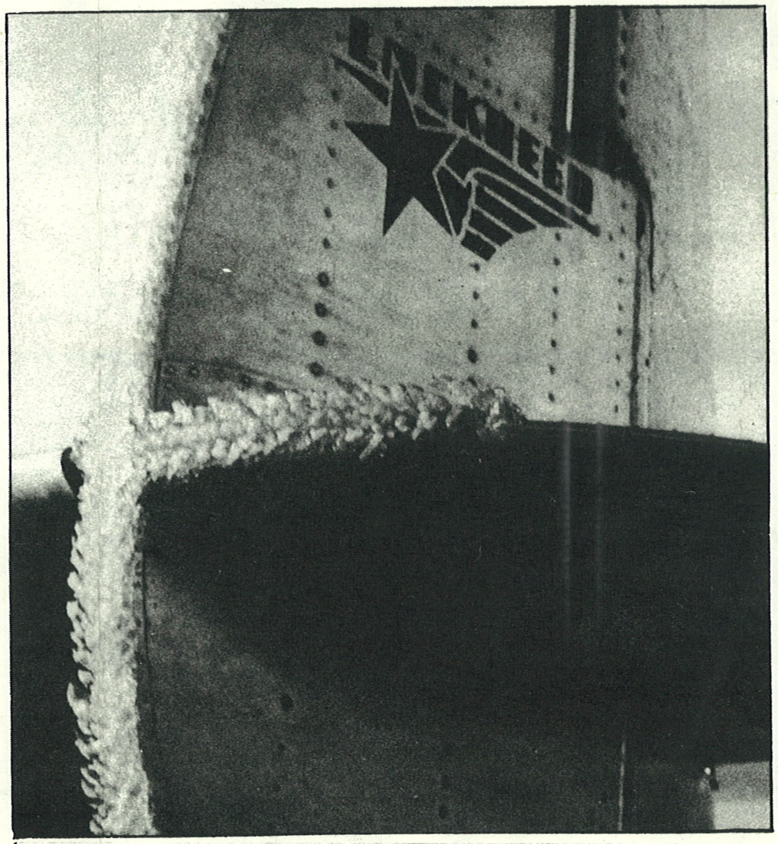


FIG. 1 - ICING EFFECTS ARE CUMULATIVE.

For ice to form on the surface of an aircraft, the air temperature at flight level must be approximately 32° F. or lower, and the aircraft must be flying through visible moisture; such as clouds, rain, drizzle, or wet snow. These conditions are essential to the formation of what is generally referred to as WING ICING.

As a general rule, icing is most likely when the flight temperature is between 32° F. and 20° F., but it is a fallacy to assume that icing of major importance can not occur at lower temperatures -- it sometimes occurs at a temperature of 0° F., or even lower. Icing at these low temperatures results when the water droplets suspended in the air, even though cooled to far below freezing, remain in a liquid state until disturbed. However, they freeze almost immediately on contact with the moving aircraft.

There are two main types of wing icing -- RIME ICE and CLEAR ICE. Rime ice has a white, or milky, appearance. It appears as rough shapes of granular deposits of ice that accumulate on the leading edges of wings, tail surfaces, antenna posts, and so on. When dissected, its interior frequently is found to be composed of very tiny

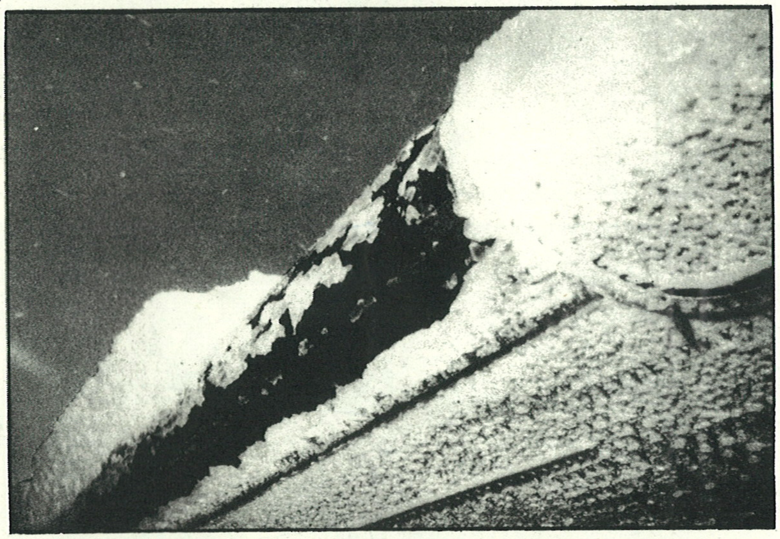


(NACA Photo)

FIG. 2 - CLEAR ICE ON VERTICAL FIN AND OUTBOARD STABILIZER. INBOARD SECTION IS FREE OF ICE DUE TO USE OF HEAT TYPE DE-ICING SYSTEM.

opaque ice pellets or grains, frequently combined with a light, feathery, ice crystal structure. It tends to build forward into the air stream, but it does not ordinarily adhere to the contour of the wing other than a limited area centered about the leading edges. However, it sometimes builds forward from rivet heads or other small projections.

Clear ice is a transparent or translucent coating having a glassy appearance. It may be compared with the glaze type of ice which forms on trees and other objects when rain falls to the earth during freezing weather. It adheres very firmly to the wing surfaces and is difficult to remove. It usually forms first on the leading edges and gradually spreads back taperingly along the wing and other surfaces.



(NACA Photo)

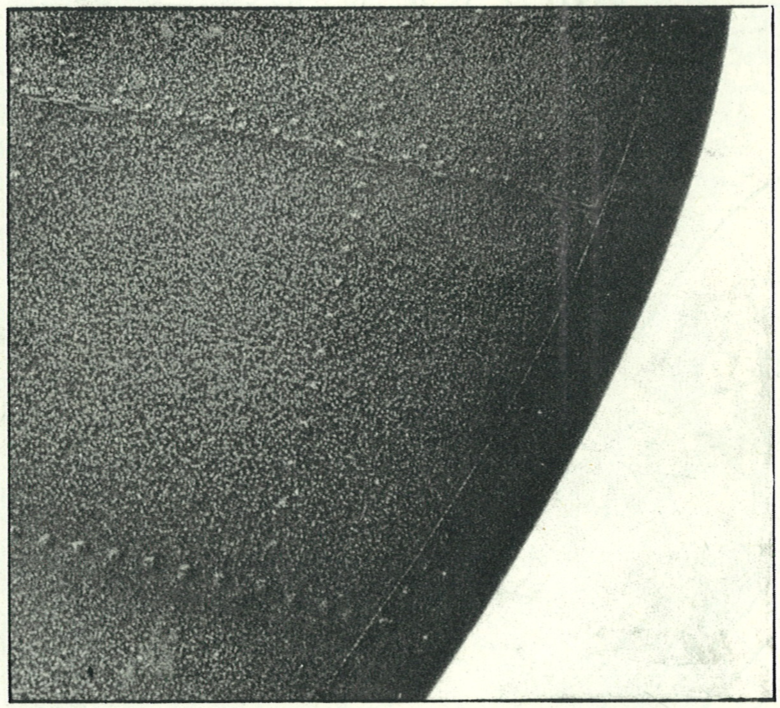
FIG. 3 - RIME ICE WITH SOME CLEAR (GLAZE) ICE ON RIGHT OUTER WING PANEL: LOOKING TOWARD WING TIP.

Large, supercooled water droplets (droplets having a temperature lower than 32° F., but unfrozen), tend to form clear ice, while very small supercooled water droplets, wet snow, and soft sleet tend to form rime ice on the aircraft. Ice formations are often a mixture of clear and rime icing. Figure 2 shows an example of a rough formation of clear ice and Figure 3, rime ice.

Ice on Aircraft...

Frost is a whitish, feathery, crystalline structure. It forms on the upper surfaces of unsheltered aircraft on clear, calm nights when the air is damp and the temperature of the aircraft's surfaces falls to below 32° F. Frost occasionally forms on an aircraft in flight as a result of its flying from a level where the temperature is well below freezing to one where the temperature is considerably higher and the humidity is high. It results from sudden chilling of the moist air by contact with the still cold aircraft surfaces. Frost formed in flight usually evaporates rapidly.

Frost very seriously affects the performance of an aircraft and aviation safety groups have repeatedly stressed the great importance of removing all frost from an aircraft before attempting a take-off. Figure 4 shows frost on the upper wing surface of an aircraft.



(NACA Photo)

FIG. 4 - FROST ON UPPER SURFACE OF METAL WING.

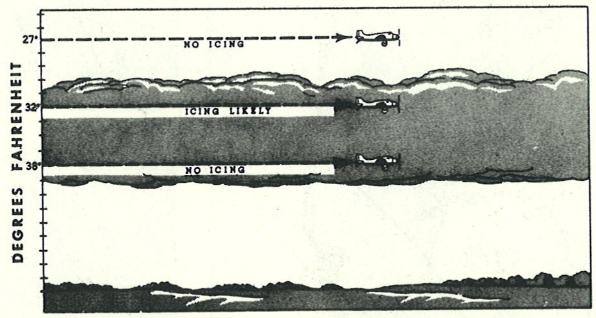


FIG. 5 - ICE FORMS WHEN TEMPERATURE IS BELOW FREEZING AND THERE IS VISIBLE MOISTURE.

Figure 5 shows how an aircraft avoids icing by flying outside the clouds or at altitudes where the temperature is not favorable for ice formation.

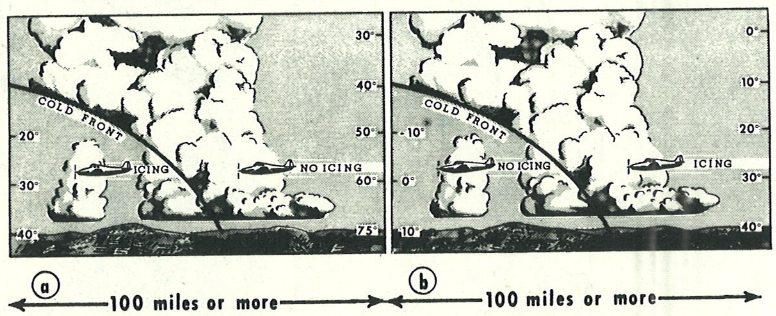


FIG. 6 - PROBABLE ICING CONDITIONS IN THESE TWO EXAMPLES OF COLD FRONTS ARE DISSIMILAR BECAUSE OF DIFFERENT AIR MASS TEMPERATURES.

Figure 6 shows two examples of icing conditions that might be found near a cold front. The differences in the icing conditions in Cases A and B are due to the different temperatures. In Case A, the pilot would not expect to encounter any icing ahead of the front, but he would pick up ice when the aircraft enters the clouds where the air is colder. In Case B, icing would be likely when flying in the clouds ahead of the cold front, since the temperature and moisture conditions would be favorable. On flying well into the cold air behind the front, the aircraft would be in very cold air (lacking in an abundance of supercooled droplets), and the probability of picking up ice when in the clouds would be less.

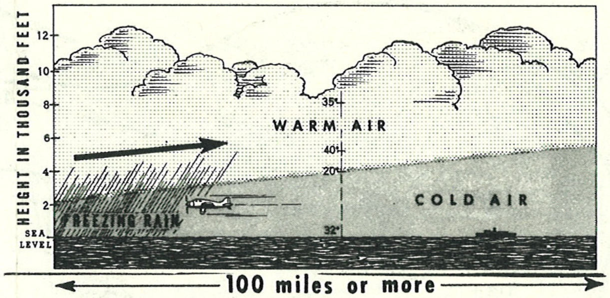


FIG. 7 - EXAMPLE OF FREEZING RAIN UNDER A WARM FRONT.

Freezing rain, which forms clear (glaze) ice, is found most often along a warm or stationary front. Figure 7 is a cross-section drawing of such a frontal condition. As the warm, moist air is lifted over the frontal surface, some moisture must fall out in the form of rain or other forms of precipitation. In this case, the rain forms in air that is well above freezing. But as it falls to the earth, it passes through a layer of air that is below freezing. The rain drops may be cooled to below freezing and yet remain in the liquid state, or they may freeze, thereby turning into sleet. The surfaces of an aircraft flying in the cold air would have a temperature below freezing and if it encountered supercooled rain droplets, they would freeze on the airplane.

Freezing rain is very difficult to remove and if the accumulation of ice continues it is often necessary for the aircraft to take some alternate action to get out of the freezing rain. One way of escaping the ice would be a gradual climb into the warm air above. (A gradual climb is preferred because the high angle of attack in a steep climb favors the formation of ice on the underside of the wing, an area not protected by conventional wing de-icing systems.) Also, if the air temperature at some lower flight level is at least several degrees above freezing, the icing could be escaped by descending. Climbing to get out of the freezing rain sometimes introduces other problems -- the airplane may already have a heavy load of ice that makes it impossible to climb into the warm air and the pilot then has no alternative but to continue flight at his present level or seek a more favorable condition at a lower altitude. If sleet is encountered at flight level, it is very likely that climbing to a higher altitude would result in encountering freezing rain.

Careful flight planning and full use of weather information will help the pilot to minimize the icing problem.

SUMMARY

1. Expect icing at any time you are flying in clouds or visible moisture; such as rain, drizzle, or wet snow, if the temperature at flight level is near freezing or lower.

2. To avoid clear or rime ice, remain clear of clouds or precipitation areas in which the temperature is near freezing or lower.

3. If you must fly in icing conditions, you may normally expect to find less icing at levels where the temperature is lower than 15° F. to 20° F., except in the case of cumulus or cumulonimbus clouds.

4. To get out of freezing rain, (a) climb into the warmer layer of air that will be found above the frontal surface, or (b) descend to a lower altitude if it is known that there are non-freezing temperatures at a lower level.

5. Expect faster ice accretion rates in convective type clouds (such as stratocumulus, cumulus, cumulonimbus) and lesser ice accretion rates in stratified clouds (such as stratus and altostratus).

6. Remove all frost from an aircraft before attempting a take-off.

NEXT ISSUE OF THIS SERIES: THE JET STREAM -- A Band Of Very Fast Winds Encircling The Earth At High Altitudes.

AVIATION SERIES NO. 3

WEATHER BUREAU

THE JET STREAM

A Band of Very Fast Winds Found at High Altitudes

U. S. WEATHER BUREAU

When pilots of World War II started flying B-29's over the western Pacific, some found the winds at flight levels so strong they were unable to reach the target areas and still have sufficient fuel to return to their bases. When the first cases of extreme and unexpected winds -- some in excess of 200 miles per hour -- were reported by the pilots, there was considerable skepticism for such wind speeds were then almost unheard of in aviation circles.

These flights in the early 1940's were among the first encounters with the JET STREAM -- a phenomenon of considerable importance to the pilot of high altitude aircraft and to weather as a whole.

Prior to the experiences of the B-29 pilots flying near Japan, some technical investigations had been made which indicated that very fast winds were occasionally imbedded in portions of the general west-to-east flow of air that prevails at high altitudes, but few knew very much about these winds or suspected their significance.

The experiences of the B-29 pilots with extremely strong winds spurred meteorologists to learn more about the structure and behavior of the wind patterns in the higher portions of the atmosphere. Aided by newer weather instruments for measuring wind conditions aloft, and pilot reports made available as a result of the increasing number of aircraft operating at these high levels, meteorologists were able to establish a number of important facts about jet streams.

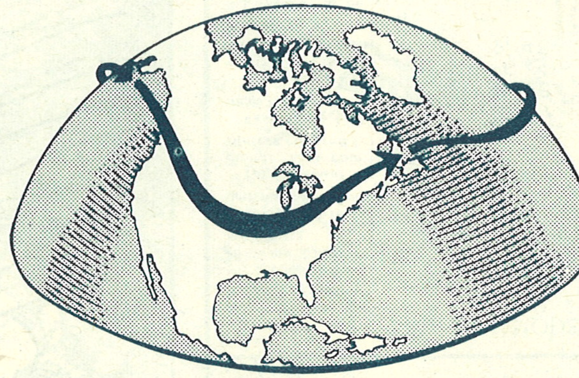


FIG. 1. - THE JET STREAM MAY ENCIRCLE AN ENTIRE HEMISPHERE.

The jet stream has been likened to a narrow current moving around the hemisphere in wave-like patterns. Its intensity varies with the seasons, being generally most pronounced in winter. It may sometimes be charted around an entire hemisphere, but more often it is broken up into several discontinuous segments. Occasionally, the jet stream divides over some regions leaving two main belts of very strong winds a considerable distance apart. In other cases, smaller, detached "fingers" of very strong winds are found some distance from the parent jet stream. A pictorialization of a jet stream over the Northern Hemisphere is shown in Figure 1. To describe the structure of the jet stream, we must take into account its variations in three dimensions.

Figure 2 represents a cross section through a strong, well defined jet stream as it might appear over the central United States. It is important to keep in mind that in this illustration the vertical scale has of necessity been greatly exaggerated; the height shown is about eight miles but the distance between the two cities is about 300 miles. Therefore, even though the lines of equal wind speed about the core of the jet stream are shown as approximately circular, the areas they delineate are, in reality, very much elongated.

Figure 3 shows areas of different wind speeds along the axis of the same well developed jet stream as they might appear on a map of the conditions at about 30,000 feet. From this chart it can be seen that the wind speeds along a jet stream are not constant but that there are areas where the speeds reach a definite maximum and other areas where the speeds are much lower. The difference in wind speeds between the areas of maximum and minimum winds along the axis of a jet stream may sometimes be well over 100 miles per hour. The areas of faster and slower winds move along the jet stream axis and may show large changes from day to day. Sometimes, especially in winter, there may be more than one jet stream charted at the same time over a hemisphere. On occasion, there will be two jet streams over the continental United States. For example, one along the northern border and another well to the south, perhaps over the southern tier of states.

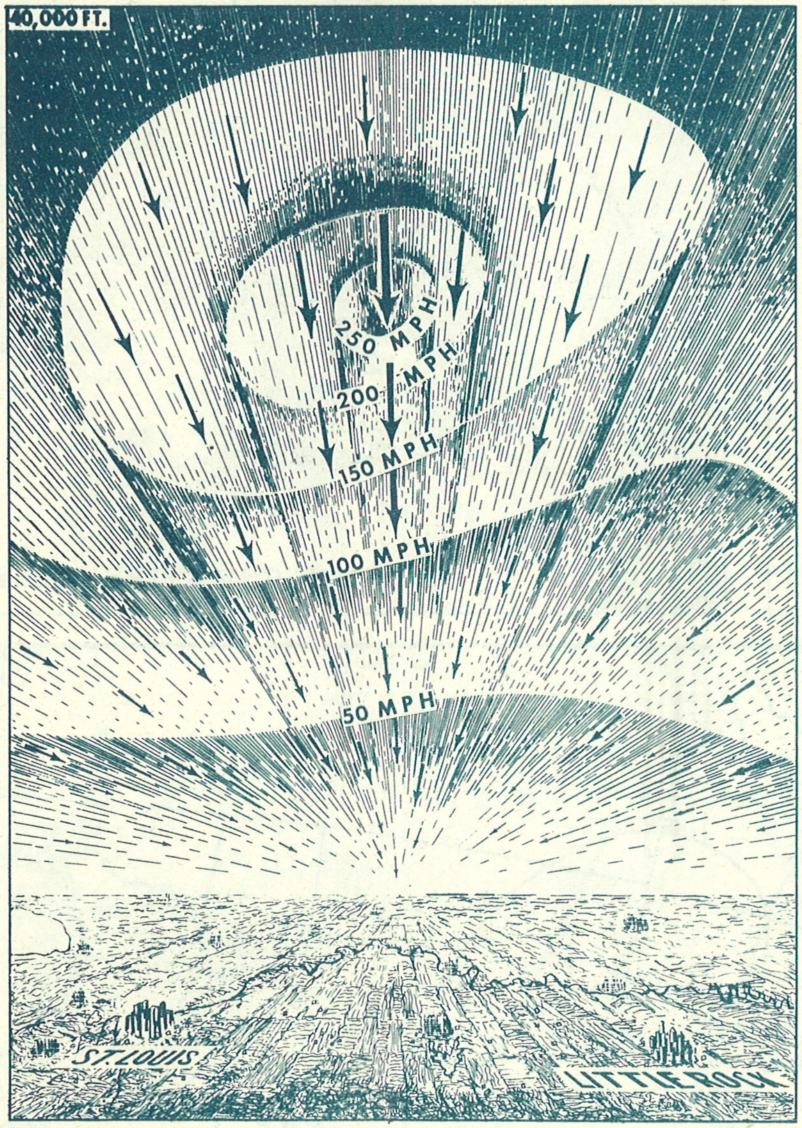


FIG. 2. - A CROSS-SECTION THROUGH A JET STREAM SHOWING THE CORE OF VERY FAST WINDS.

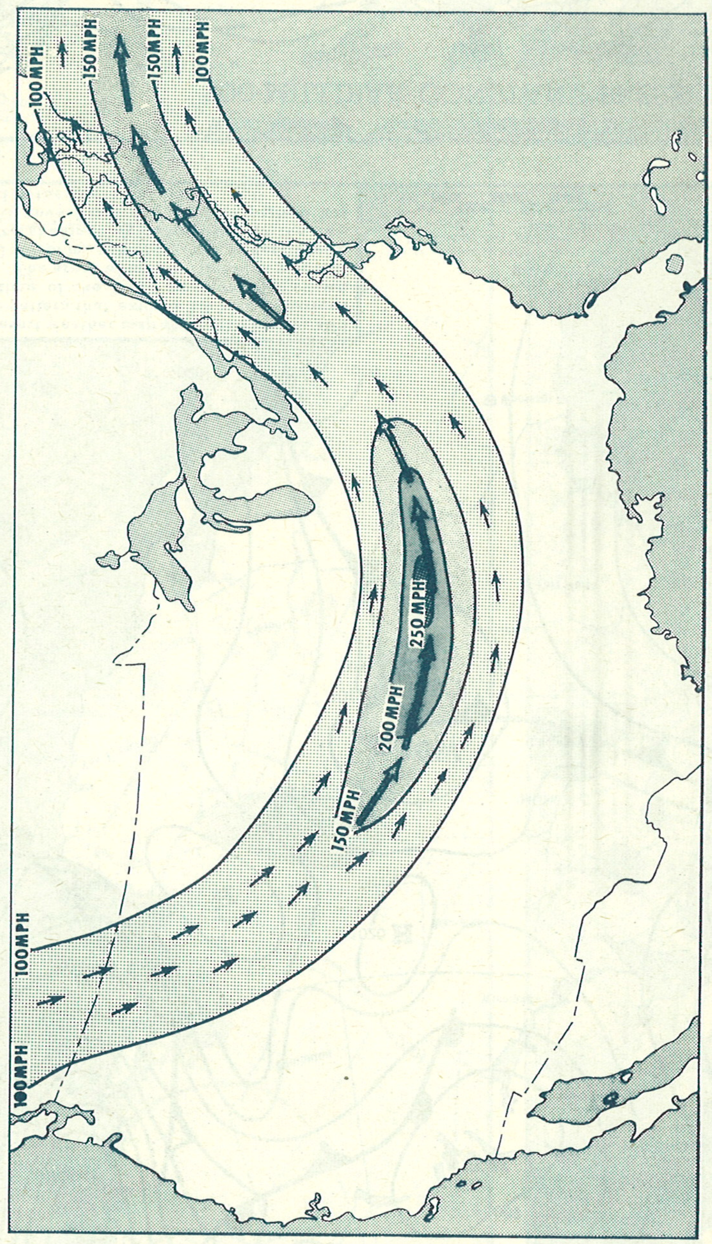


FIG. 3 - WINDS ABOUT THE JET STREAM VARY AS SHOWN BY THE LINES OF EQUAL WIND SPEEDS.

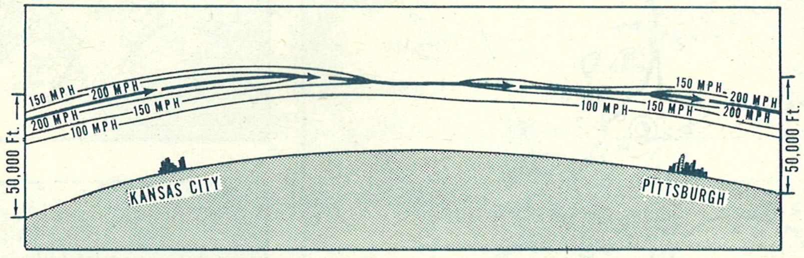


FIG. 4 - THE HEIGHT OF THE CORE OF THE JET STREAM IS NOT ALWAYS UNIFORM.

Figure 4 illustrates a jet stream as it might appear when looking at it from the side. Here again the definite areas where the winds are much faster than in other portions of the jet stream are clearly visible. The illustration also shows that the height of the jet stream core is not uniform.

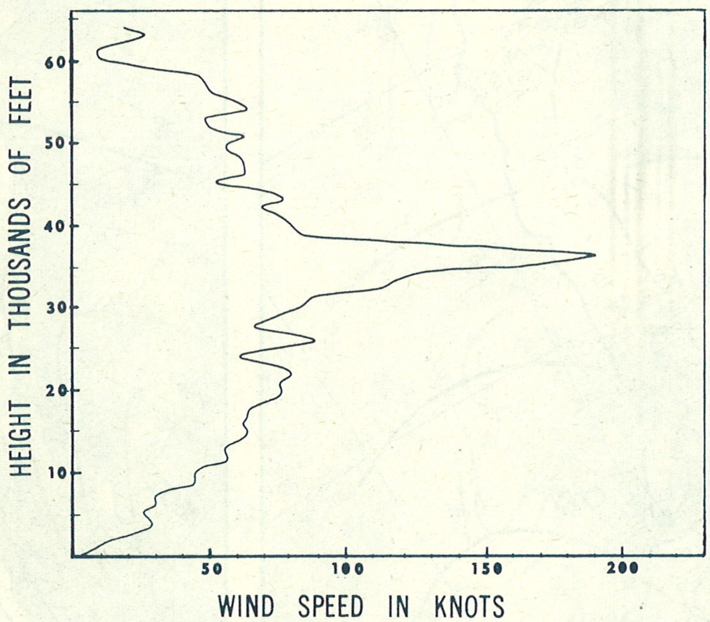


FIG. 5 - GRAPH OF THE ACTUAL WIND CONDITIONS FOUND IN ONE CASE OF A JET STREAM.

The wind decreases rapidly as one moves away from the core of the jet, both horizontally and vertically. A comparison of Figures 2 and 3 shows that the rate of change of wind speed that would be encountered by an airplane flying across the jet stream would be much less than would be experienced when climbing or descending through it. During such a climb or descent, it is not unusual to experience changes in wind speed of more than 30 knots within a thousand feet. Very large changes in wind speed with changes in height are illustrated in Figure 5, which shows the graph of an actual wind observation through a jet stream.

Because the jet stream often shifts position from day to day and tends to migrate with the seasons, its position at any particular time can best be determined by reference to specially constructed weather charts. The meteorologist makes use of various methods to find a jet stream and to keep track of its changes. Actual observations of the wind conditions as reported by pilots and as determined by weather stations are very important to this work. Figure 6 shows one of the special electronic devices used to track the flight of a free balloon as it ascends into the atmosphere and to thereby compute the wind direction and speed at different levels.

Because the spacing between these special upper air observing stations is usually well in excess of several hundred miles, it is possible for a jet stream to lie between adjacent stations and not be evident from their reports. Therefore, the meteorologist must make use of various indirect means of analysis to supplement available wind reports.

It may be seen that if it were possible for a pilot to fly downwind within a jet stream, the cruising range of his aircraft could be greatly extended. Conversely, flying against the jet stream would seriously limit the cruising range of the most modern high speed transport aircraft. Knowing the position of the jet stream is an important consideration in planning long range, high altitude flights. When winds are favorable, fuel loads can be reduced and more of the aircraft's capacity diverted to payload.

In addition to its importance to the pilot, the jet stream is a very important phenomenon to the meteorologist. The location and intensity of the jet stream and its northward and southward shifts are most important to him because the jet must be carefully considered in determining whether or not certain storm systems will intensify.

Not only is the jet stream of importance to the pilot because of its effects on payload and range, but it can be important to him in other ways. The clear air turbulence sometimes encountered without warning when flying at high altitudes has been found to be closely associated with the jet stream. This turbulence is believed to be caused by the shearing or "tearing" effect that occurs when adjacent air currents move at different speeds. "Clear air turbulence" will be discussed further in the next issue of this aviation series.

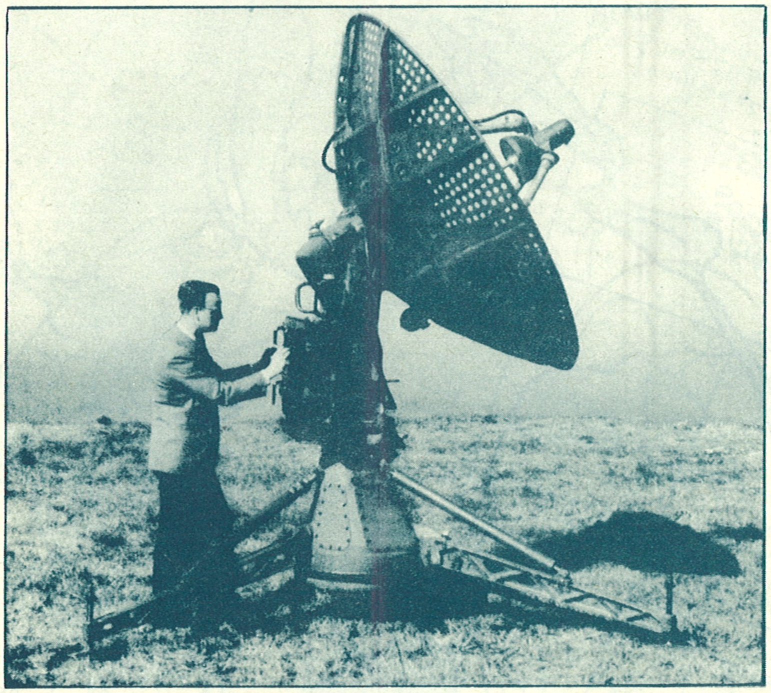


FIG. 6 - ELECTRONIC EQUIPMENT USED TO DETERMINE WIND SPEEDS AND DIRECTIONS TO ALTITUDES IN EXCESS OF 50,000 FEET.

AVIATION SERIES NO. 4

TURBULENCE. . .
Its CAUSES and EFFECTS

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TURBULENCE...

To the airman, the atmosphere is considered turbulent when irregular whirls or eddies in the air displace the aircraft from its normal path to the extent that bumps or jolts are felt. The occasional turbulence that is noted when flying may range from just a few annoying bumps to the infrequent cases of turbulence severe enough to cause structural damage to an aircraft.

It is helpful to the pilot to understand the principal causes of the turbulence that affects aircraft because such knowledge is often useful in recognizing the weather conditions that are favorable for turbulence, and because it helps the pilot to plan flights so as to have the least turbulence.

To study aircraft turbulence it is convenient to classify it into three main groups -- (1) the disturbed air flow that results when there are vertical air currents such as caused by convection, (2) the disturbed air flow that results when air moves over obstructions such as irregular terrain, and (3) the disturbed air flow that is associated with wind shear. It is not unusual for two or even all three of these factors to be acting at the same time. Another class of turbulence, which can be considered "man-made" rather than the direct result of weather conditions, is discussed in the last section of this article.

Turbulence Caused By Convective Currents

A form of turbulence frequently encountered is that associated with vertically moving air, and found in and below convective type clouds, such as cumulus or cumulonimbus. These vertically moving currents are usually caused by heating of the air near the earth's surface and are therefore found mostly on warm summer afternoons when the wind is light. As the warm ground heats the air, bubbles of heated air -- sometimes up to several hundred yards in diameter -- form next to the ground. If heated enough or disturbed in some way these bubbles of warm air will rise as convective currents until they reach a level where the temperature of the rising air is the same as the sur-

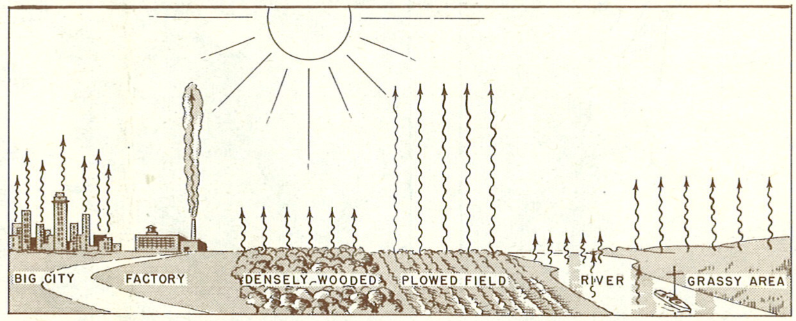

FIG. 1 - STRENGTH OF CONVECTIVE CURRENTS VARIES ACCORDING TO THE GROUND CONDITIONS.

rounding air -- usually a height of several thousand feet or more.

The strength of a convective current depends, in part, on the extent to which the ground below it is heated. Figure 1 illustrates that bare ground, such as sandy areas or plowed fields, is heated more than ground which has a grass cover or other vegetation, thus causing stronger convective currents. Rising columns of air can be present without one seeing a convective type cloud because the rising air may not contain sufficient moisture to form a cloud. Also, compensating downward moving currents are found near areas of rising air, thus adding to the turbulence effects. Convective type turbulence also occurs when a cold air mass moves over a warm surface and it may occur if the air aloft is being replaced by colder air to the extent of making the atmosphere unstable.

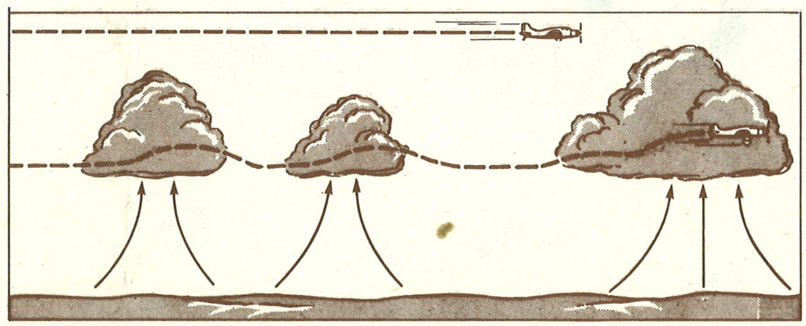

FIG. 2 - AVOIDING CONVECTIVE TURBULENCE BY FLYING ABOVE CUMULUS CLOUDS.

TURBULENCE...

Figure 2 shows how a pilot could avoid convective type turbulence by flying above the convective currents whose upper limits are in this case marked by cumulus clouds. Figures 3a and 3b illustrate the effect of different convective currents on a landing approach.

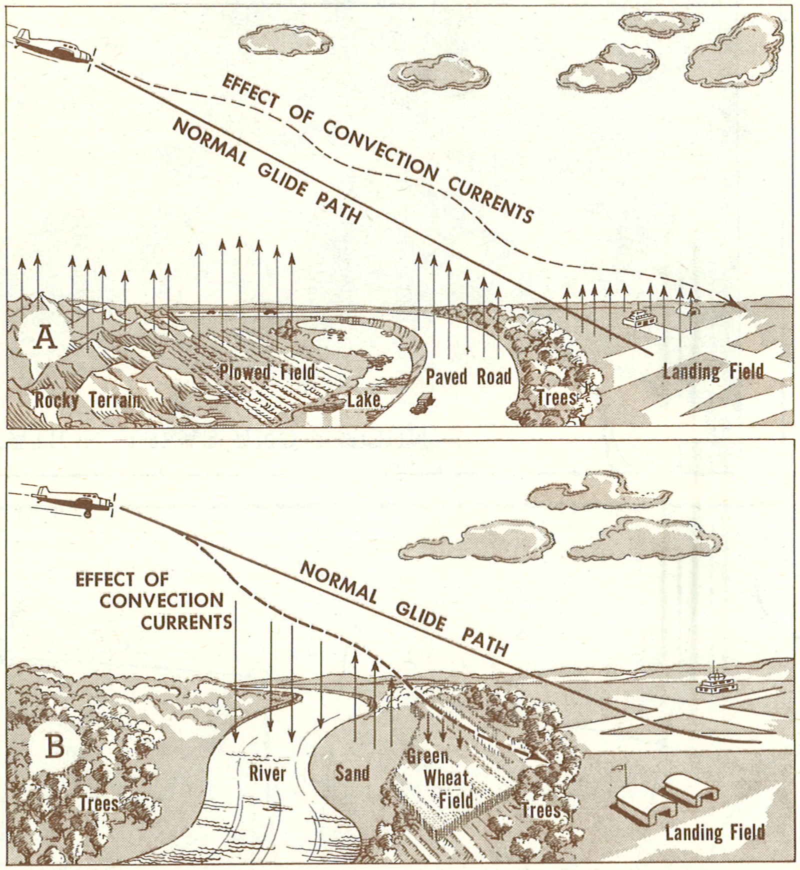

FIG. 3 - VERTICAL AIR CURRENTS MAY CAUSE PILOT TO OVERSHOOT (A) OR UNDERSHOOT (B), DEPENDING ON STRENGTH AND DISTRIBUTION OF CONVECTION.

Turbulence Caused By Irregular Terrain

When the air near the surface flows past objects such as buildings, bluffs and hills the normal horizontal flow is transformed into complicated patterns of eddies and other irregular wind movements. Some of these effects are illustrated in Figure 4, while Figure 5 shows how buildings or other obstructions near a landing area can cause dangerous turbulence.

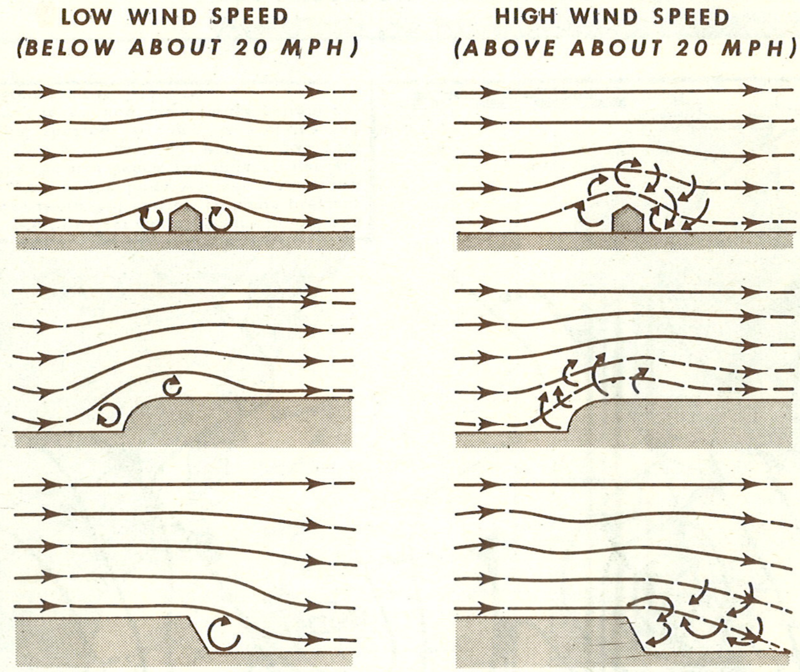

FIG. 4 - SURFACE OBSTRUCTIONS CAUSE EDDIES AND OTHER IRREGULAR WIND MOVEMENTS.

The degree of turbulence experienced when flying in air that is moving over hills, ridges or mountains depends partly on the roughness of the terrain, and on the speed of the wind. This type of turbulence may be of only minor significance in the case of a light wind blowing over rolling hills. In such cases, its effects are seldom noticeable to heights in excess of a few hundred feet. However, with somewhat faster winds and larger obstructions, the turbulence increases and extends to higher levels. If the winds blowing across a mountain range are strong enough, the resulting turbulence on the lee side can reach dangerous proportions, and the associated updrafts and downdrafts may extend to heights considerably above the general level of the mountain crests. These conditions are generally referred to as "Standing Waves." Standing waves will be discussed in more detail in No. 5 of this special Aviation Series.

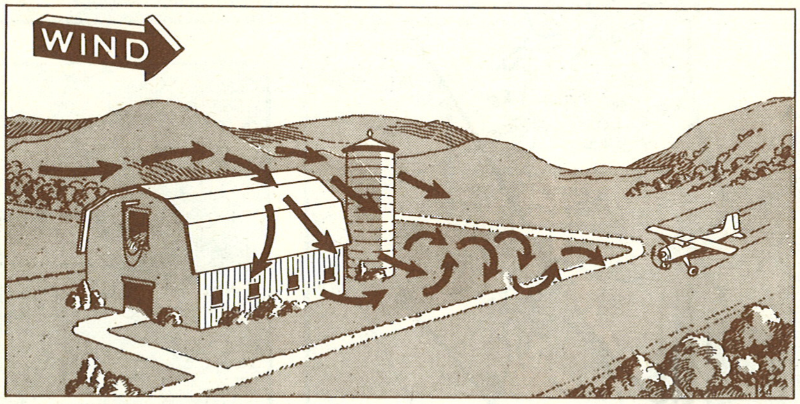

FIG. 5 - BUILDINGS OR OTHER OBSTRUCTIONS ON WINDWARD SIDE OF LANDING AREA MAY CAUSE TURBULENT AIR.

Pilots who must fly in the turbulent conditions resulting when strong winds flow over mountains have found that, as a general rule, the turbulence effects are less if the flight is made at an altitude of at least several thousand feet above the crest. However, this is not always the case. With smaller types of aircraft, it is considered good practice not to attempt a flight over mountains when very strong winds are blowing across them. Under such conditions the turbulence may be severe enough to cause structural damage and the downdrafts may exceed the aircraft's rate of climb and thereby carry it to the ground.

Turbulence Caused By Wind Shear

Turbulent flight conditions are frequently encountered in the general vicinity of the jet stream. (The jet stream was described in No. 3 of this Aviation Series.) It is in the vicinity of the jet stream that the proper conditions of wind shear and air stability contributing to turbulence are found. Since this turbulence may occur in perfectly clear air without any visual warning in the form of clouds, it is often referred to as "clear air turbulence." Clear air turbulence is not always limited to the vicinity of the jet stream, but may occur at times in other isolated regions of the atmosphere. A very narrow zone of wind shear, with its accompanying turbulence, is sometimes found as one climbs or descends through a temperature inversion. An extreme form of wind shear that is of considerable importance to aircraft landing and takeoff operations is that associated with strong inversions near the surface. A typical case is shown in Figure 6. In this example a pocket of calm, cold air has formed in the valley as a result of night-time cooling, but the moving, warmer air above has not been appreciably affected. Due to the difference in speed of the superimposed bodies of air, a narrow layer of very turbulent air is formed. An aircraft climbing or descending through the shear zone will encounter considerable turbulence. In extreme cases a departing aircraft might encounter a loss of flying speed on reaching this turbulent zone if the direction of flight is the same as the wind direction in the warm air. The conditions which cause this type of turbulence are confined mostly to the colder climates, such as in Alaska and the northern portions of the United States, and occur almost entirely during winter.

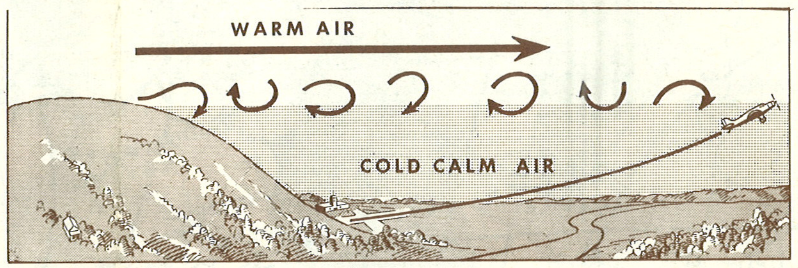

FIG. 6 - TURBULENT AIR AT THE BOUNDARY BETWEEN CALM, COLD AIR AND MOVING, WARM AIR ABOVE.

"Man-made" Turbulence

Most pilots are aware that very localized but momentarily heavy turbulence may be encountered when passing through the wake of another aircraft. A mild form of this kind of turbulence can be demonstrated by flying a carefully executed 360° turn so as to encounter one's own wake. It is important to remember, however, that landing and departing aircraft cause disturbed air in the approach path to runways, and highly disturbed air may be encountered when landing behind large transport type aircraft. (See Figure 7.) In such cases, the size of the aircraft, plus use of engine power during most of the approach, can cause the wake to be so turbulent as to be of major concern to pilots of lighter aircraft and in some cases, smaller multi-engined aircraft. In fact, there are many cases on record where lighter aircraft landing behind a heavier aircraft have encountered turbulence so severe as to result in complete loss of control, some at altitudes too low to effect recovery.

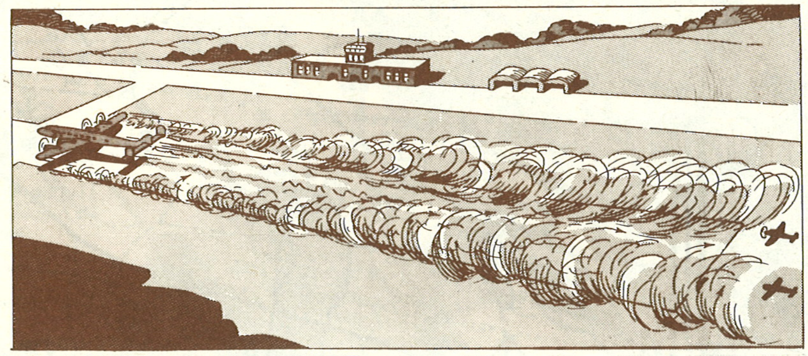

FIG. 7 - LANDING AIRCRAFT LEAVE WAKE OF TURBULENT AIR.

Because there is hardly ever any visible indication of "wake" turbulence, the only clue the landing pilot may have to its existence is to note whether a heavy aircraft has landed on his runway or an intersecting runway shortly before. With calm or very light wind conditions this turbulent air motion sometimes looms over the runway or in the approach area for several minutes or more. However, when the wind is blowing at an angle across the runway, the disturbed air is carried out of the approach path.

Aviation safety groups have recommended that to minimize the possibility of encountering this low-level turbulence, pilots of the smaller types of aircraft should allow as much time as possible before landing behind a heavy aircraft -- up to several minutes during calm or very light wind conditions. It has also been suggested that if "wake" turbulence is suspected, and there is a cross-runway component of the wind, landings and takeoffs be made on the upwind side of the runway.

AVIATION SERIES NO. 5

THE MOUNTAIN WAVE...

What it MEANS to the PILOT

●

U. S. WEATHER BUREAU

THE MOUNTAIN WAVE...

Airmen and others have long known that airflow over mountainous terrain is apt to be quite erratic, particularly when winds are over 25 knots or so. However, until recently, relatively little has been known as to the magnitude and nature of airflow disturbances caused by mountain barriers. To the research meteorologist, it presents a challenge to gain a better understanding of the physical processes and to reduce motions to precise mathematical equations. To the pilot flying in mountainous country, the relationship is somewhat closer, involving personal comfort and in some cases, safety. The practicing meteorologist, in handling his day-to-day forecasting and pilot briefing duties, is concerned with both aspects, for theoretical knowledge as to the behavior of mountain winds enables him to do a better job in the practical work of issuing forecasts and briefing pilots.

In the past, numerous aircraft accidents have occurred in mountainous areas in strong wind situations, for which no satisfactory explanation was derived at the time. To make mountain flying safer, a considerable amount of research work in recent years has been directed towards gaining a better understanding of air flow over mountain barriers. Although much has been learned, present knowledge is far from complete. This paper reviews in non-technical language those developments of particular interest to the pilot.

First indications of mountain wave phenomena came from sailplane pilots searching for rising air currents. Gliding and slope soaring enthusiasts had long taken advantage of the rising air currents on the windward side of a mountain, and have known that in general there is a descending flow on the lee side. However, during the 1930's, pilots had observed that strong currents, rising to great heights, were occasionally encountered to the lee of a mountain. Following this discovery, record flights (30,000 feet and higher) were made by utilizing these strong currents to the lee of the Alps. The present altitude record of 44,500 feet was established here in this country in 1952 during a period of strong wave activity to the lee of the Sierra Nevada mountains near Bishop, California. From the first-hand observations of many pilots coupled with theoretical studies, a better understanding of the typical mountain wave pattern gradually emerged. It became

Photo by C. S. Patterson - U. S. W. B.

FIG. 1 - TYPICAL CLOUD FORMATIONS WITH MOUNTAIN WAVE DEVELOPMENT. THE CAP CLOUD, PARTIALLY COVERING THE MOUNTAIN TO THE LEFT, THE ROLL CLOUD, PARALLEL TO THE MOUNTAIN AND EXTENDING ACROSS MOST OF THE PICTURE, AND THE LENTICULAR CLOUDS IN THE UPPER RIGHT. AIR FLOW IS FROM LEFT TO RIGHT.

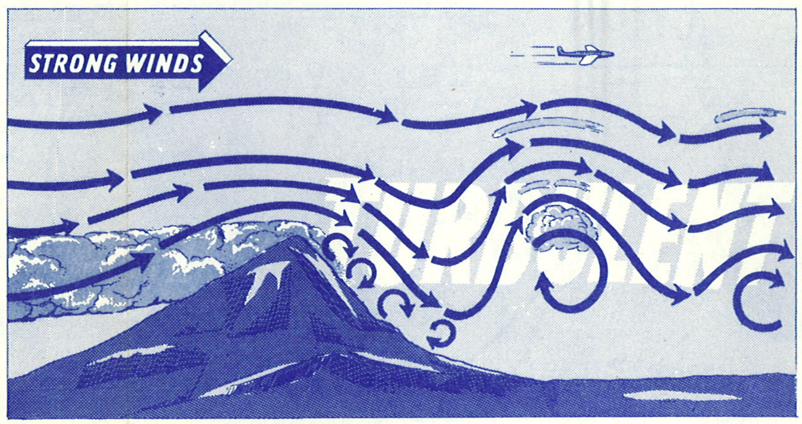

FIG. 2 - SCHEMATIC DIAGRAM SHOWING AIR FLOW IN A MOUNTAIN WAVE. COMPARE THE POSITIONS OF THE CAP CLOUD, ROLL CLOUD, AND LENTICULAR CLOUDS IN THIS DIAGRAM WITH THE PHOTOGRAPH IN FIG. 1.

apparent that the ascending currents were not random updrafts, but rather, occurred in fairly systematic wave patterns.

The characteristics of a typical mountain wave are shown in Figures 1 and 2. Figure 1 is a photograph showing the cloud formations normally found with wave development, and Figure 2 illustrates schematically the airflow in a similar situation. It can be seen here that the air flows fairly smoothly with a lifting component as it moves along the windward side of the mountain. The wind speed gradually increases, reaching a maximum near the summit. On passing the crest, the flow breaks down into a much more complicated pattern with downdrafts predominating. An indication of the possible intensities can be gained from verified records of sustained downdrafts (and also updrafts) of at least 3,000 feet per minute, and other reports well in excess of this figure. Turbulence in varying degrees can be expected as shown in Figure 2, and is apt to be particularly severe in the lower levels. Proceeding downwind, perhaps 5 to 10 miles from the summit, the airflow begins to ascend as part of a definite wave pattern. Additional waves, generally less intense than the primary wave, may form downwind (in some areas six or more have been reported), not unlike the series of ripples that form downstream from a submerged rock in a swiftly flowing river. Indications of three waves can be seen in Figure 3. However, the pilot is concerned for the most part with the first wave, because of its more intense action and proximity to the high mountain terrain. The distance between successive waves (wave length) usually ranges from 2 to 10 miles, depending largely on the existing wind speed and atmospheric stability, but wave lengths up to 20 miles have been reported.

From the pilot's standpoint, it is important to know how to identify a wave situation, and having identified it, to plan his flight so as to avoid the wave hazards. Characteristic cloud forms peculiar to wave action provide the best means of visual identification. The lenticular (lens shaped) clouds in the upper right of Figure 1 are smooth in contour. These clouds may occur singly or in layers at heights usually above 20,000 feet, and may be quite ragged when the airflow at that level is turbulent. The roll cloud forms at a lower level, generally near the height of the mountain ridge, and can be seen extending across the center of Figure 1. The cap cloud, shown partially covering the mountain slope on the left in Figure 1, must always be avoided in flight because of turbulence, concealed mountain peaks, and on the lee slope, strong downdrafts. The lenticulars, like the roll clouds and cap cloud, are stationary...constantly forming on the windward side and dissipating on the lee side of the wave. The cloud forms themselves are a good guide to the degree of turbulence with generally smooth air flow in and near smooth clouds, and turbulent conditions if these clouds appear ragged or irregular. In Figure 1 this suggests smoother conditions at the lenticular level rather than near the roll clouds. However, close proximity of smooth and turbulent areas is a characteristic of the wave, so that a smooth flight part way into a wave is no assurance of continued smooth conditions from that point on.

While clouds are generally present to forewarn the presence of wave activity, it is possible for wave action to take place when the air is too dry to form clouds. This of course increases the likelihood of flying into a wave area unexpectedly.

In planning a flight where wave activity is suspected, there are several conditions to look for as indications of whether or not waves may develop and, roughly, their intensity.

1. Wind flow of about 25 knots or more roughly perpendicular to the mountain range. Wave action rapidly decreases as the winds shift from this direction.
2. An increase in wind speed with altitude up to and above the mountain top height and in some cases on up to the tropopause (roughly 40,000 feet). Within limits, wave action becomes more intense with stronger winds, but very strong winds (over 100 knots in the free air above the ridge) may eliminate smooth wave flow patterns entirely. In the latter situation, expect very severe and chaotic turbulence.
3. For sustained wave action, the air must be

...continued on Page 7

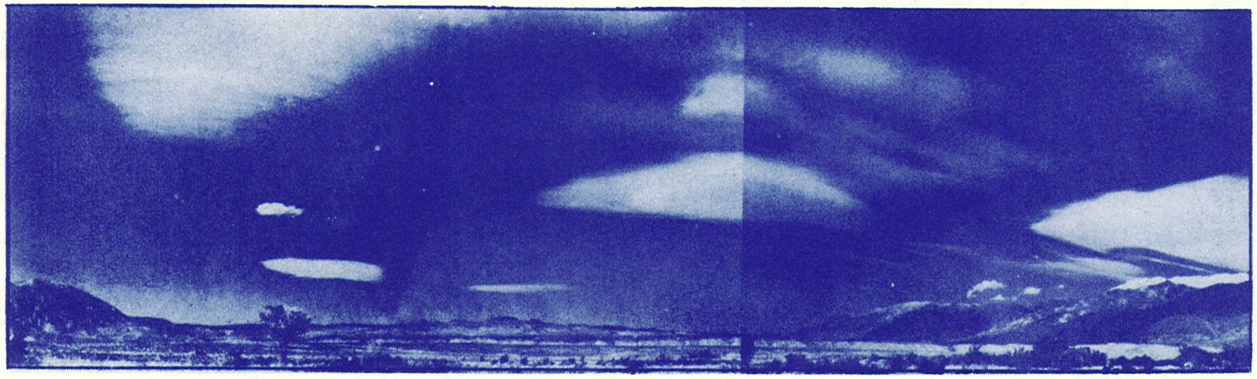

Photo by Robert Symons

FIG. 3 - MULTIPLE WAVE FORMATION TO THE LEE OF A MOUNTAIN RANGE. AIR FLOW IS FROM LEFT TO RIGHT.

This illustration, an example of the "Sierra Wave" near Bishop, California, is a composite of three photographs and portrays the lenticular cloud bands of three separate waves. The distance between successive clouds (wave length) in this case is approximately 12 to 15 miles. The predominant clouds, lenticulars, are at an estimated altitude of 35,000 feet. A small roll cloud is forming below the first wave on the left. Terrain in the foreground is roughly 4,000 and the mountain ranges over 12,000 feet.

stable for a thickness of several thousand feet in the vicinity of the mountain ridge. In unstable air the inherent irregular vertical motions tend to break up the wave action before it forms.

Suggested SAFEGUARDS when flying into an area of suspected wave conditions:

1. If practicable, avoid flight into the wave area. Otherwise, observe the following precautions.
2. Avoid ragged and irregular shaped lenticular and roll clouds -- the irregular shape indicates turbulent airflow.
3. Approach the mountain range at a 45-degree angle rather than directly, particularly when flying upwind; so that if it suddenly appears impracticable to continue, a quick turn can be made away from the ridge.

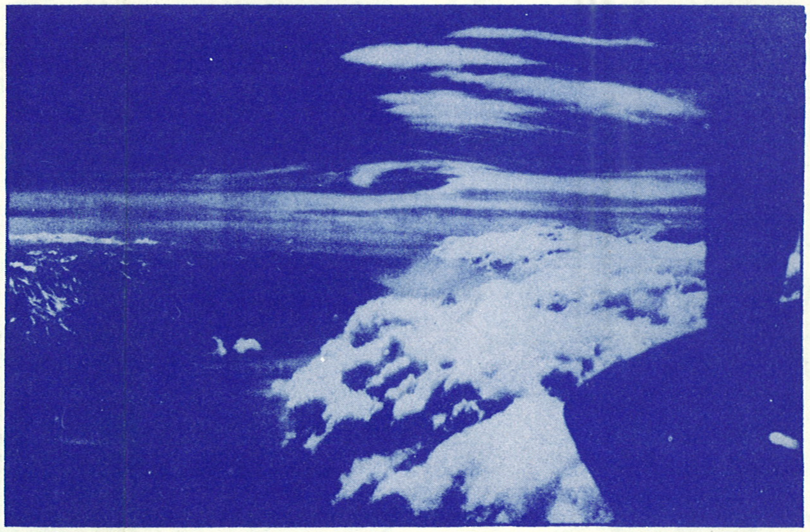

Photo by Robert Symons

FIG. 4 - A WELL DEVELOPED WAVE SITUATION WITH POWERFUL UPDRAFTS ABOVE AND SLIGHTLY UPWIND OF THE ROLL CLOUD. THE TWIN ENGINED AIRPLANE FROM WHICH THIS PICTURE WAS TAKEN CLIMBED FROM 15,000 TO 30,000 FEET WITH BOTH PROPS FEATHERED.

Photo by Robert Symons

FIG. 5 - AN UNUSUAL FORM OF LENTICULAR CLOUD ASSOCIATED WITH A MOUNTAIN WAVE.

4. Because of strong downdrafts and turbulence and the hazards of instrument flight near mountain level, avoid flight into a cloud deck lying on the mountain ridge (cap cloud), even if it means turning back.

5. Because of heavy turbulence and downdrafts, fly clear of the roll cloud.

6. Do not place too much confidence in the altimeter. <u>In a wave condition it can be read over 1,000 feet higher than actual altitude.</u>

7. It is possible when flying into the wind to utilize updraft areas to gain a safe altitude for crossing the mountain range. In particular look for rising currents upwind of the roll cloud, and also the lenticular altocumulus if they are near flight level. As it is not always possible to pinpoint the updraft areas, caution should be used in employing this procedure.

AVIATION SERIES NO. 6

STORM DETECTION RADAR

How it HELPS the PILOT

●

U. S. WEATHER BUREAU

STORM DETECTION RADAR...

Although practically unheard of by the general public until near the end of World War II when its military capabilities first became known, RADAR (from RAdio Direction And Ranging) has since been adapted to a wide variety of peacetime assignments in fields ranging from highway traffic patrol to weather observation. We are concerned here with radar applications in connection with the latter activity.

Many technical advances have been made in radar engineering in the past few years. The art of radar weather observing has only recently been developed to the point where we know with reasonable certainty the features that are needed in a weather radar set, and some of the unique services that radar can perform for meteorology.

Radar equipment consists essentially of a very short wave (microwave) directional radio transmitter and receiver. The transmitter sends forth brief pulses of energy which are radiated from the antenna in a directed beam. By electronic timing of the interval (which is on the order of millionths of a second) between the transmitted signal and the reception of the reflected signal (echo), it is possible to determine the distance to the reflecting object. These alternating energy pulses and "listening" periods are repeated many times a second, and inasmuch as the antenna rotates in a complete circle every few seconds, scanning the entire horizon is made possible. The nominal range of a good weather radar set is 150-200 miles, although under special conditions, echoes have been received from much greater distances. The distances and bearings of detected objects are electronically computed and are automatically registered on a glass screen or "scope" somewhat similar to a television screen. Thus, a continuous representation of the position of reflecting objects is maintained.

Radar detects microwave energy reflected from various objects such as buildings, mountains, aircraft, water droplets and snow or ice particles. In the case of meteorological elements, the intensity (brightness) of reflection is dependent upon the size and number of the water droplets or ice particles and their range. Many large

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Radar detects microwave energy reflected from various objects such as buildings, mountains, aircraft, water droplets and snow or ice particles. In the case of meteorological elements, the intensity (brightness) of reflection is dependent upon the size and number of the water droplets or ice particles and their range. Many large rain drops produce strong echoes, a few fine rain drops or snow flakes produce weaker echoes, while cloud particles are so minute that they produce very weak echoes (or none at all) on a standard weather detection radar scope. Thus radar does not detect thunderstorms or hurricanes directly, but instead depicts only that portion of the disturbance which contains sufficiently large and numerous water droplets or ice crystals to produce the echoes observed on the scope.

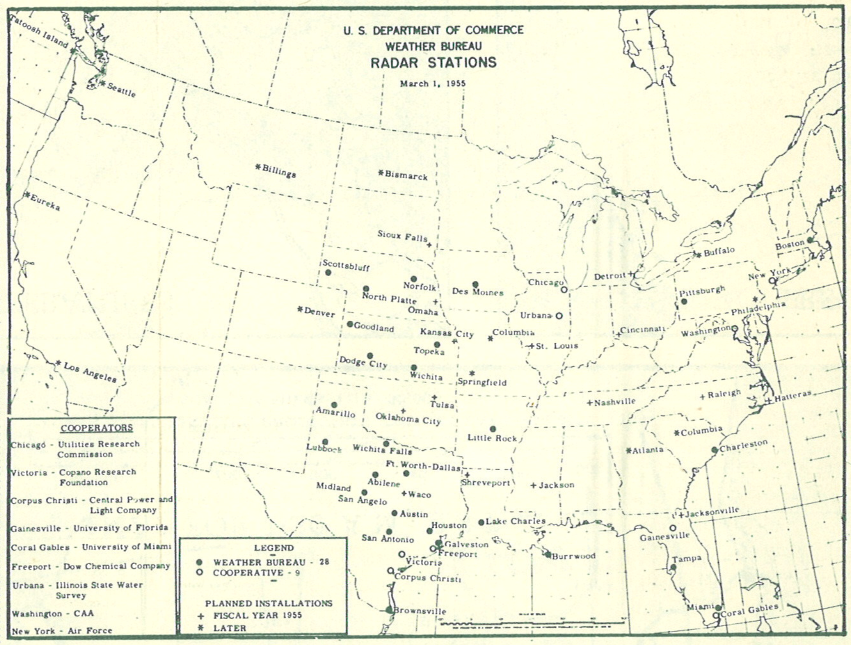

FIG. 1 - MAP SHOWING THE LOCATION OF WEATHER BUREAU RADAR INSTALLATIONS IN THE UNITED STATES

There are now 37 Weather Bureau offices equipped with radar (Figure 1) and additional installations are planned as funds permit. The majority of these installations are located in the Central and South-central part of the country, where there is a predominance of thunderstorm and squall line activity.

Once a storm area has been detected, the movement and

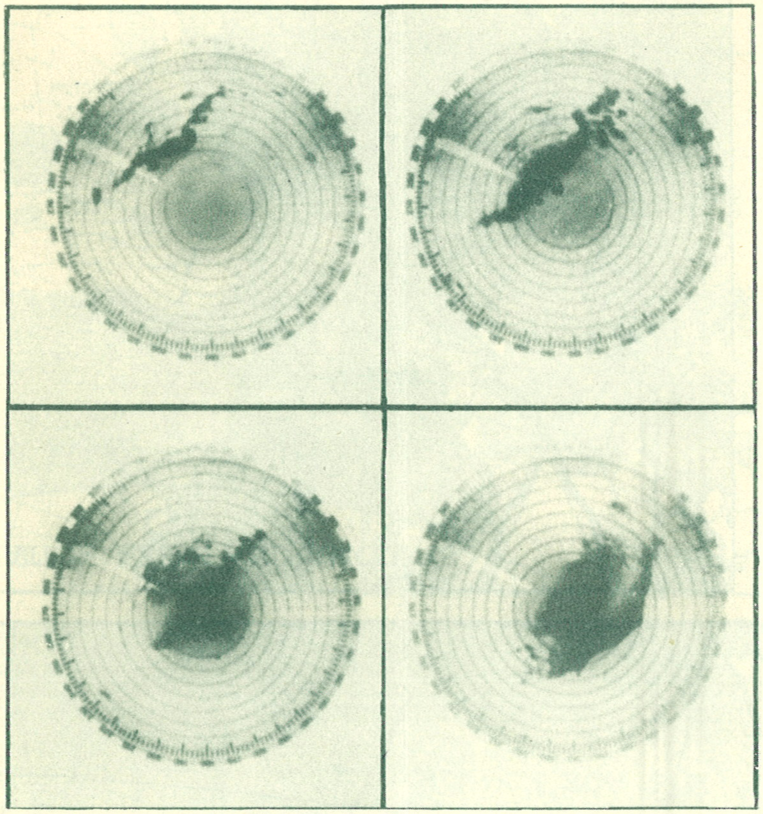

FIG. 2 - SEQUENCE OF PHOTOGRAPHS OF THE RADAR SCOPE AT VICTORIA, TEXAS DURING THE PASSAGE OF A COLD FRONT OCT. 25-26, 1953. THESE FOUR ILLUSTRATIONS COVER A PERIOD OF APPROXIMATELY THREE HOURS. THE DISTANCE BETWEEN THE CONCENTRIC RINGS (RANGE MARKERS) IS 25 MILES.

growth of the system can readily be determined by making successive observations and noting the changes in position and size of the echoes. Figure 2 shows the progress of a cold front as it approaches and passes Victoria, Texas, This type of information is particularly valuable in areas where the weather reporting network is sparse. In addition to aiding in the preparation of forecasts and issuance of warnings for the local area, reports of significant radar observations (RAREPS) are transmitted on the weather teletypewriter circuits for forecasting and flight planning activities at other locations.

The types of radar equipment commonly used for meteorological observations employ a wave length of from

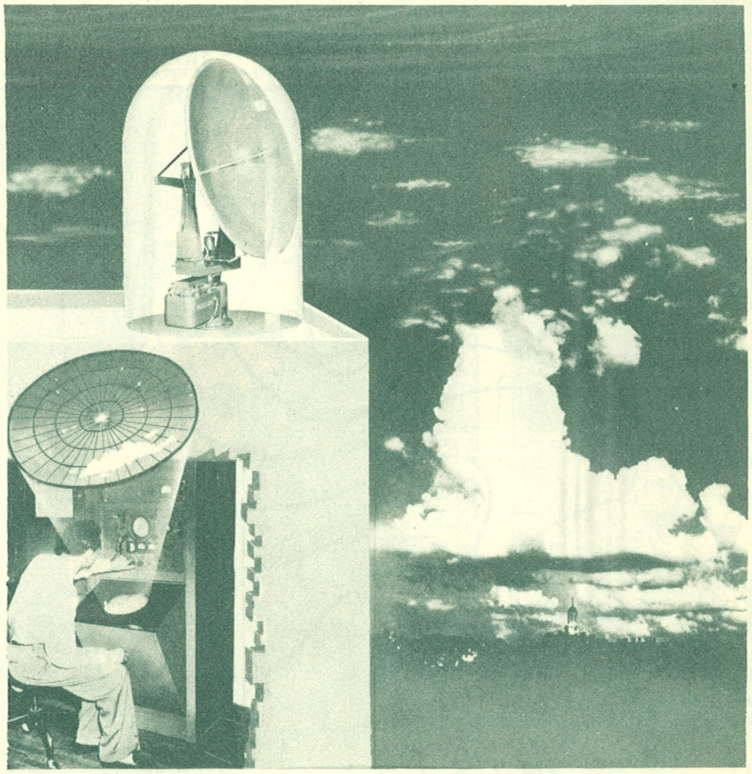

FIG. 3 - WEATHER DETECTION RADAR EQUIPMENT SHOWING ROTATING ANTENNA ON TOP OF BUILDING AND WEATHER OBSERVER VIEWING SCREEN OF RADAR SET. SIMULATED PROJECTION OF SCREEN SHOWS HOW A THUNDERSTORM CONDITION ABOUT 75 MILES AWAY APPEARS ON SCREEN.

3 to 10 centimeters. A wave length of 3 cm. is more suitable for the detection of light rain or snow than is 10 cm., but the shorter wave length is unable to penetrate extensive areas of heavy rain to "see" more distant storms. Because of primary interest in severe weather developments (for the issuance of warnings), and the need for a good signal range under storm conditions (to survey as large an area as possible) the Weather Bureau adopted 10 cm. equipment employing a comparatively large (72-inch diameter) antenna as the most suitable for their particular needs.

The type of radar in general use by the Weather Bureau has two scopes; the Plan Position Indicator (PPI) and the "A" scope. The PPI scope, enlarged for clarity in the simulated projection in Figure 3, presents a polar coordinate plot of the range and azimuth of any echo of sufficient reflecting power that falls within the range of the radar beam. In normal operation the antenna is directed to scan along the horizon. However, the antenna can be tilted upward for a determination of the height of the top of the storm. This height value can be computed by trigonometry, using the distance from the antenna to the cloud (range) and the antenna elevation angle.

The "A" scope presents a plot of echo signal strength against range along the azimuth at which the antenna is pointed, and is useful in interpreting the echo patterns seen on the PPI scope.

Radar has also proved to be well adapted to the problem of hurricane tracking, particularly when the storm is offshore and ship or island reports are scarce or nonexistant. The Weather Bureau has a number of installations in the Southeastern part of the country and along the Atlantic coast, primarily for the detection and tracking of hurricanes.

Figure 4 is a photograph of a typical hurricane echo as seen on the PPI scope. As can be seen, the outstanding feature of a hurricane echo is the pattern of curved bands spiraling inward toward the hurricane center or "eye."

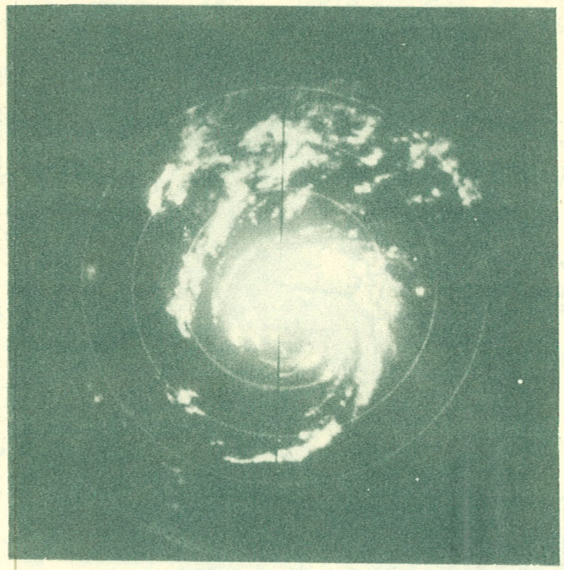

FIG. 4 - TYPICAL HURRICANE ECHO AS SEEN ON RADAR SCOPE. NOTE CHARACTERISTIC SPIRAL PRECIPITATION BANDS AND WELL DEFINED "EYE." RANGE MARKER SPACING IS 25 MILES.

These curved bands frequently exist as far as 200-300 miles in advance of the eye. Because radar provides the meteorologist with a continuous, up-to-the-minute plot of the rain areas, and most importantly, those surrounding the "eye," it is possible to detect changes in the path or speed of movement of the system. The radar information thus helps greatly to assure that warnings can be issued in time for necessary precautions to be taken. This, of course, is dependent upon the availability of a radar observing network capable of intercepting the hurricane path.

How can a pilot obtain radar weather information? Directly from the Weather Bureau if he visits or telephones a Weather Bureau office while planning for a flight. If in flight, he can obtain it by tuning his radio to the CAA Communications Station. All available radar weather reports are broadcast which indicate the existence of important weather within the flight information area of the station. Usually these reports are included in the regular broadcasts made at 15 and 45 minutes past the hour. However, any special radar weather reports that may be received are usually broadcast as soon as possible after receipt. Arrangements have also been made by the CAA for the Air Defense Command of the U.S.A.F. to provide vectoring service through storm areas to civil aircraft in flight. Details on this program can be obtained from the CAA.

A new radar weather application, and one that will undoubtedly prove to be of real value to the pilot, is that of air-borne radar. In the course of several research projects, a large number of flights in transport type aircraft have been conducted through thunderstorm and heavy rain areas. By reference to the radar screen, it has been demonstrated that the pilot can select a safe and comparatively smooth path through the thunderstorms and showers by avoiding the localized areas of heavy precipitation. Since the local intensity of precipitation is of prime importance in detecting areas of strong turbulence and since the relative intensities of precipitation can be determined by radar, it can be seen that radar is well suited for this work.

The question is frequently asked whether radar can be improved to provide more information than that indicated above. The outlook is very encouraging. Special weather radar equipment has been built and is in limited use, providing a higher degree of detail than is possible to obtain with the present Weather Bureau units. For example, the new sets are able to give an indication of the height of the freezing level, the degree of turbulence in the air (using the precipitation intensity method), and to differentiate between rain and snow. As all of this information is of great importance to flight planning and actual flight operations, it is only a matter of time before equipment with these features will come into more general use. There is no doubt but that further refinements and developments will continue to be made and that radar will play an increasingly important role in the safe and efficient operation of the nation's aircraft.

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AVIATION SERIES NO. 7

THUNDERSTORMS
Part One

U. S. WEATHER BUREAU

THUNDERSTORMS. . .

The thunderstorm represents one of the most formidable weather hazards for the pilot flying in Temperate and Tropical Zones. Though the effects of the thunderstorm tend to be localized, the turbulence, high winds, heavy rain, and occasionally hail, accompanying the thunderstorm makes it well worth the pilot's effort to study its characteristics.

Thunderstorms are the result of moisture and temperature conditions in successive levels of the atmosphere being such that the air mass becomes unstable and overturning of the air begins. Once vertical motions are started in unstable air, the resulting buoyancy forces cause the air that is warmer than the surrounding air to continue to rise as a convective current. When the rising currents are sufficiently strong and other factors are favorable, a thunderstorm will begin to form.

In the thunderstorm the upward motions of air are accompanied by compensating downdrafts, both within and outside the thunderstorm cloud. These currents form separate areas of vertically moving air and are called "thunderstorm cells." Strong turbulence is associated with the vertical currents in the cells. By contrast the boundaries of the thunderstorm cells tend to have relatively smooth air.

The successive stages of the life cycle of a thunderstorm cell are known as the "cumulus stage," the "mature stage," and the "dissipating stage."

The Cumulus Stage

Every thunderstorm begins as a cumulus cloud, but only a small number of such clouds actually grow into thunderstorms. On any particular day, the number of thunderstorm cells that occur is determined principally by the stability of the air, but whether or not an individual cumulus cloud will grow to pass through the entire thunderstorm life cycle depends on a number of factors.

The main feature of the cumulus stage of the thunderstorm cell is its updraft. Measurements made of thunderstorms during this stage show that the upward current

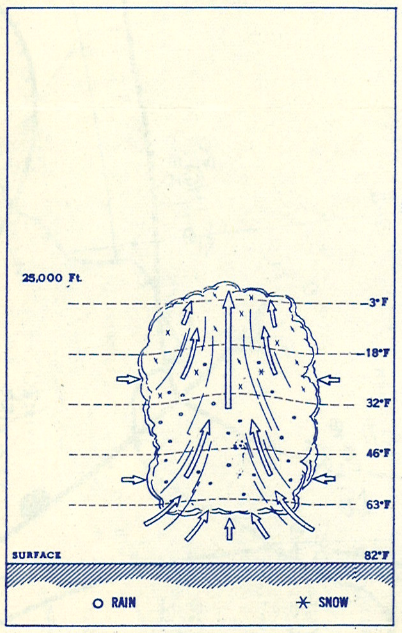


FIG. 1 - IDEALIZED CROSS SECTION OF A THUNDERSTORM CELL IN THE CUMULUS STAGE.

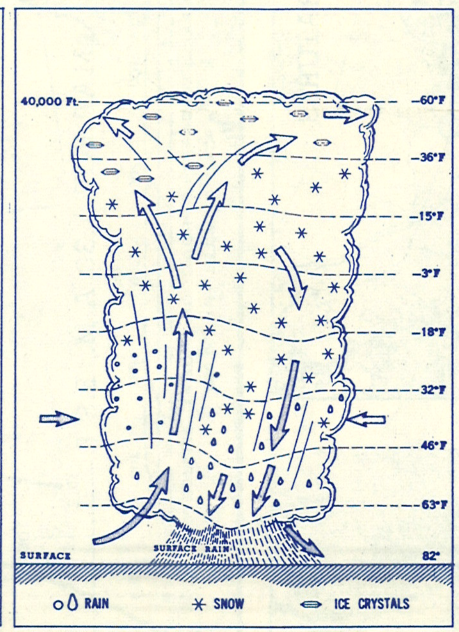


FIG. 2 - IDEALIZED CROSS SECTION OF A THUNDERSTORM CELL IN THE MATURE STAGE.

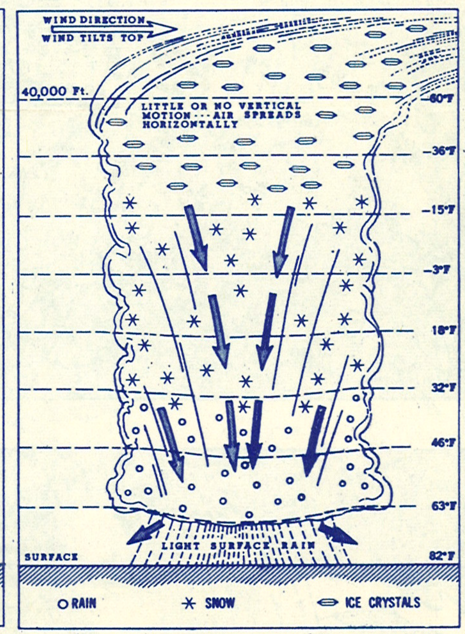


FIG. 3 - IDEALIZED CROSS SECTION OF A THUNDERSTORM CELL IN THE DISSIPATING STAGE.

may extend from near the ground to above 25,000 feet. The strength of this updraft area may vary as one crosses the thunderstorm cell. In this stage of the thunderstorm development, the maximum vertical speed of the updraft usually occurs at the higher altitudes and during the later portions of the cumulus stage. In such cases it is not unusual for the speed of the rising currents of air to reach 3,000 feet per minute -- equivalent to more than 30 miles per hour, or 50 feet per second.

Figure 1 shows a vertical cross section through a thunderstorm cell in the cumulus stage of development. For simplicity, the updraft in the figure is shown as symmetrical about the center of the cell, although this condition probably does not often exist in nature. During this early period of the developing thunderstorm, the air within the cloud area is everywhere warmer than that of the surrounding air. This is shown by the temperature lines in Figure 1.

At the beginning of the cumulus stage the amount of visible water and the size of the cloud droplets are small, but these continually increase as the cloud develops. Liquid water droplets form in the cloud below the freezing level while above the freezing level snow is usually found. In the main updraft, however, liquid cloud droplets and rain may be found even though the temperature is well below freezing.

The cumulus stage of a thunderstorm, counting from the time the cloud grows to reach the freezing level, usually lasts from 10 to 15 minutes.

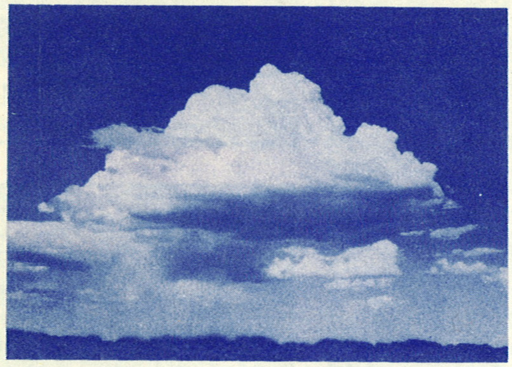
The Mature Stage

A developing thunderstorm is generally considered to have reached the mature stage when rain begins to fall to the earth from the thunderstorm cloud. The rain begins when the individual rain drops and snow formed in the updraft area of the storm reach a size that their weight can no longer be sustained by the existing updraft. At the time the rain begins, the thunderstorm cell undergoes very significant changes. In a portion of the cell where formerly an updraft existed, the air now begins to move in the opposite direction. This downdraft which begins in the middle and lower levels of the cell, gradually increases in horizontal and vertical extent.

Figure 2 shows a vertical cross section through a typical thunderstorm cell at about the middle of the mature stage. In general, the speed of the remaining updraft still increases with altitude, and some of the strongest updrafts in thunderstorm cells occur early in the mature stage where speeds may locally exceed 5,000 feet per minute. However, in the downdraft area the speed of the descending currents is more nearly uniform with speeds of 2,000 feet per minute not uncommon. The speed of the downward currents tends to lessen in about the lower 5,000 feet as a result of the earth's surface acting as a barrier to them.

An important consideration for the pilot is that the moving air in the downdraft does not come to rest at the surface of the earth, but spreads out as would any fluid striking a solid barrier. This spreading out of the downdraft produces one of the most characteristic of the surface phenomena associated with the thunderstorm -- the gusty surface wind that flows out ahead of the main storm area. The arrival of this horizontal rush of air is usually quite marked. Not only does it cause a sharp drop in temperature and a sudden rise in atmospheric pressure, but the wind speed sometimes reaches destructive force.

During the mature stage, the typical thunderstorm cell contains rain in the lowest levels, rain and snow mixed in the middle levels, and snow or ice crystals in the highest levels. With very strong updrafts, however, the liquid water may be carried up to very high levels before it can freeze. It is during the mature stage of the thunderstorm cell that hail occurs, although hail is not found in every storm. Also, it is during the mature stages of a thunderstorm cell that the turbulence reaches a maximum. The turbulence is greatest in the regions of maximum updraft and downdraft speeds, with definite zones of



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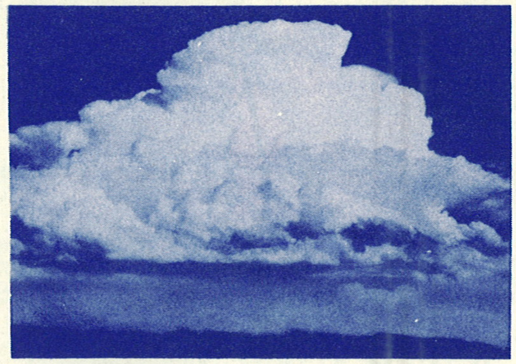

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FIG. 4 - SINGLE-CELL TYPE THUNDERSTORMS IN (A) CUMULUS, (B) MATURE, AND (C) DISSIPATING STAGES.

decreased turbulence between adjacent cells. It is usually least severe in the lowest altitudes, but even there heavy turbulence may be experienced.

As the rainfall continues throughout the mature stage of the cell, the downdraft area increases in size until, within the lower levels it extends over the entire storm area. When this occurs, the thunderstorm is considered to have reached the dissipating stage. The mature stage of a thunderstorm usually lasts for 15 to 30 minutes, but may be longer.

The Dissipating Stage

During the dissipating stage of the thunderstorm cell, the downdraft builds upward to higher and higher levels until finally the entire cell contains only downdrafts, or air with little or no vertical motion. As the downdraft condition spreads through the thunderstorm cell, the rain gradually decreases and finally the thunderstorm activity stops. Figure 3 shows the principal characteristics of the thunderstorm cell during the time the downdraft is still well defined. The duration of the dissipating stage of a thunderstorm cell, counting to the time when the vertical motion within the cloud becomes insignificant, is on the order of about 30 minutes.

Other Thunderstorm Features

The preceding discussion of the successive stages in the life cycle of a thunderstorm cell presents a somewhat idealized situation in which a single cell develops and goes through a life cycle without additional cells developing in the adjacent areas. Photographs showing single-cell type thunderstorms in the cumulus, mature, and dissipating stages are shown in Figure 4.

While it frequently happens that a thunderstorm is made up of only a single cell, there are also many cases of multi-cell thunderstorms with the individual cells at various stages of their life cycles. Such thunderstorms tend to grow over a period of hours and cover a larger area than do the single cell and more short lived thunderstorms. A multi-cell thunderstorm is shown in Figure 5.

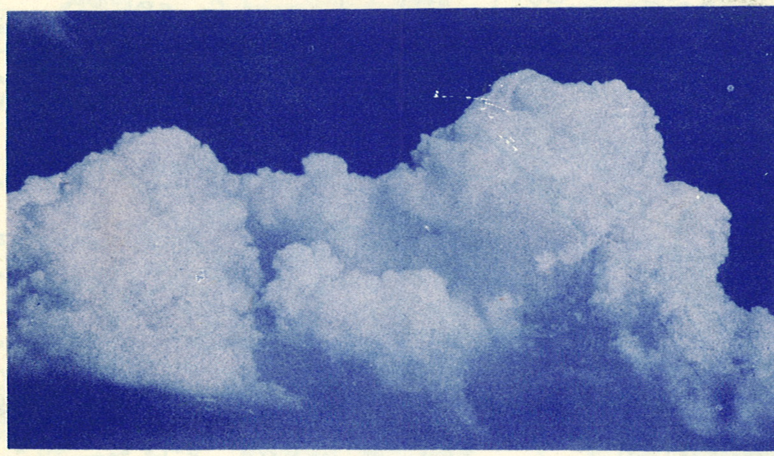

FIG. 5 - A MULTI-CELL TYPE THUNDERSTORM, LATE IN THE CUMULUS STAGE, AS SEEN IN FLIGHT.

When the wind increases rapidly with height, thunderstorm cells become tilted. As a result they tend to remain active longer than untilted ones. The reason for this is that when the cell becomes tilted, much of the precipitation released by the storm falls through only a portion of the rising air currents. Therefore, since the drag of the falling water is not imposed on the rising air currents within the thunderstorm cell, the updraft can continue until its source of energy is exhausted. Tilting of a thunderstorm cell explains why hail is sometimes encountered in a cloudless area just ahead of the storm. The appearance of a thunderstorm cloud may help the pilot to determine if the cell is tilted.

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Next Month...

Thunderstorms - Part II. Discussion of the lightning zones in thunderstorms and conditions such as hail, draft and gust intensity, and thunderstorm winds that affect aircraft operations.

AVIATION SERIES NO. 8

THUNDERSTORMS
Part Two

U. S. WEATHER BUREAU

Thunderstorms are virtually weather "factories" in that the pilot flying into one can expect to encounter great variations in the weather, some of them hazardous. Thunderstorms are often accompanied by extreme fluctuations in ceiling and visibility. Every thunderstorm has turbulence, sustained updrafts and downdrafts, precipitation, and lightning. Icing conditions, though localized, are quite common in thunderstorms, and many thunderstorms contain hail. Some of the phenomena accompanying the thunderstorm, and which are of major importance to aircraft operators, are discussed in the following paragraphs.

Drafts and Gusts

As discussed in Aviation Series Article No. 7, the direction and strength of the updrafts and downdrafts largely depends on the stage of the thunderstorm's development. In the early stages, the motion in the thunderstorm cell is mainly upward, in the later stages it is mainly downward. In the cumulus stage, the updraft may cover an area as large as 4 miles in diameter and extend to heights of 25,000 feet. In the mature stage, the updraft continues in the upper portion where it may reach heights of 60,000 feet.

For the pilot, the significance of the downdrafts and updrafts is their altitude changing effects on an aircraft flying through them. For an airplane flying through a typical thunderstorm cell at 155 knots at constant power setting and attitude, the upward change in altitude is not likely to exceed 2,000 feet, although in exceptionally severe storms upward displacements as great as 5,000 feet may occur. In general, the higher the flight altitude through the thunderstorm cell, the greater the aircraft's change in height if no correction is applied.

Downdrafts in thunderstorms are not as strong as the updrafts, and are of lesser horizontal and vertical extent. Because the downdraft continues below the base of the cloud and may exist at levels as low as 300 to 400 feet above the terrain, it may be a serious flying hazard. In general, the downdraft is strongest in middle altitudes of the thunderstorm, and the rain core is the only place where the downdraft beneath the cloud base is likely to be strong enough to be a hazard to aircraft. An airplane flying through a thunderstorm cell downdraft at 155 knots at constant power setting and attitude may be carried downward about 1,000 to 1,500 feet.

Gusts within a thunderstorm are believed to result from shear zones associated with thunderstorm drafts, and may be considered as small eddies or whirling bits of air driven by or superimposed upon the large scale drafts. Therefore, an aircraft flying through a thunderstorm cell is affected by these gusts in addition to the updrafts and downdrafts. The characteristic response of an airplane intercepting a series of gusts is a series of sharp accelerations without a systematic change of altitude, accompanied by pitch, yaw, or roll deflections.

In speaking of the strength of thunderstorm gusts, the term "effective gust velocity" is used as an approximation of the acceleration a "sharp edged gust" would produce on an aircraft. American commercial aircraft are designed for gust loads equivalent to an effective gust velocity of 30 feet per second at the design cruising speed (V_C), and an effective gust velocity of 40 feet per second at the design rough air speed (V_B). Aircraft operators should keep in mind that whether an aircraft encountering strong gusts will stall or structurally fail depends on a number of variables including forward speed, attitude, and load distribution. The most critical of these is forward speed. If an aircraft encounters an effective gust velocity approaching 40 feet per second when flying at its rough air speed, it may only stall, while if the same effective gust velocity were encountered when flying at the design cruising speed, structural damage would probably result.

In the years 1946-1949 the Weather Bureau, Air Force, Navy and National Advisory Committee for Aeronautics carried out a joint thunderstorm research project. In over 12,000 miles of thunderstorm flying at altitudes ranging from 5,000 feet to 26,000 feet, there were almost 600 encounters of gust velocities of 16 feet per second or more, 76% of them occurring between 10,000 feet and 21,000 feet. Of these encounters, there were 46 cases of gust velocities of 28 feet per second or more.

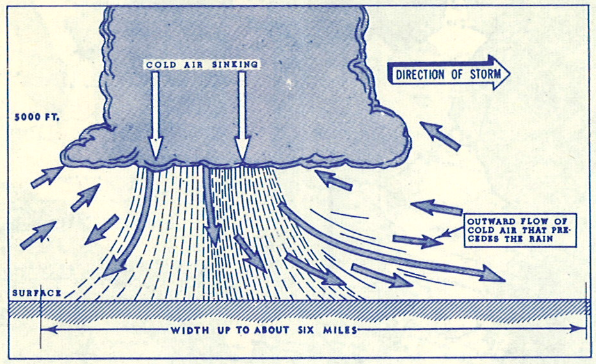

FIG. 1 - COLD AIR DOME BENEATH A THUNDERSTORM CELL IN THE MATURE STAGE. ARROWS REPRESENT DEVIATION OF WIND FLOW. DASHED LINES INDICATE RAINFALL.

In general, most of the high speed gusts are found at altitudes of 5,000 to 10,000 feet below the top of the thunderstorm cloud. It is important to point out, however, that even though the turbulence at the low levels is usually less than in higher parts of the cloud, it frequently is strong enough to be classified by pilots as "heavy to extreme."

Surface Winds and Low Level Turbulence

At about the time the thunderstorm reaches the mature stage and the rain begins, a downdraft starts in the lower and middle levels of the thunderstorm. This large body of descending air is the direct cause of the outflow of strong gusty surface winds that move out in advance of the main storm area.

Figure 1 shows the nature of the wind outflow from the thunderstorm and how it is formed from the settling of the dome of cold air which accompanies the rain core. The arrival of this outflow may result in a radical and abrupt change in wind speed and direction. In general, the strongest thunderstorm winds occur on the forward side of the storm and at the time and place the downdraft first reaches the surface. The speed of the thunderstorm wind depends on a number of factors, but local surface winds reaching 50 to 75 miles per hour for a short time are not uncommon. Because it can extend for several miles in advance of the thunderstorm itself, the thunderstorm wind is a highly important consideration for pilots preparing to land or take off in advance of a storm's arrival. Also, many thunderstorm winds are strong enough to do considerable structural damage and capable of overturning or otherwise damaging even medium sized aircraft that are parked and not adequately secured.

The outflow of air ahead of the thunderstorm sets up considerable low level turbulence. Over relatively even ground most of the important turbulence associated with this outrush of air will be within a few hundred feet of the ground, but it extends to progressively higher levels as the roughness of the terrain increases.

Hail

Hail may be regarded as one of the worst hazards of thunderstorm flying. It usually occurs during the mature stage of cells having an updraft of more than average intensity, and is found with the greatest frequency between the 10,000-foot and 15,000-foot levels. As a rule, the larger the storm the more likely it is that hail will occur. If the pilot can avoid the more active portions of the storm, the chances of encountering hail are reduced. However, there is little reason to believe that hail can be avoided completely, because with tilted cells the hail may fall through the clear air outside the thunderstorm cell.

Hail can do considerable damage to aircraft as illustrated in Figure 2.

Lightning

The thunderstorm changes the normal electric field, in which the earth is negative with respect to the air above it, by making the upper portion of the thunderstorm cloud positive and the lower part negative. This negative charge then induces a positive charge on the ground. The distribution of the electric charges in a typical thunderstorm are shown in Figure 3. The lightning first occurs between the upper positive charge area and the negative charge area immediately below it. Lightning discharges are considered to occur most frequently in the area bracketed roughly by the 32° F and the 15° F temperature levels. However, this does not mean that all discharges will be confined to this region, for as the thunderstorm develops, lightning discharges may occur in other areas, and from cloud to cloud as well as cloud to ground. Lightning can cause considerable damage to aircraft, especially to the radio equipment.

Photo Courtesy National Advisory Committee for Aeronautics

FIG. 2 - EXAMPLE OF HAIL DAMAGE TO AIRCRAFT

THUNDERSTORM FLYING

In the Thunderstorm Project more than 1300 flights were made through thunderstorms with F-61 "Black Widow" airplanes. While the investigations were carried out in

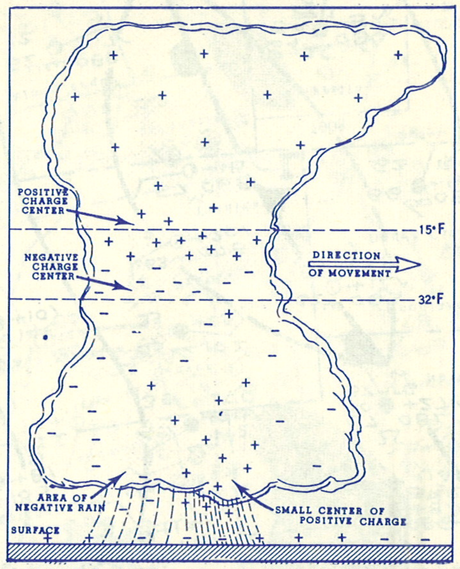

FIG. 3 - LOCATION OF ELECTRIC CHARGES INSIDE A TYPICAL THUNDERSTORM CELL.

Florida and Ohio, it is believed that the conclusions concerning flight conditions listed below are generally representative of many (but not necessarily all) thunderstorm conditions in other parts of the nation.

1. The chance of severe or extreme turbulence within thunderstorms is greatest at higher altitudes, with most cases of severe and extreme turbulence about 8,000 to 15,000 feet above terrain. The least turbulence may be expected when flying at or just below the base of the main thunderstorm cloud.
2. The heaviest turbulence is closely associated with the areas of heaviest rain.
3. The strongest updrafts are found at heights of about 10,000 feet or more above the terrain; in extreme cases updrafts in excess of 65 feet per second occur. Downdrafts are less severe, but downdrafts on the order of 20 feet per second are quite common.
4. The probability of lightning strikes occurring is greatest near or slightly above the level of freezing temperature.

THUNDERSTORMS. . .

The experience of airlines and others operating large aircraft has shown that it is possible to fly thunderstorms in reasonable safety IF crews are experienced in thunderstorm flying, IF suitable aircraft are used, and IF the proper flight techniques are used. Much study has gone into developing techniques for thunderstorm flying, but not all pilots experienced in thunderstorm flying are in full agreement on what are the best techniques. A number of rules generally accepted by experienced pilots and which appear to be substantiated by the Thunderstorm Project are listed here:

1. Before entering the storm reduce air speed to the aircraft's design rough air speed (V_B) to reduce structural stresses.
2. Fly at constant attitude and power settings so far as possible. (Erratic air speed readings result from vertical drafts past the pitot tube and the clogging effects of rain.)
3. Avoid all unnecessary maneuvering to prevent adding maneuver loads to those already being imposed by turbulence.
4. Do not use the autopilot. (Being a constant-altitude device, the autopilot will dive the airplane to compensate for an updraft, and climb the airplane in a downdraft. The result is that in the first case excessive air speeds may be built up, and in the latter case the air speed may approach the stalling speed.)
5. Hold a reasonably constant heading that will take you through the storm in the shortest time.

BECAUSE OF THE POTENTIAL HAZARDS OF THUNDERSTORM FLYING, IT OBVIOUSLY IS NOTHING SHORT OF FOLLY FOR PILOTS OF SMALL AIRCRAFT TO ATTEMPT TO FLY THUNDERSTORMS. An indication of the stresses that can occur may be taken from a number of cases on record where modern 4-engined transports have suffered structural damage as a result of flying through violent thunderstorms. It is well substantiated that so far as flying is concerned, there is no such thing as a "mild" thunderstorm.

COMING NEXT MONTH "Flying Weather Information - What is available to the pilot."

AVIATION SERIES NO. 9

FLYING WEATHER INFORMATION

What is AVAILABLE to the PILOT

U. S. WEATHER BUREAU

FLYING WEATHER INFORMATION...

Weather is vital to successful planning and completion of flight operations. To meet this need various weather reporting and forecasting services are available.

The U. S. Weather Bureau is responsible for providing basic weather information for the general public, commerce, and agriculture. As a part of this responsibility, the Weather Bureau aids aviation by providing observations of flying weather conditions and regularly issuing flying weather forecasts. It also furnishes pilots with flight weather briefings so far as its resources permit. These reporting and briefing services are available without cost to all pilots through the several hundred airport offices of the Weather Bureau. At some two hundred other locations where there are no government weather stations the Civil Aeronautics Administration's airways communications stations, by agreement with the Weather Bureau, furnish flying weather information to pilots.

FIG. 1 - METEOROLOGIST MAKING RECORDING FOR AUTOMATIC CONTINUOUS FLYING WEATHER BROADCAST ON ARCOLA L/M-F RADIO RANGE

FLYING WEATHER INFORMATION...

The telephone numbers of Weather Bureau stations are listed in the CAA Flight Information Manual as a convenience to pilots who wish to telephone the nearest weather station for information before departing. Pilots who do not find it possible to telephone or visit a Weather Bureau station for a complete weather briefing, may receive the latest available reports of weather conditions existing at a number of places by tuning in the scheduled weather broadcasts made at 15 and 45 minutes past each hour over CAA air navigational radio facilities.

FIG. 2 - PILOT OBTAINING FLYING WEATHER INFORMATION FROM AUTOMATIC CONTINUOUS BROADCAST OF STATION KWO35, NEW YORK

The Weather Bureau and CAA are jointly developing systems for the continuous broadcast of aviation weather reports and forecasts, plus Notices to Airmen, over low-frequency radio range stations. As of this writing, one such test installation has been operating successfully for more than six months, broadcasting on the Arcola (Virginia) L/MF radio range. Figure 1 shows some of the equipment used in this continuous broadcast service.

Figure 2 shows a pilot receiving weather briefing via another type continuous radio broadcast from a special VHF station operated by the Weather Bureau at New York. A similar broadcast also serves the Chicago area.

FIG. 3 - PILOTS' SELF-HELP WEATHER BRIEFING STAND PROVIDED BY FLIGHT SERVICE OPERATOR. WEATHER BUREAU REPORTS AND FORECASTS RECEIVED BY PRIVATELY LEASED WEATHER TELETYPEWRITER

Aircraft operators who wish to have their own weather facilities may enter into an agreement with the Department of Commerce for a receiving-only connection to the national weather teletypewriter system by applying to the Chief, U. S. Weather Bureau, Washington 25, D. C. Such a connection will provide them with several hundred reports each hour, plus written forecasts at frequent intervals, thus making available most of the weather information needed to carry out flight operations. A weather briefing room having a privately leased weather teletypewriter is shown in Figure 3.

At some locations weather information may also be obtained from private weather consulting firms who make it a business to handle specific weather problems of their clients. Such firms can give special and individualized attention to the needs of their customers. Some business corporations make considerable use of flying weather information in connection with operation of their own aircraft, and have found it to be to their advantage to engage private weather consultants.

The weather information available to pilots at most weather stations can be divided into three main classes; (1) MAPS of the weather, (2) REPORTS of current weather conditions, and (3) FORECASTS of expected changes in the flying weather. Each of these has a definite place in studying the weather for a flight, but each item also has certain limitations. No one of them is a substitute for the other, and it is to the pilot's advantage to utilize all of the aids to determine the weather conditions he may expect to encounter on a particular flight.

Reports of existing weather conditions are the most universally used of all aviation weather information. There is an extensive network of surface weather observing stations in the continental United States, as well as Alaska and Hawaii, where detailed observations of flying weather conditions are made each hour, or more often if the weather is changing rapidly. Among other reports available to the pilot are those of radar observations, which help to define rain and thunderstorm areas, and reports from pilots concerning the in-flight weather encountered. Reports of the weather as seen by pilots while in flight are a very important part of the entire weather reporting system. No one can tell more about the severity of a front, the intensity of the icing in the clouds, or the actual flying weather conditions between reporting stations than a pilot who has just flown through it. That is why the Weather Bureau is always anxious to obtain these informal first-hand reports and arranges to give them wide distribution via the teletypewriter circuits and to post them for ready reference at weather stations.

Forecasts of the flying weather are issued at regular intervals by the Weather Bureau for all sections of the continental United States, Alaska, and Hawaii. The "area" type forecasts describe such conditions as the location of areas of low clouds, heights of cloud bases and cloud tops, surface visibilities, and the development and movement of severe weather phenomena such as thunderstorms and line squalls. They also contain information on the height of the freezing level and zones of expected icing and turbulence. Forecasts of winds aloft expected at the various flight levels for a number of hours in advance are also made at frequent intervals.

Detailed forecasts for specific air terminals, known as "terminal forecasts," are issued for well over 300 of the principal air terminals in the Nation. These forecasts state in specific terms the ceiling, visibility, and wind conditions expected at each particular location.

Figure 4 shows an aviation weather display typical of that found at most Weather Bureau airport stations. This display is maintained for the convenience of the pilot and includes weather maps, aviation weather reports (including reports volunteered by pilots), radar weather reports, upper wind information, and Area and Terminal forecasts. Charts and posters along the back of the display help the pilot interpret the various information, if he needs assistance. Also in this panel is a chart showing times of sunrise and sunset for all parts of the country. This chart is helpful to pilots who wish to complete their flights during daylight hours.

The pilot who is not familiar with the form of the various written reports and forecasts may wonder why they are not written in plain language. Because each report contains a large amount of information, it is necessary to

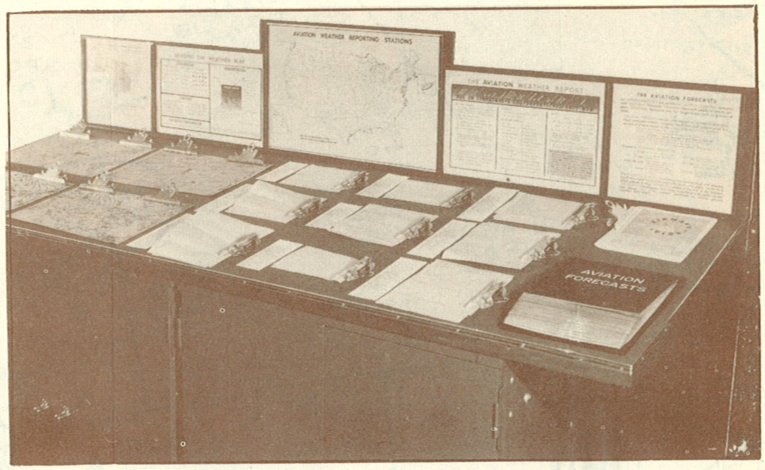

FIG. 4 - DISPLAY OF PILOT WEATHER INFORMATION AT TYPICAL WEATHER BUREAU STATION

use abbreviations and symbols so the many hundreds of reports furnished each hour can be transmitted on the teletypewriter circuits in the time available.

Pilots are encouraged to learn to interpret the hourly reports as well as aviation forecasts. The chart shown in Figure 5 explains the hourly weather reports. The form of the terminal forecasts is almost identical to that of the hourly observations except that pressure, temperature, dew point, and altimeter setting are, of course, not forecast.

In using the reports, pilots are encouraged to keep in mind that the regularly available reports can only show conditions as they existed at a particular time and at a particular place. Conditions between stations may be different. Also, there is no assurance that the conditions will remain unchanged, so it is most important to also review the forecasts to see if important changes are expected that would affect the plan of flight.

Pilots having questions about the aviation weather services that are available should feel free to inquire at any Weather Bureau station.

LOCATION IDENTIFIERS	"SPECIAL" REPORT ⊹	SKY AND CEILING	VISIBILITY WEATHER AND OBSTRUCTION TO VISION	SEA-LEVEL PRESSURE	TEMPERATURE AND DEW POINT	WIND	ALTIMETER SETTING	REMARKS
MKC	S4	15⏀M25⊕	4R-K	132/	58/56	↑7/	993/	RB05 ⊕V⏀

SKY AND CEILING

Sky cover symbols are in ascending order. Figures preceding symbols are heights in hundreds of feet above station.

Sky cover Symbols are:

○ = Clear: Less than 0.1 sky cover.

⏀ = Scattered: 0.1 to less than 0.6 sky cover.

⦶ = Broken: 0.6 to 0.9 sky cover.

⊕ = Overcast: More than 0.9 sky cover.

+ Dark — Thin

-X = Partial Obscuration: 0.1 to less than 1.0 sky hidden by precipitation or obstruction to vision (bases at surface).

X = Obscuration: 1.0 sky hidden by precipitation or obstruction to vision (bases at surface).

Letter preceding ceiling indicates how ceiling height was measured. Thus:

A = Aircraft E = Estimated P = Precipitation
B = Balloon M = Measured W = Indefinite
(V = Variable ceiling)

VISIBILITY

Reported in Statute Miles and Fractions.
(V = Variable Visibility)

WEATHER SYMBOLS

A = Hail	S = Snow
AP = Small Hail	SG = Snow Grains
E = Sleet	SP = Snow Pellets
EW = Sleet Showers	SW = Snow Showers
IC = Ice Crystals	T = Thunderstorm
L = Drizzle	T+ = Heavy Thunderstorm
R = Rain	ZL = Freezing Drizzle
RW = Rain Showers	ZR = Freezing Rain

INTENSITIES are indicated thus:

-- Very Light	(no sign) Moderate
— Light	+ Heavy

OBSTRUCTION TO VISION SYMBOLS

D = Dust	H = Haze	BD = Blowing Dust
F = Fog	IF = Ice Fog	BN = Blowing Sand
GF = Ground Fog	K = Smoke	BS = Blowing Snow

WIND

↓ N	← E	↑ S	→ W
↓↙ NNE	←↖ ESE	↑↗ SSW	→↘ WNW
↙ NE	↖ SE	↗ SW	↘ NW
←↙ ENE	↑↖ SSE	→↗ WSW	↓↘ NNW

Speed in Knots follows direction arrows. C indicates "Calm". + indicates "Gusty". Peak speed follows "gusty" sign.

ALTIMETER SETTING

The first figure of the actual altimeter setting is always omitted from the report.

DECODED REPORT
Kansas City: Special observation #4, 1500 feet scattered clouds, measured ceiling 2500 feet overcast, visibility 4 miles, light rain, smoke, sea level pressure 1013.2 millibars, temperature 58°, dew point 56°, wind south 7 knots, altimeter setting 29.93 inches, rain began 5 minutes past the hour, overcast occasionally broken.

⊹ S Indicates important change.

FIG. 5 - KEY TO AVIATION WEATHER REPORT

AVIATION SERIES NO. 10

CEILING...

How it is DETERMINED and what it means to the PILOT

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U. S. WEATHER BUREAU

"Ceiling" has been a key word in aviation for a long time. Questions like "What's the ceiling?" or "What will the ceiling be at my destination when I arrive?" come up countless times.

For some 30 years following the Wright Brothers' historic powered flights at Kitty Hawk, North Carolina in 1903, few pilots attempted continuous flight within clouds because the instruments and techniques needed to fly "blind" had not yet been perfected for general use. Thus in these early years, most flights were made below the clouds and pilots thereby avoided the possibility of having to make their descents under "blind" conditions in case the cloud layer had no openings through which a normal descent could be made.

Just how the word "ceiling" came to be adopted as an aviation weather term is open to some conjecture. It likely came into general use because for all practical purposes, the height of the base of the lowest extensive cloud layer was for many years the limit above which continued flight was not feasible, and this cloud height then became the pilots' flight "ceiling."

The "Ceiling" Concept

For practical purposes the pilot can think of "ceiling" as the lowest height at which more than half of the sky is covered by clouds.*

Determining Cloud Heights

To report the ceiling the weather observer must first determine the height of the bases of the clouds. There are several ways to determine this. One is to use the reports of the cloud heights received from pilots flying in the immediate vicinity of the airport. In the absence of reports from pilots, the observer can estimate the height, relying on his experience and knowledge of cloud forms. Or, if he has the necessary instruments, he can measure the cloud height.

To measure cloud heights, the observer may use a ceiling light or a ceilometer. A typical system for measuring cloud heights is shown in Figure 1.

Balloons, too, are sometimes used to determine cloud heights by noting how long it takes the balloon to reach the cloud base. However, the accuracy of this method is

*It sometimes happens that thick smoke, haze or dust also cover all or part of the sky and must be considered in determining the ceiling condition.

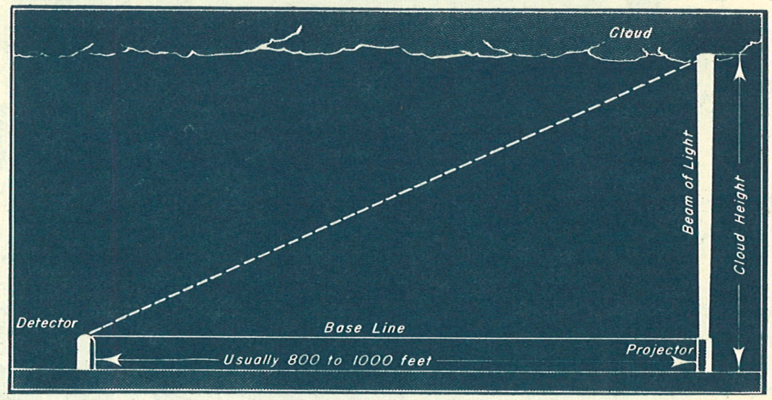


FIG. 1 - CLOUD HEIGHTS CAN BE MEASURED WHEN THE DISTANCE BETWEEN THE VERTICAL LIGHT BEAM AND THE "SCANNER" IS KNOWN, AND THE ELEVATION ANGLE IS MEASURED.

rather limited because vertical air currents often cause the balloon to rise at speeds other than the normal rate.

When the clouds forming a ceiling are not clearly distinguishable due to conditions such as fog or dust, the observer classifies the ceiling report as "indefinite" so that users of the report may know that the measurement was not made under the most favorable conditions.

Technically, when precipitation hides the cloud bases, the ceiling report is classified as a "precipitation" ceiling, again indicating to the user that a precise measurement was not possible.

So pilots and others using a weather report may know how reported ceiling heights were determined, all reports show the method used by prefixing the ceiling height value with one of several selected letter designators. "M" is used to indicate a measured ceiling, "A" indicates the ceiling height was reported from an aircraft in the immediate vicinity of the field, "B" means the ceiling was determined by releasing a balloon, "W" means an indefinite measurement due to some obscuring condition, "P" that the measurement was made under precipitation conditions, and "E" that the ceiling height was estimated.

Cloud Amounts and Ceilings

We have already shown that the total amount of sky cover determines whether or not there is a "ceiling." Thus, to report the weather, the observer must determine the extent of the cloudiness as well as the cloud heights.

CEILING...

Amounts of sky cover are determined by how many "tenths" of the sky is covered by each layer. If a cloud layer covers from one-tenth to five-tenths of the sky, the clouds are said to be "scattered," if it covers six-tenths through nine-tenths of the sky, it is classified as "broken." If the cloud layer covers all (ten-tenths) of the sky, it is referred to as "overcast."

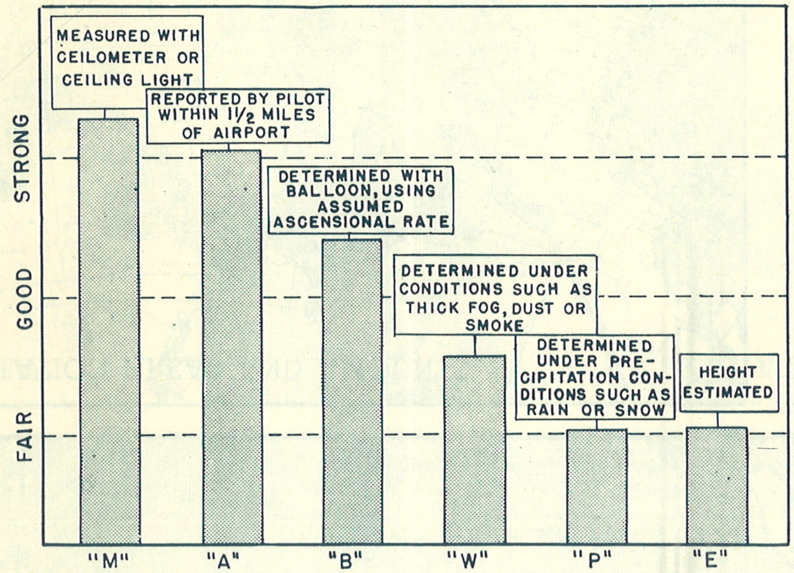


FIG. 2 - THE AVERAGE DEGREE OF CONFIDENCE THAT CAN BE EXPECTED OF REPORTS OF CEILING HEIGHTS DETERMINED BY DIFFERENT METHODS.

When a cloud layer is predominantly transparent, it may be reported as "thin scattered," "thin broken," or "thin overcast." (The corresponding symbols are: -⦶ , -⦷ , and -⊕ .) Because of their transparency, "thin" clouds are not considered to contribute to a ceiling condition.

Referring to Figure 3, let us assume that the observer determines the height of both cloud layers, namely, 1000 feet and 2000 feet. Whether the ceiling will be reported as 1000 feet (the height of the lower layer) or 2000 feet (the height of the upper layer) depends on the amount of sky covered by the lower layer. In this figure, the lower layer alone covers less than one-half of the sky as seen by the observer, so by definition it is not sufficient to constitute a ceiling. The condition would be reported "Scattered clouds at 1000 feet, ceiling measured 2000 feet overcast." In report form it would read 1Ø⦶M2Ø⊕,

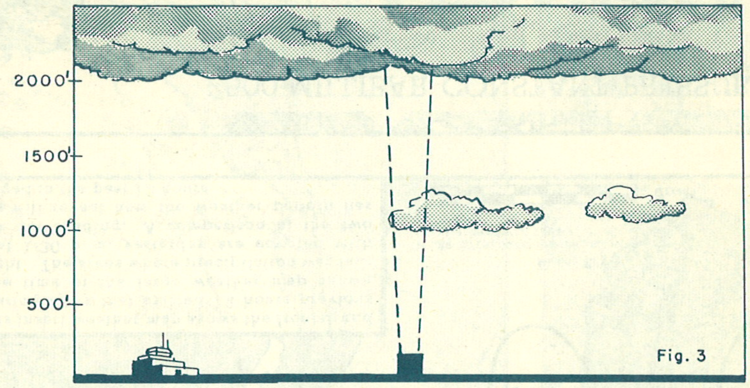


FIG. 3 - BECAUSE THE LOWER CLOUDS DO NOT COVER MORE THAN HALF OF THE SKY THEY DO NOT CONSTITUTE A CEILING, BUT THE OVERCAST AT 2000 FEET DOES.

where the symbol ⦶ means "scattered clouds," ⊕ means overcast, and heights are in hundreds of feet. Now, let us assume that the lower clouds increase until they hide more than half of the sky from the observer's view, as shown in Figure 4. According to the definition of ceiling, the ceiling is now 1000 feet instead of 2000 feet. The sky condition report would then be "ceiling measured 1000 feet, broken clouds, 2000 feet overcast," or, in symbol form, M1Ø⦷2Ø⊕ , where the symbol ⦷ means broken clouds. It should be noted that in these examples (Figures 3 and 4) the cloud heights did not change, only the amount of the lower clouds changed sufficiently to make the lower layer the "ceiling" rather than the upper layer.

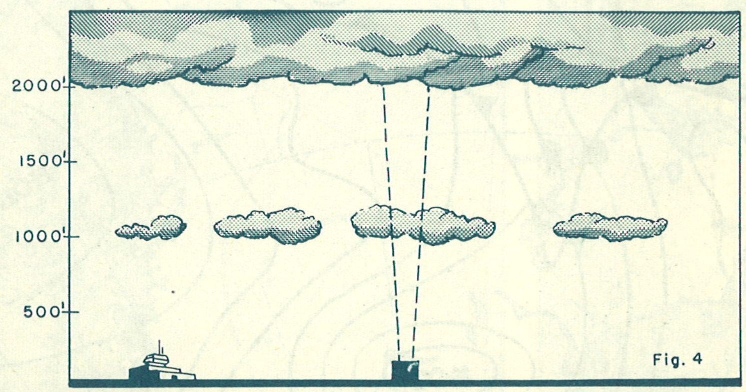
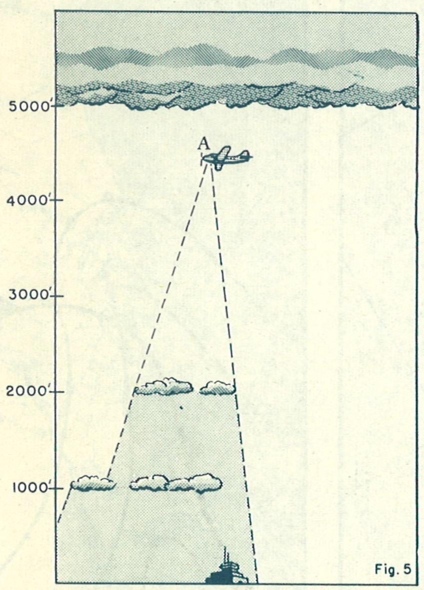


FIG. 4 - AN INCREASE OF CLOUDS AT THE LOWER LAYER RESULTS IN THE CEILING BEING REPORTED 1000 FEET INSTEAD OF 2000 FEET AS IN THE PREVIOUS FIGURE.

Sometimes there are several layers of clouds. A three-layer situation in which it is assumed the heights of the layers have been measured is shown in Figure 5. Here we come to use what is known to weather observers as the "summation principle." This is an observing rule which says that to determine the ceiling one must consider the amount of clouds in each of the several layers, in ascending order of height, until a height is reached where the total amount of sky covered by the clouds as seen by an observer on the ground is more than one-half. (Note we have again come back to our simplified definition of ceiling.) The condition shown in Figure 5 would be reported as "Scattered clouds at 1000 feet, scattered clouds at 2000 feet, ceiling measured 5000 feet overcast," written 1Ø⦶2Ø⦶M5Ø⊕. Let us assume the middle layer of clouds moves to the right as shown in Figure 6. Now a ground observer would be able to see most of the middle layer as well as the lower layer and he would report the condition as "Scattered clouds at 1000 feet, ceiling measured 2000 feet, broken clouds, 5000 feet overcast," written 1Ø⦶M2Ø⦷5Ø⊕ .



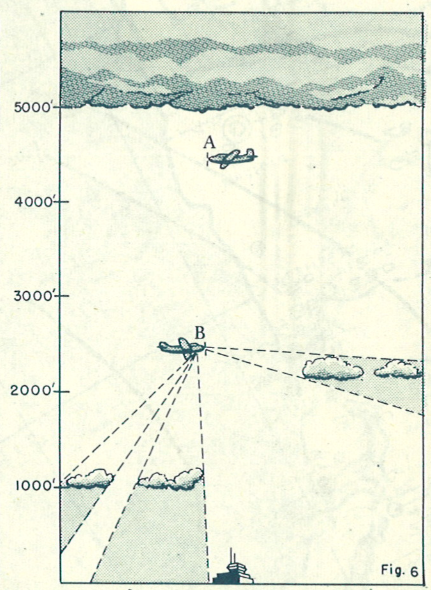
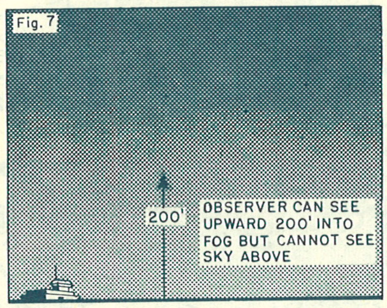


FIG. 5 - HERE THE TWO LOWER LAYERS COMBINED DO NOT CONSTITUTE A CEILING BECAUSE THEY DO NOT COVER MORE THAN HALF THE SKY. CEILING IS REPORTED 5000 FEET.

FIG. 6 - A CHANGE IN THE RELATIVE POSITION OF THE TWO LOWER LAYERS HAS RESULTED IN HIDING MORE THAN HALF THE SKY FROM THE GROUND OBSERVER'S VIEW. THIS CONDITION WOULD BE REPORTED AS "SCATTERED CLOUDS AT 1000 FEET, CEILING 2000 FEET BROKEN CLOUDS, 5000 FEET OVERCAST."

Why, then, does the observer in the first case report a ceiling of 5000 feet and in the other a ceiling of 2000 feet while the total amount of clouds in each of the two lower layers has remained unchanged? Again, it is because of the difference in the total amount of sky covered by the two lower layers.

Now, let us see what these conditions might mean to the pilot. In Figure 5 a pilot flying well above the lower layers of clouds (Point A) probably would find the clouds obscuring only a small portion of the earth's surface from his view and consider the clouds to be scattered. In Figure 6 a pilot flying at the same level probably would agree with the observer that the clouds below obscure more than half of the earth's surface from his view and thereby constitute a ceiling, as reported. However, a pilot flying at Point B (Figure 6) might be able to see much more of the ground and argue that the clouds are only scattered.



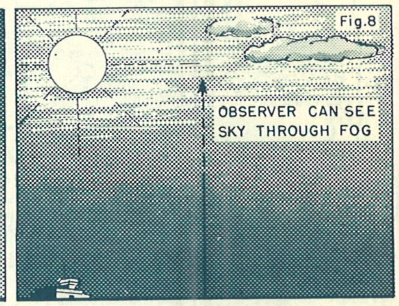


FIG. 7 - WHEN THE SKY IS COMPLETELY HIDDEN BY FOG, THE OBSERVER REPORTS "OBSCURATION."

FIG. 8 - WHEN THE SKY IS PARTIALLY OBSCURED BY FOG, THE OBSERVER MAY REPORT "PARTIAL OBSCURATION."

Most ceiling reports are based on conditions as seen by an observer on the ground, and due to differences in point of observation, there will sometimes be differences between the cloud amount and ceiling as determined by the pilot in flight and the observer at the weather station.

Obscured Skies

The primary purpose of flying weather observations is to give the pilot as much information as possible about the existing weather conditions. From experience it was found that to report the sky condition only in terms of scattered, broken, or overcast was not always sufficient to adequately describe existing conditions, so two additional symbols, "X" and "-X," have come into use. The symbol "X" means "obscuration," a condition when the sky is entirely hidden from the ground observer's view by an obstruction to vision like fog, and its base extends downward to the ground. When the weather observer reports an "obscuration" he adds to his report information to indicate the vertical visibility. For example, if the sky is obscured by dense fog but the observer determines that he can see upward into the fog 200 feet, he will report "Ceiling indefinite 200 feet, sky obscured." This would be written W2X.

If the obscuring phenomena hides only part of the sky, the observer reports "partial obscuration," using the symbol "-X" (read "Partial obscuration"). A partial obscuration never constitutes a ceiling because it is at the surface and the sky is partially visible.

In summary, when the observer reports "obscuration," he is in effect saying "The sky is obscured from my vision by surface based phenomena. I can not see any clouds above it or determine the sky cover." If he reports "partial obscuration" he is in effect saying "The sky is partially obscured by a surface based phenomena, but I can see enough to report the sky conditions that exist above it." Figures 7 and 8 pictorialize some "obscuration" conditions.

Other Ceiling Facts

Ceiling heights are always reported in hundreds of feet above the ground, not sea level. However, reports of cloud tops are always in Mean Sea Level since that reference is most convenient to pilots flying cross country. (For the same reason, forecasts of heights of cloud tops, and levels of icing and turbulence are stated in sea level.)

Cloud bases are seldom smooth and of uniform height. Measurements made with the new "rotating beam" type ceilometer, which measures cloud heights ten times per minute, show that during low ceiling conditions cloud heights may vary several hundred feet in a matter of minutes. This is an explanation of why pilots landing under low visibility conditions sometimes find the ceiling higher or lower than that reported.

NEXT MONTH: Visibility -- How it is determined and what it means to the pilot.

AVIATION SERIES NO. 11

VISIBILITY... How it is DETERMINED and what it means to the PILOT

●

U. S. WEATHER BUREAU

VISIBILITY...

"Ceiling" and "visibility" -- two terms that are fundamental in aviation terminology -- probably are used more than any others in discussing flying weather. Seldom does a pilot check on the flying weather without paying particular attention to the visibility conditions; for "visibility," together with "ceiling," holds the answer to many flight problems.

One may ask "What is visibility?" or "When the weather observer reports two miles visibility, just what does this mean?"

Visibility has been defined as " . . . the greatest distance an object can be seen and identified." In actual practice this means the greatest distance that prominent objects such as buildings, trees, water towers or natural landmarks can be seen clearly enough to definitely establish their identity.

How Visibility is Determined

Weather observers must rely almost entirely on visual

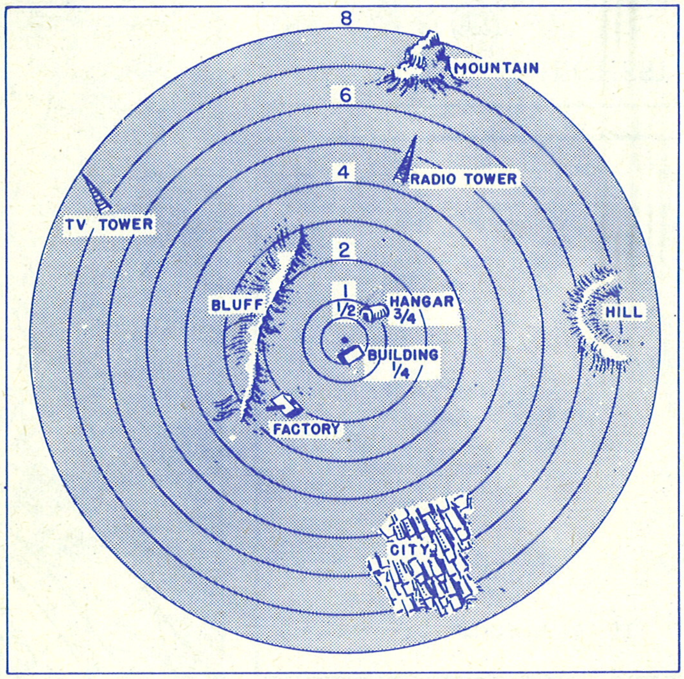


FIG. 1 - ALL WEATHER STATIONS HAVE A CHART SIMILAR TO THIS TO SHOW VISIBILITY MARKERS.

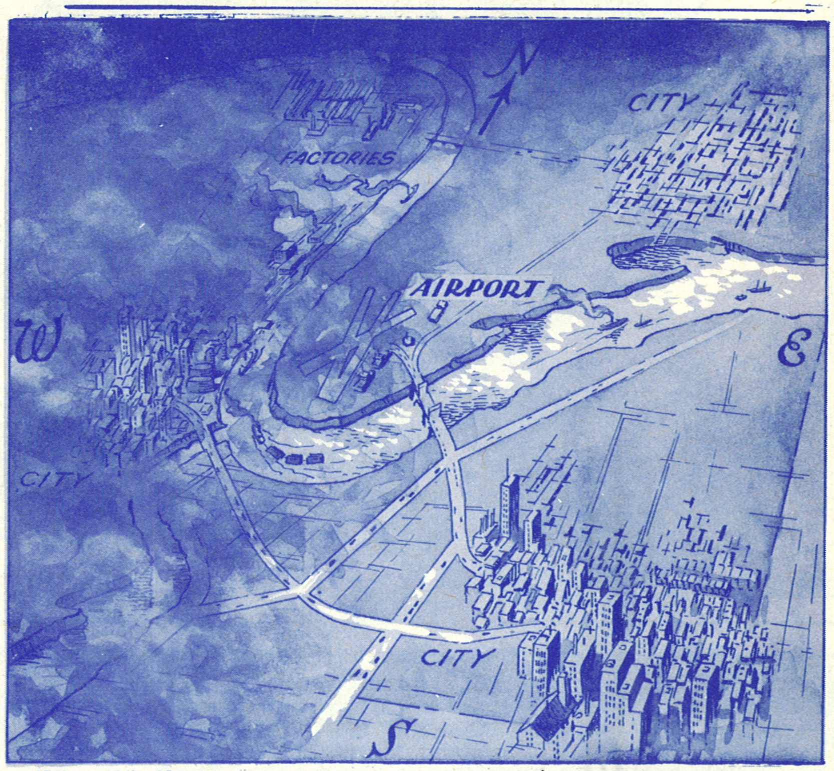


FIG. 2 - HERE SMOKE HAS CAUSED DIFFERING VISIBILITY WITH CHANGE IN DIRECTION, WHEN APPROACHING THIS AIRPORT PILOT VISIBILITY WILL DEPEND ON DIRECTION OF APPROACH.

observation, rather than instruments, to determine visibility. It is possible to measure the transparency of the atmosphere over a fixed path with special instruments, but in daily practice the visibility conditions about the entire airport periphery are more readily determined visually. The observer knows the distance from the weather station to various prominent objects within visual range of the airport, and uses these references when determining the visibility. To make visibility observations at night, the observer judges the transparency of the atmosphere by how well permanent lights of known intensity and distance can be seen. Figure 1 represents a typical map such as is kept at all weather stations to show the distance and direction of the various permanent landmarks, or other reference points used in determining visibility.

VISIBILITY...

It is not unusual for the visibility in one direction to be different from that in another. For discussion purposes let us assume that the weather observer determines the visibility to be three miles to the north and south of the station, five miles to the east, and one mile to the west. (See Figure 2.) Standard weather observing procedures are to report the "prevailing" visibility as the maximum visibility that is common to more than half of the surrounding horizon. In this case, the "prevailing" visibility would be three miles, and this value would be included in the body of the observation report. However, to state only the "prevailing" visibility would not tell the whole story. A pilot approaching the airport from the east and expecting three miles visibility would find it considerably better, while a pilot approaching from the west would find the visibility much lower. To make certain that such important differences are made known to pilots of arriving and departing aircraft, the observer explains the variations in visibility by adding special remarks to the end of the observation. A written weather report including the conditions discussed above, namely; prevailing visibility three miles, visibility five miles to the east, and one mile to the west, might appear as follows:

M8⊕3F- 174/65/63↑3/ØØ3 VSBY E5 W1

Sometimes the visibility is variable so that new observations can not be made with sufficient frequency to keep up with the rapidly fluctuating conditions. When the prevailing visibility is less than three miles, and variable, the observer adds remarks to the observation report to indicate the degree of variability. In such a case, the observation report shown above might appear thus:

M8⊕2F- 174/65/63↑3/ØØ3 VSBY 2V3

Tower Visibility

When the prevailing visibility is less than three miles, and if there is a control tower at the airport, the visibility observations are made from the tower instead of from the usual weather station observing site. There is advantage in this practice because the control tower, having an unobstructed view in all directions, can immediately note any important changes in visibility and use this new information in its traffic control work.

Sometimes the visibility at the ground level is different from that observed from the control tower. Therefore, any differences between tower visibility and ground level visibility are explained for the pilot by adding remarks to the observation report to show also the ground level visibility. Such information could, for example, be very valuable to a pilot making an approach during a ground fog condition because it would indicate that a marked reduction in visibility could be expected during the final stages of the landing.

In-flight Visibility Versus Surface Visibility

All pilots are familiar with the fact that in-flight visibility frequently is not the same as the surface visibility. Such differences are caused by unequal distribution of the obscuring particles, such as smoke, haze, or fog, and because the pilot sees these conditions from a different angle than does the observer on the ground. For example, a fog near the surface may seriously restrict the ground observer's visibility, but to the pilot flying over the airport it may appear as only a thin film through which the airport runways and buildings are visible. (See Figures 3 and 4.) At other times, haze or smoke may be lifted sufficiently to result in rather good visibility at the surface, but the pilot in flight may be able to see very little of ground objects.

Snow is another condition in which effective visibilities at the surface and in flight are different. Due to the speed of the aircraft, the relative motion of the snowflakes is almost horizontal, causing them to strike the windshield or to flow around it in such numbers that the result is only a white blur that can result in almost total loss of forward visibility. (See Figure 5.)

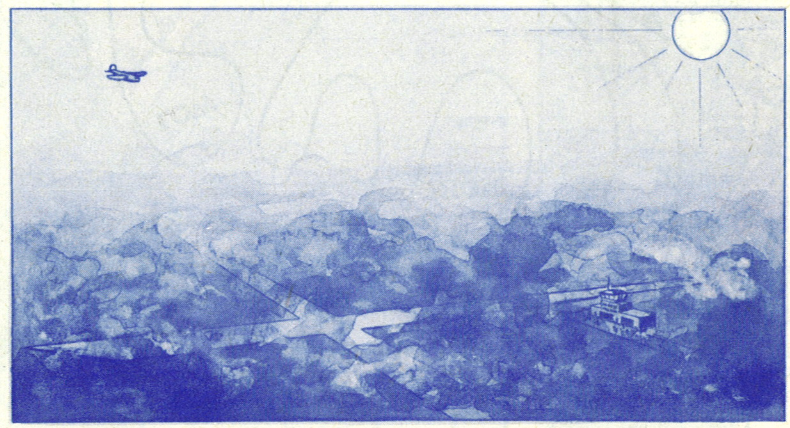


FIG. 3 - PILOT MAY BE ABLE TO SEE RUNWAYS THROUGH GROUND FOG.

An example of how surface visibilities and those observed in flight can differ may be taken from the following pilot account of an actual approach to Nantucket (Mass.) Airport:

"... Over Martha's Vineyard, I was still able to see landmarks 15 to 20 miles away, while at the same time the radio broadcast gave the visibility as two miles at Nantucket. Arriving over the western edge of the Island, I was able to see quite clearly the buildings and terrain as well as the airport several miles ahead. I began to wonder about the reported two-mile visibility. Realizing I was in a controlled area, I called for an IFR clearance. After taking my place in the stack and flying the required holding pattern, I became more and more disgusted with the visibility report, as I could see at least 15 miles and possibly more. When it came my turn to land, I still could see the airport. On descending, the haze suddenly became thicker and thicker and I soon found myself on instruments. When I landed, I estimated the ground visibility and felt that it was in agreement with the two miles reported by the observer."

Other Factors Affecting Visibility

When the sun is within about 45° of the horizon the pilot's

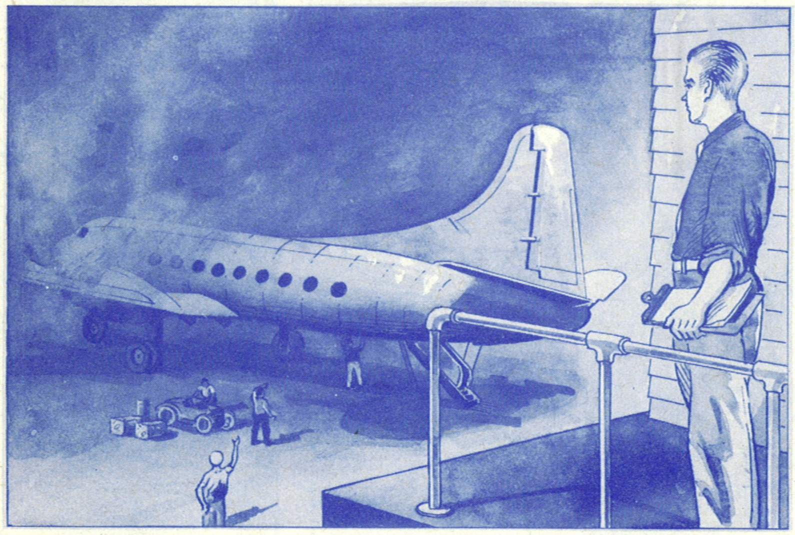


FIG. 4 - HOW THE SAME GROUND FOG CONDITION MAY APPEAR AT THE SURFACE.

FIG. 5 - PILOT'S FORWARD VISIBILITY IN SNOW CAN APPROACH ZERO EVEN THOUGH SNOW IS NOT HEAVY.

effective visibility may vary considerably, depending on whether he is looking toward or away from the sun. When there is considerable haze, dust or smoke in the air, the pilot's effective visibility when looking toward the sun may be on the order of a fraction of a mile, while in other directions it may be several miles or more. The pilot's effective in-flight visibility also depends on the nature of the objects used as ground references. Haze or smoke tend to make white or grey objects difficult to see, while brightly colored objects are affected least.

Visibility for Instrument Landings

When the visibility about an airport is not uniform, as illustrated in Figures 3 and 4, it frequently happens that the visibility along a particular runway and airport approach lane is significantly better or worse than that observed from the weather station. Thus, the regular report of the visibility at the weather station may or may not be representative of the conditions the pilot may encounter on landing.

When low clouds, fog or similar weather phenomena require that an "instrument" landing be made, pilots approaching an airport need information on the visibility conditions that exist in the approach lane to the runway. Especially does the pilot need advance information on the height at which he can first expect to see the runway. It is during this period that the aircraft has descended to within a few hundred feet of the ground and there is little time remaining for the pilot to make the necessary transition from full instrument flight to visually positioning the aircraft over the runway threshold area to complete the landing.

As of this writing, Government and industry are working together to find solutions to the complex problems involved in low visibility approaches. Comprehensive field tests are in progress. Measurements are being made of "runway visual range" -- the distance along the runway at which objects can be seen from the cockpit of an airplane. A new device known as a Transmissometer (see Figure 6) is being used to measure the transparency of the atmosphere over a fixed path alongside and parallel to the runway, and methods have been developed to measure sky brightness and ground illumination. Results from these and related measurements are encouraging, and offer promise that the time is not too far distant when it will be feasible for airliners to land regularly under extremely low visibility conditions that now cause flight cancellations or diversions to other airports.

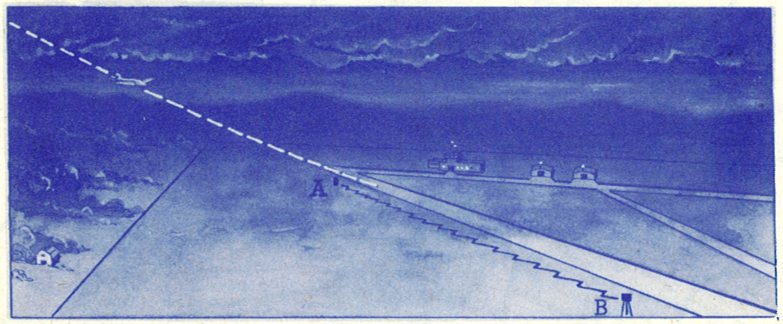


FIG. 6 - INTENSITY OF BEAM RECEIVED AT "A" FROM "B" DETERMINES RUNWAY VISIBILITY.

AVIATION SERIES NO. 12

TIPS ON WEATHER FOR VFR FLIGHT

●

U. S. WEATHER BUREAU

Whether the pilot realizes it or not, when he flies by visual reference he is keeping his wings level, maintaining the desired attitude, and to some extent holding his course by visual reference. This visual reference requires an horizon. It may be the natural horizon -- the division of earth and sky as we see it in the distance -- or it may be the effective horizon determined by the existing weather conditions.

The effective horizon distance may be thought of as representing the maximum distance over which the pilot can distinguish objects on the ground to determine whether he is flying level. When the horizon is the natural horizon the pilot's job is the easiest. But, as the pilot's visual range is reduced by weather, his "flying horizon" drops below the natural horizon until finally it is no longer an horizon at all, but only a very restricted area directly below through which the pilot may possibly see the ground. Somewhere between these two extremes is the limit below which it is no longer possible to continue to fly an airplane without the aid of special instrumentation and the training necessary to properly use these aids.

Any reduction in distance of the pilot's "flying horizon" to less than that of the natural horizon is always the result of "weather." (See Figures 1 and 2.) This may be due to dust or smoke reducing the normal transparency of the atmosphere, or it may be due to particles of moisture forming haze, fog, clouds, or combinations of these. If the reduction in visibility is caused by clouds, it almost invariably results in sudden and complete loss of visual reference. If it is due to dust, haze, fog, drizzle, rain, or snow the reduction in effective horizon distance is usually more gradual. In the case of clouds, there is in each instance an altitude above which the aircraft can not be flown and still permit the pilot to see the ground well enough to fly by visual reference. Also, the thicker the fog, haze, dust, or smoke the less the slant visibility.

The weather problems of the strictly VFR pilot are in many respects quite different from those of the instrument pilot. This is because the VFR pilot must at all times have an effective horizon and he must be able to

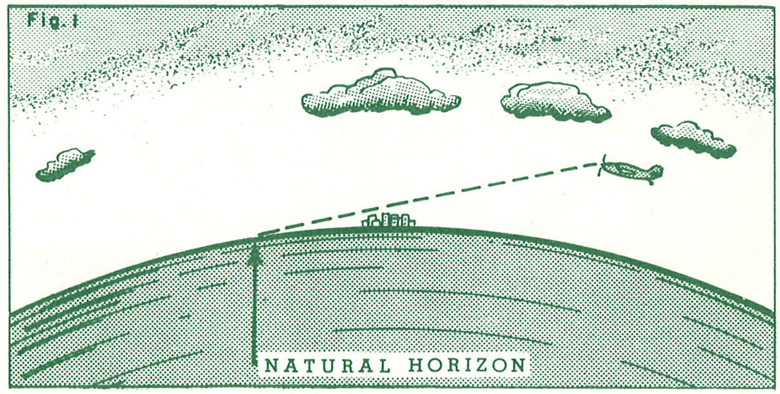


FIG. 1 - WHEN WEATHER IS CLEAR HORIZON IS PLAINLY VISIBLE AND IS AN AID TO CONTROLLING AIRCRAFT BY VISUAL REFERENCE.

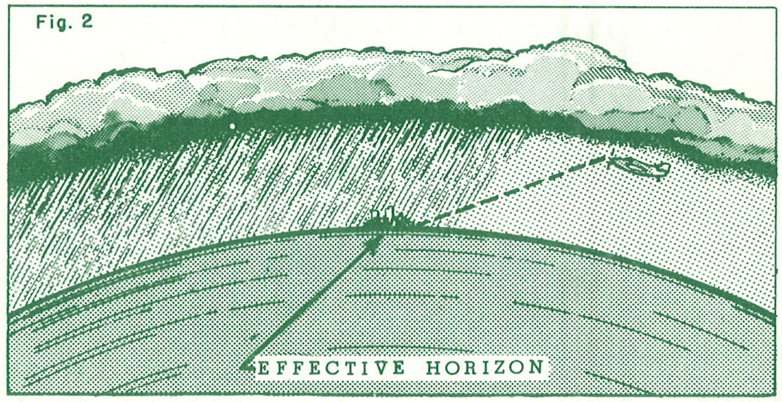


FIG. 2 - WHEN VISIBILITY IS LOW EFFECTIVE HORIZON IS CLOSER AND DIFFUSED, MAKING CONTROL OF AIRCRAFT'S HEADING, ATTITUDE AND BANK BY VISUAL REFERENCE MORE DIFFICULT.

see ahead well enough to avoid collision with such objects as mountains, buildings, radio or TV towers, and other aircraft in flight. Thus, the height of the clouds, and the air-to-ground visibility are of prime importance to safe VFR operations.

Low Clouds

It is often convenient to think of all clouds as being stratified horizontally, and with flat bases. Experience shows, however, that this is usually not the case. Clouds, especially low ones, seldom have smooth, horizontal bases. Many of them have very irregular bases with occasional cloud fragments of sufficient size to blot out the VFR pilot's ground reference hanging hundreds of feet below them.

The pilot who is flying under a low overcast that is barely high enough for visual navigation below the clouds should expect to find considerable variations in the cloud heights, especially if the winds are light. This condition is illustrated in Figure 3. In those cases

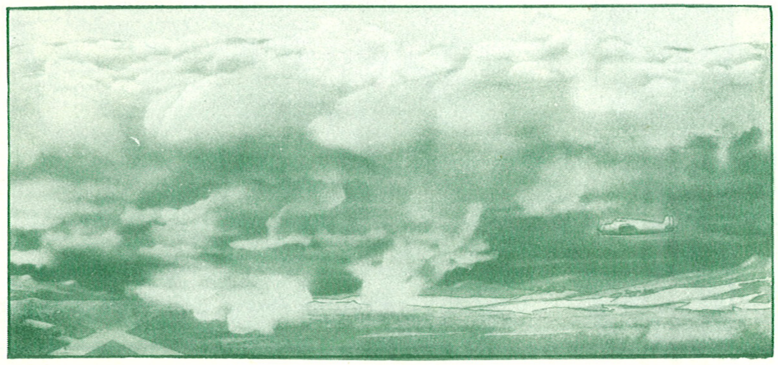


FIG. 3 - LOW CLOUDS USUALLY HAVE RAGGED AND VARIABLE BASES.

where the terrain is uneven, the variations in cloud heights may be quite pronounced. It is not uncommon to find such low clouds banked solidly against a mountain ridge as shown in Figure 4. Pilots planning VFR flight over mountainous or very irregular terrain should study, and if possible discuss with a meteorologist, the possible effects of terrain on ceiling and visibility conditions along the route of flight.

Visibility

Low clouds frequently have poor visibility below them. This may be due to haze, or to various forms of precipitation such as drizzle or rain. Also, if the clouds are fairly thick they will cut out considerable sunlight. This lack of sunlight further reduces the pilot's effective visibility during foggy or rainy weather and is an important factor in bringing about early darkness.

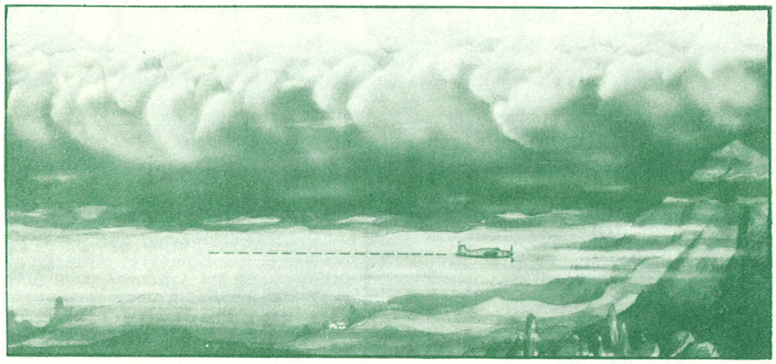


FIG. 4 - CLOUDS ARE OFTEN BANKED AGAINST MOUNTAINS.

The visibility from an airplane to the ground is often not the same as the visibility seen by the ground observer. Sometimes the pilot's visibility is better; sometimes the ground observer's visibility is better. In the case of ground fog, it often happens that a pilot in flight can see the ground through the fog from his flight level, but the ground station's visibility is seriously restricted. At other times, the ground observer may have reasonably good visibility, perhaps on the order of 8 to 10 miles, but haze or smoke will be dense enough to make flight difficult. Examples of those conditions are shown in Figures 5 and 6.

Snow, even if very light, can seriously limit the air-to-ground visibility. It is a condition that has given a great many VFR pilots considerable difficulty because they assumed that reports of only light snow indicated weather would be satisfactory for their flights. The following is quoted from an article that appeared in the CONNECTICUT AVIATION NEWSLETTER and is reproduced by permission of the Connecticut Department of Aeronautics.*

> "Snow, being opaque, presents a much greater hazard to visibility than all but the hardest of rainstorms. We've all noticed, at some time or another, how greatly a snowstorm can reduce surface visibility. Multiply this by the fact that you are flying into this snow at speeds of 100 miles per hour, and you can realize that you're

*Article by L. J. Rosser, rated pilot and ground instructor.

not going to be able to see very far -- often less than half a mile. Add to this the fact that the snow is often 'wet' and you have added the probability of icing to your troubles.

"This opaqueness of snow also offers another problem. The snow itself frequently obscures the base of the cloud from which it is falling, which, from the pilot's viewpoint, leaves no clearly defined ceiling and a definite 'in the soup' feeling. To further confuse the situation, the falling snow will blend into the snow-covered ground which, coupled with the severely reduced visibility, leaves the pilot with no horizon for reference. Robbed of both ceiling and horizon as reference points, the non-instrument pilot often finds vertigo setting in -- that condition where his 'senses' or 'feelings' misinform him concerning the attitude of his craft. This all too often leads to his stalling his craft, or spiralling in.

"This does not mean that a well-equipped light plane should NEVER be flown during conditions of snow. A light, dry snow will do no more than somewhat reduce the visibility. But it does mean that every pilot should regard any snow situation with a wary eye. Moderate to heavy snows are generally to be avoided for VFR flights, and a pilot flying in a light snow condition should always be keenly alert for any changes in intensity which could bring on a worsening condition.

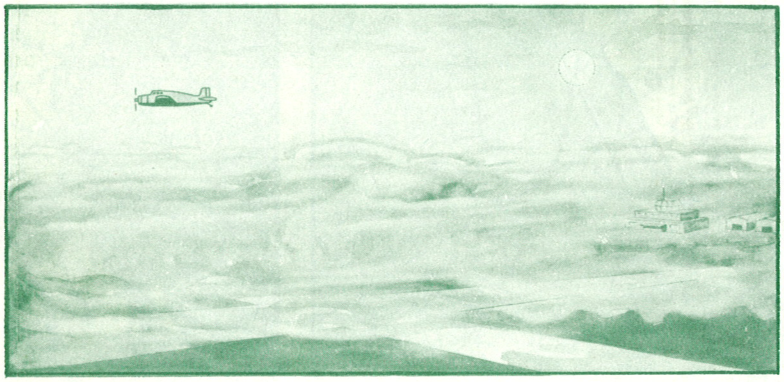


FIG. 5 - EXAMPLE OF GROUND FOG CAUSING POOR VISIBILITY AT SURFACE WHILE VISIBILITY ALOFT REMAINS GOOD.

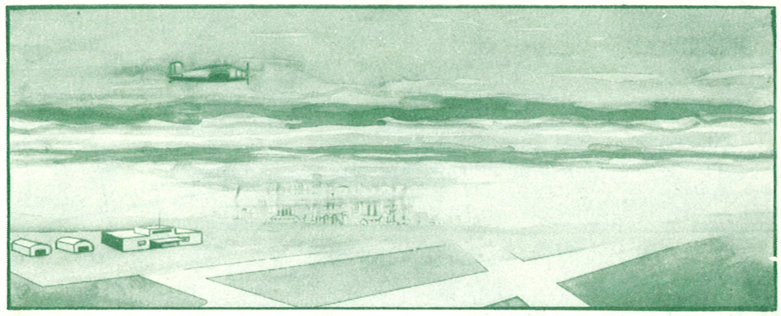


FIG. 6 - EXAMPLE OF SMOKE AND HAZE ALOFT WITH BETTER VISIBILITY AT SURFACE.

"The pilot will also do well to consider seriously a forecast that calls for occasional snow showers or flurries along his route. We tend to think of a snow shower as being light and of short duration -- short, spasmodic bursts of snow with intermittent periods of being 'in the clear.' However, when in the air at normal cruising speeds, those 'occasional' showers keep coming up with disturbing frequency -- often being entered so frequently as to seem like continuous snow. Unlike the observer on the ground who can wait for the individual showers to come to him, the pilot is flying into one after another! As a condition which produces snow flurries is seldom a local situation, but usually is widespread throughout a large area, it becomes impractical to try to weave or dodge through a series of showers. With visibility reduced by the snow and a constantly changing course as the pilot searches for clear areas, it becomes very easy to lose one's bearings and add being lost to one's problem. Rough air, which nearly always is found in snow shower conditions, can further add to the pilot's discomfort.

"A little forethought and planning can always save a pilot trouble when it comes to cross-country flying. A preflight check of the enroute and forecast weather, a close observation of developing conditions encountered, and a willingness to make a 180° turn when poor conditions are found, can bring many a flight to a successful conclusion."

Other Tips

There are other weather phenomena that are of importance in visual flight operations. Some of these were discussed in earlier articles of this special Aviation Series and are listed here for reference:

- No. 2 Ice on Aircraft -- Its Causes and Effects
- No. 4 Turbulence -- Its Causes and Effects
- No. 5 The Mountain Wave -- What It Means to the Pilot
- No. 7 Thunderstorms -- Part I
- No. 8 Thunderstorms -- Part II

Weather and the VFR Regulations

Frequent mention is made in this article to "flight by visual reference," generally known among pilots as the VISUAL FLIGHT RULES or "VFR." The Civil Air Regulations state certain ceiling and visibility conditions below which flight by visual reference is prohibited. Different limits apply depending on whether the flight is being made within a control area or a control zone, or outside of these. While the VFR limits may be thought of as absolute minimums for VFR flight, it does not follow that any weather condition in which the ceiling and visibility is equal or higher than these minimums is adequate for safe visual flight. To properly assess the flight weather conditions consideration must be given to additional factors such as wind, turbulence, icing and thunderstorms. It is for this reason that Weather Bureau practice in pilot briefing is to apprise the pilot of the weather elements that may be of importance to the flight, rather than to describe the conditions solely in terms of whether or not it meets one of the several VFR criteria.

AVIATION SERIES NO. 13

FRONTS... THEIR SIGNIFICANCE TO FLYING

U. S. WEATHER BUREAU

FRONTS...

A front is a boundary between two large air masses having noticeably different temperature or moisture conditions. To indicate the scale of the frontal phenomena, we should think of these air masses as being so large that they may spread over hundreds of thousands of square miles, and that everywhere along the air mass boundary there is a front, provided there is a sharp temperature or moisture difference between that air mass and the adjacent air mass. Thus, while fronts may extend upward only a mile or two, they usually extend hundreds of miles horizontally.

Fronts seldom are precise boundaries. Rather, they are transition zones several miles or more in width.

Frontal surfaces can be likened to the boundary between two unlike fluids such as oil and water in a vessel. In the same way that the lighter oil will tend to overlie the heavier water, the warm air (being lighter than the cold air) will tend to move up over the cold air rather than mix. However, unlike the case of the oil over water in the vessel, in which the boundary layer is horizontal, the frontal surfaces are sloped in the direction of the colder air mass.

Fronts do not exist indefinitely. They are formed, then gradually destroyed by the vast and complicated circulations of the atmosphere. Fronts are prolific producers of "weather" of the kind that is important to the pilot. This is so because the interaction between the cold and warm air masses causes air to be lifted, and lifting of the air usually causes clouds to form and then precipitation to fall in the form of rain or snow.

Not all fronts produce bad flying weather. Some fronts, because they are not supplied sufficient moisture, or perhaps because there is insufficient lifting of the warm air to cause clouds and precipitation to form, will hardly be noticeable to the pilot flying through them.

In the following pages each of several different types of fronts are shown and their principal features described. The reader should keep in mind that, for purposes of illustration, the vertical scale has been made much larger than the horizontal scale. Thus, the fronts are shown with much greater slope than they have in reality. Also, in the first three illustrations, the probable areas of precipitation have been omitted for sake of more clearly showing the frontal structures and typical cloud patterns. In all cases, the fronts are considered to move from left to right.

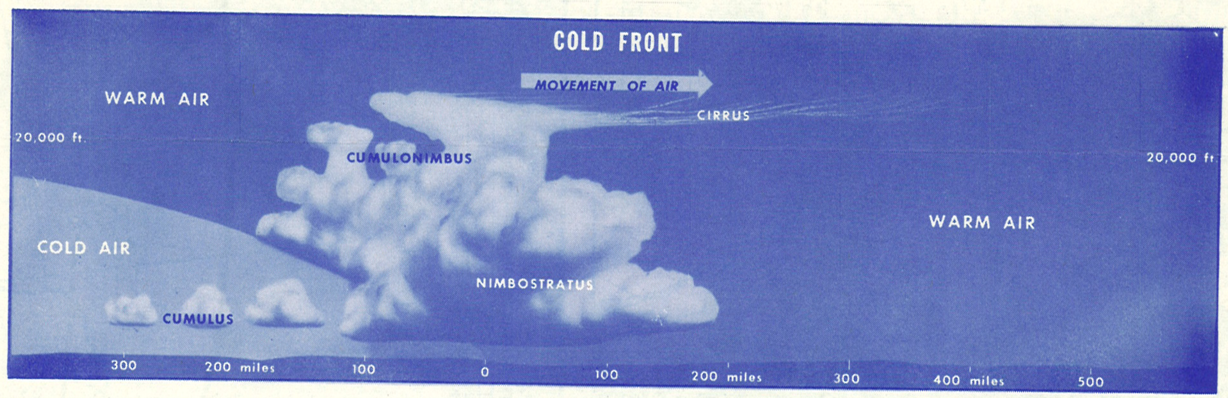


FIG. 1 - EXAMPLE OF A COLD FRONT

A front is called a COLD FRONT when the cold air is overtaking and replacing warm air. This illustration shows how the cold layer, being heavier, wedges under the warm air, and how the warm air is forced aloft. Usually the warm air is moist, and lifting causes it to cool and form clouds. Sometimes lifting causes the air to become "unstable," so it tends to rise of its own accord after being lifted past a certain level. This may cause "cauliflower" type clouds to form that can grow into thunderstorms as shown here. Some clouds also form in the cold air to the rear of the cold front. The boundary between the cold and warm air masses is called the "frontal surface."

Very marked weather changes take place along cold fronts, and some of the most hazardous flying weather is found in cold-front zones.

In flying toward a typical cold front, towering cumulus clouds will first appear on the horizon, with cirrus clouds above. As one draws closer the clouds will become thicker, and rain and possibly thunderstorms will be encountered. In the cold season there may be snow rather than rain and thunderstorms. Skies clear rapidly on passing through the front.

This describes a typical cold front. Actual weather encountered may in some cases be noticeably different.

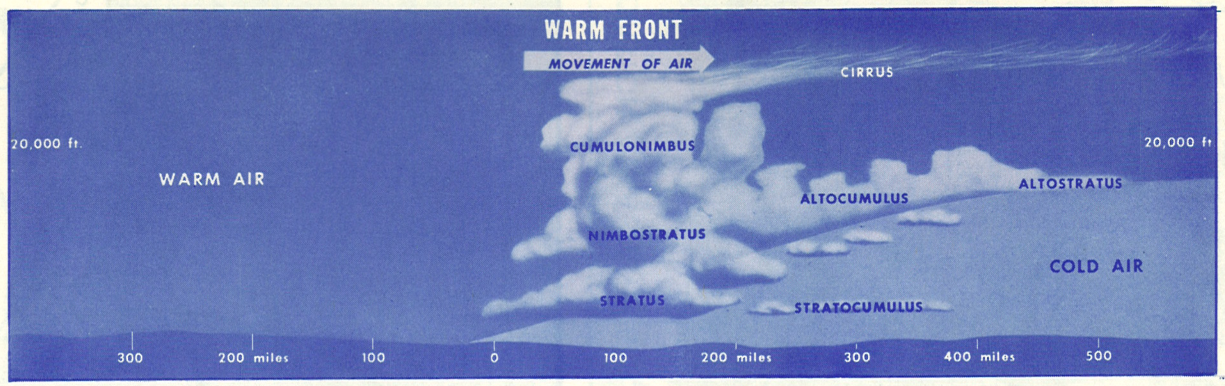


FIG. 2 - EXAMPLE OF A WARM FRONT

A WARM FRONT is a front in which warm air is overtaking and replacing cold air. In the warm front the warm air flows up over the thin wedge of heavier cold air below it, and forms a broad band of clouds. In this example the warm air is unstable and thunderstorm clouds are forming among the layer-type clouds. In this case, the precipitation would be spotty, and might extend from where the frontal surface intersects the ground to several hundred miles in advance of the front. Should the warm air remain stable, however, it would form a broad band of layer-type clouds hundreds of miles in advance of the front, with an extensive area of continuous rain or drizzle. This precipitation would cause low clouds and fog to form over a wide area to hamper aircraft operations.

In winter, rain falling from the warm air into the cold air below will sometimes freeze on aircraft flying in the cold air.

The slope of warm front surfaces is flatter than that of cold fronts, an average value being about one mile in 100 miles. Warm fronts are seldom as well defined as cold fronts, the surface boundary between the warm and cold air masses being a broad transition zone.

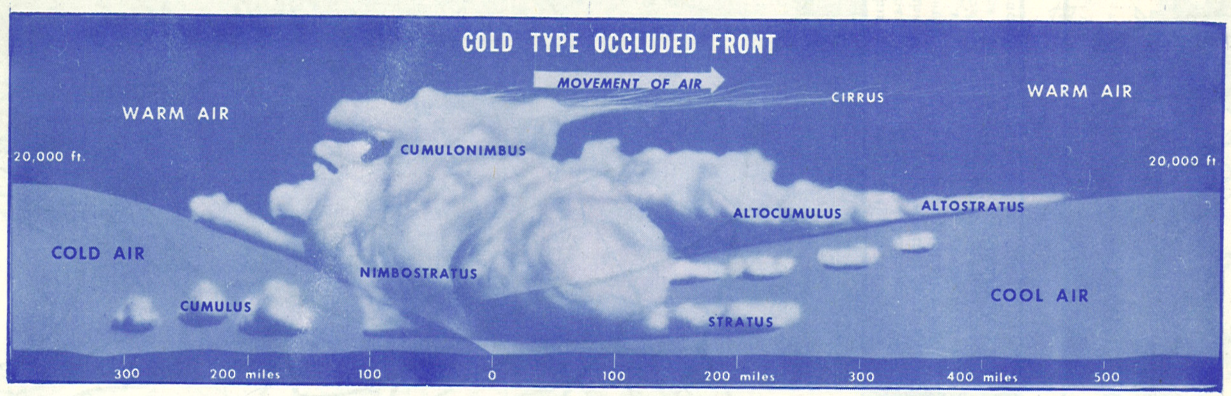


FIG. 3 - EXAMPLE OF A COLD TYPE OCCLUDED FRONT

As a LOW approaches the end of its life cycle it is usual for its associated cold and warm fronts to merge. Such a frontal combination is called an OCCLUDED FRONT.

This cross section of a "cold" type occluded front shows how the cold air on the left and the cool air on the right have overlapped to lift the warm air and trap it aloft. The forced lifting of the warm air causes clouds and precipitation. The precipitation often causes large areas of clouds and fog to form near the ground.

There is also a "warm" type occluded front. In the warm type the relative positions of the "cold" and "cool" layers are the reverse of that shown in the figure. Instead of the colder, and therefore heavier, air mass on the left wedging under the other layers, the air on the right would then be the colder and heavier, and the other layers would move up over it.

For the pilot, there is little practical difference between these types of occlusions. In the cold type occluded front shown here most of the cloudy weather and precipitation occurs near or to the rear of the intersection of the two colder air masses, but in the warm type occlusion it occurs mostly in advance.

Stationary Fronts

Sometimes adjacent cold and warm air masses exert about equal force on one another with the result that neither is replacing the other. Such a stationary situation is referred to as a STATIONARY FRONT. If the front should start to move it will become either a cold front or a warm front, depending on whether the warm air or cold air is being forced to recede.

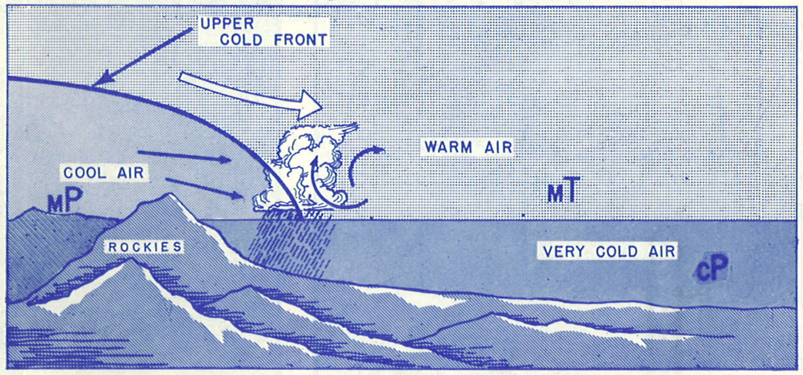


FIG. 4 - EXAMPLE OF AN UPPER COLD FRONT

The structure of the stationary front is somewhere between that of the cold front and the warm front. The flying weather conditions that occur along the stationary front are similar to those of a warm front but usually not as intense. An annoying feature of the stationary front is that it often persists in an area for several days, and thereby hampers flight operations.

Upper Fronts

An upper front is one where the interaction between two different air masses is taking place at some height above the ground. A typical upper cold front as found in the United States is shown in Figure 4. In this case there is a very cold air mass banked against the eastern slope of the Rocky Mountains, with warmer air lying above it. When a cool air mass from the Pacific moves in over the Rockies, it must act against the warm air mass aloft for it cannot displace the colder and heavier air mass that is already over the area. In this case, the cold front aloft acts very much like the conventional cold front except that the entire action takes place aloft.

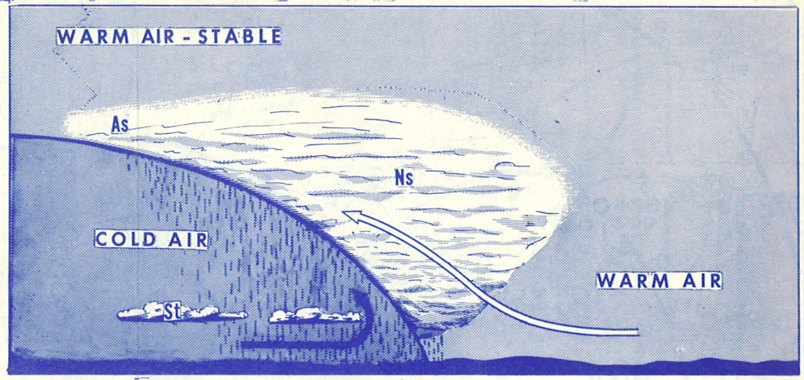


FIG. 5 - A SLOW MOVING COLD FRONT WITH STABLE WARM AIR

Some Special Cases of Fronts

For the pilot's purposes, cold fronts can be divided into two general types; the slow-moving or retarded front, and the fast-moving front. These types often change gradually from one to the other. In extreme cases cold fronts have been observed to move with speeds of 60 or more miles per hour, but they normally move at less than half this speed.

With the slow-moving cold front, there is a rather general upgliding motion of the warm air over the frontal surface which results in the formation of a relatively broad cloud pattern in the warm air lying above the cold layer. If this warm air is stable, the clouds will

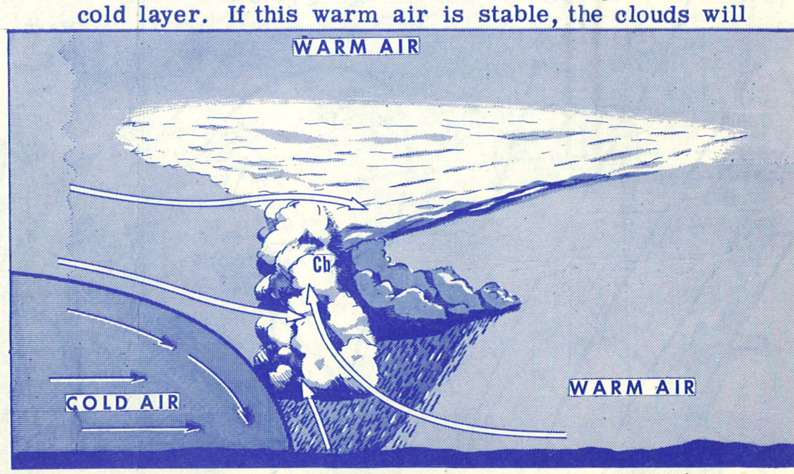


FIG. 6 - A FAST MOVING COLD FRONT WITH UNSTABLE WARM AIR

be of the layer type as shown in Figure 5, but if the warm air is unstable, heavy cumulus clouds or thunderstorms will form.

In the fast-moving cold front, there is downward moving air in the area immediately on both sides of the frontal surface, but upward moving air in the area ahead of the front as shown in Figure 6. Also, surface friction retards the movement of the cold air near the ground and makes the leading edge of the front rather blunt, or steep. It is this steepness of the frontal surface that causes the weather to be concentrated in a narrow band along the forward edge of the cold front. If the warm air is moist and unstable, showers and thunderstorms may form in the warm air just ahead of the front. In some cases an almost continuous line of thunderstorms may form along or ahead of the front. However, if the warm air is stable, an overcast sky of layer-type clouds may occur for some distance ahead of the front, and be accompanied by precipitation. In this case, the low ceilings, poor visibilities and heaviest precipitation will usually be limited to a narrow band along the front.

Inactive Fronts

Some pilots may wonder why they encounter practically no weather of importance along a route over which the meteorologists' map shows a front. This difference is explained by the fact that the meteorologist is keeping track of the boundaries between differing air masses because he knows it is in these areas where unfavorable flying weather, if it does not already exist, is most likely to occur in the future. The charting of bad weather areas not associated with fronts -- and these are sometimes quite extensive - is handled another way.

Flying Through a Front

Following are some of the weather conditions the pilot may expect to encounter when flying through a front from the warm air to the cold air:

1. The wind will shift in 25 to 50 miles.
2. In a cold front, turbulence will be encountered in the frontal zone.
3. Temperatures will fall.
4. Clouds will lower
5. Precipitation, possibly thunderstorms, will be encountered.
6. Icing may occur in clouds or precipitation if the temperature at flight level is below freezing.