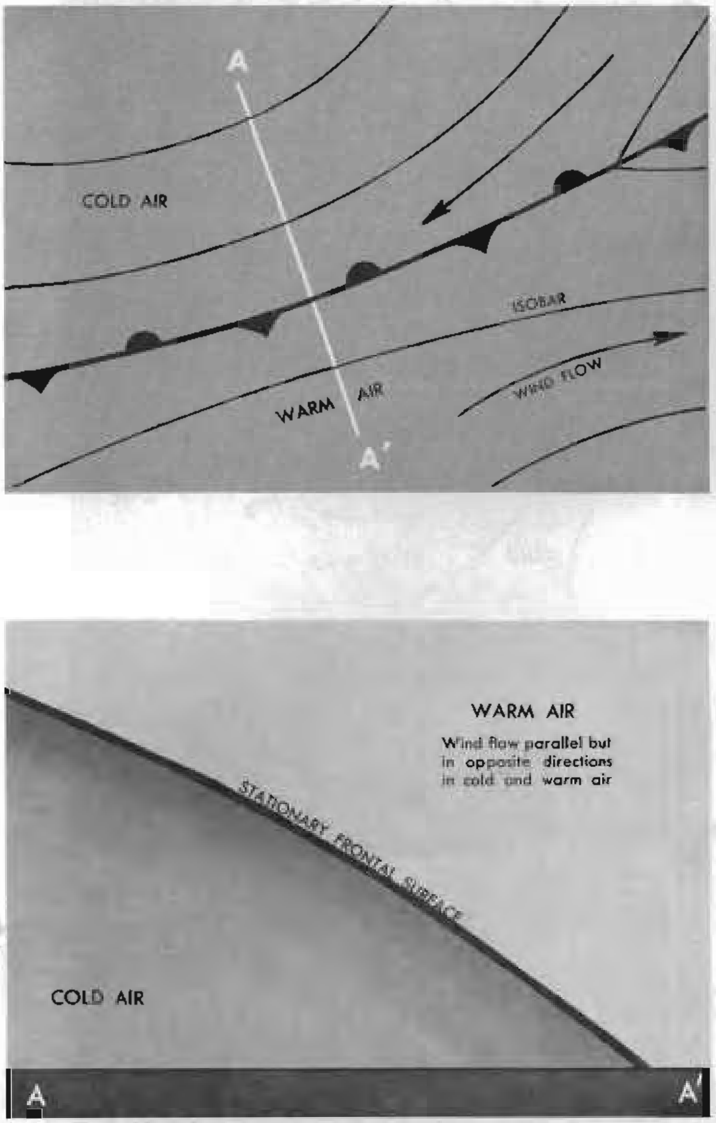
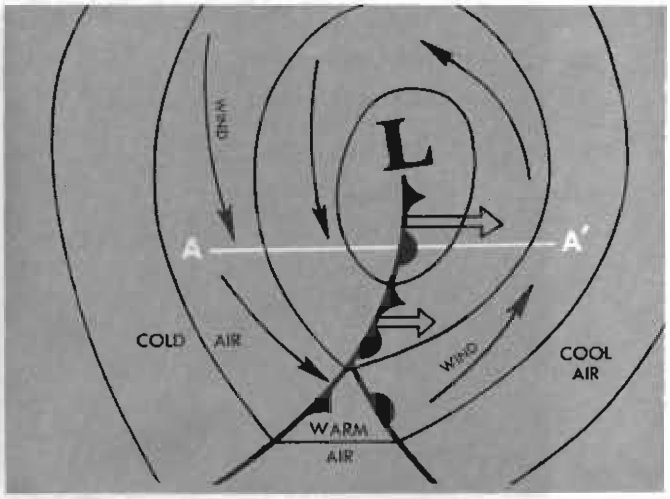


Figure 8–6. Stationary Front



(Note that before the occlusion was formed, the portion labeled "occlusion" would have been labeled "cold front")

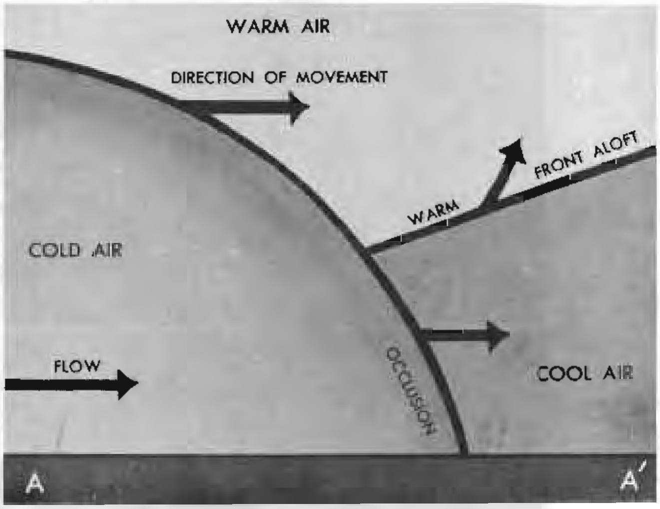


Figure 8–7. An Occluded Front (A Cold-Type)

Wind

Near the earth's surface the discontinuity of wind across a front is primarily a matter of a change in the direction. In flying across a front, a simple rule (which applies in the northern hemisphere) is that the wind shift necessitates a change in heading to the right in order to maintain the original ground track.

Wind speed is often very much the same on both sides of a front. In many cases, however, the wind speed increases abruptly after the passage of a cold front and decreases after the passage of a warm front, although it can be the reverse. In general, wind speed is greater in the colder air mass.

CLASSIFICATION OF FRONTS

Fronts are generally classified according to the relative motions of the air masses involved. The four chief classifications are defined here and are pictured schematically in the accompanying illustrations.

- A cold front is a front whose motion is such that cold air displaces warm air at the surface. (Figure 8-4.)
- A warm front is a front whose motion is

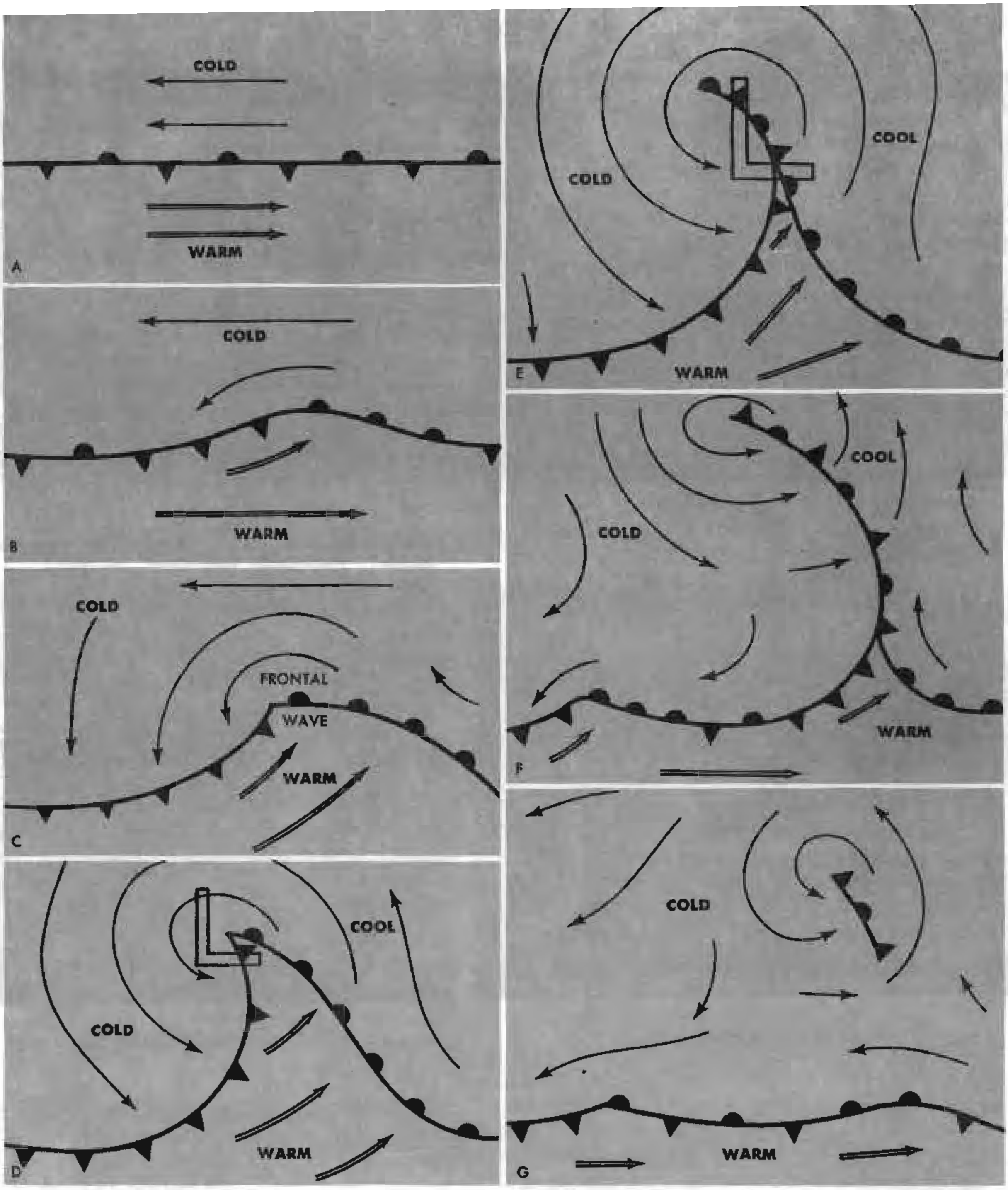


Figure 8–8. The Life Cycle of a Frontal Wave

such that warm air replaces cold air at the surface. (Figure 8-5.)

- A stationary front is a front which has little or no motion. (Figure 8-6.)
- The complex front resulting when a surface cold front overtakes a warm front is called an occluded front, or an occlusion. (Figure 8-7.)

Several subtypes, not listed here, are mentioned in the discussion on *frontal weather* later in this chapter.

Frontal Waves and Cyclones

Frontal waves and cyclones (areas of low pressure) are primarily the result of the interaction of two air masses; and they usually form on slow-moving cold fronts or stationary fronts.

In the initial condition in Figure 8-8, the winds on both sides of the front are blowing parallel to it (A). Small disturbances to the steady state of this wind, which are often not obvious on the weather map, as well as perhaps uneven local heating and irregular terrain, may start a wave-like bend in the front (B). If this tendency persists and the wave increases in amplitude, a counterclockwise (cyclonic) circulation is set up. One section of the front begins to move as a warm front, while the adjacent section begins to move as a cold front (C). This sort of deformation is called a frontal wave.

The pressure at the peak of the frontal wave falls and a low-pressure center is formed. The cyclonic circulation becomes stronger, and the components of the winds perpendicular to the fronts are now strong enough to move the fronts, with the cold front moving faster than the warm front (D). When the cold front catches up with the warm front, the two of them are said to occlude (close together), and the process or result is called an occlusion (E). This is the time of maximum intensity for the wave cyclone.

As the occlusion continues to extend outward, the cyclonic circulation diminishes in intensity (the low pressure area weakens) and the frontal movement slows down (F). Sometimes a new frontal wave may now begin to form on the long westward trailing portion of the cold front. In the final stage, the two fronts have become a single stationary front again. The low center with its remnant of the occlusion has disappeared (G).

Frontogenesis and Frontolysis

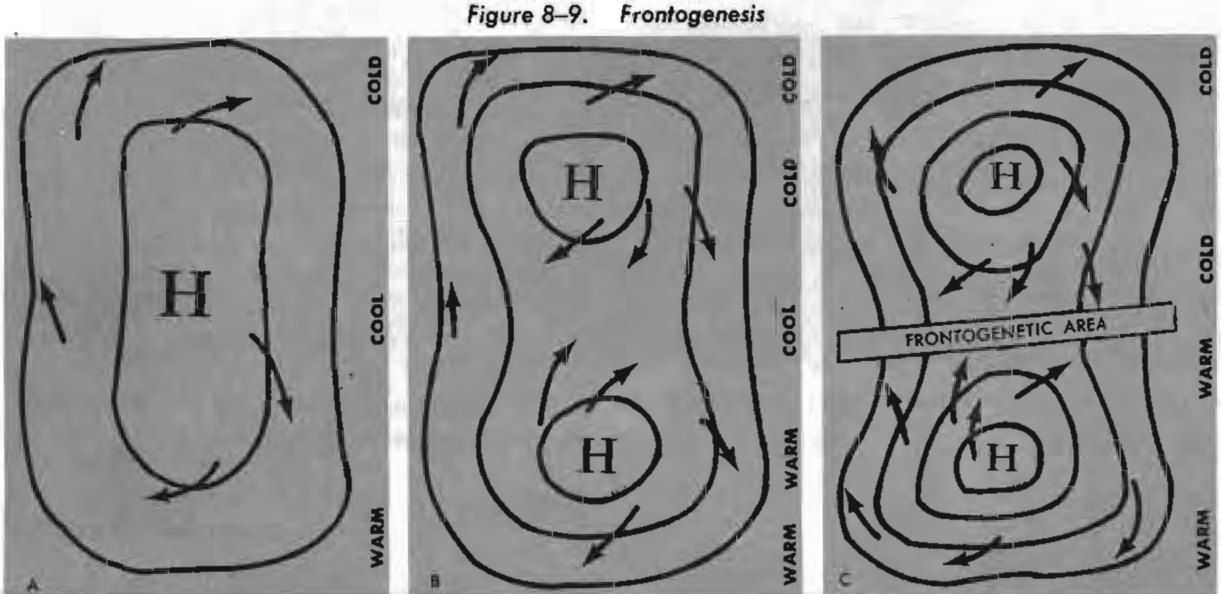
In the preceding sections, we have considered the nature of fronts, how they move, and how they change from one type to another. The question might well be asked: Do fronts ever have beginnings and endings, or do they exist continuously? It will help to answer the question if we recall the definition of a front — a transition zone between two differing air masses.

NOTE

The term, FRONTOGENESIS, is used to refer to situations in which the horizontal gradient of an air mass property, usually density, increases to the point where a relatively sharp zone of transition occurs (a front forms). The necessary wind flow pattern usually develops concurrently with the development of the front.

FRONTOGENESIS. A common example is when a large, high pressure system with a shape somewhat as shown in Figure 8-9 (A) develops. Because of the large range of latitude covered, the air at the northern end remains colder than the air at the southern end, although the change from one end to the other is gradual. If the circulation is slow, the two ends, being modified by their underlying surfaces, will grow to be more unlike. If at this time there is slightly rising pressure at the two ends, the resulting flow of air, represented by the arrows in (B), carries some of the cool air southward and some of the warm air northward. If this persists, there will come a time

Figure 8–9. Frontogenesis



when the temperature change near the middle of the air mass can no longer be considered a gradual one. This is a frontogenetic (front-forming) area, as marked in (C), and it is only a matter of time before the contrast is so great that we can distinguish two air masses where there used to be one. The front between them is a stationary one.

In the preceding paragraph, only temperature was mentioned. Actually, similarly-produced discontinuities in other air mass properties, notably water vapor content, are important factors in generating a front.

FRONTOLYSIS. When a front lies between two air masses associated with weakening centers of pressure, as shown in Figure 8-10 (A), the two flows of air toward the front are light. On both sides of the front, there is no longer sufficient influx of the different air masses to maintain the air mass contrast. The slowly moving air on both sides of the front is being modified by the same kind of underlying surface. The zone of transition (front) becomes more and more diffuse, merging with both air masses (B). After a while it is no longer possible to recognize the different air masses; the front has disappeared (C). The forecaster's term for this action is frontolysis (front-breaking-down).

FRONTAL WEATHER

The weather associated with fronts and frontal movements is called frontal weather. It is more complex and variable than air mass weather. The type and intensity of frontal weather is determined largely by such factors as the slope of the front, the water vapor content and stability of the air masses, the speed of the frontal movement, and the relative motion of the air masses at the front. Because of the variability of these factors, the frontal weather may range from a minor wind shift with no clouds or other visible weather activity, to severe thunderstorms accompanied by low clouds, poor visibility, hail, and severe turbulence and icing. In addition, the weather associated with one section of a front is frequently quite different from that in other sections of the same front.

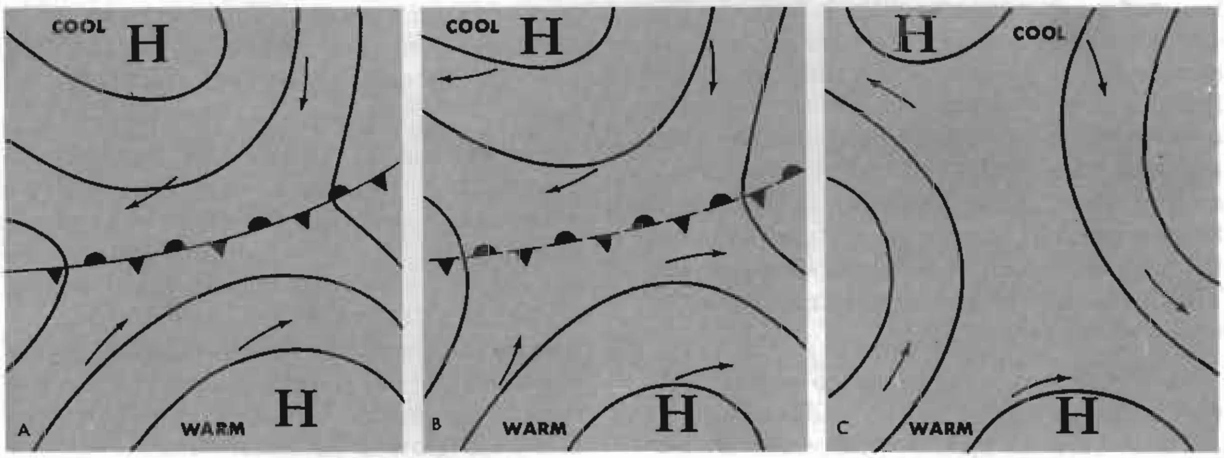


Figure 8–10. Frontolysis

WARM FRONTS. Warm fronts move at relatively slow speeds and usually have gentle slopes. The speed of the advancing warm air, perpendicular to the front, is greater than that of the retreating cold air. Thus, the warm air not only replaces the cold air at the surface, but also slides up over it along the frontal slope. This active upglide produces a cloud system which, in some instances, may extend as far as 1,000 miles in advance of the surface position of the front.

The clouds associated with the warm front are predominantly *stratiform* and appear in

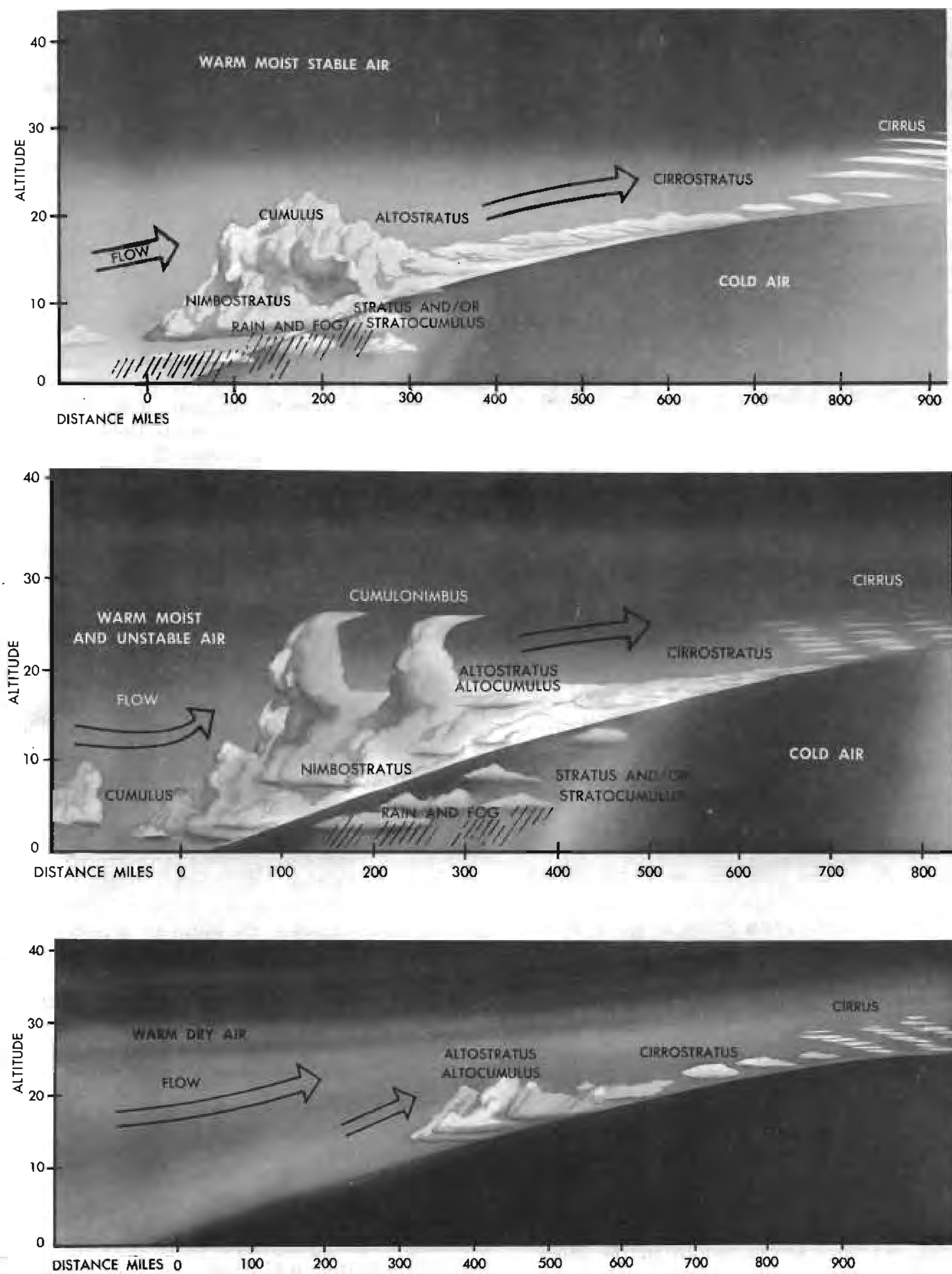


Figure 8–11. Three Typical Warm Fronts

the following sequence with the approach of the front: *cirrus, cirrostratus, altostratus,* and *nimbostratus.* The cirrus and cirrostratus clouds can be observed hundreds of miles in advance of the front. These clouds thicken rapidly. As their bases gradually lower with the approach of the front, they become altostratus. This is usually between 300 and 500 miles ahead of the front (at the surface). Precipitation may begin to fall from the altostratus.

The amount and type of clouds and precipitation vary with the character of the air masses involved. Three situations are described in the following paragraphs and in Figure 8-11.

(A) When the over-running warm air is moist and stable, nimbostratus clouds with continuous light precipitation will be found for as much as 300 miles ahead of the front. The bases of the clouds lower rapidly as additional clouds form in the cold air under the frontal surface. These additional clouds which form in the cold air are *stratus* clouds when the cold air mass is stable, and are *stratocumulus* clouds when the cold air mass is unstable.

(B) When the over-running air is moist and unstable, *cumulus* and *cumulonibus* clouds (thunderstorms) are frequently imbedded in the nimbostratus and altostratus clouds. In such cases, heavy rainshowers (intense and intermittent) occur along with the continuous light precipitation.

(C) When the over-running warm air is dry, it must ascend to relatively high altitudes before condensation can occur. In these cases, usually only the *high* and *middle* clouds will be found.

Visibility is usually good under the cirrus and altostratus clouds. It decreases rapidly in the precipitation area. In addition, when the cold air is stable, an extensive fog area may develop ahead of the front, and visibility becomes extremely low in this area.

Since the cloud system of a warm front is quite extensive, a flight through or along a warm front may require a considerable amount of instrument flying. When the cumulonimbus clouds are embedded in the other clouds, they are normally not visible at low and medium altitudes, and sometimes are not distinguishable at high altitudes. It is possible to fly into them without any advance warning.

At the surface, the passage of a warm front is characterized by a wind shift, a temperature increase, and an end of the precipitation. There will be a rapid improvement in visibility and a rapid dissipation of the clouds, unless the warm air is moist; in which case clouds, showers, and poor visibility may persist for some time after the frontal passage in the area between the warm and cold fronts (warm sector).

Cold Fronts. Cold fronts usually move faster and have a steeper slope than warm fronts. The cold fronts that move very rapidly have very steep slopes in the lower levels and narrow bands of clouds, which are predominantly just ahead of the front. The slower moving cold fronts have less steep slopes and their cloud systems may extend far to the rear of the surface position of the fronts. These characteristics are shown in the accompanying illustrations.

In referring to these pictures while reading the following paragraphs, the reader should keep in mind that only two of several possible combinations are shown. Both fast-moving and slow-moving cold fronts may be associated with either stability or instability, either moist or dry air masses. Accordingly, the reader should mentally modify the pictures as he reads.

When the warm air involved in a cold front situation is moist and stable, the clouds are predominantly stratiform (nimbostratus, altostratus, cirrostratus) with moderate precipitation. However, when the warm air is moist and unstable (or has a tendency to be unstable), the clouds are predominantly cumuliform and precipitation is in the form of moderate or heavy showers. A line of thunderstorms frequently develops along a fast-moving cold front which is displacing warm, moist, unstable air. Sometimes under these conditions, a line of strong convective activity is projected between 50 and 200 miles ahead of the front, and roughly parallel to it. If this develops into a line of thunderstorms, it is called a *squall line.* On the other hand, when the warm air is very dry, little or no cloudiness is associated with a cold front.

When the cold air behind the front is moist

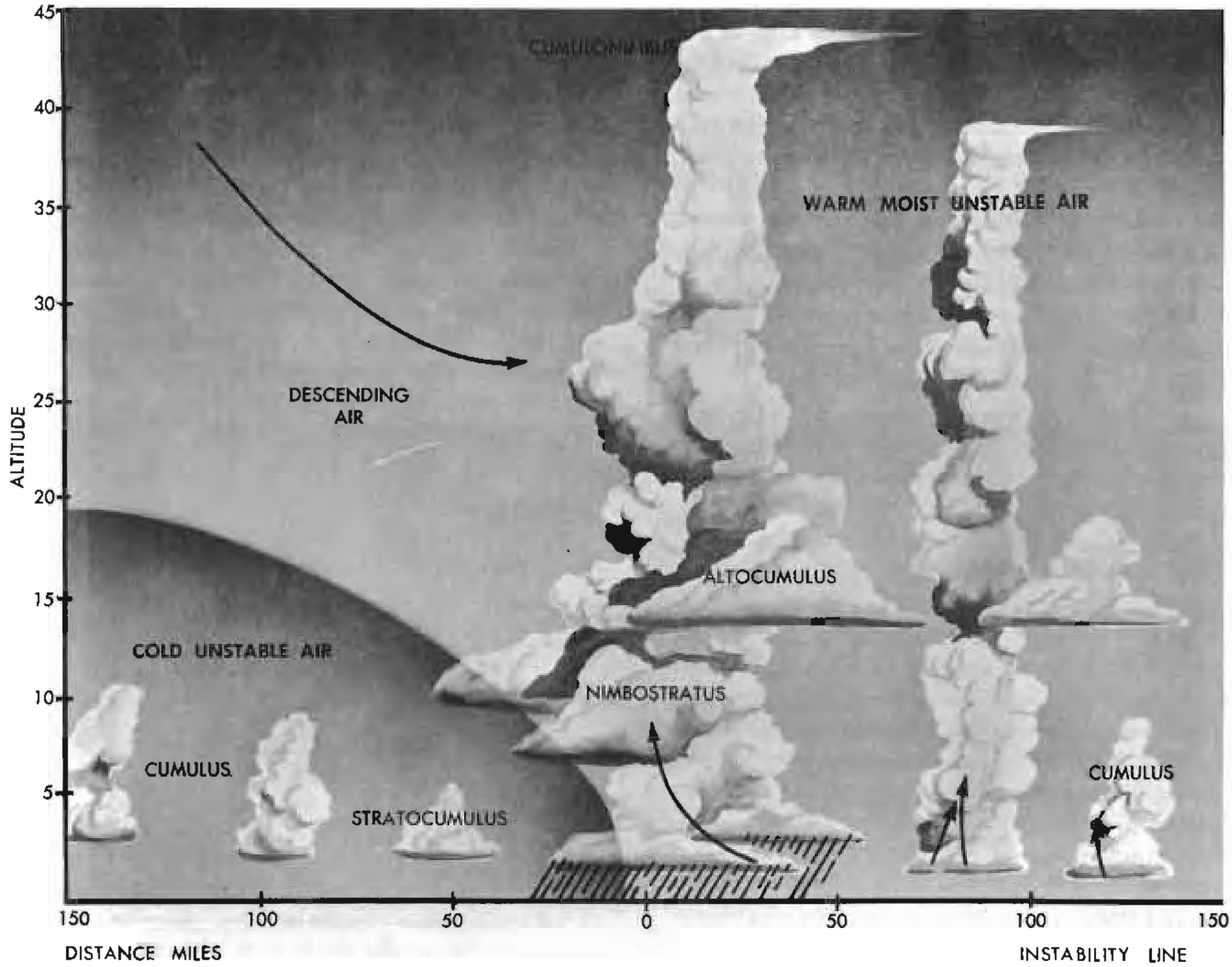


Figure 8–12. A Fast-moving Cold Front

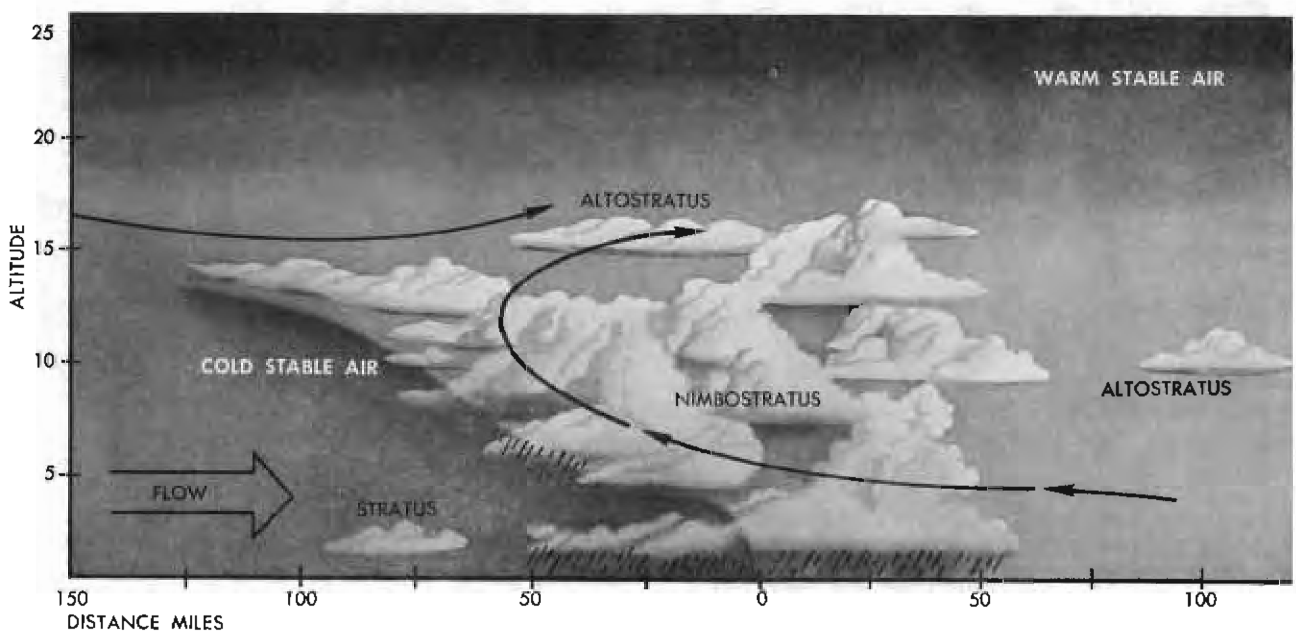


Figure 8–13. A Slow-moving Cold Front

and stable, a deck of stratus clouds and/or fog may persist for some time after the frontal passage. Similarly, when the cold air is moist and unstable, cumulus clouds and showers may occur for some time after the frontal passage. When the cold air mass is very dry, clouds will generally not be found in the cold air, except as a result of moistening by precipitation falling from above the frontal surface.

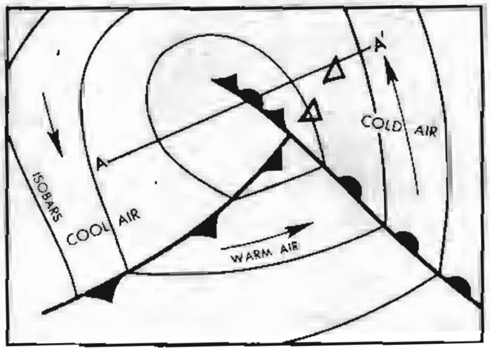
At the surface, a cold front passage is characterized by a temperature decrease, a wind shift, and on occasion, gusty winds.

Although the weather associated with cold fronts is concentrated in a narrower band than that associated with warm fronts, it often presents more serious flying hazards.

STATIONARY FRONTS. On occasion, both cold and warm fronts gradually lose their speed and, for a period of time, have no discernible steady movement. During this period of retarded or fluctuating motion, they are called *stationary fronts*. The slope, cloud sequence, and weather associated with stationary fronts may be like a warm front or a cold front or just a belt of cumuliform clouds, depending on the recent past history of the front, the temperature contrast across the front aloft, the direction of the winds near the front, and so forth. A cold front which has just become stationary often tends to change from cold frontal to warm frontal characteristics.

OCCLUDED FRONTS. In the section on *Frontal Waves and Cyclones*, we learned that fronts frequently have bends, or waves, in them. Under such conditions, one section moves toward the cold air as a warm front, while an adjacent section moves toward the warm air as a cold front. When the cold front section moves faster than the warm front section, it eventually overtakes the warm front. The warm air mass (warm sector) which was between the fronts, is lifted up off the surface by the two colder air masses. The resulting front is called an occluded front, or an occlusion. There are two types of occlusions — the *warm front type* and the *cold front type*.

Warm Front Occlusion. In the warm-front occlusion, the air ahead of the warm front is colder than the air behind the overtaking cold



The cross section of the warm front occlusion shown below occurs at line AA' on the weather map above

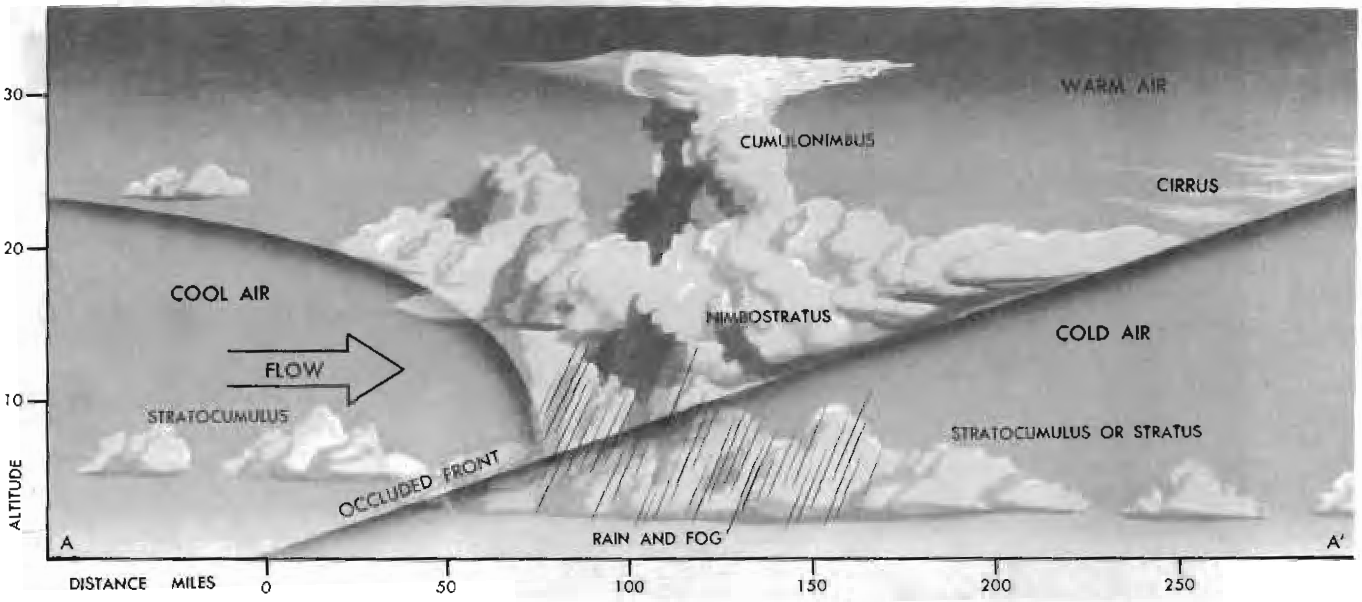
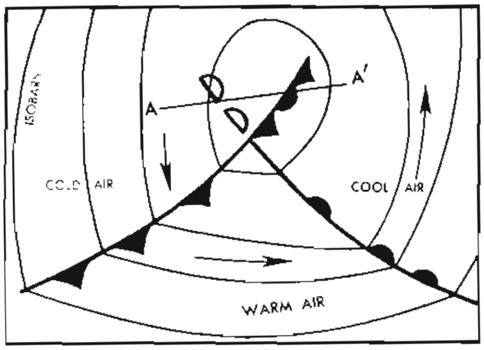


Figure 8–14. A Warm-Front Occlusion



The cross section of the cold front occlusion shown below occurs at line A A′ in the weather map at the left.

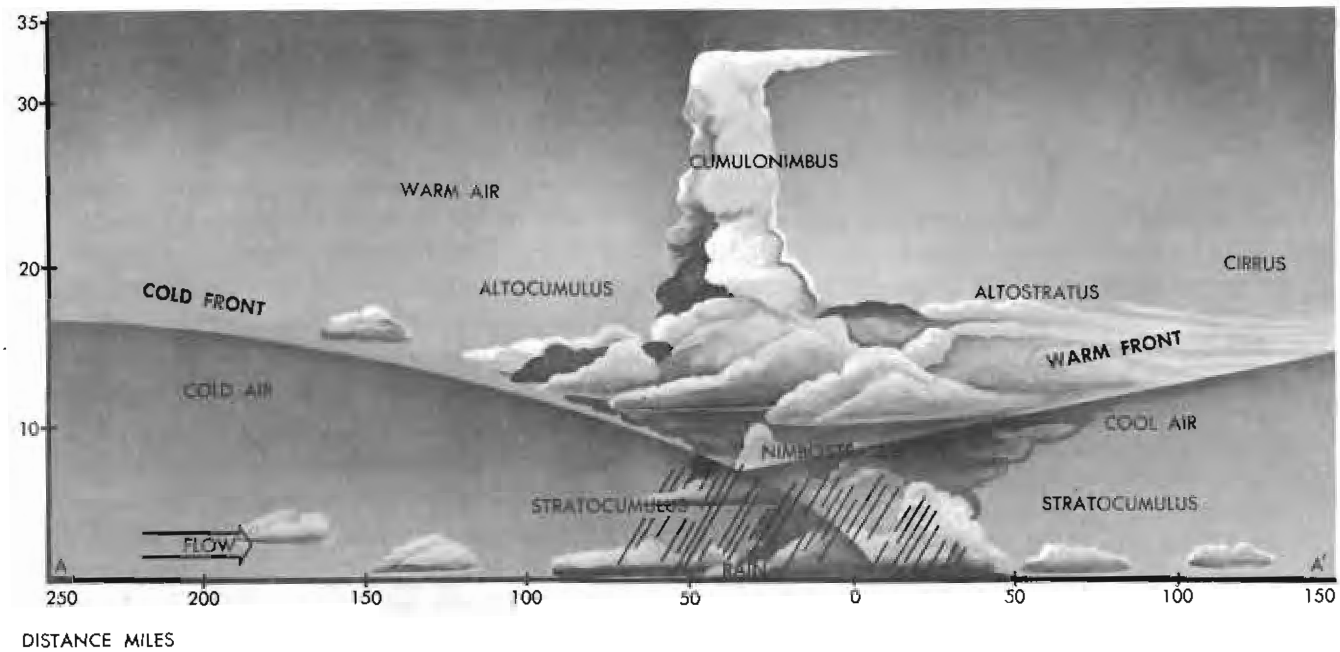


Figure 8–15. A Cold-Front Occlusion

front. When the cold front overtakes the warm front, both the warm air ahead of the cold front and the cool air behind it slide up over the colder air which is ahead of the warm front. Thus, the cold front itself moves up over the warm front, pushing the warm air ahead of it, and it becomes an *upper cold front.* At the surface, the situation resembles that found with a warm front (in this case, cool air is replacing cold air), hence the name *warm front occlusion.* This type of occlusion is not common over the interior of the United States.

The weather associated with warm front occlusions has the characteristics of both warm and cold fronts, as the accompanying illustration shows. The sequence of clouds ahead of the occlusion is similar to the sequence of clouds ahead of a warm front, while the cold front weather occurs near the upper cold front. If either the warm or cool air which is lifted is moist and unstable, showers (and sometimes thunderstorms) may develop. Weather conditions change rapidly in occlusions, and are usually most severe during the initial stages of development. However, as the warm air is lifted to higher and higher altitudes, the weather activity diminishes. Warm front occlusions are found predominantly along the west coast of continents.

Cold Front Occlusion. In the cold-front occlusion, the air ahead of the warm front is less cold than the air behind the overtaking cold front. When the cold front overtakes the warm front, both the warm air behind the warm front and the cool air ahead of it are lifted by the colder air coming in behind the cold front. Thus, the warm front itself is lifted by the under-cutting cold front, and it becomes an *upper warm front*. At the surface, the situation resembles that found with the cold front (in this case, cold air is displacing cool air), hence the name, *cold front occlusion*.

In the occlusion's initial stage of development, the weather and cloud sequence ahead of the occlusion are similar to that associated with warm fronts; while the cloud and weather near the surface position of the front are similar to that associated with cold fronts. As the occlusion develops and the warm air is lifted to higher and higher altitudes, the warm front prefrontal cloud system disappears, and the weather and cloud system become similar to those of a cold front. Cold front occlusions form predominantly over continents or along their east coasts, and are more common than warm-front-type occlusions.

CHAPTER 9

Restrictions to Visibility

Visibility (or visual range) is generally defined as the greatest distance that prominent objects can be seen and identified by unaided, normal eyes. As an aircrew member, you will be concerned with the following types of visibilities: *horizontal surface (ground) visibility*, *flight (air to air) visibility*, and *slant range (pilot's visibility along glide path)*.

Prevailing horizontal surface visibility is the easiest of the three to measure, and is included in surface weather reports. No practical method has yet been devised to determine flight and slant range visibilities, so forecasters depend primarily on weather reports from aircrews. Slant range visibility is of vital importance in the approach zone when aircraft, especially the jet type, must land under conditions of low ceiling and/or surface visibility. On many occasions, flight and slant range visibilities are quite different from surface visibility.

The type and intensity of restrictions to visibility depend largely on the stability of the associated air mass. Stable air is favorable for the formation of fog, low clouds, and light precipitation which restrict visibility. Likewise, haze and smoke are trapped in stable layers of the atmosphere. On the other hand, unstable air produces vertical currents which tend to lift and dissipate fog, as well as lift and spread haze and smoke. Blowing dust, blowing snow, and heavy rain showers, which also reduce visibility, are associated primarily with unstable air masses.

In this chapter we will briefly discuss fog, haze, and other phenomena which restrict visibility. Unless specifically stated otherwise, the term *visibility* in the following discussions refers to horizontal surface visibility.

FOG

Fog is one of the most common and difficult weather hazards encountered in aviation. Since it occurs on the ground, it is primarily a hazard during takeoff and landing operations. Fog generally reduces visibility to values of less than three miles, and on many occasions to zero. Flight visibility is generally good above fog, while slant range visibility is usually near zero in fog.

Fog is a suspension of minute water droplets in the atmosphere. It is usually gray and, of course, "feels" damp. There is similarity between low clouds and fog. The only distinction between the two is that the base of fog is from the earth's surface, upward through 50 feet, and the base of clouds must be at least 51 feet above the ground.

The conditions that are most favorable to the formation of fog are light surface winds, high relative humidities, and an abundance of condensation nuclei. Light winds tend to deepen fog through mixing, although as wind speeds increase beyond certain values (dependent on stability and type of fog) the fog usually dissipates or lifts and becomes low stratus clouds.

Fog is generally more prevalent in coastal areas, where more water vapor is available, than it is inland. Fog is not only more persistent in industrial regions, because of the high concentration of condensation nuclei, but also frequently forms there when the relative humidity is less than 100%. In most areas of the world, fog occurs more frequently during the colder half of the year than the warmer half.

Figure 9–1. The Formation of Radiation Fog

Fog is formed when water vapor in the air condenses, either as a result of cooling the air or of adding water vapor to the air, which in turn leads to the following classification:

1. Fog formed by the cooling process (cooling fogs).

a. Radiation fog — formed by moist air in contact with the earth's surface which is undergoing nocturnal radiational cooling.

b. Advection fog — formed by moist air moving over a colder surface.

c. Upslope fog — formed by moist air which cools because of expansion as it moves up rising terrain.

2. Fog formed by evaporation (evaporation fogs).

a. Frontal fog — formed by evaporation of rain into the colder air mass under a frontal slope.

b. Steam fog — forms when cold air moves over a much warmer water surface.

Fogs which are produced by the cooling process generally occur within an air mass and for this reason are sometimes called air mass fogs. It should be noted that steam fog, which forms primarily within air masses, is produced by a different process: the addition of moisture. The processes that produce cooling fogs also tend to stabilize the lower layers of the atmosphere and thus produce surface inversions.

The classification of fog given here is really a classification of the various processes contributing to fog formation. Actual fogs cannot always be placed uniquely in these categories. One of the most common fog situations in the eastern United States is due to a combination of advection and radiation, and steam fog is equally due to advection and evaporation.

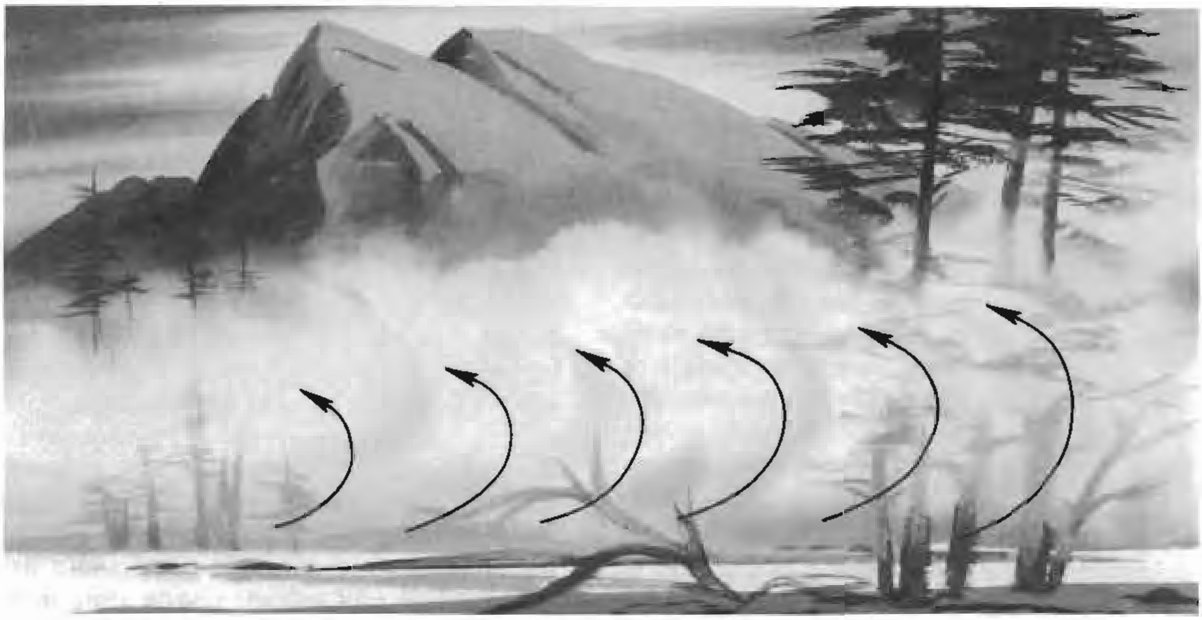


Figure 9–2. The Result of Turbulent Mixing by Light Winds

Radiation Fog

The atmospheric conditions which are most favorable for the formation of radiation fog are clear skies, light winds, and high relative humidities. These conditions occur most frequently when a land area is under the influence of a high pressure cell.

Radiation fog, sometimes called ground fog, forms on clear, nearly calm nights when the ground loses heat very rapidly. The air in contact with the ground is cooled by conduction, the relative humidity increases, and condensation occurs.

Light wind up to about 5 knots produces a slight mixing of air which spreads the cooling through a deeper layer, as shown in the illustration *Turbulent Mixing by Light Winds*. This tends to deepen the fog. If a complete calm exists when all other factors are favorable for the formation of radiation fog, usually

Figure 9–3. Advection Fog Forms over the Gulf States as Warm, Moist Air Moves over Cold Ground

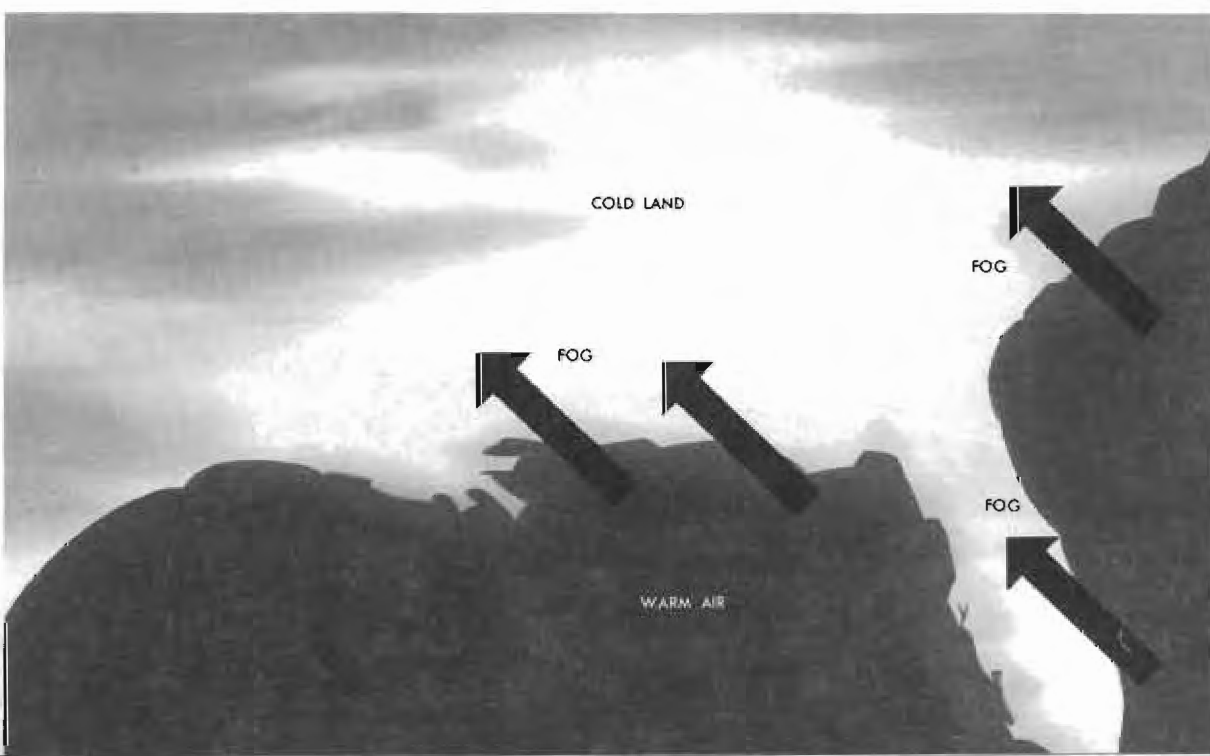


Figure 9–4. Fog in California — Air Moving over Colder Ocean Surface Near Shore

only very shallow layers of fog will form. Radiation fogs do not form at sea because the sea surface does not undergo extensive radiational cooling at night as the land surfaces do.

Advection Fog

Advection fog is very common along coastal regions and at sea. It is produced by cooling the lower layers of warm, moist air as the air moves over a colder surface. Advection fog deepens as the wind speed increases up to about 15 knots. However, when the wind speed is much stronger than 15 knots, the resulting turbulence usually lifts the fog, and stratus clouds form.

As the illustration shows, advection fog is common in the Gulf States area during the winter when the relatively warm, moist air from the Gulf moves inland over the colder surfaces.

In summer, the cold water along the east coast of continents frequently produces advection fogs, as warm, moist air moves from land to sea. The sea fog is then frequently blown inland during the afternoon by sea breezes. Advection fog often forms in coastal areas when cold water from the ocean depths rises to the surface of the sea and produces cold sea-surface temperatures. This type of advection fog, which is shown in the illustration,

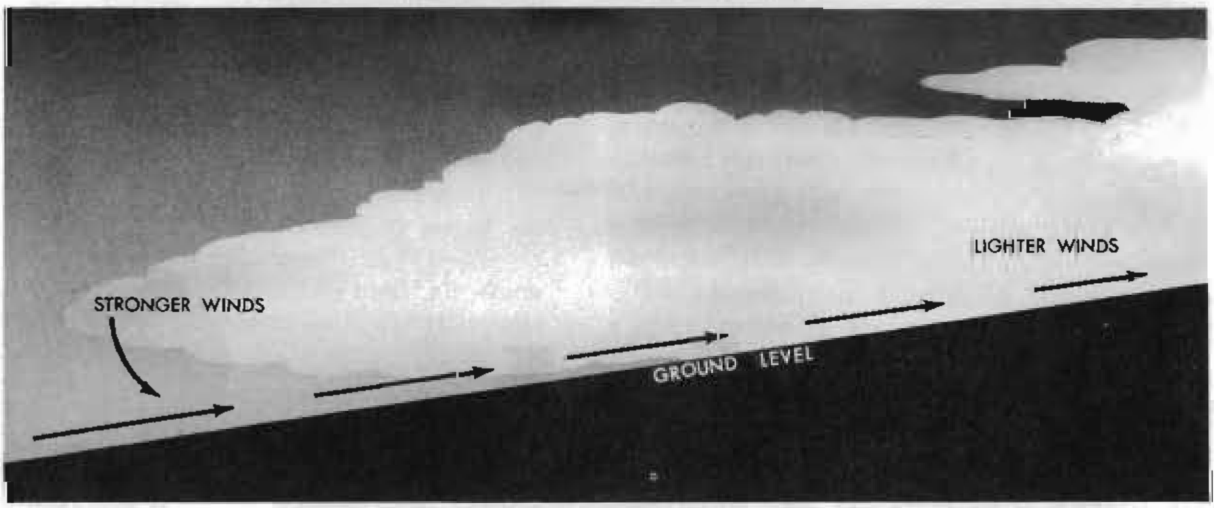


Figure 9–5. Upslope Fog — Stronger Winds and Turbulence Lift Fog Layer as a Stratus Cloud

is common along the California coast in summer.

Sea fogs are common over the higher latitudes of the oceans in summer as winds from lower latitudes carry moist air over successively colder waters.

Upslope Fog

Upslope fog is formed by the movement of stable air up a sloping land surface. As the illustration indicates, the air rises up the slope and is cooled by expansion. When this cooling is sufficient to produce condensation, fog forms. An upslope wind is necessary for the formation and maintenance of upslope fog. As with other types of fog, when the wind becomes quite strong the fog lifts and becomes low stratus clouds. This type of fog is frequently observed on the high plateaus and eastern slopes of the Rockies when easterly winds from the Mississippi Valley and Gulf Coast ascend the slopes. They also occur on the piedmont east of the Appalachians.

Frontal Fog

The most important type of frontal fog forms in the cold air mass under the warm frontal surface. Some of the precipitation from the over-running warm air evaporates as it falls through and saturates the colder air. Such frontal fogs occur frequently in winter and are usually associated with warm fronts, and occasionally with cold fronts or stationary fronts. Frontal fogs form rapidly and usually cover a wide area.

Steam Fog

Steam fog is produced by the movement of cold air over a warmer water surface. It forms when the evaporation of water vapor into the cold air is intense enough to produce condensation. Steam fog rises from the sea surface like smoke, and therefore is occasionally called *sea smoke.*

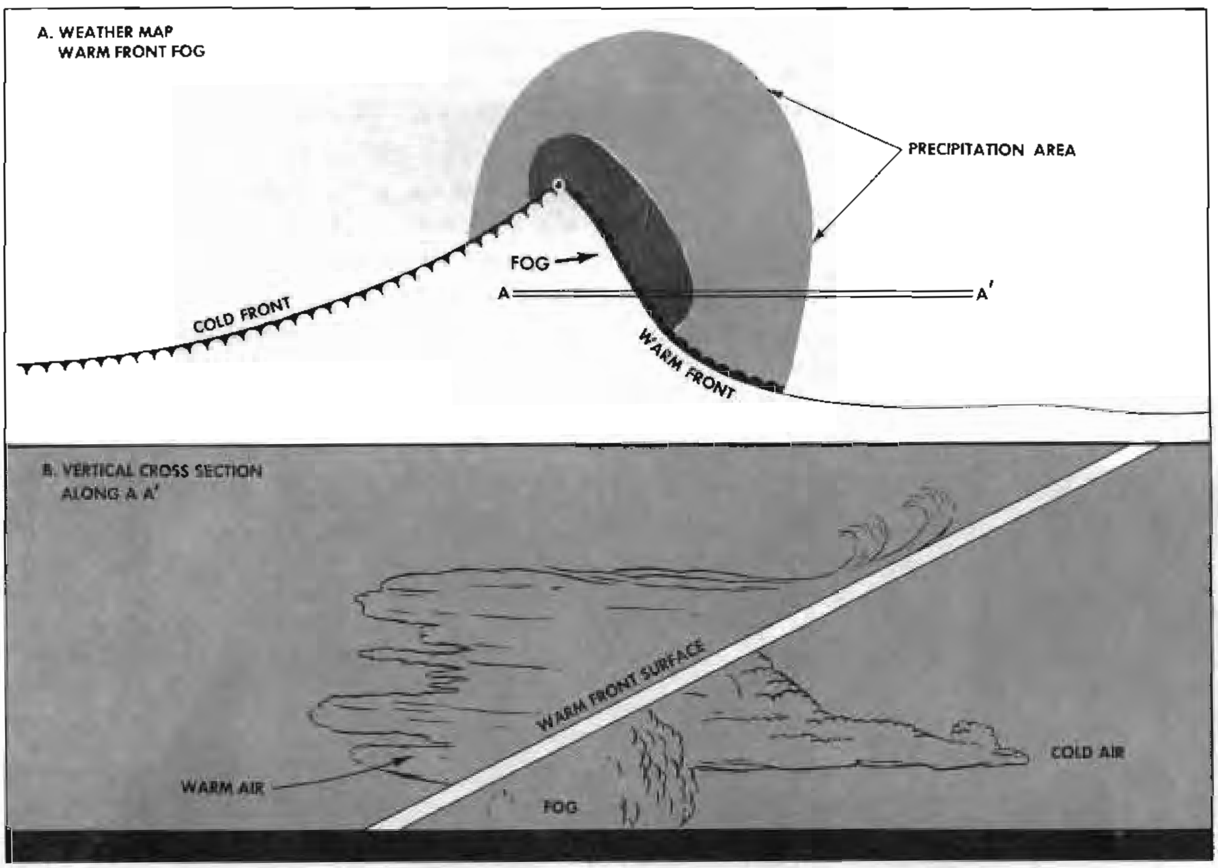


Figure 9–6. Warm Front Fog

Figure 9–7. Steam Fog

The conditions which produce steam fog — that is, the advection of cold air over a much warmer surface — tend to make the lower layer of the air mass unstable, because the air is heated from below. Steam fog is observed over rivers and lakes of the temperate zone in the autumn, and over open water areas of the polar regions in winter.

Ice (Crystal) Fog

When the air temperature is below about –25° F, any water vapor in the air condensing into droplets is quickly converted into ice crystals. A suspension of ice crystals in the air at the surface of the earth is called *ice fog.* Ice fog occurs mostly in the arctic regions, and is mainly an artificial fog produced by human activities, occurring locally over settlements and airfields where hydrocarbon fuels are burned. (Burning one pound of a common hydrocarbon fuel produces 1.4 pounds of water.)

When the air temperature is approximately –30° Fahrenheit or lower, ice fog frequently forms very rapidly in the exhaust gases of aircraft, automobile, or other types of combustion engines. When there is little or no wind, it is possible for an aircraft to generate enough ice fog during landing or takeoff to cover the runway and a portion of the airfield. Depending on the atmospheric conditions, ice fogs may persist for periods which vary from a few minutes to several days.

There is also a fine *arctic mist* of ice crystals which persists as a haze over wide expanses of the arctic basin during winter; it may extend upward through much of the troposphere — a sort of cirrus cloud reaching down to the ground.

Figure 9–8. Ice Fog

Haze and Smoke

When the fine dust, salt particles, or other impurities which are normally highly dispersed in the atmosphere, are trapped and concentrated in a limited layer, the resulting restriction to visibility is called *haze*. When we view distant objects against a dark background through haze, they appear to be veiled in pale blue, pale yellow, or white, depending on the density, illumination, and nature of the particles. The density of haze near the ground increases as the stability of the air increases. Surface-based haze layers often extend to altitudes of about 15,000 feet through convectional mixing, with a sharp boundary at the top called a *haze line* or *dust horizon* when seen from above.

The greatest restriction to visibility in haze usually occurs when looking in the direction of the sun; then the visibility is frequently zero. In fact, it is often hazardous to land an aircraft into the sun when haze conditions exist. Visibility in haze is best in the vertical, particularly looking down.

Smoke usually restricts visibility when it is trapped under an inversion in stable air, and is usually concentrated on the downwind side of industrial areas. The surface, slant, and flight visibilities in smoke are similar to those in haze.

Smoke from forest fires is frequently transported great distances at high levels. In such cases, very poor flight and slant range visibilities in dense smoke at flight altitudes may be encountered, even though the lower levels are free from smoke.

Since smoke particles are nuclei upon which water vapor condenses, and since the conditions leading to radiation fog produce stable air near the ground, smoke and fog frequently occur together in industrial areas. This mixture is sometimes called *smog*.

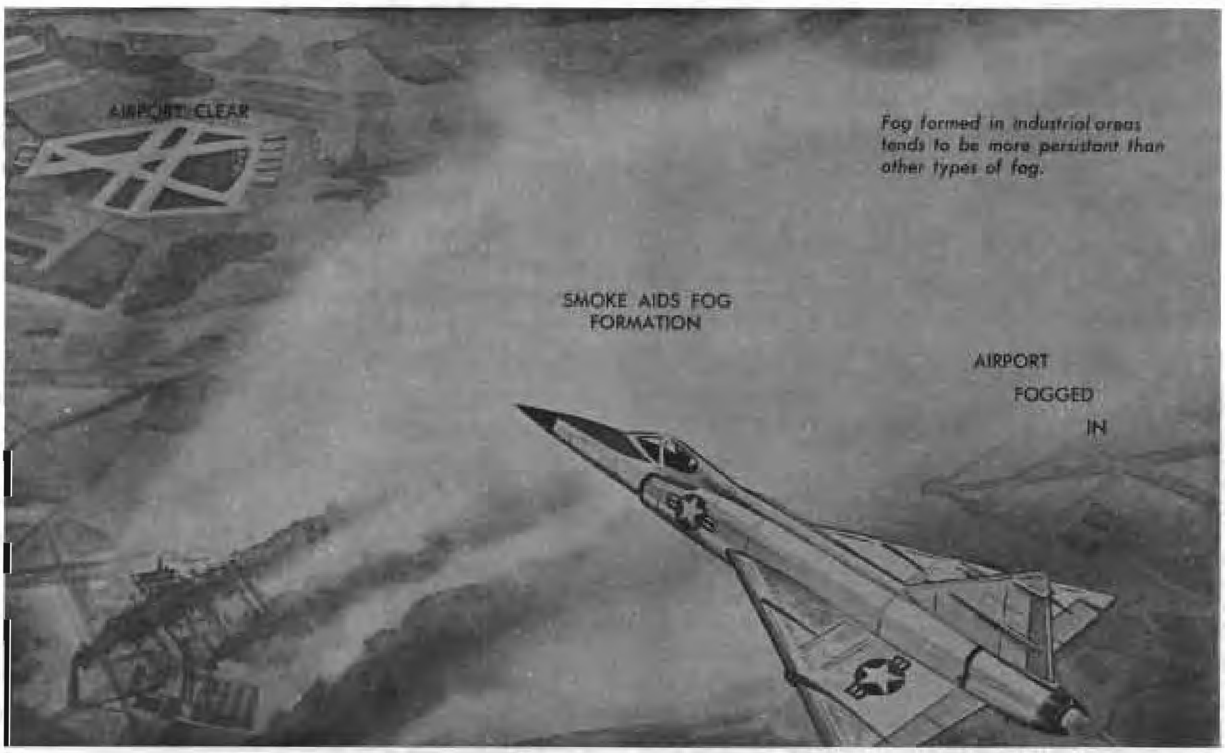


Figure 9–9. Smog

Blowing Snow, Dust, and Sand

Blowing dust is observed in semiarid regions when the air is unstable and the winds are relatively strong. The strong winds and vertical currents may spread the dust over wide areas and lift it to great heights. Surface, flight, and slant-range visibilities are reduced to very low values in blowing dust. Sand storms are more local and occur where loose sand is found in desert regions. The blowing sand is seldom lifted above 50 feet.

Blowing snow reaching a few feet above the ground observed over snow-covered regions when the wind is very strong, can be as troublesome as ground fog.

Precipitation

Rain, except in brief, heavy showers, rarely reduces the surface visibility to less than one mile. However, when rain streams over the windshield of an aircraft, it will greatly reduce the visibility to the outside. This is often called *cockpit visibility.*

Drizzle and snow usually reduce the visibility to a greater extent than does rain. Drizzle, which is common in stable air, is generally accompanied by fog, haze, or smoke. The visibility is frequently reduced to zero in heavy snowfall.

Clouds

Flight and slant-range visibilities vary from about one-half mile in light or thin clouds to zero in dense clouds. Since there is little or no slant visibility until the pilot penetrates the base of the cloud, low ceilings present visibility problems during landing operations.

Surface-Based and Total Obscurations

When the sky or clouds are partially or totally hidden from a ground observer by precipitation, or by other restrictions to visibility (smoke, fog, haze, and the like) whose *bases* are on the ground, the sky is said to be *obscured.*

When the sky or clouds are totally obscured, the reported ceiling is the vertical visibility from the ground. For example, if all the sky is hidden by fog and the vertical visibility is 500 feet, an obscuration ceiling of 500 feet is reported. This obscuration ceiling of 500 feet is quite different from a cloud ceiling of 500 feet. In the latter case, the pilot can normally expect to see the ground and the runway on the glide path when the aircraft penetrates the cloud base at 500 feet above the ground. This situation is sketched in Figure 9–10.

However, in the case of the obscuration ceiling, the obscuring phenomenon (precipitation, fog, haze, smoke, or the like) reaches to the surface and the pilot normally will *not* be able to see the runway or approach lights during an approach, even after penetrating the level of the reported obscuration ceiling. Notice this situation in Figure 9–11. (The pilot will be able to see the ground directly beneath his aircraft when he passes through the altitude of the reported vertical visibility — 500 feet in Figure 9–11, and, of course, will often make visual contact with the runway only after reaching an altitude considerably lower than the reported vertical visibility.)

Of more concern than seeing the ground directly beneath his aircraft is seeing some distance ahead of the aircraft and, more specifically, the runway or approach lights.

TELETYPE REPORT EXAMPLES

Total Obscurations

1. W1 X 1/16F

The symbols mean respectively:

W — indefinite ceiling and is generally used with fog.

1 — vertical visibility estimated to nearest 100 feet — thus it is 100 feet in the example.

X — total obscuration. The entire sky dome and clouds are obscured from the observer.

1/16 — horizontal prevailing visibility is 1/16 statute miles.

F — symbol for fog.

This would be read: "*indefinite ceiling one hundred feet obscured, visibility 1/16 of a mile in fog.*"

2. W5X½S

The symbols mean respectively:

W — precipitation obscuration or that the sky dome or clouds are obscured by falling precipitation, frequently snow.

5 — vertical visibility estimated in hun-

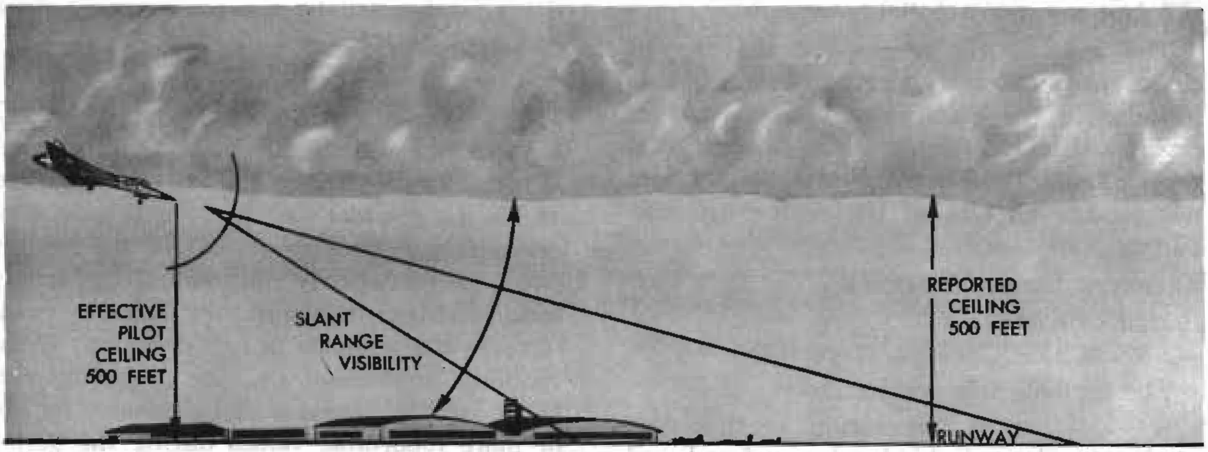


Figure 9–10. Cloud Ceiling of 500 Ft. with no Restriction to Visibility Below Clouds

dreds of feet — thus it is 500 feet in the example.

X — total obscuration

½ — horizontal prevailing visibility in statute miles and fractions thereof. In the example it is one-half of a mile.

S — snow. In the example the S means snow of moderate intensity.

Heavy snow would be shown as S+.

Light snow would be shown as S—.

Very light snow would be shown as S— —.

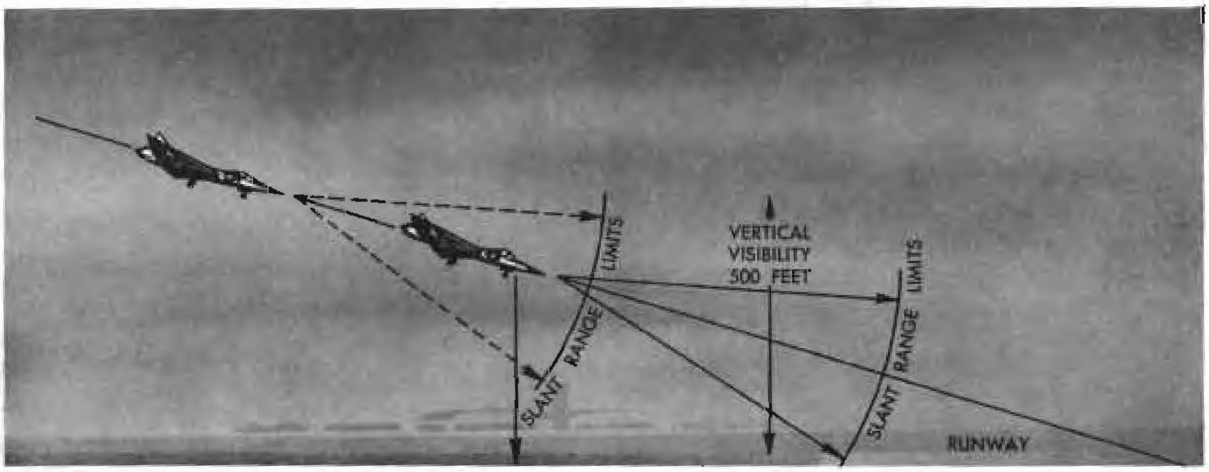
This would be read: "*indefinite ceiling five hundred feet obscured, one-half of a mile visibility in moderate snow.*"

Partial Obscurations

When 1/10 through 9/10 of the sky dome or clouds is visible through the obscuring phenomenon at the point of observation, the obscuration is reported as partial. Since the ground observer can see through the obscuration, or a portion of the sky dome is not hidden by the obscuring phenomenon, vertical visibility is not reported for partial obscurations as it is for a total obscuration. However, when clouds are visible with a partial obscuration, their heights and amounts are reported.

Partial obscurations present the same landing operation problems as the total obscuration. The pilot still has no idea of the slant-range visibility, or the altitude at which he

Figure 9–11. Surface Based Obscuration with Vertical Visibility (Obscured Ceiling) of 500 Ft.



will first see approach lights on runway.

The amount (in tenths) of the sky or clouds obscured by a partial obscuration is included in the remarks section of weather reports. Although this may help to clarify the reported conditions in many cases, it still does not provide an idea of the slant-range visibility.

TELETYPE REPORT EXAMPLE

Partial Obscurations

–XM5 ⊕ 3FHK 186/64/62/0000/003/F6

The symbols mean respectively:

–X — partial obscuration, or that part of the sky dome is hidden by surface-based phenomena.

M — indicates the method by which the base of the visible clouds was determined and generally refers to the use of a ceiling light, ceilometer, or cloud base-height measuring instruments.

5 — base of the visible clouds in hundreds of feet. In the example it is 500 feet.

⊕ — broken sky condition, or the portion of the sky obscured by the obscuring phenomena plus the portion covered with clouds is 6/10 through 9/10.

3 — horizontal prevailing visibility in statute miles (see below).

F — Fog

H — haze

K — smoke

186 — sea level pressure of 1018.6 millibars

64 — temperature in degrees Fahrenheit

62 — dew point temperature in degrees Fahrenheit

0000 — surface winds are calm

003 — altimeter setting in inches of mercury; thus, 30.03".

F6 — indicates that six-tenths of the sky dome is obscured by the obscuring phenomena; or, fog 6/10.

Prevailing Visibility

Prevailing visibility is that visibility which is normally reported in the weather sequence, and is the *greatest* visibility which is equalled or surpassed throughout half of the horizon circle, not necessarily continuous. Under uniform conditions the prevailing visibility is the same as the visibility in any direction. If the visibility is variable, i.e., the prevailing visibility rapidly increases and decreases by one or more reportable values during the period of the observation, the average of all observed values is used as the prevailing visibility. The visibility is reported as variable only if the prevailing visibility is less than 3 miles.

Runway Visibility

Runway visibility (RV) is an instrumentally or visually derived value that best represents the horizontal distance a pilot can see down the active runway in the direction of takeoff or landing. When high intensity runway lights are operative, runway visibility observations will take this into account and the reported visibility will be the maximum possible with the lights on.

Runway Visual Range

Runway visual range (RVR) is an instrumentally derived value, based on standard calibrations, that represents the horizontal distance a pilot will see down the runway from the approach end; it is based on the sighting of either high intensity runway lights or on the visual contrast of other targets—whichever yields the greater visual range.

Turbulence

Atmospheric turbulence is caused by random fluctuations of wind flow which are instantaneous and irregular — so much so that to accurately describe the random fluctuations by other than statistical analysis is almost impossible. Since aircraft operate in the atmosphere, the effects of turbulence on aircraft operations warrant consideration.

In general, turbulence can be approached from the standpoint of causative factors and described by a subjective scale of degrees of intensity of turbulence. The Air Weather Service has listed several meteorological criteria to aid in determining what degree to assign to a given turbulence situation. The four degrees of turbulence listed by Air Weather Service are: (1) Light; (2) Moderate; (3) Severe; and (4) Extreme.

For the purposes of this discussion we shall divide turbulence according to the following causative factors:

1. *Thermal* — caused by localized vertical convective currents due to surface heating or unstable lapse rates, and cold air moving over warmer ground.

2. *Mechanical* — resulting from wind flowing over irregular terrain.

3. *Frontal* — resulting from the local lifting of warm air by cold air masses, or the abrupt wind shift (shear) associated with most cold fronts.

4. *Large Scale Wind Shear* — marked gradient in wind speed and/or direction due to general variations in the temperature and pressure fields aloft. Two or more of the above causative factors often work together. In addition, turbulence is produced by "man-made" phenomena, such as in the wake of aircraft.

THERMAL CAUSES

Vertical air movements or convective currents develop in air which is heated by contact with a warm surface. This heating from below occurs when either cold air is advected (moved horizontally) over a warmer surface, or the ground is strongly heated by solar radiation.

The strength of convective currents depend in part on the extent to which the earth's surface below has been heated and this, in turn, depends on the nature of the surface. Notice in the illustration that barren surfaces, such as sandy or rocky wasteland and plowed fields, are heated more rapidly than surfaces covered with grass or other vegetation. Thus, barren surfaces generally cause stronger convection currents. In comparison, water surfaces are heated more slowly. This difference in surface heating between land and water masses is responsible for the turbulence experienced by aircrews when crossing shorelines on hot summer days.

When air is very dry, convective currents may be present although convective-type clouds (cumulus) are absent. The related illustration shows how pilots can avoid convective

Figure 10–1. Strength of Convective Currents Vary According to Ground Conditions

(thermal) turbulence by flying above the levels reached by convective currents. The general upper limits of the convective currents are often marked by the tops of cumulus clouds which form in them when the air is moist, or by haze lines. Varying surfaces often affect an aircraft's final approach to a considerable extent, as shown.

If the atmosphere is already unstable in an area where convection currents have been initiated by thermal effects, the convective currents will be sustained, or even accelerated, by the atmosphere. Instability can also be achieved by the advection of cold air into an area, which may result in forming a layer of

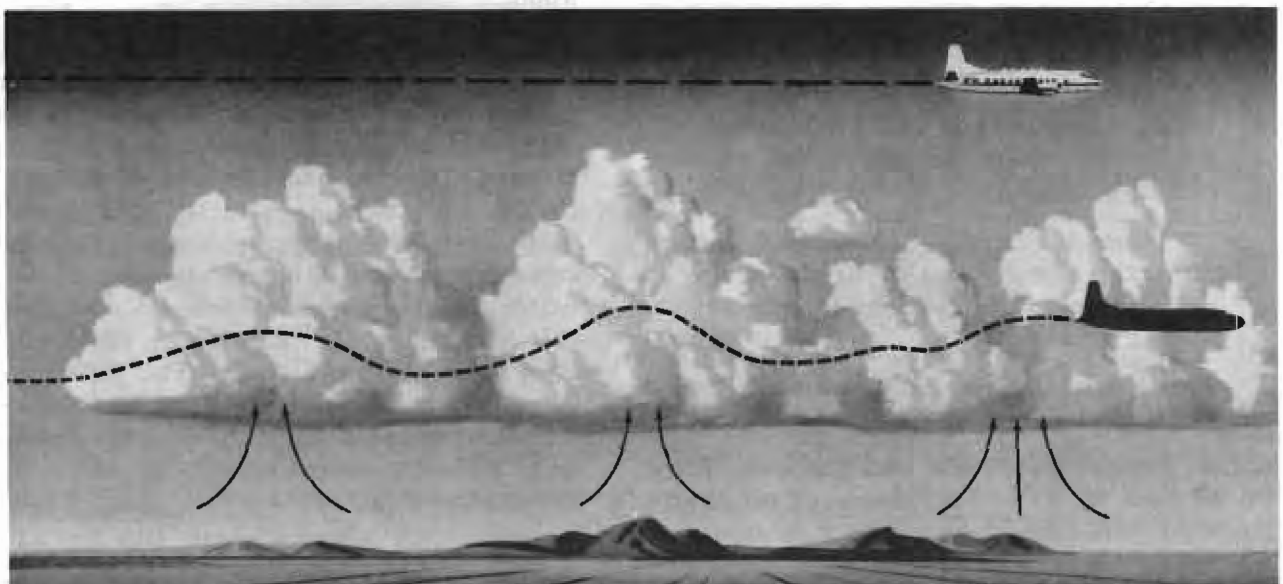


Figure 10–2. Avoiding Convective Turbulence by Flying Above Cumulus Clouds

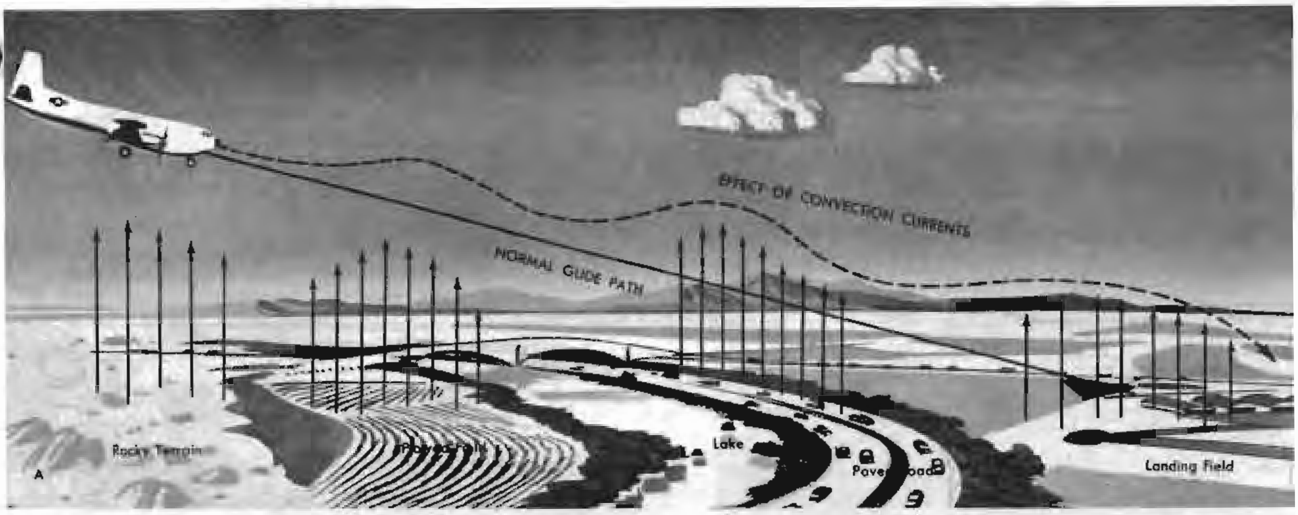


Figure 10–3. Effect of Convective Currents on Final Approach

Vertical air currents may cause pilot to overshoot or . . .

Figure 10–4.

. . . under shoot depending on strength and distribution of convection

instability at the surface or aloft. Convective currents may then be inaugurated by this unstable situation. Note in the sketch, Figure 10–5, that the replacing of warm air aloft by colder air may result in the formation of a layer in which the lapse rate is more unstable, causing turbulence.

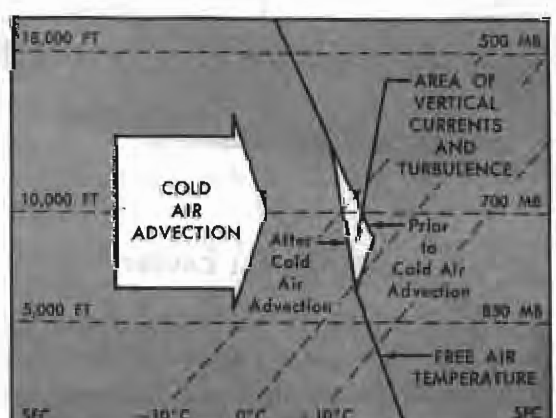


Figure 10–5. Turbulence Aloft Caused by Advection of Cold Air

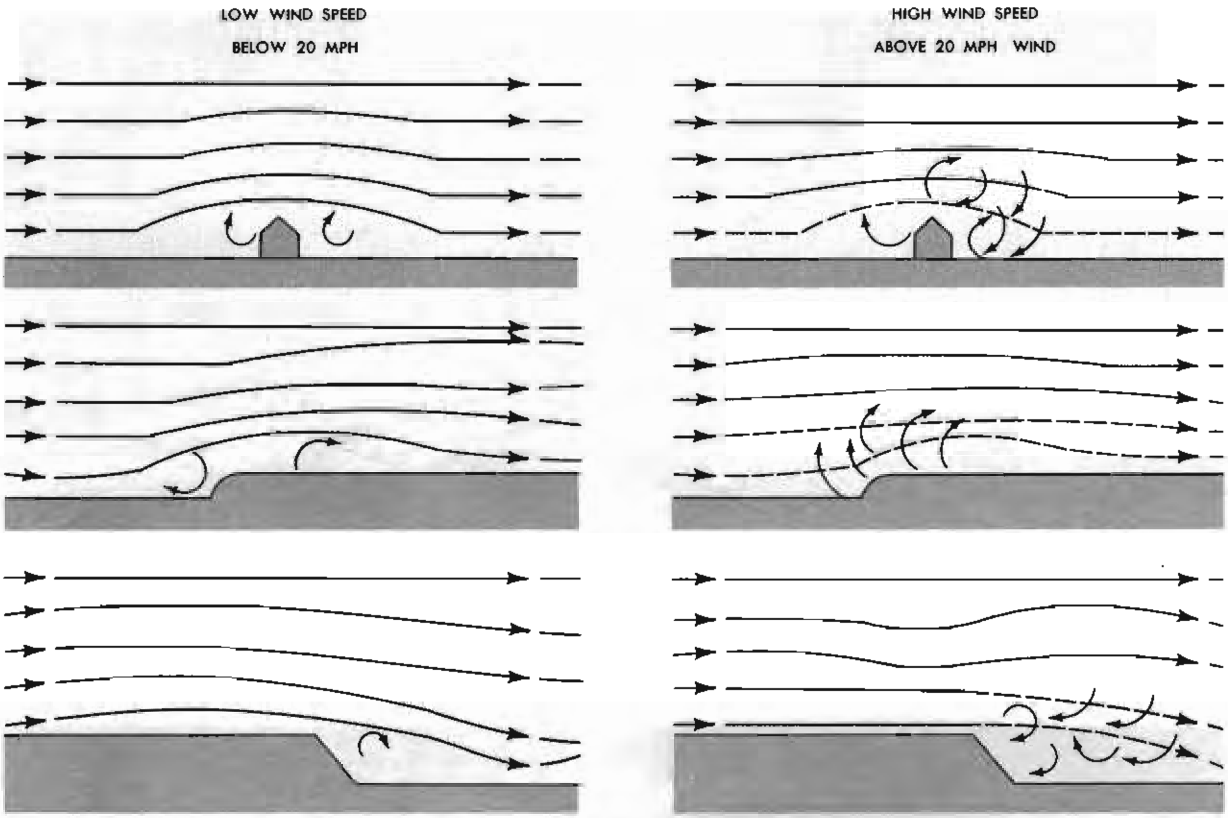


Figure 10–6. Surface Obstructions Cause Eddies and Other Irregular Wind Movements

Figure 10–7. Building or other Obstructions on Windward Side of Landing Area May Cause Turbulent Air

MECHANICAL CAUSES

When the air near the surface of the earth flows over obstructions, such as irregular terrain (bluffs, hills and mountains) and buildings, the normal horizontal wind flow is disturbed and transformed into a complicated pattern of eddies and other irregular air movements. The related illustration shows how surface obstructions cause mechanical turbulence. Note how the buildings or other obstructions near an airfield can cause turbulence.

Figure 10–8. Typical Wave Clouds as Seen from Below (Wind Blowing from the Right)

The strength and magnitude of mechanical turbulence depend upon the speed of the wind, the roughness of the terrain (or nature of the obstruction), and the stability of the air. Stability seems to be the most important factor in determining the strength and vertical extent of the mechanical turbulence.

Mechanical turbulence has only minor significance when a light wind blows over irregular terrain. In such cases, the turbulence is usually only a few hundred feet thick. When the wind blows faster and the obstructions are larger, the turbulence increases and extends to higher levels.

When strong winds blow approximately perpendicular to a mountain range, the resulting turbulence may be quite severe. Associated areas of steady updraft and downdraft may extend to heights from 2 to 20 times the height of the mountain peaks. Under these conditions when the air is stable, large waves tend to form on the lee side of the mountains and extend up to the lower stratosphere for a distance up to 100 miles or more downwind. These are referred to as *standing waves* or *mountain waves*, and may or may not be accompanied by turbulence. Pilots, especially glider pilots, have reported that the flow in these waves is often remarkably smooth. Others have reported severe turbulence.

Note in Figure 10–9 that the mountains are at the right and the wind flow is from right to left. The cap cloud is shown on the mountain range crest to the right in the illustration. The roll cloud appears in the lower left-center portion of the sketch with the pile of lenticular (lens-shaped) clouds one above the other fanning out above and sloping a little windward toward the mountain range. Turbulence is most likely in the lee area up to the height of the montains and again near the tropopause.

The airflow is fairly smooth and has a lifting component as it moves up the windward side of the mountain range. The windspeed gradually increases, reaching a maximum near the peak of the mountain. On passing the peak, the flow breaks down into a much more complicated pattern with downdrafts predominating. Downwind, perhaps 5 to 10 miles from the peak, the air flow begins to ascend as part of a definite wave pattern which has been induced into the general flow by the mountain range. Additional waves, generally less intense than the primary wave, may form farther downwind.

The aircrew member is concerned, for the most part, with the first wave, because of its more intense action and proximity to the high mountain terrain. Severe turbulence frequently can be found out to 150 miles downwind when the winds are greater than 50 knots at mountain top level. Moderate turbulence often can be experienced out to 300 miles under the previously stated conditions. When the winds are less than 50 knots at mountain peak level, a lesser degree of turbulence may be experienced. (See definitions of degrees of turbulence, Page 10–9.) Wave formation with roll clouds seems to require a certain degree of stability and a sufficient increase of wind speed with height in the middle troposphere.

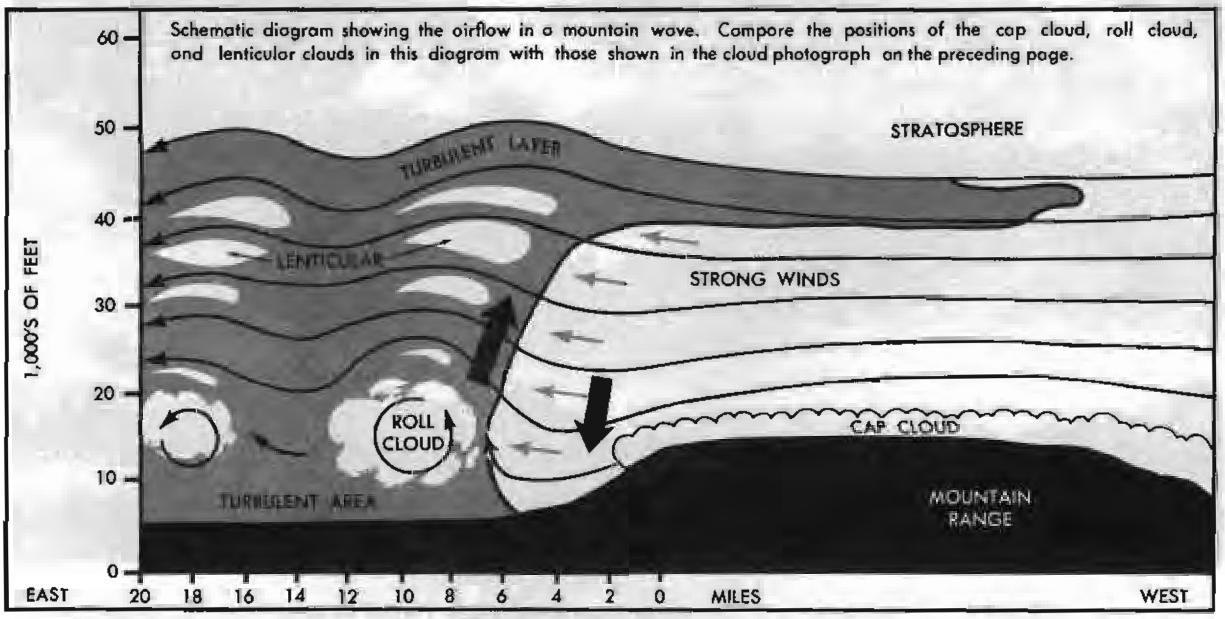


Figure 10–9. Mountain Wave Turbulence

Characteristic cloud forms, peculiar to wave action, provide the best means of visual identification. Although the lenticular clouds in Figure 10–9 are smooth in contour, they may be quite ragged when the airflow in that level is turbulent. These clouds may occur singularly or in layers, at heights usually above 20,000 feet. The roll cloud forms at a lower level, generally about the height of the mountain ridge. The cap cloud usually obscures both sides of the mountain peak. The lenticular clouds, like the roll and cap clouds, are stationary in position. The cloud formations themselves are a useful guide to the location of turbulence.

Some of the most dangerous features of the mountain wave are the turbulence in and below the roll cloud, the downdrafts just to the lee side of the mountain peaks and to the lee side of the roll clouds. The cap cloud must always be avoided in flight because of turbulence and concealed mountain peaks.

While clouds are generally present to forewarn the presence of mountain 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 unexpectedly.

Tips on Flying the Mountain Wave

The six rules listed have been suggested for flight over mountain ranges where waves exist:

1. If possible, fly around the area when wave conditions exist. If this is not feasible, fly at a level which is at least 50 percent higher than the height of the mountain range. Be cautious to attain or maintain the minimum safe altitude (terrain elevation plus 50%) during climb-out to cruising altitude, and descents for landings.
2. Avoid the roll clouds, since they are the areas with the most intense turbulence of the mountain wave.
3. Avoid the strong downdrafts on the lee side of mountains.
4. Avoid high lenticular clouds, particularly if their edges are ragged.
5. Do not place too much confidence in pressure altimeter readings near mountain peaks. They may indicate altitudes which are more than 1,000 feet higher than the actual altitude.
6. Penetrate turbulent areas at air speeds recommended for your equipment.

FRONTAL CAUSES

Frontal turbulence is caused by the lifting of warm air by a frontal surface leading to instability and/or the mixing or shear between the warm and cold air masses. The vertical currents in the warm air are strongest when the warm air is moist and unstable. The most severe cases of frontal turbulence are generally associated with fast moving cold fronts. In these cases, mixing between the two air masses as well as the differences in wind speed and/or direction (wind shear) add to the intensity of the turbulence.

Excluding the turbulence that would be encountered in any thunderstorms along the front, the accompanying diagram illustrates the wind shift that contributes to the formation of turbulence across a typical cold front. As a general rule, the wind speed is greater in the colder air mass.

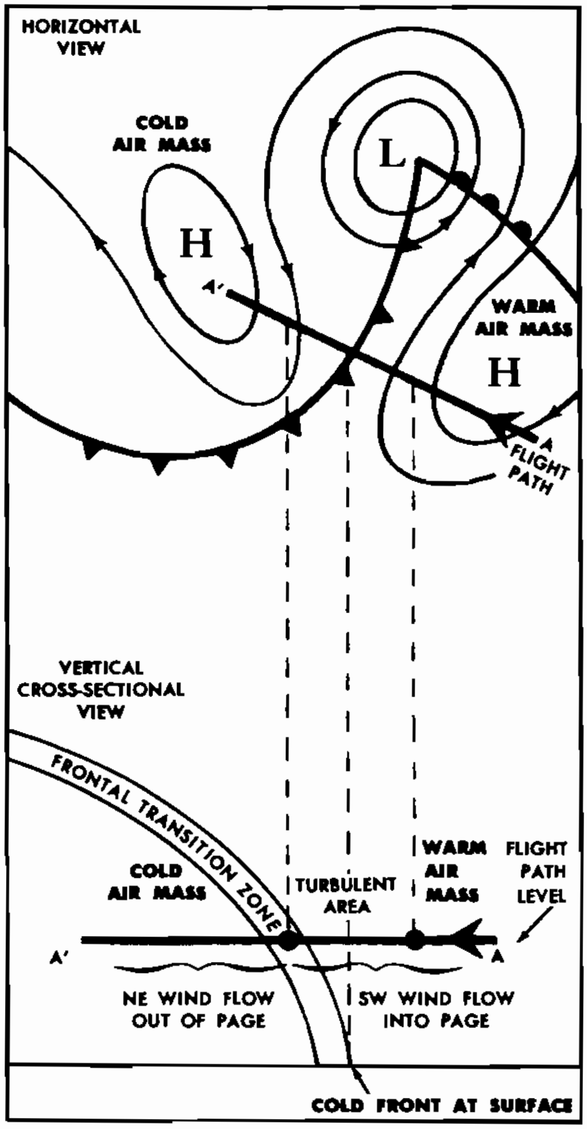


Figure 10–10. Turbulence Across a Typical Cold Front

Figure 10–11. Turbulent Air at the Boundary Between Calm, Cold Air and Moving Warm Air Above

Figure 10–12. Landing Aircraft Leave Wake of Turbulent Air

WIND SHEAR CAUSES

A relatively steep gradient in wind velocity along a given line or direction (either vertical or horizontal) produces churning motions (eddies) which result in turbulence. The greater the change of wind speed and/or direction in the given direction, the more severe the turbulence. Turbulent flight conditions are frequently encountered in the vicinity of the jet stream (see Chapter 15), where large shears in the horizontal and vertical are often found. Since this type of 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* (CAT). Clear-air turbulence is not necessarily limited to the vicinity of the jet stream, and may occur in isolated regions of the atmosphere during various situations (see Chapter 15). For example: the turbulence in a mountain wave can also be classified as clear-air turbulence because the identifying clouds in the wave do not necessarily have to occur for the turbulence to be present.

A narrow zone of wind shear, with its accompanying turbulence, will sometimes be encountered by aircrews as they climb or descend through a temperature inversion. These inversions can and do occur anywhere from just above the surface to the tropopause. However, the tropopause is often the most significant inversion.

An extreme form of wind shear that is of considerable importance to aircraft landing and takeoff operations is that which is associated with strong inversions near the ground. In the example, a pocket of calm, cold air has formed in the valley as a result of nighttime cooling, but the warmer air moving over it has not been affected appreciably. Due to the difference in velocity between the two bodies of air, a narrow layer of very turbulent air is formed. An aircraft climbing or descending through this zone will encounter considerable turbulence (as well as changes in lift). Refer to Figure 10–11.

Moderate turbulence may be encountered, momentarily, when passing through the wake of another aircraft. On landing and departing, the wake of aircraft produces turbulence in the approach path to and along runways. The turbulence in the wake of heavy aircraft is usually of concern to pilots of lighter aircraft.

DEGREES OF TURBULENCE DEFINED

In order to further clarify the discussion of aircraft turbulence, the following description of conditions favorable to the various Air Weather Service Categories of turbulence intensity are listed here:

Light Turbulence

Light turbulence is subjectively defined as a nearly ambient condition of turbulence over extensive areas and at any altitude. The more intense turbulence in this class is experienced in small cumuliform clouds. It is also found at low levels over rough terrain with surface wind speed less than 25 knots. It is experienced at low levels over unequally heated land areas during the period of maximum heating and at night over warm water areas.

Moderate Turbulence

Moderate turbulence is subjectively defined in relation to:

- The mountain wave when the strongest winds at mountain top level perpendicular to the ridge line are 20 to 50 knots or more. Moderate turbulence is *frequently* found from the surface to 10,000 feet above the tropopause and as much as 300 miles leeward of mountains, or within cirrus clouds associated with the wave.
- The mountain wave when the strongest winds at mountain top level perpendicular to the ridge line are 25 to 50 knots. Moderate turbulence is *frequently* found between the surface and the tropopause from the ridge line of mountains to 150 miles leeward, or within cirrus clouds associated with the wave.
- Thunderstorms, and is *frequently* found in, around, and above dissipating thunderstorms, or within the cirrus tops.
- The jet stream, and is *frequently* found within a layer between the height of the jet core and 5000 feet below the core of the jet; and from the core to 250 miles toward the cyclonic (cold) side of the core, or within cirrus clouds associated with the jet.
- Cumuliform clouds, and is *usually* found within thick or towering cumulus.
- Strong surface winds, and is *usually* found near the ground when surface winds exceed 25 knots.
- Upper trough, cold low, or front aloft, and is *frequently* found where vertical wind shear exceeds 6 knots per 1000 feet or horizontal wind shear exceeds 40 knots per 150 miles.
- Unstable atmosphere, and is *frequently* found at low levels where the atmosphere is unstable, but moisture is insufficient for thunderstorms or towering cumulus to form.

Severe Turbulence

Severe turbulence is subjectively defined in relation to:

- The mountain wave when the strongest winds at mountain top level perpendicular to the ridge line are 50 knots or more. Severe turbulence is *usually* found from the surface to the tropopause, and from the ridge line to 150 miles leeward.
- The mountain wave when the strongest winds at mountain top level perpendicular to the ridge line are 20 to 50 knots. Severe turbulence will *usually* be found leeward of mountains up to 50 miles downstream.
- Thunderstorms, and is *usually* found in and around mature thunderstorms.
- The jet stream, and is *infrequently* found within a layer between the height of the jet core and 5000 feet below the core, and approximately 50 to 150 miles towards the cyclonic (cold) side of the jet core.
- Cumuliform clouds, and is *infrequently* found in towering cumulus.

Extreme Turbulence

Extreme turbulence is subjectively defined in relation to:

- The mountain wave when the strongest winds at mountain top level perpendicular to the ridge line are 50 knots or more. Extreme turbulence is *usually* found at low levels, leeward of the mountains in or near the rotor cloud, if present.
- The mountain wave when the strongest winds at mountain top level perpendicular to the ridge line are 20 to 50 knots. Extreme turbulence is *infrequently* found at low levels, leeward of mountains.
- Thunderstorms, and is *frequently* found within a growing cell (indicated by hail, heavy rain, strong radar echo gradients or almost continuous lightning).
- Strongest forms of convection, wind shear or standing wave action, and is *usual*.