Chapter 6
STABLE AND UNSTABLE AIR

To a pilot, the stability of his aircraft is a vital concern. A stable aircraft, when disturbed from straight and level flight, returns by itself to a steady balanced flight. An unstable aircraft, when disturbed, continues to move away from a normal flight attitude.

So it is with the atmosphere. A *stable* atmosphere resists any upward or downward displacement. An *unstable* atmosphere allows an upward or downward disturbance to grow into a vertical or convective current.

This chapter first examines fundamental changes in upward and downward moving air and then relates stable and unstable air to clouds, weather, and flying.

CHANGES WITHIN UPWARD AND DOWNWARD MOVING AIR

Anytime air moves upward, it expands because of decreasing atmospheric pressure as shown in figure 40. Conversely, downward moving air is compressed by increasing pressure. But as pressure and volume change, temperature also changes.

When air expands, it cools; and when compressed, it warms. These changes are *adiabatic*, meaning that no heat is removed from or added to the air. We frequently use the terms *expansional* or *adiabatic cooling* and *compressional* or *adiabatic*

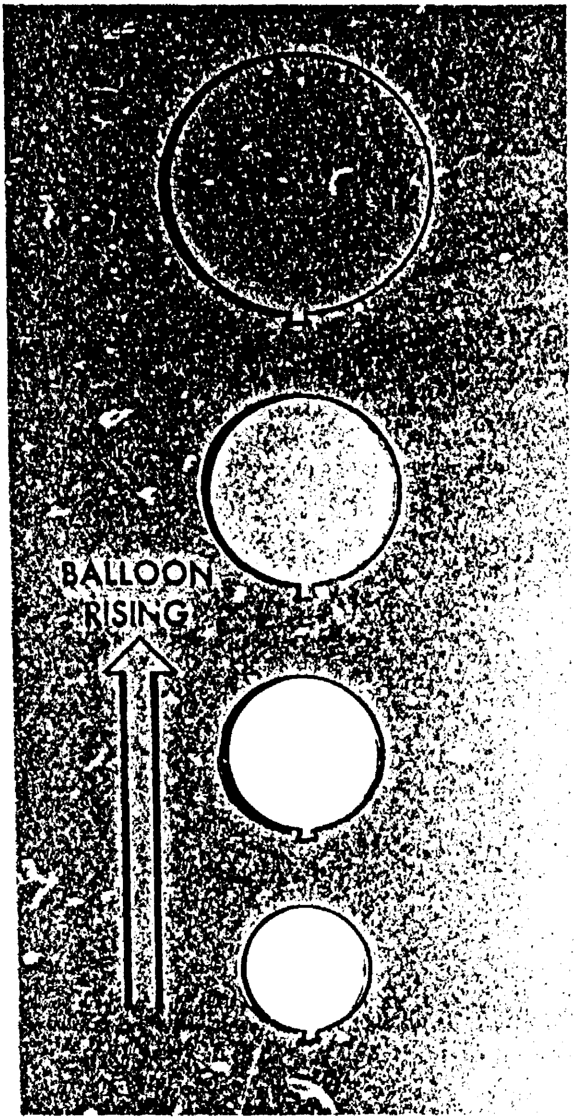

Figure 40. Decreasing atmospheric pressure causes the balloon to expand as it rises. Anytime air moves upward, it expands.

heating. The adiabatic rate of change of temperature is virtually fixed in unsaturated air but varies in saturated air.

UNSATURATED AIR

Unsaturated air moving upward and downward cools and warms at about 3.0° C (5.4° F) per 1,000 feet. This rate is *the "dry adiabatic rate of temperature change"* and *is independent of the temperature of the mass of air through which the vertical movements occur.* Figure 41 illustrates a "Chinook Wind"—an excellent example of dry adiabatic warming.

SATURATED AIR

Condensation occurs when *saturated* air moves upward. Latent heat released through condensation (chapter 5) partially offsets the expansional cooling. Therefore, *the saturated adiabatic rate of cooling is slower than the dry adiabatic rate.* The saturated rate depends on saturation temperature or dew point of the air. Condensation of copious moisture in saturated warm air releases more latent heat to offset expansional cooling than does the scant moisture in saturated cold air. Therefore, *the saturated adiabatic rate of cooling is less in warm air than in cold air.*

When saturated air moves downward, it heats at the same rate as it cools on ascent *provided* liquid water evaporates rapidly enough to maintain saturation. Minute water droplets evaporate at virtually this rate. Larger drops evaporate more slowly and complicate the moist adiabatic process in downward moving air.

ADIABATIC COOLING AND VERTICAL AIR MOVEMENT

If we force a sample of air upward into the atmosphere, we must consider two possibilities:

(1) The air may become colder than the surrounding air, or

(2) Even though it cools, the air may remain warmer than the surrounding air.

If the upward moving air becomes colder than surrounding air, it sinks; but if it remains warmer, it is accelerated upward as a convective current. Whether it sinks or rises depends on the ambient or existing temperature lapse rate (chapter 2).

Do not confuse existing lapse rate with adiabatic rates of cooling in vertically moving air.* The difference between the existing lapse rate of a given mass of air and the adiabatic rates of cooling in upward moving air determines if the air is stable or unstable.

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*Sometimes you will hear the dry and moist adiabatic rates of cooling called the dry adiabatic lapse rate and the moist adiabatic lapse rate. In this book, *lapse rate* refers exclusively to the existing, or actual, decrease of temperature with height in a real atmosphere. The dry or moist adiabatic lapse rate signifies a prescribed rate of expansional cooling or compressional heating. An adiabatic lapse rate becomes real *only* when it becomes a condition brought about by vertically moving air.

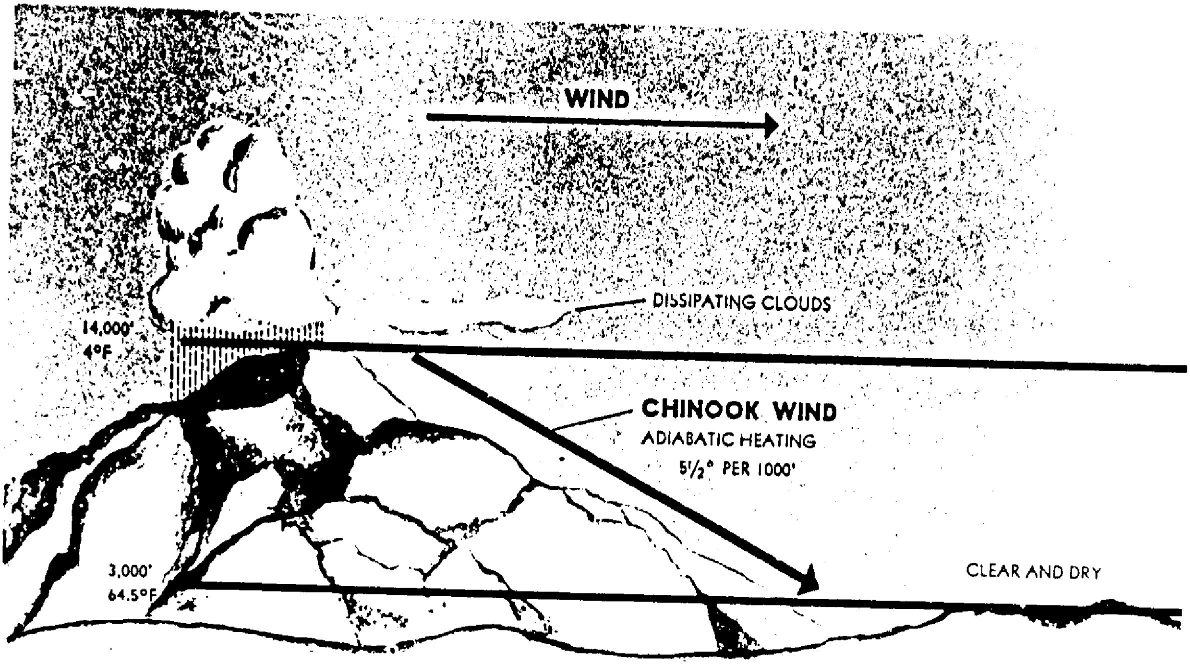

FIGURE 41. Adiabatic warming of downward moving air produces the warm Chinook wind.

STABILITY AND INSTABILITY

Let's use a balloon to demonstrate stability and instability. In figure 42 we have, for three situations, filled a balloon at sea level with air at 31° C—the same as the ambient temperature. We have carried the balloon to 5,000 feet. In each situation, the air in the balloon expanded and cooled at the dry adiabatic rate of 3° C for each 1,000 feet to a temperature of 16° C at 5,000 feet.

In the first situation (left), air inside the balloon, even though cooling adiabatically, remains warmer than surrounding air. Vertical motion is favored. The colder, more dense surrounding air forces the balloon on upward. This air is unstable, and a convective current develops.

In situation two (center) the air aloft is warmer. Air inside the balloon, cooling adiabatically, now becomes colder than the surrounding air. The balloon sinks under its own weight returning to its original position when the lifting force is removed. The air is stable, and spontaneous convection is impossible.

In the last situation, temperature of air inside the balloon is the same as that of surrounding air. The balloon will remain at rest. This condition is neutrally stable; that is, the air is neither stable nor unstable.

Note that, *in all three situations, temperature of air in the expanding balloon cooled at a fixed rate.* The differences in the three conditions depend, therefore, on the temperature differences between the surface and 5,000 feet, that is, on the ambient lapse rates.

HOW STABLE OR UNSTABLE?

Stability runs the gamut from absolutely stable to absolutely unstable, and the atmosphere usually is in a delicate balance somewhere in between. A change in ambient temperature lapse rate of an air mass can tip this balance. For example, surface heating or cooling aloft can make the air more unstable; on the other hand, surface cooling or warming aloft often tips the balance toward greater stability.

Air may be stable or unstable in layers. A stable layer may overlie and cap unstable air; or, conversely, air near the surface may be stable with unstable layers above.

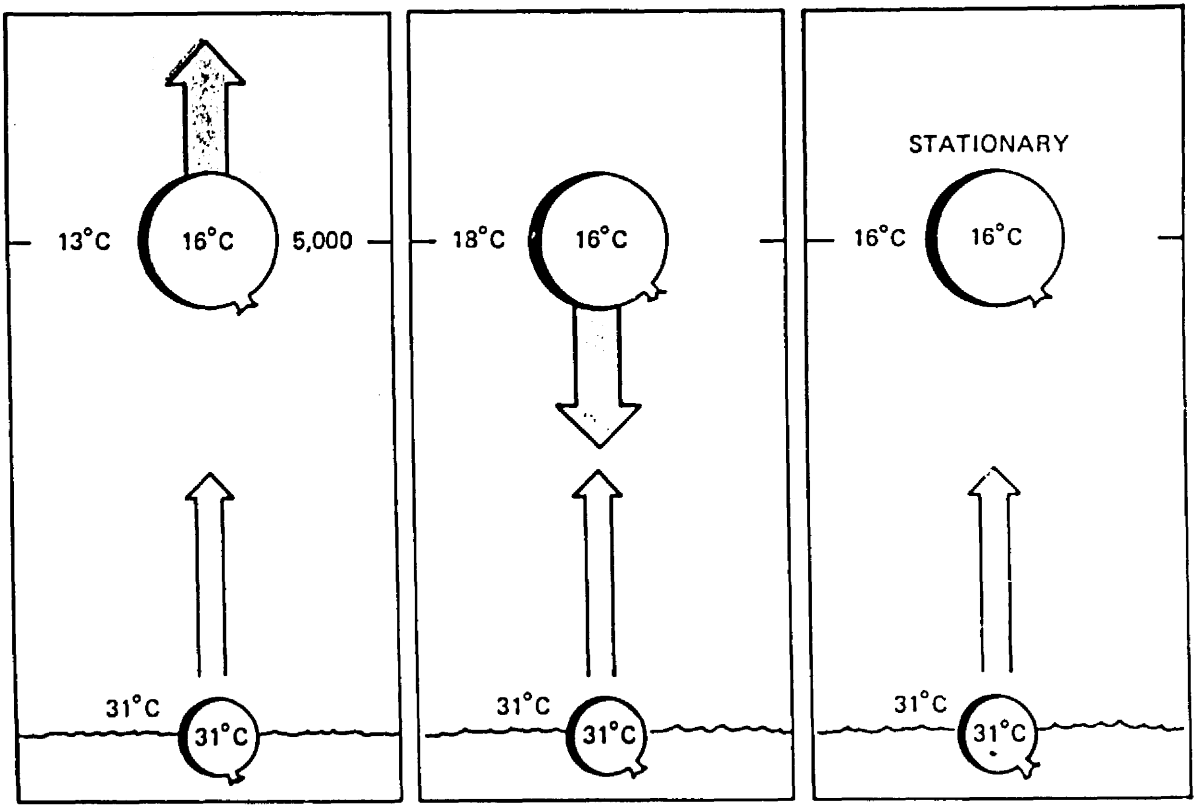

FIGURE 42. Stability related to temperatures aloft and adiabatic cooling. In each situation, the balloon is filled at sea level with air at 31° C, carried manually to 5,000 feet, and released. In each case, air in the balloon expands and cools to 16° C (at the dry adiabatic rate of 3° C per 1,000 feet). But, the temperature of the surrounding air aloft in each situation is different. The balloon on the left will rise. Even though it cooled adiabatically, the balloon remains warmer and lighter than the surrounding cold air; when released, it will continue upward spontaneously. The air is unstable; it favors vertical motion. In the center, the surrounding air is warmer. The cold balloon will sink. It resists our forced lifting and cannot rise spontaneously. The air is stable—it resists upward motion. On the right, surrounding air and the balloon are at the same temperature. The balloon remains at rest since no density difference exists to displace it vertically. The air is neutrally stable, i.e., it neither favors nor resists vertical motion. A mass of air in which the temperature decreases rapidly with height favors instability; but, air tends to be stable if the temperature changes little or not at all with altitude.

CLOUDS—STABLE OR UNSTABLE?

Chapter 5 states that when air is cooling and first becomes saturated, condensation or sublimation begins to form clouds. Chapter 7 explains cloud types and their significance as "signposts in the sky." Whether the air is stable or unstable within a layer largely determines cloud structure.

Stratiform Clouds

Since stable air resists convection, clouds in stable air form in horizontal, sheet-like layers or "strata." Thus, within a *stable* layer, clouds are *stratiform.* Adiabatic cooling may be by upslope flow as illustrated in figure 43; by lifting over cold, more dense air; or by converging winds. Cooling by an underlying cold surface is a stabilizing process and may produce fog. If clouds are to remain stratiform, the layer must remain stable after condensation occurs.

Cumuliform Clouds

Unstable air favors convection. A "cumulus" cloud, meaning "heap," forms in a convective updraft and builds upward, also shown in figure 43. Thus, within an *unstable* layer, clouds are *cumuliform;* and the vertical extent of the cloud depends on the depth of the unstable layer.

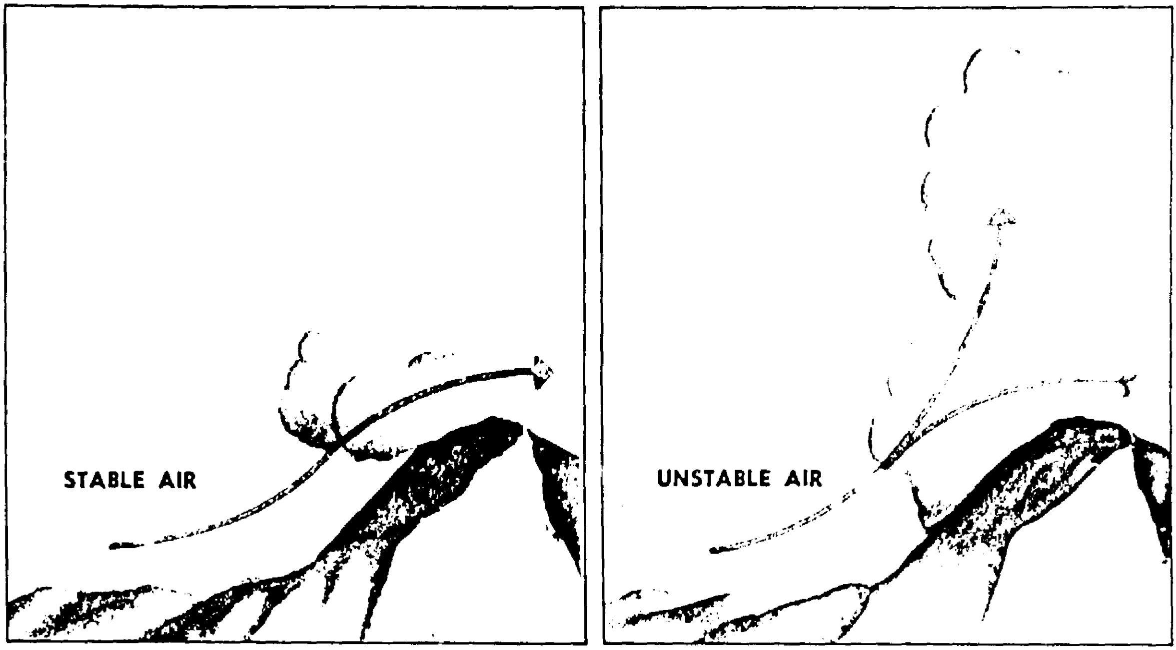

FIGURE 43. When stable air (left) is forced upward, the air tends to retain horizontal flow, and any cloudiness is flat and stratified. When unstable air is forced upward, the disturbance grows, and any resulting cloudiness shows extensive vertical development.

Initial lifting to trigger a cumuliform cloud may be the same as that for lifting stable air. In addition, convection may be set off by surface heating (chapter 4). Air may be unstable or slightly stable before condensation occurs; but for convective cumuliform clouds to develop, it must be unstable after saturation. Cooling in the updraft is now at the slower moist adiabatic rate because of the release of latent heat of condensation. Temperature in the saturated updraft is warmer than ambient temperature, and convection is spontaneous. Updrafts accelerate until temperature within the cloud cools below the ambient temperature. This condition occurs where the unstable layer is capped by a stable layer often marked by a temperature inversion. Vertical heights range from the shallow fair weather cumulus to the giant thunderstorm cumulonimbus—the ultimate in atmospheric instability capped by the tropopause.

You can estimate height of cumuliform cloud bases using surface temperature-dew point spread. Unsaturated air in a convective current cools at about 5.4° F (3.0° C) per 1,000 feet; dew point decreases at about 1° F (5/9° C). Thus, in a convective current, temperature and dew point converge at about 4.4° F (2.5° C) per 1,000 feet as illustrated in figure 44. We can get a quick *estimate* of a convective cloud base in thousands of feet by rounding these values and dividing into the spread or by multiplying the spread by their reciprocals. When using Fahrenheit, divide by 4 or multiply by .25; when using Celsius, divide by 2.2 or multiply by .45. This method of estimating is reliable only with instability clouds and during the warmer part of the day.

When unstable air lies above stable air, convective currents aloft sometimes form middle and high level cumuliform clouds. In relatively shallow layers they occur as altocumulus and ice crystal cirrocumulus clouds. Altocumulus castellanus clouds develop in deeper midlevel unstable layers.

Merging Stratiform and Cumuliform

A layer of stratiform clouds may sometimes form in a mildly stable layer while a few ambitious convective clouds penetrate the layer thus merging stratiform with cumuliform. Convective clouds may be almost or entirely embedded in a massive stratiform layer and pose an unseen threat to instrument flight.

WHAT DOES IT ALL MEAN?

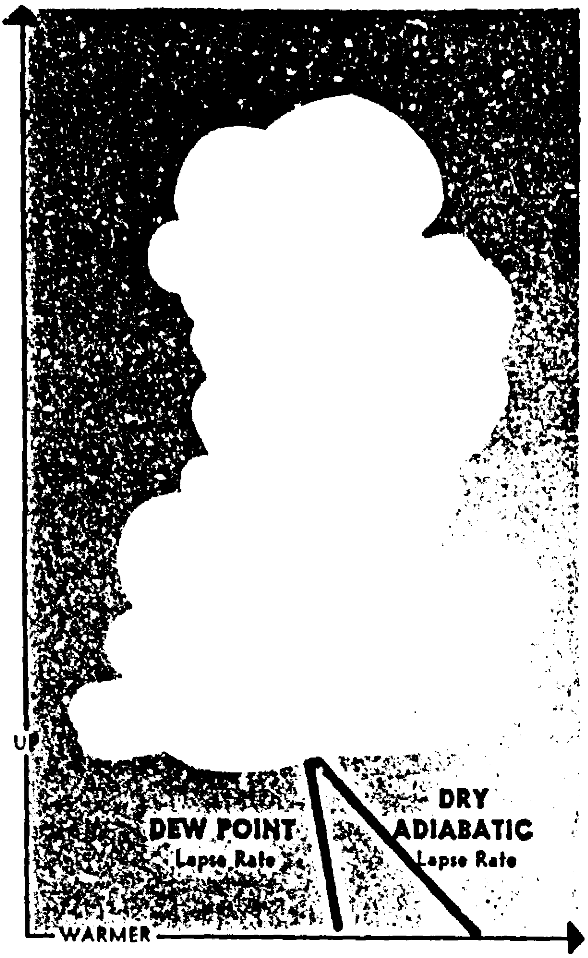

FIGURE 44. Cloud base determination. Temperature and dew point in upward moving air converge at a rate of about 4° F or 2.2° C per 1,000 feet.

Can we fly in unstable air? Stable air? Certainly we can and ordinarily do since air is seldom neutrally stable. The usual convection in unstable air gives a "bumpy" ride; only at times is it violent enough to be hazardous. In stable air, flying is usually smooth but sometimes can be plagued by low ceiling and visibility. It behooves us in preflight planning to take into account stability or instability and any associated hazards. Certain observations you can make on your own:

1. Thunderstorms are sure signs of violently unstable air. Give these storms a wide berth.
2. Showers and clouds towering upward with great ambition indicate strong updrafts and rough (turbulent) air. Stay clear of these clouds.
3. Fair weather cumulus clouds often indicate bumpy turbulence beneath and in the clouds. The cloud tops indicate the approximate upper limit of convection; flight above is usually smooth.
4. Dust devils are a sign of dry, unstable air, usually to considerable height. Your ride may be fairly rough unless you can get above the instability.
5. Stratiform clouds indicate stable air. Flight generally will be smooth, but low ceiling and visibility might require IFR.
6. Restricted visibility at or near the surface over large areas usually indicates stable air. Expect a smooth ride, but poor visibility may require IFR.
7. Thunderstorms may be embedded in stratiform clouds posing an unseen threat to instrument flight.
8. Even in clear weather, you have some clues to stability, viz.:
   a. When temperature decreases uniformly and rapidly as you climb (approaching 3° C per 1,000 feet), you have an indication of unstable air.
   b. If temperature remains unchanged or decreases only slightly with altitude, the air tends to be stable.
   c. If the temperature increases with altitude through a layer—an inversion—the layer is stable and convection is suppressed. Air may be unstable beneath the inversion.
   d. When air near the surface is warm and moist, suspect instability. Surface heating, cooling aloft, converging or upslope winds, or an invading mass of colder air may lead to instability and cumuliform clouds.