
REALM OF FLIGHT
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REALM OF FLIGHT

Presenting Practical Information About Weather
In Relation to the Piloting of Private Aircraft

Revised May 1963

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Introductory Note

REALM OF FLIGHT is one of a series of booklets (prepared originally by the Civil Aeronautics Administration) to provide the private pilot with information essential to safe operation of his aircraft.

These texts, by presenting basic and elementary information, also will serve as a basis for further study of theoretical and technical material already available in many publications.

Hundreds of thousands of Americans who intend to become active participants in "the air age" thus will be enabled to acquire facts and guidance essential to that participation, with opportunity to make advanced studies if they so desire.

REALM OF FLIGHT has drawn upon many sources: the practical experience of pilots, the scientific knowledge of specialists, and the large amount of information available in such publications as the Department of the Air Force Manual No. 105–5, "Weather for Aircrew Trainees"; U. S. Weather Bureau, "Aviation Series Pamphlets"; and Federal Aviation Agency Technical Manual No. 104, "Pilots' Weather Handbook". The latter book is recommended particularly for those who wish to make a more detailed study of weather as it affects flight.

The Federal Aviation Agency was accorded the unstinting cooperation of the United States Weather Bureau, the Civil Aeronautics Board, and the Government Printing Office, in preparation of the publication. Drawings of weather maps were prepared by the U. S. Weather Bureau. It is impracticable to express appreciation specifically to all who contributed to the planning, the accuracy of material, and the format.

This publication is the responsibility of the FAA's Flight Standards Service.

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I. Weather Information for the Pilot

What does a private pilot need to know about weather? Despite the development of many ingenious devices, improvements in aircraft design, power plants, radio aids, and navigation techniques, safety in flight is still subject to conditions of limited visibility, turbulence, and icing.

For private pilots, most of whose flights are conducted in smaller aircraft not equipped with elaborate and expensive instruments, a knowledge of the atmosphere and the behavior of weather is tremendously important to avoid hazardous flight conditions.

The uninitiated may wonder why the pilot needs more than the general information available to him from the predictions of the "weather man." The answer to this question is well known by experienced pilots. The meteorologist's predictions are based upon movements of large air masses and upon local conditions at specific points where weather stations are located. The air masses do not always perform as predicted, and the weather stations are sometimes spaced rather widely apart; therefore, it is necessary for the pilot to understand the weather conditions occurring between the stations, as well as conditions he encounters which are different from those indicated by the weather reports.

Moreover, the meteorologist can only predict the weather conditions likely to occur; the pilot must decide whether his particular flight may be hazardous, considering his type of aircraft and equipment, as well as his own flying ability, experience, and physical limitations.

The following text is necessarily brief. It is not intended for a meteorologist, but is designed to help the pilot by giving him a general background of weather knowledge together with the following basic information:

1. Aids provided by the Weather Bureau and the FAA to furnish the pilot with weather information.
2. Sources of weather information available to the pilot.
3. The special knowledge needed by the pilot to understand the weather terms commonly used.
4. The interpretation of weather maps, teletypewriter sequences, flying-weather forecasts and other data.
5. The conditions of clouds, wind, and weather which are merely inconvenient, those which are dangerous, and those which can be used to advantage by the pilot.
6. How to avoid dangerous conditions.
7. The significance of the cloud formations and precipitation which the pilot encounters in flight, and the procedures advisable in the interest of safety.

Although it is undoubtedly true that no amount of information will take the place of actual experience, this discussion of weather characteristics will furnish the pilot with practical suggestions for avoiding trouble while he is learning, and will provide a basis upon which he may build sound judgment as he gains experience.

Aids to the Pilot

The U. S. Weather Bureau has established a network of approximately 500 airport weather stations throughout the United States as a means of determining current weather and predicting future weather.

At most of these stations, trained personnel are on duty 24 hours a day, making observations and sending hourly reports to central locations.

Because weather near the surface of the earth often is the result of conditions at high altitudes, about 150 of the Weather Bureau's stations release and track balloons every 6 hours to determine the wind direction and speed at the upper levels. The Weather Bureau also operates approximately 65 radiosonde stations, from each of which a radio transmitting device attached to a balloon ascends every 12 hours to altitudes in excess of 10 miles, providing a complete record of temperature, pressure, and humidity at the higher levels.

Every 6 hours, this information is assembled and plotted on weather maps, together with other data collected by radio, telephone, and telegraph. The maps provide specific information concerning the weather in all parts of the country and furnish the meteorologists with material from which they are able to make weather predictions.

Four times daily, each flight advisory weather service center issues forecasts especially designed to indicate flying conditions anticipated for the following 12 hours, "area" forecasts for each of the 24 areas into which the United States has been divided for forecast purposes, and "terminal" forecasts for more than 350 of the more important air terminals.

This service is made available to pilots at airports and weather stations, as well as by radio broadcasts. In addition, trained meteorologists are on duty, day and night, at more than 200 air terminals to chart and analyze weather reports and to discuss weather conditions with pilots.

A further aid to pilots is the "Pre-Flight" service, which may be obtained by telephone from the local Weather Bureau Airport Station, or the FAA Flight Service Station if there is no local Weather Bureau Station. To take full advantage of this special service, the following procedure should be used when telephoning for weather information, as it will help the briefer to serve you:

1. Identify yourself as a pilot. (Many callers want information for purposes other than flying.)
2. State your intended route, destination, intended time of takeoff and approximate time en route.
3. Advise if you intend to fly only VFR.

By the intelligent use of all these specific aids, coupled with a fundamental knowledge of weather characteristics, the pilot should be able to understand the present weather, be aware of changes likely to occur, and thus plan and make his flight with safety.

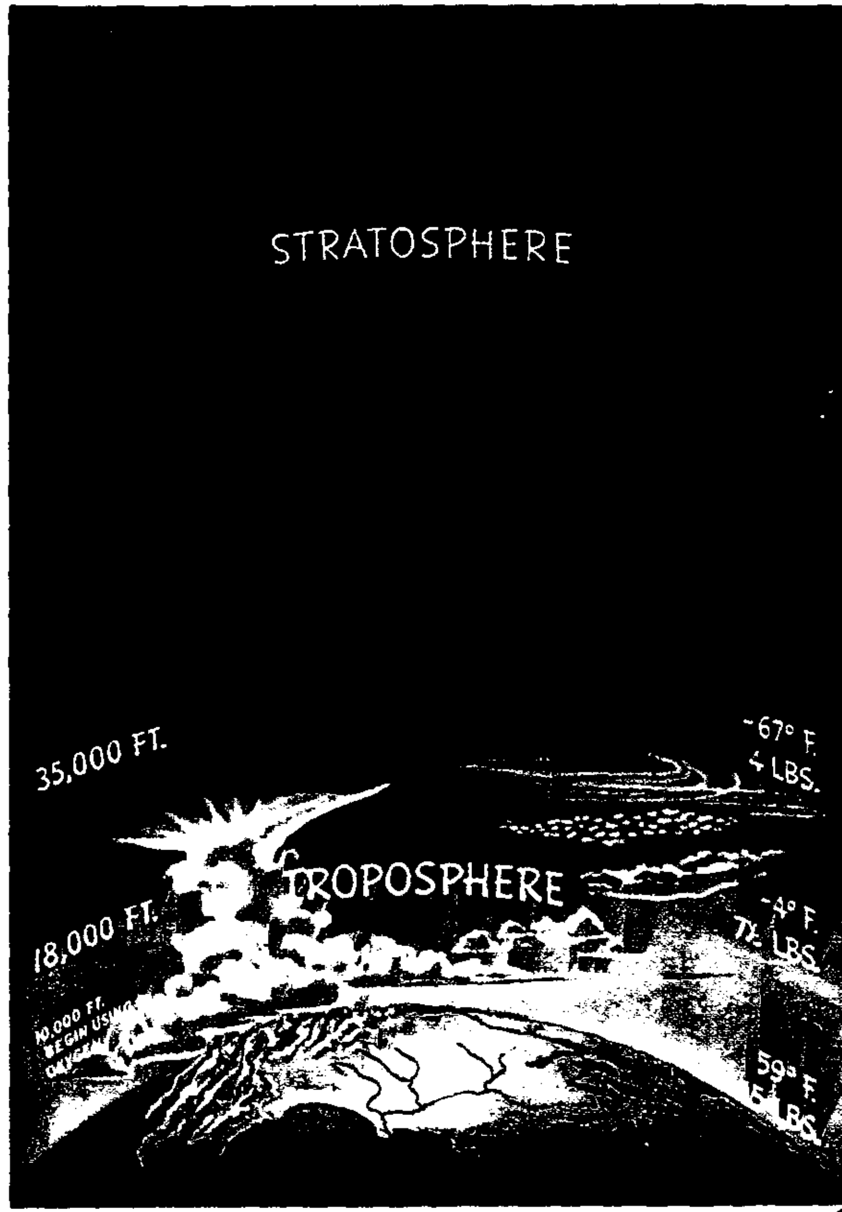

Figure 1. The troposphere and stratosphere form "The Realm of Flight."

II. The Nature of the Atmosphere

We live at the bottom of an ocean of air called the atmosphere. This ocean extends upward from the earth's surface for a great many miles, gradually becoming thinner as it nears the top. The exact upper limit has never been determined, but has been estimated to be anywhere from a few hundred miles to a few thousand miles. Near the surface the air is relatively warm owing to contact with the earth.[1] (The temperature in the United States averages about 59° F. the year round.) As altitude increases the temperature decreases by about 3½° F. for every 1,000 feet,[2] until the air reaches a temperature of about 67° F. below zero at 7 miles above the earth.

For practical purposes of flight, the atmosphere has often been classified into two layers:* the upper layer, where temperature remains practically constant, is known as the "stratosphere";[3] the lower layer, where the temperature changes, is known as the "troposphere."[4] (See fig. 1.) The private pilot has no occasion to go as high as the stratosphere, and anyway it is extremely uncomfortable up there; so his interest naturally centers in the lower layer—the troposphere. In this region all of our weather occurs and practically all of our flying is carried on. The top of the troposphere lies from 5 to 10 miles above the earth's surface.

*The scientific classification of the upper atmosphere and the realm of outer space has been completely revised on the basis of information recently obtained from rocket and satellite space exploration.

[1] Heat reaches the earth in the form of short waves from the sun. These waves pass through the air without warming it appreciably. The surface of the earth absorbs this heat and returns it to the air principally by contact (conduction).

[2] This is known as the "normal lapse rate."

[3] "Strato" indicates a uniformity (lack of change).

[4] "Tropo" means changing.

Obviously a body of air as deep as the atmosphere has tremendous weight. It is hard to realize that the normal sea-level pressure upon our bodies is about 15 pounds per square inch, or a total of 20 tons upon the average man. The reason we don't collapse is that this pressure is equalized by an equal pressure within the body. In fact, if the pressure were suddenly released, the human body would explode like a toy balloon. As we fly upward in the atmosphere, we not only become colder (it is usually freezing above 18,000 feet) but we also find that the air is thinner. At first we lose pressure rapidly and at 18,000 feet the pressure is only half as great as at sea level.

Oxygen and the Human Body

The atmosphere is composed of gases—about four-fifths nitrogen, and one-fifth oxygen, with approximately 1 percent of various other gases mixed in. Oxygen is essential to human life. At 18,000 feet altitude, with only half the normal atmospheric pressure, we would be breathing only half the normal amount of oxygen. Our reactions would be definitely below normal, and many of us would become unconscious. (In fact the average person's reactions become subnormal at 10,000 feet altitude.)

To overcome these unfavorable conditions at higher altitudes, pilots who are required to fly in this upper atmosphere use oxygen equipment to supply the deficiency and wear heavy clothes, often electrically heated; or they fly in sealed cabins in which the temperature, pressure, and oxygen content of the air can be maintained within proper range.

Figure 2. Barometric pressure at a weather station is expressed in terms of pressure at sea level.

III. The Significance of Atmospheric Pressure

In the preceding chapter we mentioned that the average weight, or pressure of the atmosphere, is about 15 pounds per square inch at sea level. The actual pressure at a given place and time, however, is dependent upon several factors—the altitude, the temperature, and the density of the air column. These conditions very definitely affect flight.

For ordinary flights, the most noticeable effect of difference in pressure due to altitude becomes evident in take-offs and landings, and in rate of climb. An average small plane which requires a 1,000-foot run for take-off from La Guardia Field (at sea level) will require a run almost twice as long to take off at Denver, Colo., which is 5,000 feet above sea level.[5] The climb, too, is much slower and a greater distance is required to gain sufficient altitude to clear any obstructions. In landing, the difference is not so noticeable except that the plane has greater speed when it touches the ground. (See figs. 3 and 3a.)

Measurement of Atmospheric Pressure

It might be advisable at this point to find out how pressure is measured, recorded, and reported by the Weather Bureau. A barometer is generally used which measures the height of a column of mercury in a glass tube, sealed at one end and calibrated in inches. An increase in pressure forces the mercury higher in the tube; a decrease allows some of the mercury to drain out, thus reducing the height of the column. In this way, changes of pressure register in terms of inches of mercury. The standard sea-level pressure expressed in these terms is 29.92 inches at 59° F.

If all weather stations were located at sea level, the barometer readings, when entered on the weather map, would give a correct record of the distribution of atmospheric pressure at a common level. In order to achieve this result, each station translates its barometer reading into terms of sea-level pressure. A difference of 1,000 feet of elevation makes a difference of about 1 inch in the barometer reading. Thus, if a station located 5,000 feet above sea level found the mercury to be 25 inches high in the barometer tube, it would translate and report this reading as 30 inches (25 + 5).[6] In this way, a uniform measurement can be established which, when entered upon the weather map, will show only the variations in pressure which are due to causes other than the altitude of the places where the measurements are taken. (See fig. 2.)

Since the rate of decrease in atmospheric pressure is fairly constant in the lower layers of the atmosphere, the approximate altitude can be determined by finding the difference between pressure at sea level and pressure at the given altitude. In fact this is the principle upon which the airplane altimeter operates. The scale on the altimeter, instead of indicating pressure in terms of inches of mercury, reads directly in terms of feet of altitude.[7]

[5] The purpose of the take-off run is to gain enough speed to secure lift from the passage of air over the wings. If the air is thin, more speed is required to obtain sufficient lift for take-off—hence, a longer ground run. It is also true that the engine is less efficient in thin air, and the thrust of the propeller is less effective.

[6] Actually the reduction of pressure to sea level is not so simple as given in this example.

[7] The altimeter uses a sealed vacuum cell instead of a mercury-barometer to register the differences in pressure. Altimeters are calibrated upon the assumption of standard sea-level pressure of 29.92 inches of mercury at 59° F. and an average decrease of pressure and temperature for each 1,000 feet of altitude. As suggested above, the altitude shown by the altimeter is only approximate. In addition, the altimeter is subject to installation errors, mechanical failure, and lag in recording true altitude. The chief cause of error lies in the extent to which pressure varies from the average. For this reason all altimeters embody some means of adjusting the dial so that the altimeter will indicate the elevation of the field from which the "altimeter setting" is received. (The zero reading may be set to show the ground level at a landing field, although this practice is not recommended except for beginning students.) The setting can be properly adjusted by using altimeter settings given in weather reports or, if the plane is on the ground, by turning the dial so that the needle points to the actual altitude of the landing field. The proper compensation for variation in temperature from the assumed average must be made by a computation which is of importance to pilots on instrument flight but of little significance for contact flight.

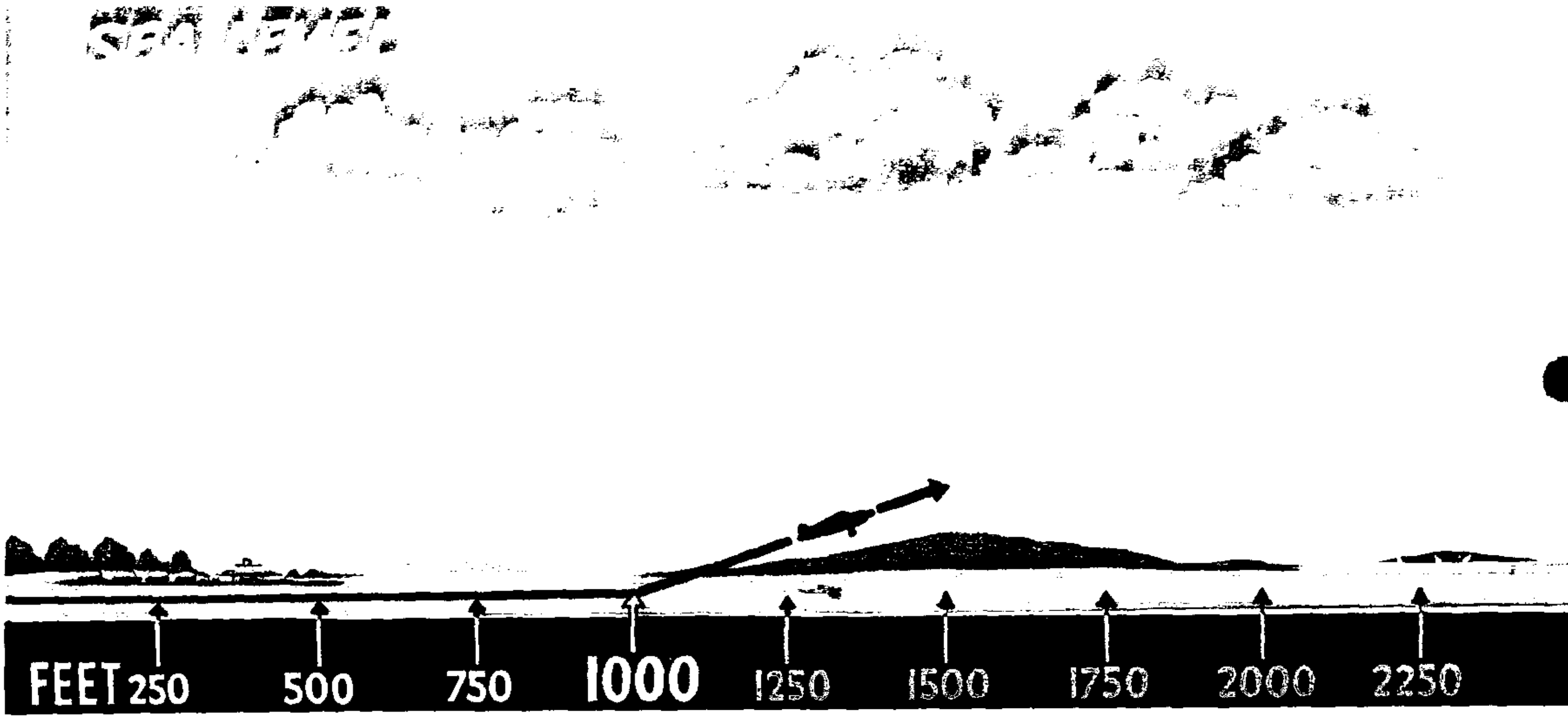

Figure 3. Atmospheric density at sea level enables a plane to take off in a relatively short distance.

Atmospheric pressure not only varies with altitude; it also varies with temperature. When air is heated it expands and has less density. If we fill a container to the brim with cold water and heat it to boiling point, we find that the water expands and some of it overflows. If we weigh the contents when cold, and again after heating, we find that the heated water weighs less. The same principle applies to air and, therefore, a cubic foot of warm air is less dense than a cubic foot of cold air. This difference in density, caused by temperature changes, affects flight in the same way as difference in density caused by elevation. For instance, at Denver on a cold day a small plane may take off with a 2,000-foot run, whereas on a hot day the air may be so thin that the plane is unable to leave the ground within the space of the available runway.

Effect of Differences in Density

Differences in density caused by changes in temperature cause changes in pressure which, in turn, create motion in the atmosphere, causing wind, clouds, and precipitation—in fact, all the phenomena which we roughly classify as "weather."

These items will be taken up in subsequent chapters. Meanwhile, we are now ready to look at a portion of the weather map called a "station model." (See fig. 4.)

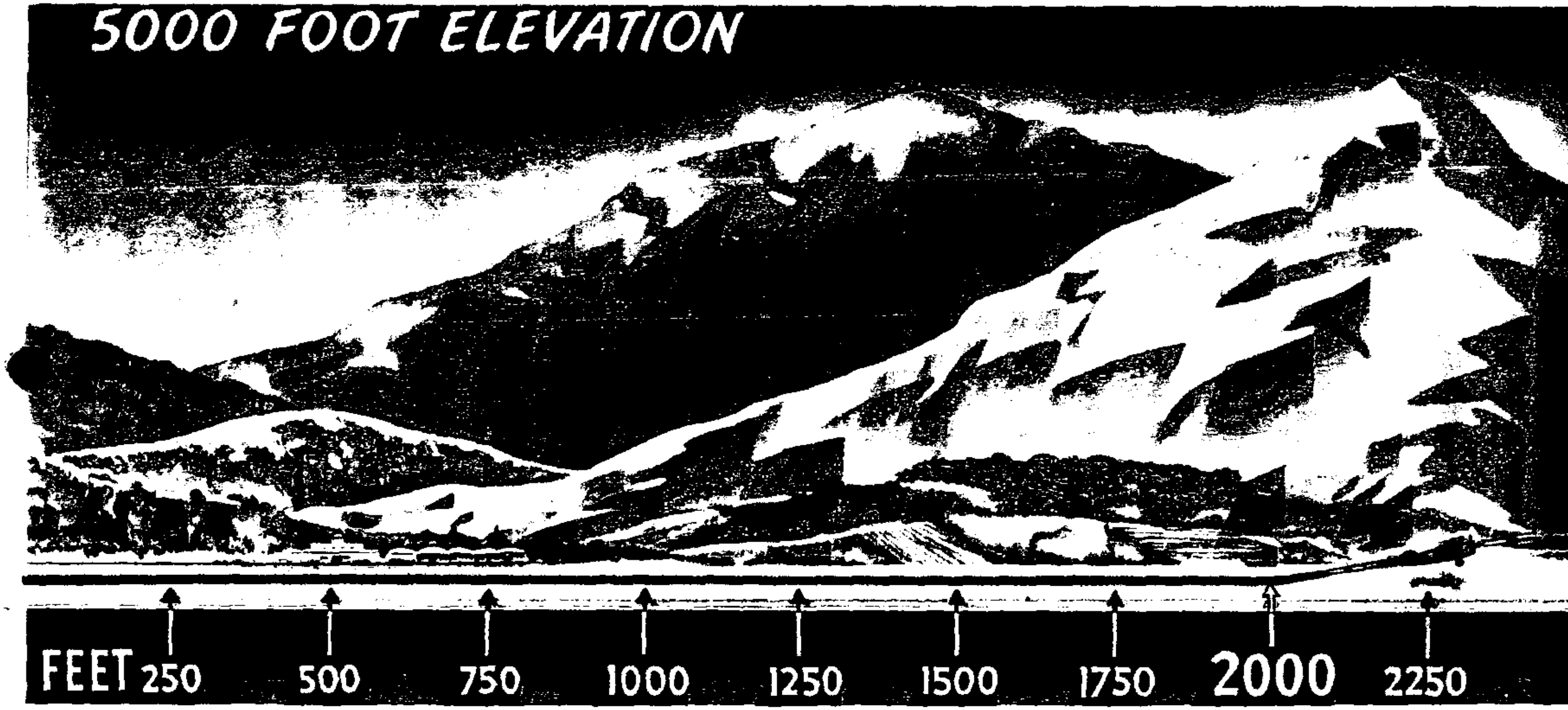

Figure 3a. The distance required for a take-off increases with the altitude of the field.

Here the meteorologist records the data received from weather stations, using an abbreviated form which the pilot can easily interpret. We shall disregard some of the items which are of little importance to the pilot; the others we shall discuss and learn to interpret in succeeding chapters.

At present we are interested in the pressure. The small circle represents the location of the station on the map. To the right, and slightly above, are three digits (203) indicating the pressure at the time of observation.

Pressure Recorded in "Millibars"

The mercury-barometer reading at the individual weather stations is converted to the equivalent sea-level pressure and then translated from terms of inches of mercury to a measure of pressure called millibars. One inch of mercury is equivalent to approximately 34 millibars; hence the normal atmospheric pressure at sea level (29.92), expressed in millibars, is 1013.2 or roughly 1,000 millibars. For economy of space the entry is shortened by omitting the initial 9 or 10 and the decimal point. The usual pressure readings range from 950.0 to 1040.0. On the station entry, a number beginning with 5 or higher presupposes an initial "9," whereas a number beginning with a 4 or lower presupposes an initial "10." For example: 653 = 965.3; 346 = 1034.6; 999 = 999.9; 001 = 1000.1, etc. The reading shown on the present station model is 203, which should be interpreted as 1020.3 millibars.

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Individually these pressure readings are of no particular value to the pilot; but when pressures at different stations are compared or when pressures at the same station show changes in successive readings, it is possible to determine many symptoms indicating the trend of weather conditions. In general, a marked fall indicates the approach of bad weather and a marked rise indicates a clearing of the weather.

The net amount of barometric change within the preceding 3 hours at each station is shown in tenths of millibars directly below the figures for atmospheric pressure. A plus or minus sign is used to show the direction of change. This number is followed by a symbol indicating special characteristics which are of no particular interest to the pilot.

On the present model the figure + 4 means that the barometer has risen a total of 4 tenths of a millibar, during the preceding 3 hours.

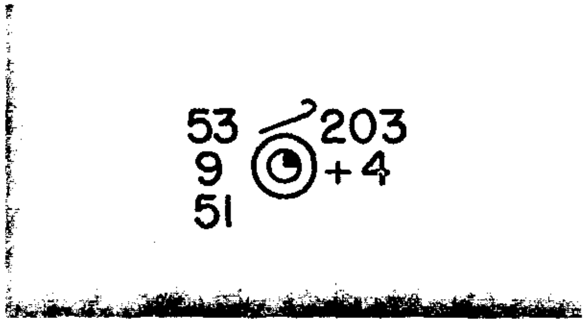


Figure 4. Station model showing method of recording atmospheric pressure by upper-right group of three digits. The numeral 203 indicates pressure of 1020.3 millibars. Change within preceding three hours is shown in tenths of millibars immediately below.

IV. Wind

The pressure and temperature changes discussed in the previous chapter produce two kinds of motion in the atmosphere—vertical movement of ascending and descending currents, and horizontal flow known as "wind." Both of these motions are of primary interest to the pilot because they affect the flight of aircraft in take-off, landing, climbing, speed, and direction; and they also bring about changes in weather, which may make a difference between safe flight and disaster.

The conditions of wind and weather occurring at any specific place and time are the result of the general circulation in the atmosphere, which will be discussed briefly in the following pages.

The atmosphere tends to maintain an equal pressure over the entire earth, just as the ocean tends to maintain a constant level. Whenever the equilibrium is disturbed, air begins to flow from areas of higher pressure to areas of lower pressure.

The Cause of Atmospheric Circulation

The factor which upsets the normal equilibrium is the uneven heating of the earth. At the equator the earth receives more heat than at areas to the north and south.[8] This heat is transferred to the atmosphere, warming the air and causing it to expand and rise. Thus, an area of low pressure is produced at the equator, and the heavier, cooler air from the north and south moves along the earth's surface toward the equator to equalize the pressure. This air in turn becomes warm and rises, thereby establishing a constant circulation which might consist of two circular paths, with air rising at the equator, traveling aloft toward the poles, and returning along the earth's surface to the equator, as shown in figure 5.

[8] This is because the rays from the sun fall more directly upon the equator than upon other latitudes. Actually, the equator referred to here is the thermal equator rather than the geographical equator. As the axis of the earth tilts during its annual revolution around the sun, the thermal equator (the belt receiving vertical rays from the sun) ranges from Lat. 23½° South to Lat. 23½° North. This is the cause of our changes in season, with the accompanying changes in temperature, humidity, precipitation, etc.

This theoretical pattern, however is greatly modified by many forces, a very important one being the rotation of the earth. In the Northern Hemisphere this rotation causes air to flow to the right of its normal path. In the Southern Hemisphere air flows to the left of its normal path. For simplicity we shall confine our discussion to the motion of air in the Northern Hemisphere. (See fig. 6.)

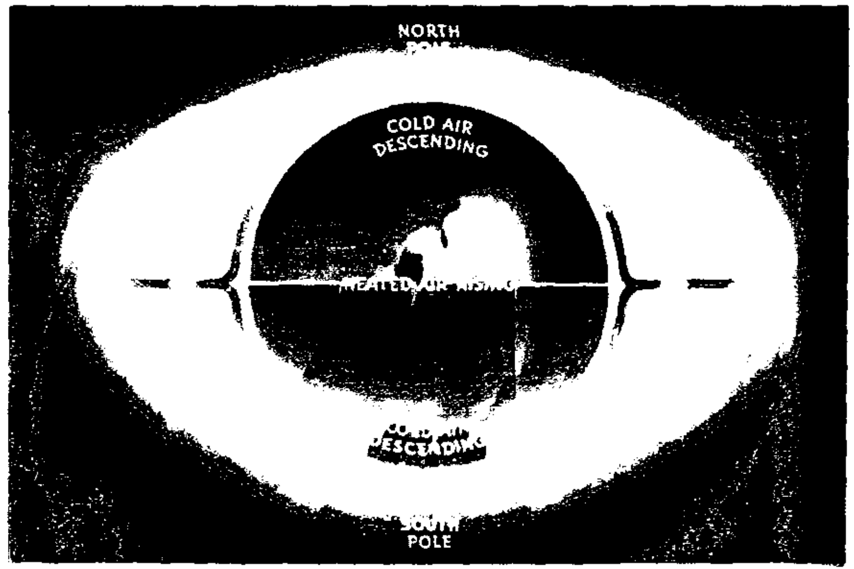


Figure 5. Heat at the equator would cause the air to circulate uniformly, as shown, if the earth did not rotate.

As the air rises and moves northward from the equator it is deflected toward the east and, by the time it has traveled about a third of the distance to the pole, it is no longer moving north-

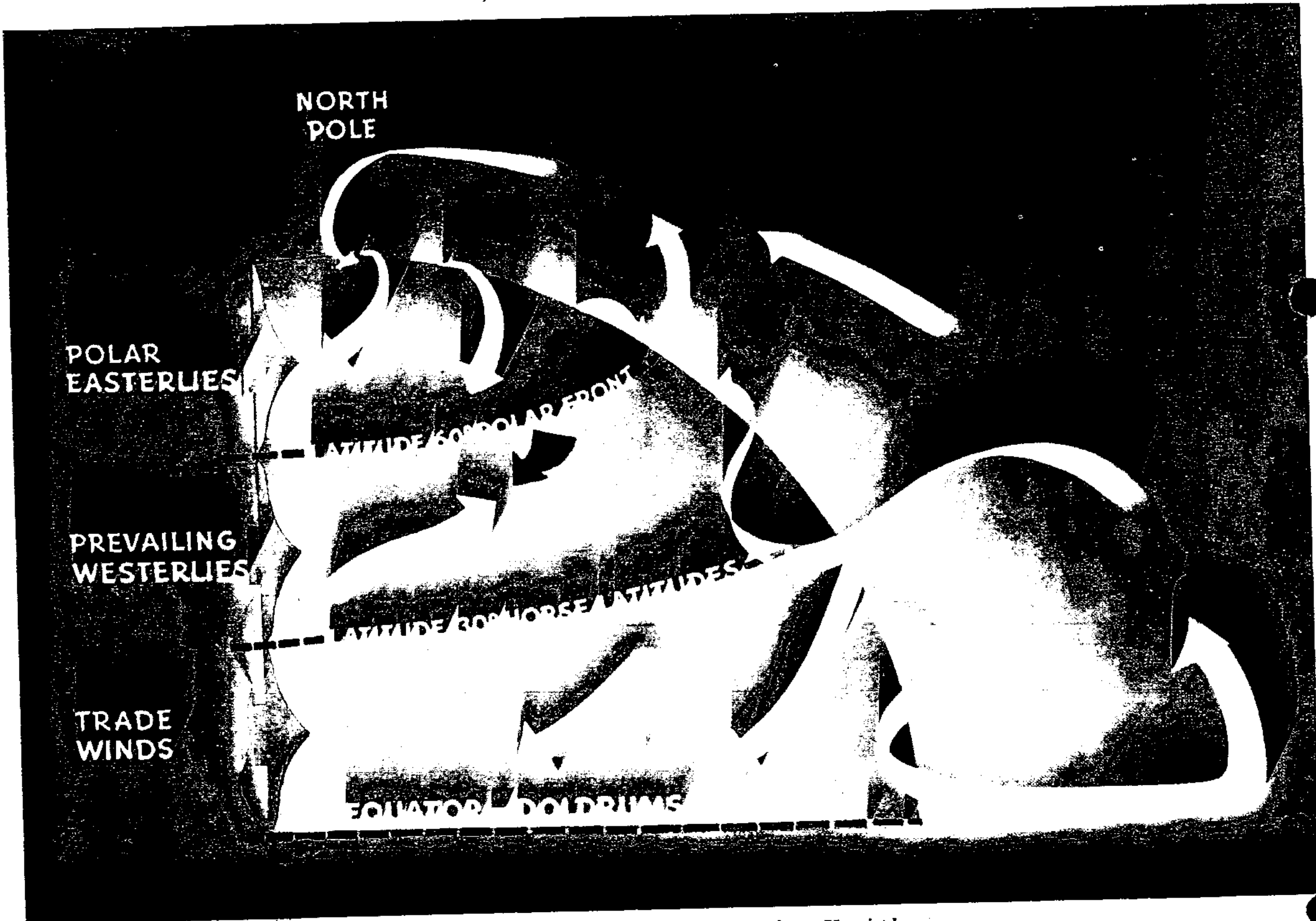


Figure 6. Principal air currents in the Northern Hemisphere.

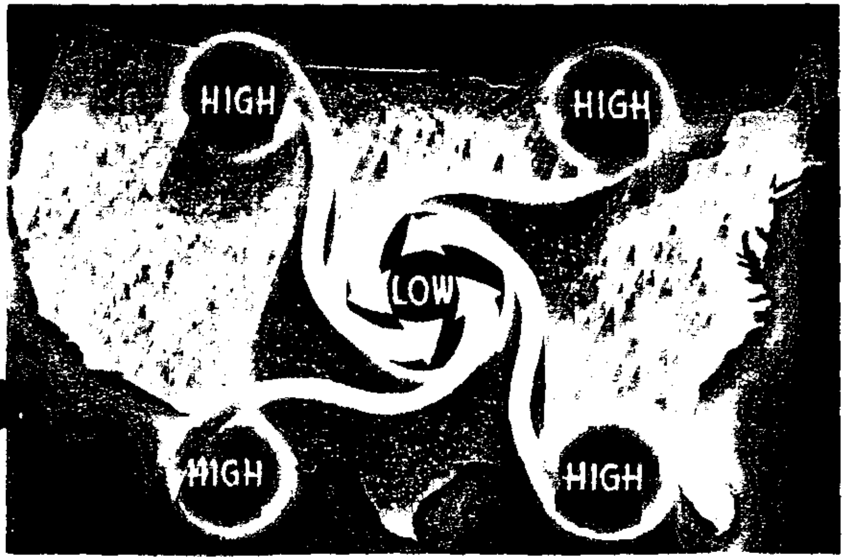


Figure 7. Circulation of wind within a "low."

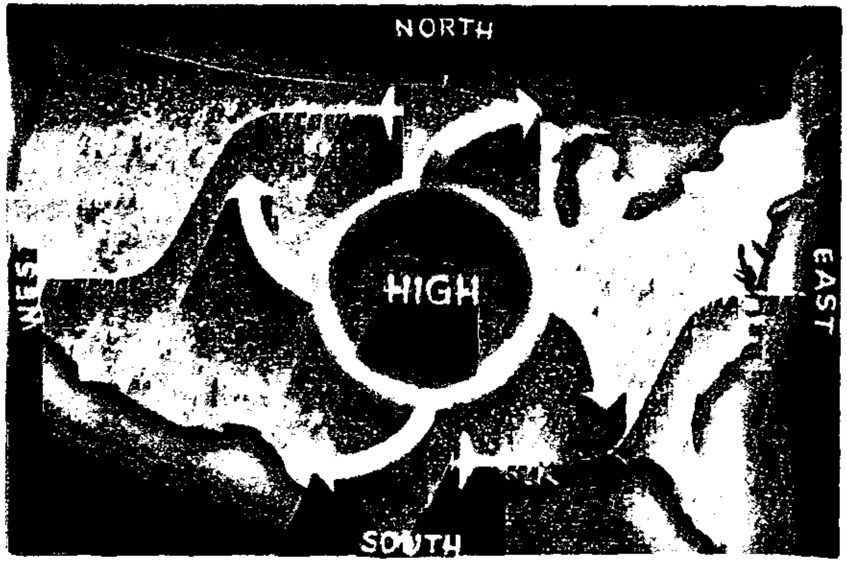


Figure 8. Use of favorable winds in flight.

ward, but eastward. This causes the air to accumulate in a belt at about latitude 30°, creating an area of high pressure.[9] Some of this air is then forced down to the earth's surface, where part flows southward, returning to the equator, and part flows northward along the surface.[10]

A portion of the air aloft continues its journey northward, being cooled en route, and finally settles down near the pole where it begins a return trip toward the equator. Before it has progressed very far southward it comes into conflict with the warmer surface air flowing northward from latitude 30°. The warmer air moves up over a wedge of the colder air, and continues northward, producing an accumulation of air in the upper latitudes.

The cold polar air is forced to break out spasmodically in waves which surge toward the equator, reducing the accumulated pressure and causing the rapid changes in weather so characteristic of the middle latitudes.

Further complications in the general circulation of the air are brought about by the irregular distribution of oceans and continents, the relative effectiveness of different surfaces in transferring heat to the atmosphere, the daily variation in temperature, the seasonal changes, and many other factors.

Regions of low pressure, called "lows," develop where air lies over land or water surfaces which are warmer than the surrounding areas. In India, for example, a low forms over the hot land during the summer months, but moves out over the warmer ocean when the land cools in winter. Lows of this type are semipermanent, however, and are of less significance to the pilot than the "migratory cyclones" or "cyclonic depressions" which form when unlike air masses come into contact.[11] These lows will be discussed in detail under "occlusions" in Chapter VII.

[9] In our latitudes a pilot making long eastward flights can nearly always climb to high altitudes and take advantage of favorable tailwinds. It is for this reason that the first trans-Atlantic flights were made from west to east.

[10] The air flowing southward is deflected toward the west, producing northeast winds, called "Trade Winds," in latitudes to the south of 30°. The air flowing northward is deflected toward the east, producing southwest winds, which become a part of the "Prevailing Westerlies," in latitudes to the north of 30°.

[11] The terms "cyclonic" and "cyclone" are generally used to indicate an area of low barometric pressure, together with its attendant system of winds, and should not be confused with tropical cyclones, tornadoes, or hurricanes, although some of their characteristics are fundamentally the same.

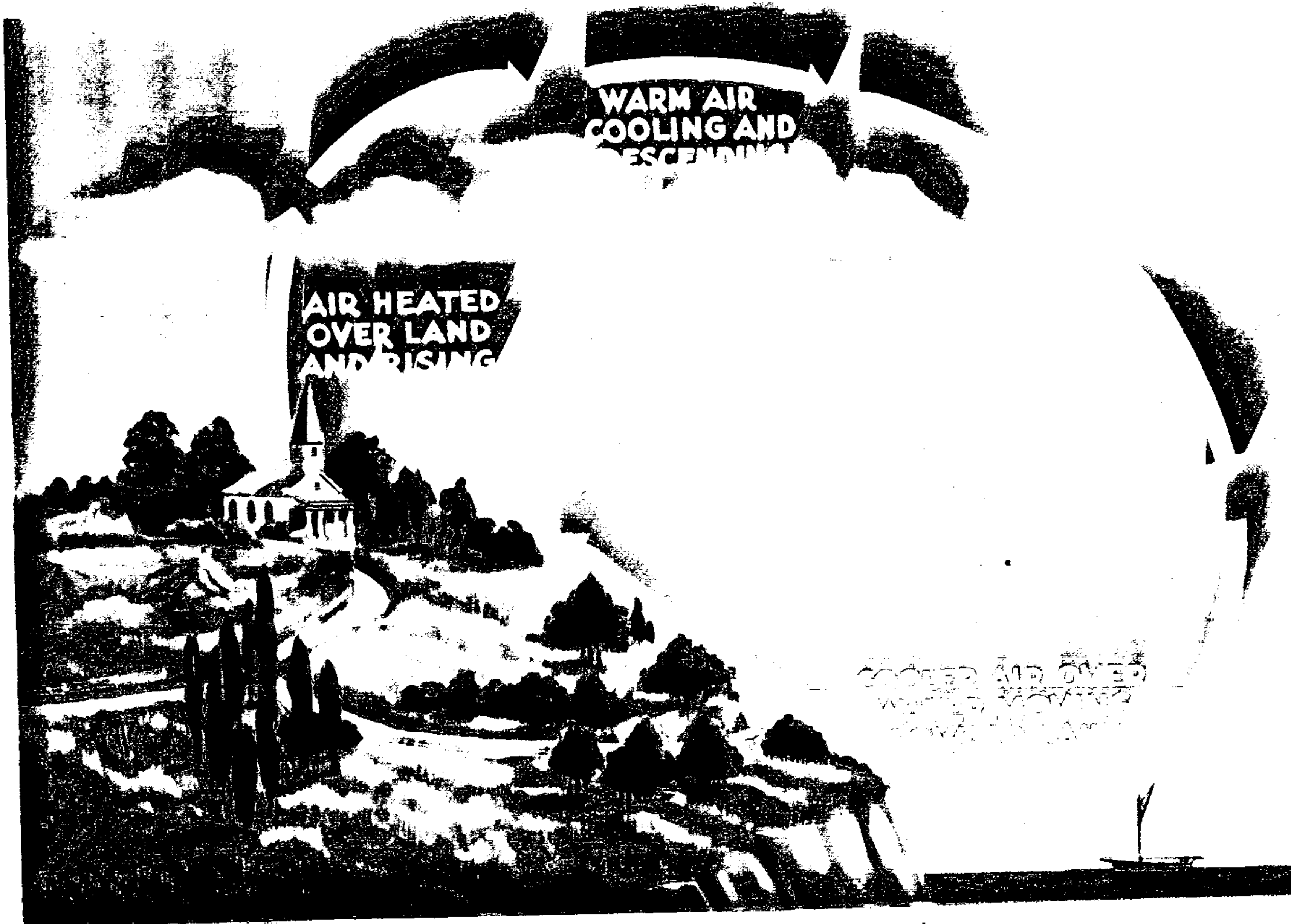
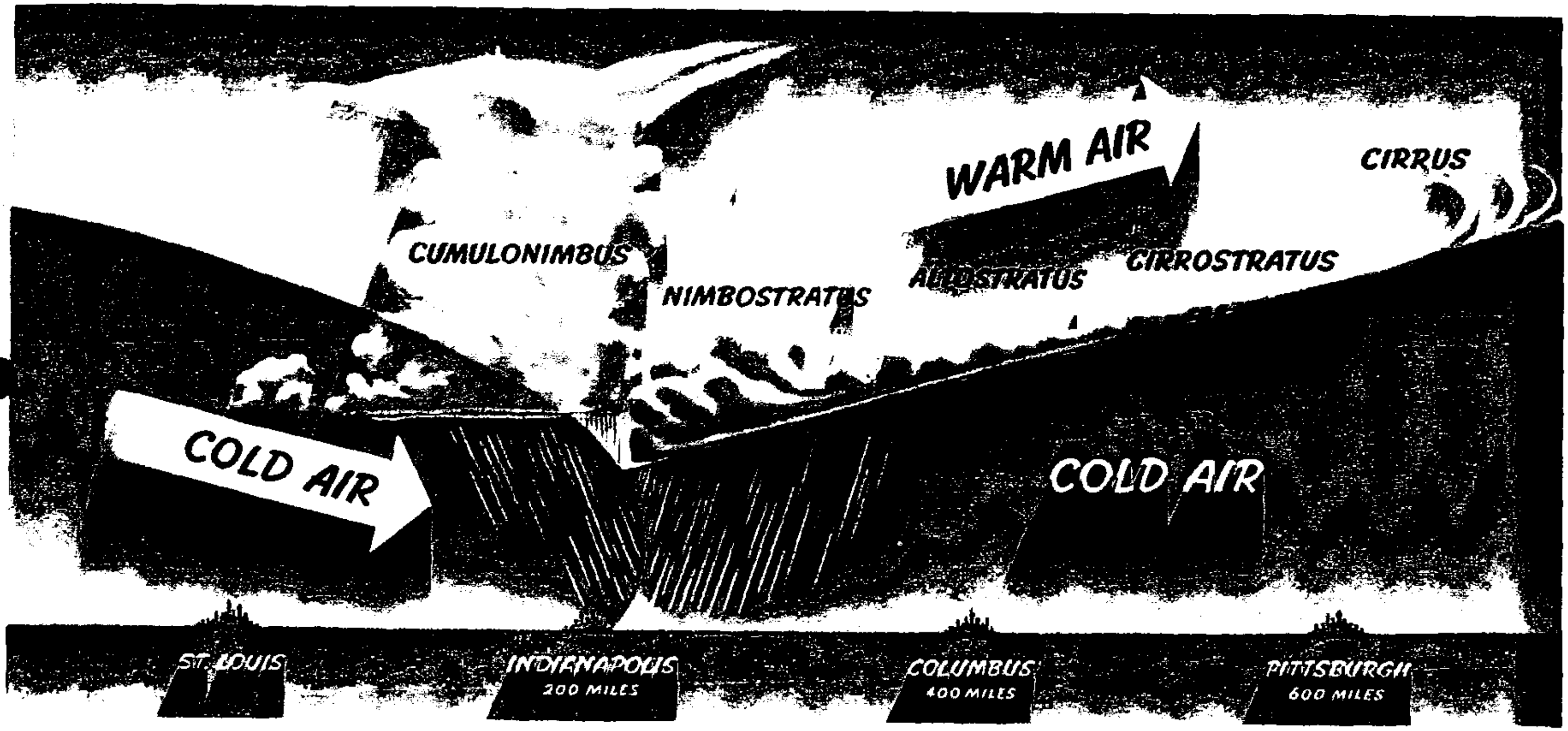


Figure 9. Convection currents form on-shore winds in daytime.



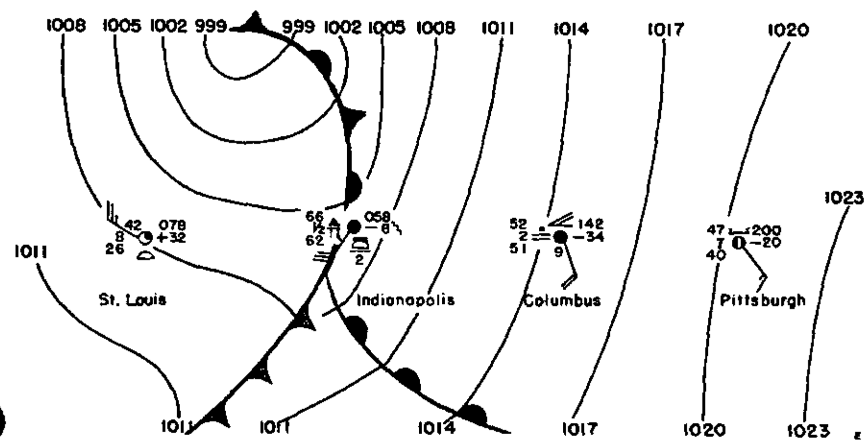


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Figure 28. An "occluded front": (upper) "cross section"; (lower left) as shown on a weather map; (lower right) as reported by teletype sequences.

bright skies, with unlimited ceilings and visibilities, we would note lowering stratus-type clouds as we neared Columbus and soon afterward we would encounter precipitation. After arriving at Indianapolis, we would find the ceiling too low for further flight. Precipitation would reduce visibilities to practically zero.

Thus, we would be forced to remain in Indianapolis until the warm front had passed, which might require a day or two.

If we wished to return to Pittsburgh, we would have to wait until the front had passed beyond Pittsburgh, which might require as long as 3 or 4 days. Warm fronts generally move at the rate of from 10 to 25 miles an hour.

On our trip to Indianapolis we probably would have noticed a gradual increase in temperature and a much faster increase in dew point, until the two coincided.

We would also have found the atmospheric pressure gradually lessening because the warmer air aloft would have less weight than the colder air it was replacing. This condition illustrates the general principle that a falling barometer indicates the approach of stormy weather.

Cold Front

Let us now consider the weather conditions accompanying a cold front. When the cold front moves forward, it acts like a snow plow, sliding under the warmer air and tossing it aloft. This causes sudden cooling of the warm air, resulting in the formation of nimbostratus clouds (if the front is moving slowly) or cumulonimbus (if the front is moving rapidly) accompanied by severe precipitation with gusty and turbulent winds. (See fig. 26.)

The slope of a cold front is much steeper than that of a warm front and the progress is generally more rapid—usually from 20 to 35 miles an hour. The weather activity is more violent and usually takes place directly at the front, instead of in advance.[16] Whereas the warm front dangers lie in low ceilings and visibilities, the cold front dangers lie chiefly in sudden storms, high winds, and turbulence. Icing conditions may be expected in both types at cloud temperatures between 32° F. and 15° F., and are possible below 15° F.

Unlike the warm front, the cold front rushes in almost unannounced, makes a complete change in the weather within the space of a few hours, and passes on. The belt of activity, often called a "squall line," is ordinarily quite narrow—50 to 100 miles in width—but is likely to extend for hundreds of miles in length, frequently lying across the entire United States in a line running from northeast to southwest. Altostratus clouds sometimes form slightly ahead of the front, but these are seldom more than 100 miles in advance. After the front has passed, the weather clears rapidly with cooler, drier air, and usually unlimited ceilings and visibilities—almost perfect flying conditions.

If we were to make the flight from Pittsburgh toward St. Louis with a cold front approaching from St. Louis, we would experience conditions quite different from those associated with a warm front. The sky in Pittsburgh would probably be somewhat overcast with stratocumulus clouds typical of a warm air mass, the air smooth, and the ceilings and visibilities relatively low although suitable for flight.

As the flight proceeded, these conditions would prevail until we reached Indianapolis. If we were wise, we would now check the present position of the cold front by consulting a recent weather map and teletype sequences, or the meteorologist. We should then probably find that the front was now about 75 miles west of Indianapolis. A pilot with judgment based upon knowledge of frontal conditions would remain in Indianapolis until the front had passed—a matter of a few hours—and then continue to his destination under perfect flying conditions.

If, however, we were foolhardy enough to continue our flight toward the approaching cold front, we would soon notice a few altostratus clouds and a dark layer of nimbostratus lying low on the horizon, with perhaps cumulonimbus in the background. Two courses would now be open to us: either to turn around and outdistance the storm, or to make an immediate landing which might be extremely dangerous on account of gustiness and sudden wind shifts.

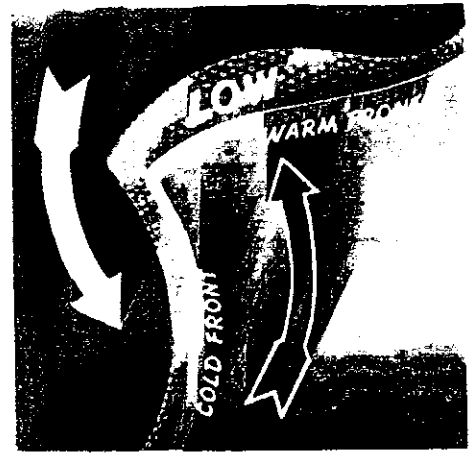
If we were to continue farther, we would be trapped in a lin

[16] In the late afternoon during the warmer seasons a prefrontal line of thunderstorms will frequently develop as much as 50 to 200 miles in advance of the actual front.

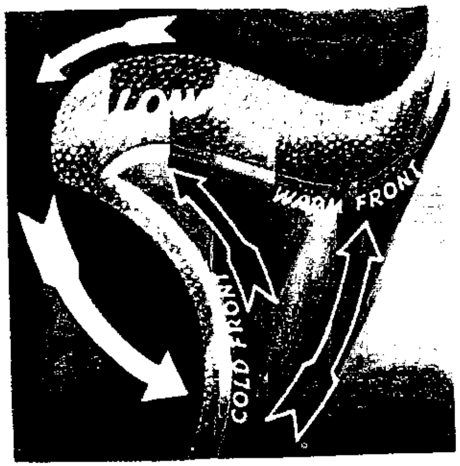
Figure 29. Three stages in the development of a typical occlusion moving northeastward.

(A) Air flowing along a front in equilibrium.

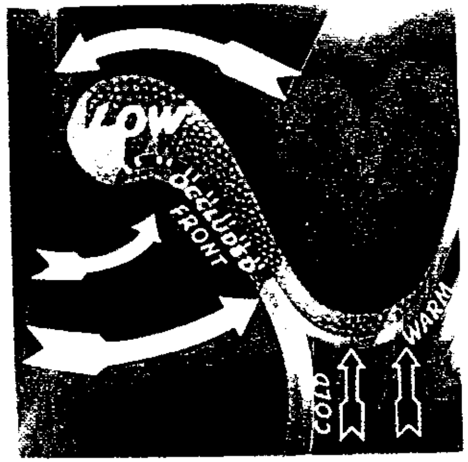
(B) Increased cold-air pressure causes "bend."



(C) Cold air begins to surround warm air.



(D) Precipitation becomes heavier.



(E) Warm air completely surrounded.

(F) Warm-air sector ends in mild whirl.

Figure 30. Development of an occlusion. If warm air were red and cold air were blue, this is how various stages of an occlusion would appear to a person aloft and looking toward the earth. (Precipitation is indicated by green.)

of squalls and cumulonimbus clouds, the dangers of which have already been described. It is inviting disaster to attempt to fly beneath these clouds and impossible for a small plane to fly above them, since they frequently extend to heights in excess of 25,000 to 35,000 feet. At low altitudes there are no safe passages through them. Usually there is no possibility of flying around them because they often extend in a line 300 to 500 miles in length.

Wind Shifts

In a previous paragraph, we mentioned "wind shifts" which perhaps requires further clarification. We remember the wind in a high blows in a clockwise spiral. When two highs are adjacent, the winds are in almost direct opposition at the point of contact as illustrated in figure 27. Since fronts always lie between two areas of higher pressure, wind shifts occur in all types of fronts, but they usually are more pronounced in cold fronts.

Occluded Front

One other form of front with which the pilot should become familiar is the "occlusion" or "occluded front." This is a condition in which an air mass is trapped between two colder air masses and forced aloft to higher and higher levels until it finally spreads out and loses its identity.

Meteorologists subdivide occlusions into two types; but so far as the pilot is concerned, the weather in any occlusion is a combination of warm-front and cold-front conditions. As the occlusion approaches, the usual warm-front indications prevail—lowering ceilings, lowering visibilities, and precipitation. Generally the warm-front weather is then followed almost immediately by the cold-front type, with squalls, turbulence, and thunderstorms.

Figure 28 is a vertical cross-section of an occlusion. Figure 29 shows the various stages as they might occur during the development of a typical occlusion. Usually the development requires 3 or 4 days, during which the air masses may progress as indicated on the map.

The first stage (a) represents a boundary between two air masses, with cold and warm air moving in opposite directions along a front. Soon, however, the cooler air, being more aggressive, thrusts a tongue under the warmer air, breaking the continuity of the boundary, as shown in (b). Once begun, the process continues rapidly to the complete occlusion as shown in (c). As the warmer air is forced aloft, it cools quickly and its moisture condenses, causing severe precipitation. The air becomes extremely turbulent, with sudden changes in pressure and temperature.

Figure 30 shows the development of the occluded front in greater detail.

Figure 31 is an enlarged view of (c) in figure 29, showing the cloud formations and the areas of precipitation.

In Figures 25, 26, and 28 a panel representing a daily weather map is placed below each cross-sectional view. These panels represent a bird's-eye view, or plan view, and show how the weather conditions are recorded. A warm front is indicated by a red line; a cold front by a blue line; an occluded front by a purple line; a stationary front by alternating red and blue dashes. The rounded and pointed projections are generally omitted from the manuscript maps, but are placed on printed or duplicated maps to distinguish the different fronts.

It should be borne in mind that the frontal lines on the weather map represent the points on the earth's surface where the fronts are located. A pilot flying west at an altitude of 5,000 feet would pass through the frontal boundary about 100 miles in advance of the point where the warm front is shown, or about 25 to 50 miles to the rear of the line on the map representing the cold front.

All the foregoing information about air masses and fronts is available to the pilot in abbreviated form on weather maps. For the pilot who understands the meaning of the symbols, a brief study of the current map will provide a fairly complete picture of the weather conditions he is likely to encounter in flight. He must realize that the facsimile synoptic map may be as much as 8 hours old, and that the fronts will have moved during that time. The meteorologist on duty will be able to supplement the weather map information with the latest data arriving hourly on the teletype sequences. He should invariably be consulted before flights are undertaken which involve long distances or which lie within areas in which frontal activity is taking place. Figure 32 represents a

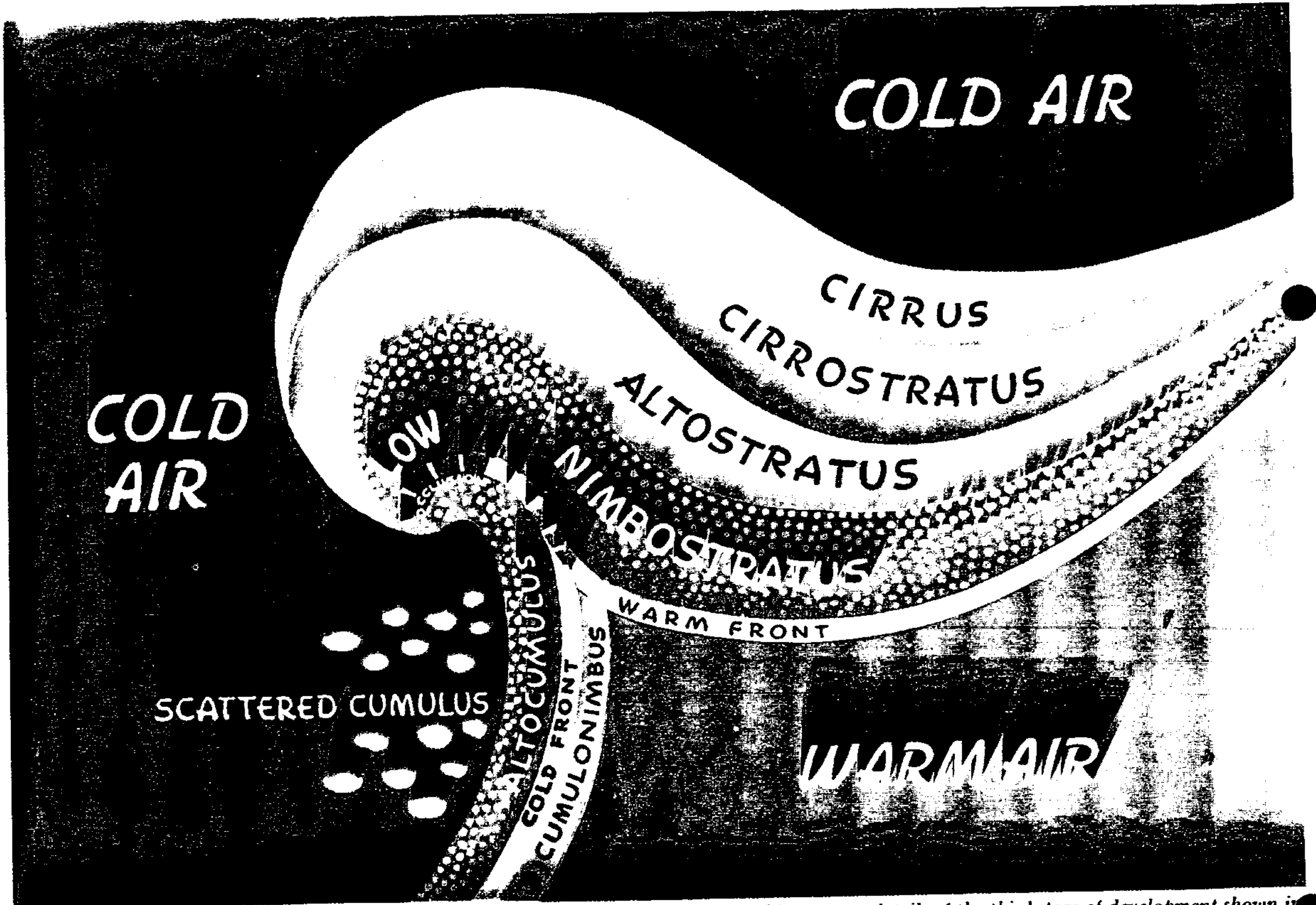


Figure 31. Cloud formations and precipitation accompanying a typical occlusion. (This presents details of the third stage of development shown in the series depicted in Figure 29.)

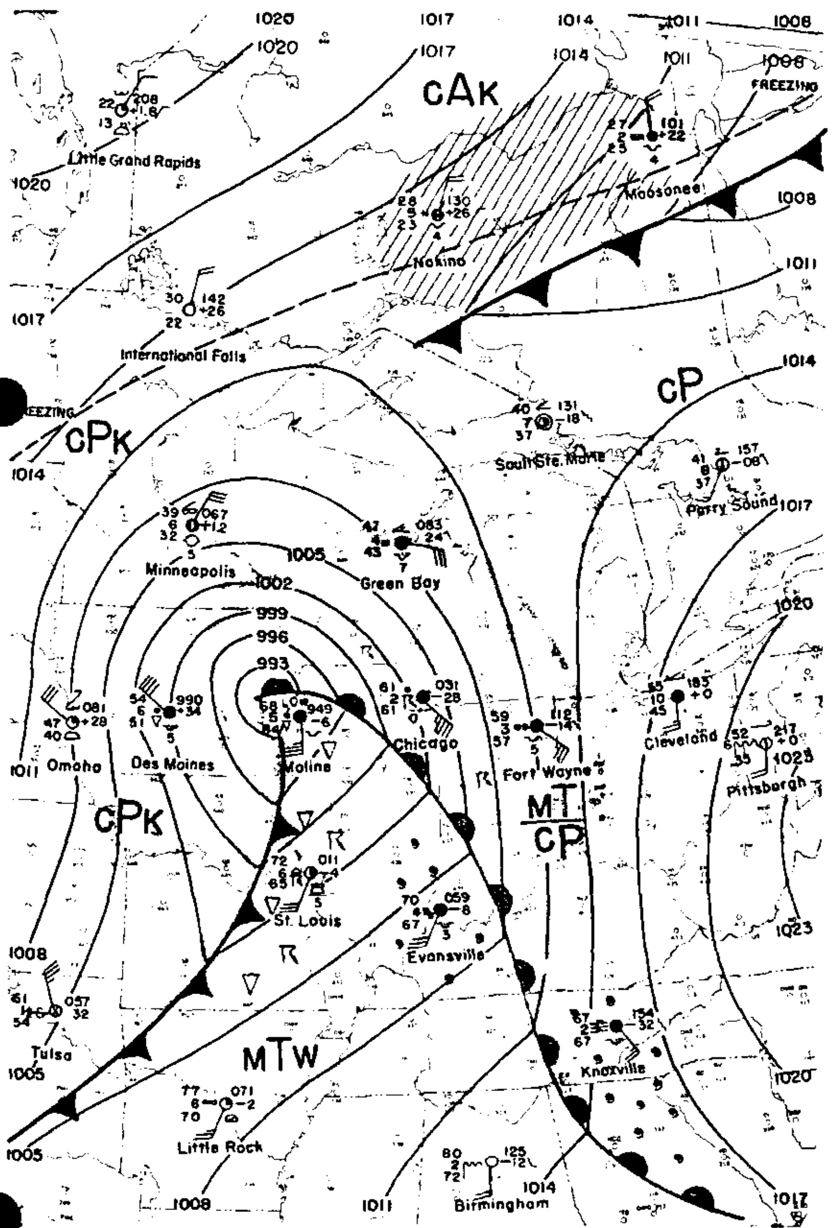


Figure 32. Section of typical weather map showing methods of indicating "weather facts" of importance to pilots.

portion of a typical weather map showing the symbols usually employed.

It must be understood, however, that the surface weather maps available to the pilot at an airport weather bureau station vary in certain respects from the printed Daily Weather Map depicted in figure 32. The surface weather maps to be found at airport stations are:

1. The facsimile synoptic surface weather map. This map is issued each 6-hour period and weather data is plotted according to the official station model. However, visibility and cloud heights are not shown since these are readily available from the hourly sequence reports.
2. The 3-hourly surface weather map plotted at many local Airport Weather Bureau Stations.

Sequence Reports

Changes in weather frequently are so rapid that conditions at the time of flight are likely to be quite different from those shown on a weather map issued several hours previously. The very latest information is available in the hourly teletype sequence reports transmitted by weather stations. The data are substantially the same as on the weather map, but the pilot must become familiar with a few symbols and abbreviations in order to read the sequences. Facility in reading these reports can be acquired in a surprisingly short time, and the reward is well worth the effort. Teletype reports are given below the panels in figures 25, 26, and 28.

The table on pages 40 and 41 presents a typical report, together with an explanation for interpreting all sequences. It will be noted that the information is presented in three groups, which might be broadly classified as:

1. Identification.
2. Visual Observations.
3. Instrumental Observations.

Interpretation of Weather Reports Sent by Teletype

DCA 212100Z 15⦶ E30⊕11/2VTRW—BD 152/68/60 →╲18+30↑ 1548E/996/DRK NW VSBY 1V2

Symbol	Item	Interpretation	Translation
		GROUP I.—DCA 212100Z	
DCA	Station identification.	Indicated by call letters. Call letters and all abbreviations are available at weather offices.	Washington, D. C.
212100Z	Date and Greenwich time	The first two digits indicate the day of the month; the next four digits give the time (on the 24-hour clock) in Greenwich time. To convert to local time *subtract* 5 hours for eastern standard time, 6 hours for central, 7 hours for mountain, and 8 hours for Pacific. Regular sequences are sent each hour on the hour. When crucial changes occur between reporting times, a special report may be sent. In this case the date-time data will follow the station identification symbol, and the letter "S", followed by a numeral, will be added.	21st day of the month, 4:00 p. m., eastern standard time.
		GROUP II.—15⦶E30⊕11/2VTRW—BD	
15⦶	Sky cover	Figures represent hundreds of feet (15=1,500 feet). Symbol indicates amount of cover: ○=clear; ⦶=scattered; ⦷=broken; ⊕=overcast. The letter "X" will be used instead of these symbols whenever fog, dust, smoke, or precipitation obscure the sky. If clouds are at varying levels, two or more sets of figures and symbols are entered in ascending order of height.	Scattered clouds at 1,500 feet.
E30⊕	Ceiling	The ceiling figure will always be preceded by one of the following letters: E=estimated; M=measured; W=indefinite; B=balloon; P=precipitation; A=reported by aircraft. If the ceiling is below 3,000 feet and is variable, the ceiling symbol will be followed by the letter "V", and in the remarks the range of height will be indicated.	Ceiling estimated 3,000 feet.
11/2V	Visibility	Figures represent miles and fractions of miles. Followed by "V" if less than 3 miles and variable. If the visibility is 6 miles or less, the reason is always given under "Precipitation" or "Obstruction."	Visibility 1½ miles, variable.
TRW—	Precipitation, thunderstorm, or tornado.	R=Rain; L=drizzLe; E=slEet; A=hAil; S=Snow; W=shoWers; T=Thunderstorm; Z=freeZing. Sometimes followed by + meaning heavy, or by — meaning light. Item omitted if there is no precipitation. Tornado is spelled out.	Thunderstorm; light rain shower.

Symbol	Item	Interpretation	Translation
BD	Obstructions to vision.	F=Fog; H=Haze; D=Dust; N=saNd; K=smoKe (sometimes the above letters are preceded by G=ground; I=ice; B=blowing).	Blowing dust.
		GROUP III.—152/68/60→↘18+30↑1548E/996/DRK NW VSBY 1V2	
		Most of the items in this group are separated by diagonal lines (/).	
152/	Pressure	Stated in millibars using same system as on the weather map (omitting initial "9" or "10").	Pressure 1015.2 millibars.
68/	Temperature	In degrees Fahrenheit	Temperature 68° F.
60	Dew point	In degrees Fahrenheit	Dew point 60° F.
→↘18+30 ↑1548E/	Wind	Wind direction is shown by arrows, either singly or in combination: ↓=North; ↓↙=North-northeast; ↙=Northeast; ←↙=East-northeast; ←=East, etc. Wind speed is indicated by figures indicating knots. (C for calm.) If followed by + = gusts; figures following the + indicate intensity of the gust peaks. If a wind shift has occurred at the station, it is indicated by an additional arrow, followed by figures showing time of shift.	Wind west-northwest, 18 knots; gusts to 30 knots; wind shift from south at 3:48 p. m., eastern time.
996/	Altimeter setting	Barometric pressure in inches for the setting of altimeters on aircraft. Given in three figures with the initial 2 or 3 omitted. A number beginning with 5 or higher presupposes an initial 2; a number beginning with 4 or lower presupposes an initial 3. (993=29.93; 002=30.02, etc.).	Altimeter setting at 29.96 inches.
DRK NW VSBY 1V2	Remarks	Any additional remarks are given in teletype symbols and in abbreviations of English words. Any items which are normally sent, but for some reason are missing from the transmission, are represented by the letter "M."	Dark overcast to the northwest. Visibility variable 1 to 2 miles.

REFERENCES FOR FURTHER STUDY

The following publications are recommended for additional study by private pilots. All may be obtained at the indicated prices from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

PATH OF FLIGHT—Explains the fundamentals of navigation in VFR flying. (70¢)

FACTS OF FLIGHT—Deals with principles of flight, basic flight maneuvers, airplane structures and engines, and related subjects. (50¢)

PRIVATE PILOT'S HANDBOOK OF AERONAUTICAL KNOWLEDGE—This booklet, heavily illustrated, contains the aeronautical knowledge required of the private pilot.

AIRMAN'S GUIDE—Issued every two weeks. (Subscription price, $7.00 a year; $3.50 additional for foreign mailing. Prices of individual copies vary depending on size.)

FLIGHT INFORMATION MANUAL—Issued annually with amendments. ($1.50)

PILOTS RADIO HANDBOOK—(75¢)

CIVIL AIR REGULATIONS—Part 43 ($1.25), Part 60 ($1.50)

FEDERAL AVIATION REGULATIONS—Part 61 (30¢)

CIVIL AERONAUTICS BOARD, SAFETY INVESTIGATION REGULATIONS—Part 320 (5¢)

WEATHER SERVICES FOR PILOTS—Describes what information is available, where to get it, and how to get it. (10¢)

In addition to the materials available from the Superintendent of Documents, there are excellent textual materials available from commercial publishers.

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