

# AVIATION WEATHER

# AVIATION WEATHER

For Pilots and  
Flight Operations Personnel

Revised 1975



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Editorial Note:

Figures 137 through 139 and 142 on pages 160, 161, and 165 have been rearranged to align with their proper legends. Corresponding corrections have been made in the Contents, page XII.

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Figures 137 through 139 on pages 160 and 161 have been rearranged in order to flow in proper sequence with the text. Corresponding corrections have been made in the Contents, page XII.

## Preface

AVIATION WEATHER is published jointly by the FAA Flight Standards Service and the National Weather Service (NWS). The publication began in 1943 as CAA Bulletin No. 25, "Meteorology for Pilots," which at the time contained weather knowledge considered essential for most pilots. But as aircraft flew farther, faster, and higher and as meteorological knowledge grew, the bulletin became obsolete. It was revised in 1954 as "Pilots' Weather Handbook" and again in 1965 under its present title.

All these former editions suffered from one common problem. They dealt in part with weather services which change continually in keeping with current techniques and service demands. Therefore, each edition became somewhat outdated almost as soon as published; and its obsolescence grew throughout the period it remained in print.

To alleviate this problem, the new authors have completely rewritten this edition streamlining it into a clear, concise, and readable book and omitting all reference to specific weather services. Thus, the text will remain valid and adequate for many years. A companion manual, AVIATION WEATHER SERVICES, Advisory Circular 00-45, supplements AVIATION WEATHER. This supplement (AC 00-45) periodically is updated to reflect changes brought about by latest techniques, capabilities, and service demands. It explains current weather services and the formats and uses of weather charts and printed weather messages. The two manuals are sold separately; so at a nominal cost, a pilot can purchase a copy of the supplement (AC 00-45) periodically and keep current in aviation weather services.

C. Hugh Snyder, National Weather Service Coordinator and Training Consultant at the FAA Academy, directed the preparation of AVIATION WEATHER and AVIATION WEATHER SERVICES. He and his assistant, John W. Zimmerman, Jr., did much of the writing and edited the final manuscripts. Recognition is given to these meteorologists on the NWS Coordinator's staff who helped write the original manuscript, organize the contents, and plan illustrations: Milton Lee Harrison, Edward A. Jessup, Joe L. Kendall, and Richard A. Mitchem. Beatrice Emery deserves special recognition for her relentless effort in typing, retyping, proofing, correcting, and assembling page after page of manuscript. Many other offices and individuals have contributed to the preparation, editing, and publication of the two volumes.

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# Introduction

Weather is perpetual in the state of the atmosphere. All flying takes place in the atmosphere, so flying and weather are inseparable. Therefore, we cannot treat aviation weather purely as an academic subject. Throughout the book, we discuss each aspect of weather as it relates to aircraft operation and flight safety. However, this book is in no way an aircraft operating manual. Each pilot must apply the knowledge gained here to his own aircraft and flight capabilities.

The authors have devoted much of the book to marginal, hazardous, and violent weather which becomes a vital concern. Do not let this disproportionate time devoted to hazardous weather discourage you from flying. By and large, weather is generally good and places little restriction on flying. Less frequently, it becomes a threat to the VFR pilot but is good for IFR flight. On some occasions it becomes too violent even for the IFR pilot.

It behooves every pilot to learn to appreciate good weather, to recognize and respect marginal or hazardous weather, and to avoid violent weather when the atmosphere is on its most cantankerous behavior. For your safety and the safety of those with you, learn to recognize potential trouble and make sound flight decisions *before* it is too late. This is the real purpose of this manual.

AVIATION WEATHER is in two parts. Part I explains weather facts every pilot should know. Part II contains topics of special interest discussing high altitude, Arctic, tropical, and soaring weather. A glossary defines terms for your reference while reading this or other weather writings. To get a complete operational study, you will need in addition to this manual a copy of AVIATION WEATHER SERVICES, AC 00-45, which is explained in the Preface.

We sincerely believe you will enjoy this book and at the same time increase your flying safety and economy and, above all, enhance the pleasure and satisfaction of using today's most modern transportation.



Part ONE

# WHAT YOU SHOULD KNOW ABOUT WEATHER



# Chapter 1

## THE EARTH'S ATMOSPHERE

Planet Earth is unique in that its atmosphere sustains life as we know it. Weather—the state of the atmosphere at any given time and place strongly influences our daily routine as well as our general life patterns. Virtually all of our activities are affected by weather, but of all man's endeavors, none is influenced more intimately by weather than aviation.

Weather is complex and at times difficult to understand. Our restless atmosphere is almost con-

stantly in motion as it strives to reach equilibrium. These never-ending air movements set up chain reactions which culminate in a continuing variety of weather. Later chapters in this book delve into the atmosphere in motion. This chapter looks briefly at our atmosphere in terms of its composition; vertical structure; the standard atmosphere; and of special concern to you, the pilot, density and hypoxia.

## COMPOSITION

Air is a mixture of several gases. When completely dry, it is about 78% nitrogen and 21% oxygen. The remaining 1% is other gases such as Argon, Carbon Dioxide, Neon, Helium, and others. Figure 1 graphs these proportions. However, in nature, air is never completely dry. It always contains some water vapor in amounts varying from almost zero to about 5% by volume. As water vapor content increases, the other gases decrease proportionately.

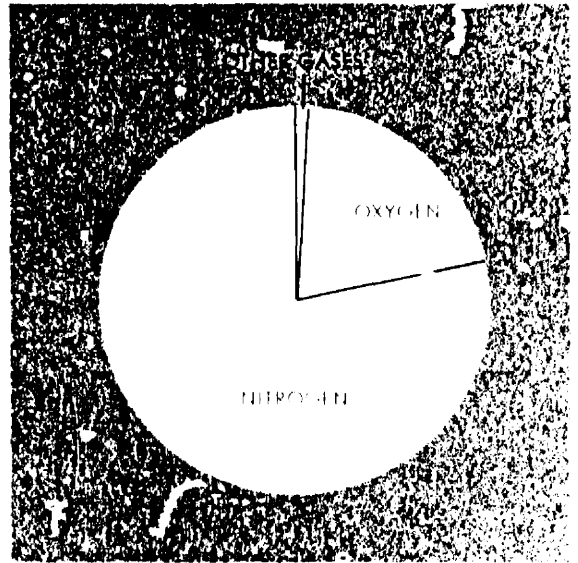


FIGURE 1. Composition of a dry atmosphere. Nitrogen comprises about 78%; oxygen, about 21%; and other gases, about 1%. When water vapor is added, the percentages decrease proportionately. Water vapor varies from almost none to about 5% by volume.

## VERTICAL STRUCTURE

We classify the atmosphere into layers, or spheres, by characteristics exhibited in these layers. Figure 2 shows one division which we use in this book. Since most weather occurs in the troposphere and since most flying is in the troposphere and stratosphere, we restrict our discussions mostly to these two layers.

The TROPOSPHERE is the layer from the surface to an average altitude of about 7 miles. It is characterized by an overall decrease of temperature with increasing altitude. The height of the troposphere varies with latitude and seasons. It slopes from about 20,000 feet over the poles to about

65,000 feet over the Equator; and it is higher in summer than in winter.

At the top of the troposphere is the TROPOPAUSE, a very thin layer marking the boundary between the troposphere and the layer above. The height of the tropopause and certain weather phenomena are related. Chapter 13 discusses in detail the significance of the tropopause to flight.

Above the tropopause is the STRATOSPHERE. This layer is typified by relatively small changes in temperature with height except for a warming trend near the top.

## THE STANDARD ATMOSPHERE

Continual fluctuations of temperature and pressure in our restless atmosphere create some problems for engineers and meteorologists who require a fixed standard of reference. To arrive at a standard, they averaged conditions throughout the atmosphere for all latitudes, seasons, and altitudes. The result is a STANDARD ATMOSPHERE with

specified sea-level temperature and pressure and specific rates of change of temperature and pressure with height. It is the standard for calibrating the pressure altimeter and developing aircraft performance data. We refer to it often throughout this book.

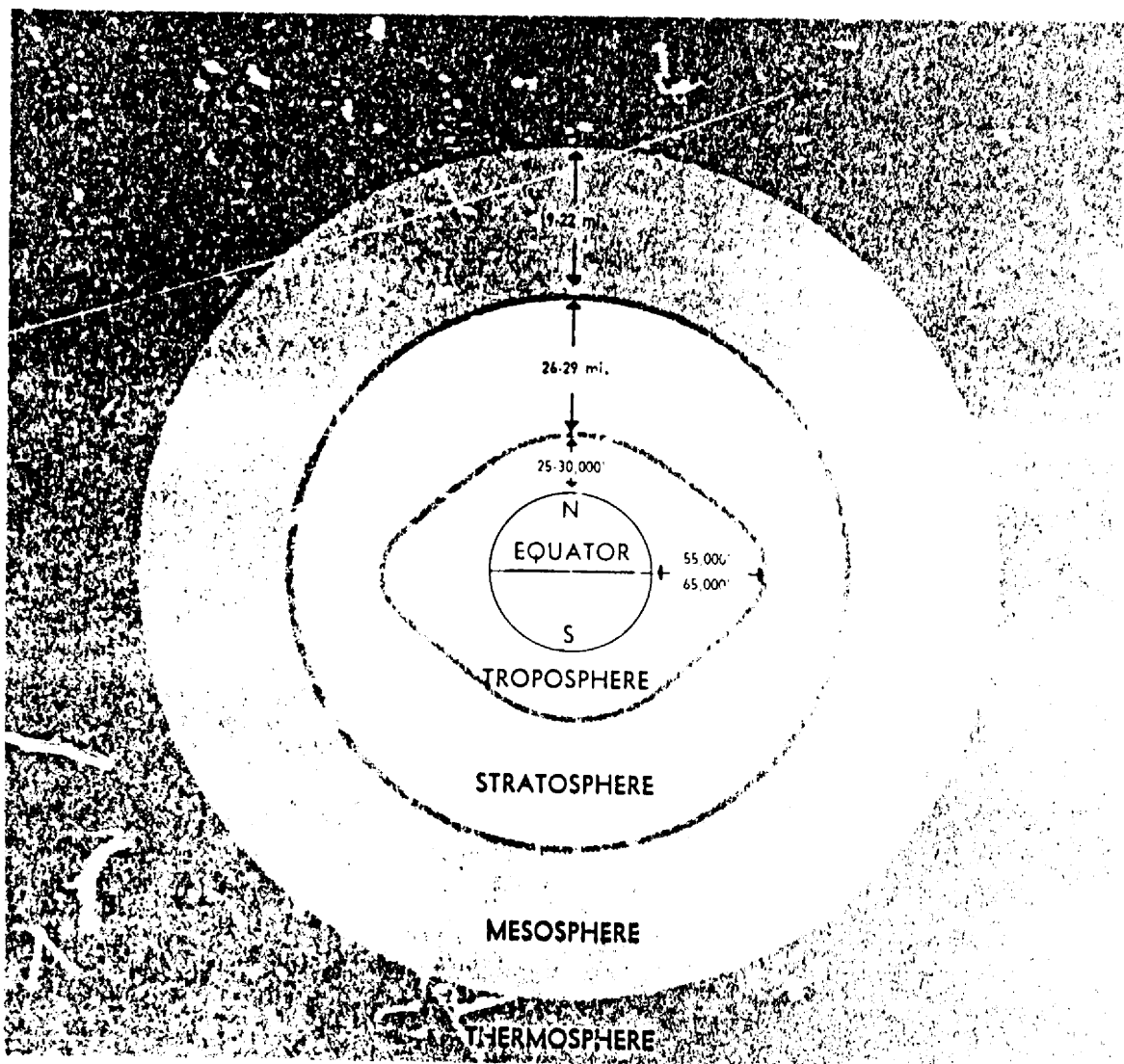


FIGURE 2. The atmosphere divided into layers based on temperature. This book concentrates on the lower two layers, the troposphere and the stratosphere.

## DENSITY AND HYPOXIA

Air is matter and has weight. Since it is gaseous, it is compressible. Pressure the atmosphere exerts on the surface is the result of the weight of the air above. Thus, air near the surface is much more dense than air at high altitudes. This decrease of density and pressure with height enters frequently into our discussions in later chapters.

The decrease in air density with increasing height has a physiological effect which we cannot ignore. The rate at which the lungs absorb oxygen depends on the partial pressure exerted by oxygen in the

air. The atmosphere is about one-fifth oxygen, so the oxygen pressure is about one-fifth the total pressure at any given altitude. Normally, our lungs are accustomed to an oxygen pressure of about 3 pounds per square inch. But, since air pressure decreases as altitude increases, the oxygen pressure also decreases. A pilot continuously gaining altitude or making a prolonged flight at high altitude without supplemental oxygen will likely suffer from **HYPOXIA**—a deficiency of oxygen. The effects are a feeling of exhaustion; an impairment of

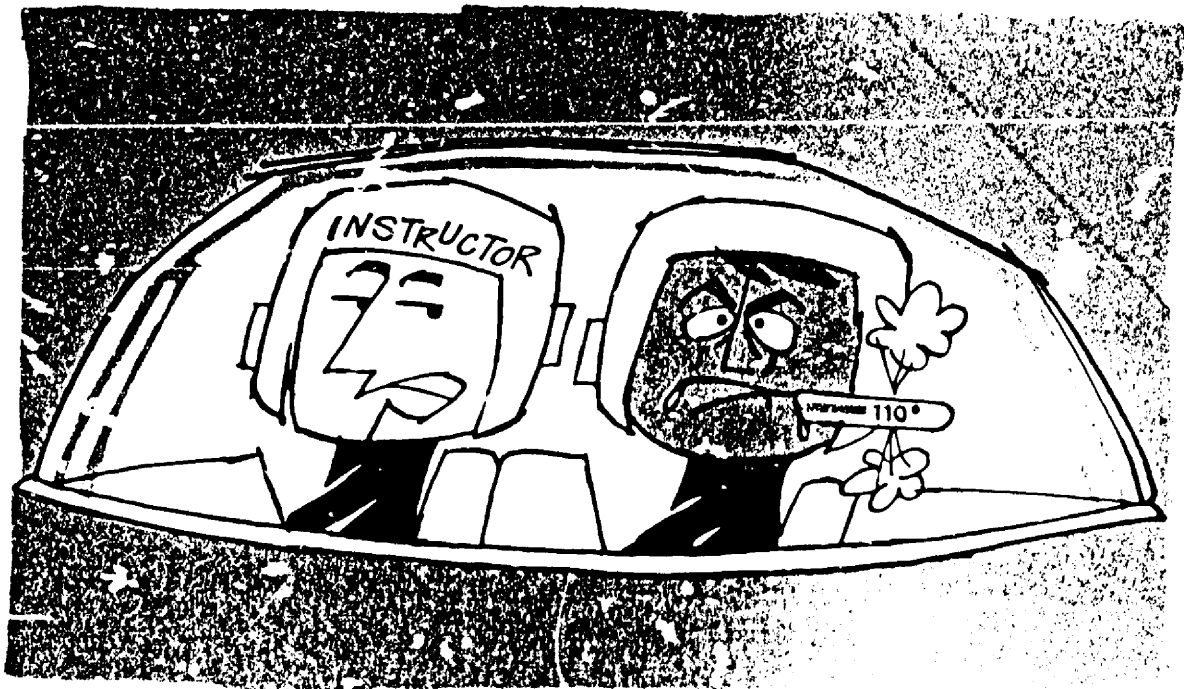


vision and judgment; and finally, unconsciousness. Cases are known where a person lapsed into unconsciousness without realizing he was suffering the effects.

When flying at or above 10,000 feet, force yourself to remain alert. Any feeling of drowsiness or undue fatigue may be from hypoxia. If you do

not have oxygen, descend to a lower altitude. If fatigue or drowsiness continues after descent, it is caused by something other than hypoxia.

A safe procedure is to use auxiliary oxygen during prolonged flights above 10,000 feet and for even short flights above 12,000 feet. Above about 40,000 feet, pressurization becomes essential.



## Chapter 2

# TEMPERATURE

Since early childhood, you have expressed the comfort of weather in degrees of temperature. Why, then, do we stress temperature in aviation weather? Look at your flight computer; temperature enters into the computation of most parameters on the computer. In fact, temperature can

be critical to some flight operations. As a foundation for the study of temperature effects on aviation and weather, this chapter describes commonly used temperature scales, relates heat and temperature, and surveys temperature variations both at the surface and aloft.

## TEMPERATURE SCALES

Two commonly used temperature scales are Celsius (Centigrade) and Fahrenheit. The Celsius scale is used exclusively for upper air temperatures and is rapidly becoming the world standard for surface temperatures also.

Traditionally, two common temperature references are the melting point of pure ice and the boiling point of pure water at sea level. The melting point of ice is 0° C or 32° F; the boiling point of water is 100° C or 212° F. Thus, the difference between melting and boiling is 100 degrees Celsius or 180 degrees Fahrenheit; the ratio between degrees Celsius and Fahrenheit is 100/180 or 5/9. Since 0° F is 32 Fahrenheit degrees colder than 0° C, you must apply this difference when comparing temperatures on the two scales. You can convert from one scale to the other using one of the following formulae:

$$C = \frac{5}{9}(F - 32)$$

$$F = \frac{9}{5}C + 32$$

where C is degrees Celsius and F is degrees Fahrenheit. Figure 3 compares the two scales. Many flight computers provide for direct conversion of temperature from one scale to the other. Section 16, AVIATION WEATHER SERVICES has a graph for temperature conversion.

Temperature we measure with a thermometer. But what makes a thermometer work? Simply the addition or removal of heat. Heat and temperature are not the same; how are they related?

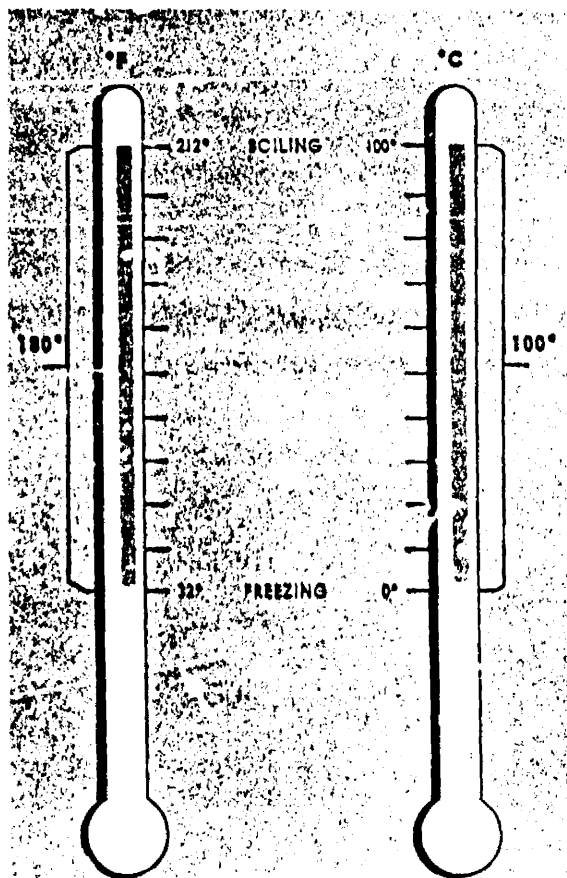


Figure 3. The two temperature scales in common use are the Fahrenheit and the Celsius. 9 degrees on the Fahrenheit scale equal 5 degrees on the Celsius.

## HEAT AND TEMPERATURE

Heat is a form of energy. When a substance contains heat, it exhibits the property we measure as temperature—the degree of “hotness” or “coldness.” A specific amount of heat absorbed by or removed from a substance raises or lowers its temperature a definite amount. However, the amount of temperature change depends on characteristics of the substance. Each substance has its unique temperature change for the specific change in heat. For example, if a land surface and a water surface have the same temperature and an equal amount

of heat is added, the land surface becomes hotter than the water surface. Conversely, with equal heat loss, the land becomes colder than the water.

The Earth receives energy from the sun in the form of solar radiation. The Earth and its atmosphere reflect about 55 percent of the radiation and absorb the remaining 45 percent converting it to heat. The Earth, in turn, radiates energy, and this outgoing radiation is “terrestrial radiation.” It is evident that the average heat gained from incoming solar radiation must equal heat lost through

terrestrial radiation in order to keep the Earth from getting progressively hotter or colder. However, this balance is world-wide; we must consider

regional and local imbalances which create temperature variations.

## TEMPERATURE VARIATIONS

The amount of solar energy received by any region varies with time of day, with seasons, and with latitude. These differences in solar energy create temperature variations. Temperatures also vary with differences in topographical surface and with altitude. These temperature variations create forces that drive the atmosphere in its endless motions.

### DIURNAL VARIATION

*Diurnal variation is the change in temperature from day to night* brought about by the daily rotation of the Earth. The Earth receives heat during the day by solar radiation but continually loses heat by terrestrial radiation. Warming and cooling depend on an imbalance of solar and terrestrial radiation. During the day, solar radiation exceeds terrestrial radiation and the surface becomes warmer. At night, solar radiation ceases, but terrestrial radiation continues and cools the surface. Cooling continues after sunrise until solar radiation again exceeds terrestrial radiation. Minimum temperature usually occurs after sunrise, sometimes as much as one hour after. The continued cooling after sunrise is one reason that fog sometimes forms shortly after the sun is above the horizon. We will have more to say about diurnal variation and topographic surfaces.

### SEASONAL VARIATION

In addition to its daily rotation, the Earth revolves in a complete orbit around the sun once each year. Since the axis of the Earth tilts to the plane of orbit, the angle of incident solar radiation varies seasonally between hemispheres. The Northern Hemisphere is warmer in June, July, and August because it receives more solar energy than does the Southern Hemisphere. During December, January, and February, the opposite is true; the Southern Hemisphere receives more solar energy and is warmer. Figures 4 and 5 show these seasonal surface temperature variations.

### VARIATION WITH LATITUDE

The shape of the Earth causes a geographical variation in the angle of incident solar radiation.

Since the Earth is essentially spherical, the sun is more nearly overhead in equatorial regions than at higher latitudes. Equatorial regions, therefore, receive the most radiant energy and are warmest. Slanting rays of the sun at higher latitudes deliver less energy over a given area with the least being received at the poles. Thus, temperature varies with latitude from the warm Equator to the cold poles. You can see this average temperature gradient in figures 4 and 5.

### VARIATIONS WITH TOPOGRAPHY

Not related to movement or shape of the earth are temperature variations induced by water and terrain. As stated earlier, water absorbs and radiates energy with less temperature change than does land. Large, deep water bodies tend to minimize temperature changes, while continents favor large changes. Wet soil such as in swamps and marshes is almost as effective as water in suppressing temperature changes. Thick vegetation tends to control temperature changes since it contains some water and also insulates against heat transfer between the ground and the atmosphere. Arid, barren surfaces permit the greatest temperature changes.

These topographical influences are both diurnal and seasonal. For example, the difference between a daily maximum and minimum may be 10° or less over water, near a shore line, or over a swamp or marsh, while a difference of 50° or more is common over rocky or sandy deserts. Figures 4 and 5 show the seasonal topographical variation. Note that in the Northern Hemisphere in July temperatures are warmer over continents than over oceans; in January they are colder over continents than over oceans. The opposite is true in the Southern Hemisphere, but not as pronounced because of more water surface in the Southern Hemisphere.

To compare land and water effect on seasonal temperature variation, look at northern Asia and at southern California near San Diego. In the deep continental interior of northern Asia, July average temperature is about 50° F; and January average, about -30° F. Seasonal range is about 80° F. Near San Diego, due to the proximity of the Pacific

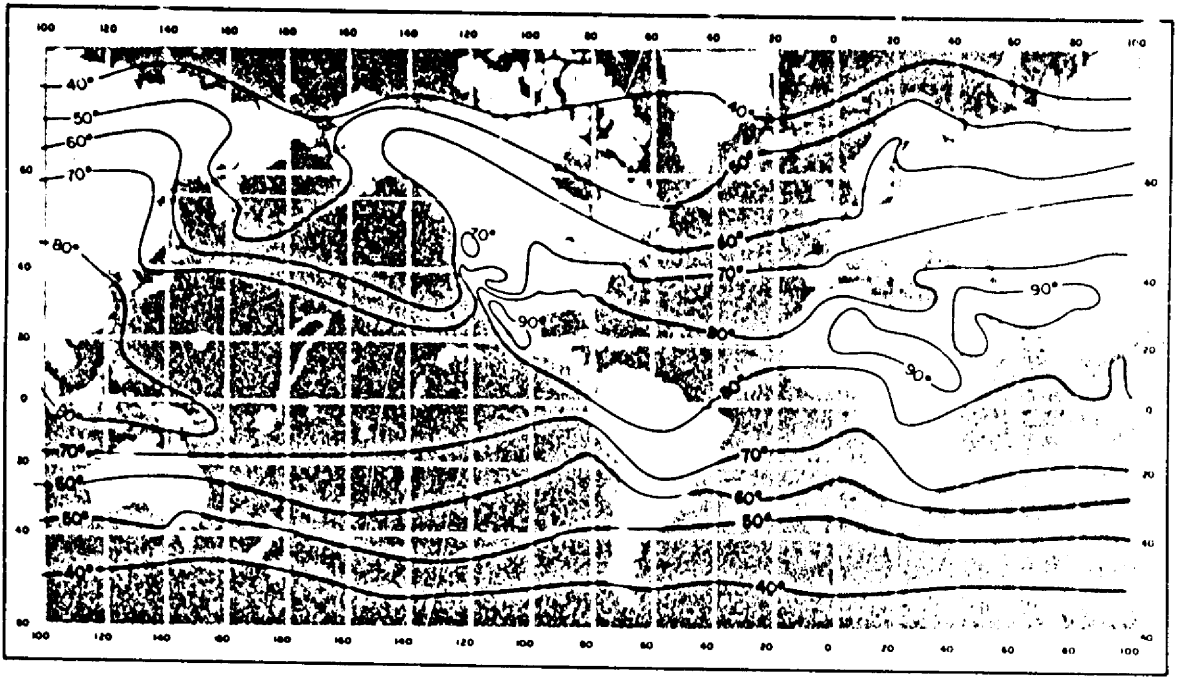


FIGURE 4. World-wide average surface temperatures in July. In the Northern Hemisphere, continents generally are warmer than oceanic areas at corresponding latitudes. The reverse is true in the Southern Hemisphere, but the contrast is not so evident because of the sparsity of land surfaces.

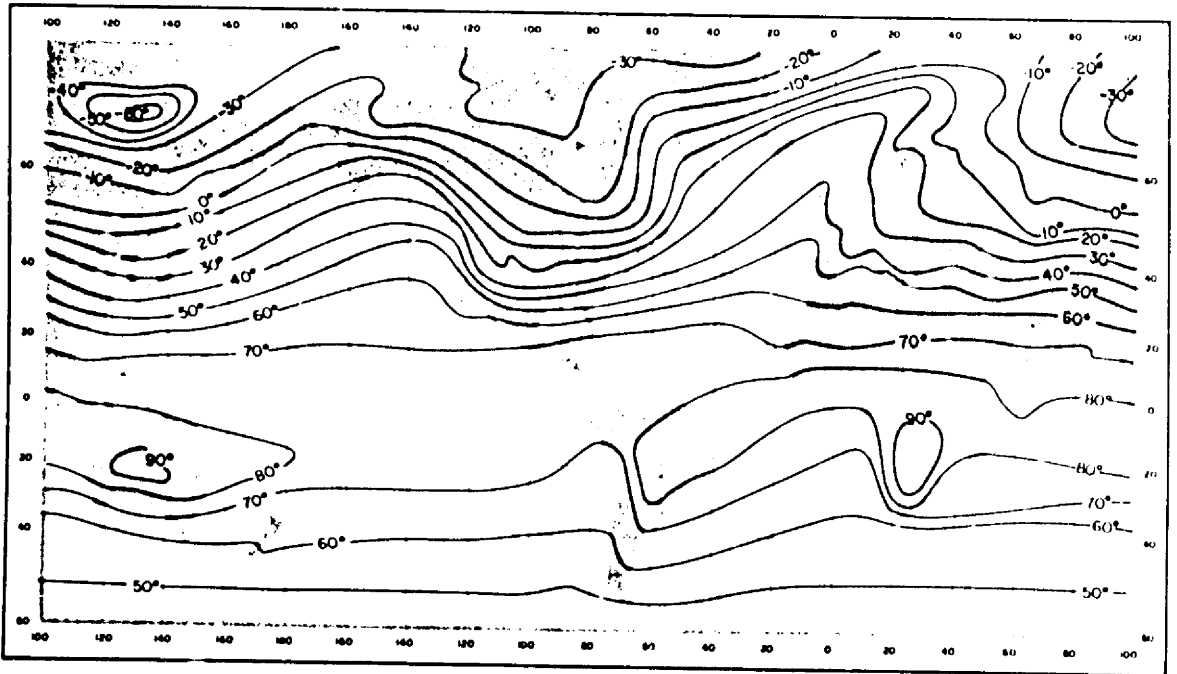


FIGURE 5. World-wide average surface temperatures in January when the Northern Hemisphere is in the cold season and the Southern Hemisphere is warm. Note that in the Northern Hemisphere, continents are colder than oceanic areas at corresponding latitudes, and in the Southern Hemisphere continents are warmer than oceans.

Ocean, July average is about 70° F and January average, 50° F. Seasonal variation is only about 20° F.

Abrupt temperature differences develop along lake and ocean shores. These variations generate pressure differences and local winds which we will study in later chapters. Figure 6 illustrates a possible effect.

Prevailing wind is also a factor in temperature controls. In an area where prevailing winds are from large water bodies, temperature changes are rather small. Most islands enjoy fairly constant temperatures. On the other hand, temperature changes are more pronounced where prevailing wind is from dry, barren regions.

Air transfers heat slowly from the surface upward. Thus, temperature changes aloft are more gradual than at the surface. Let's look at temperature changes with altitude.

## VARIATION WITH ALTITUDE

In chapter 1, we learned that temperature normally decreases with increasing altitude throughout the troposphere. This *decrease of temperature with altitude* is defined as *lapse rate*. The average decrease of temperature—average lapse rate—in the troposphere is 2° C per 1,000 feet. But since this is an average, the exact value seldom exists. In fact, temperature sometimes increases with height through a layer. An *increase in temperature with altitude* is defined as an *inversion*, i.e., lapse rate is inverted.

An inversion often develops near the ground on clear, cool nights when wind is light. The ground radiates and cools much faster than the overlying air. Air in contact with the ground becomes cold while the temperature a few hundred feet above changes very little. Thus, temperature increases

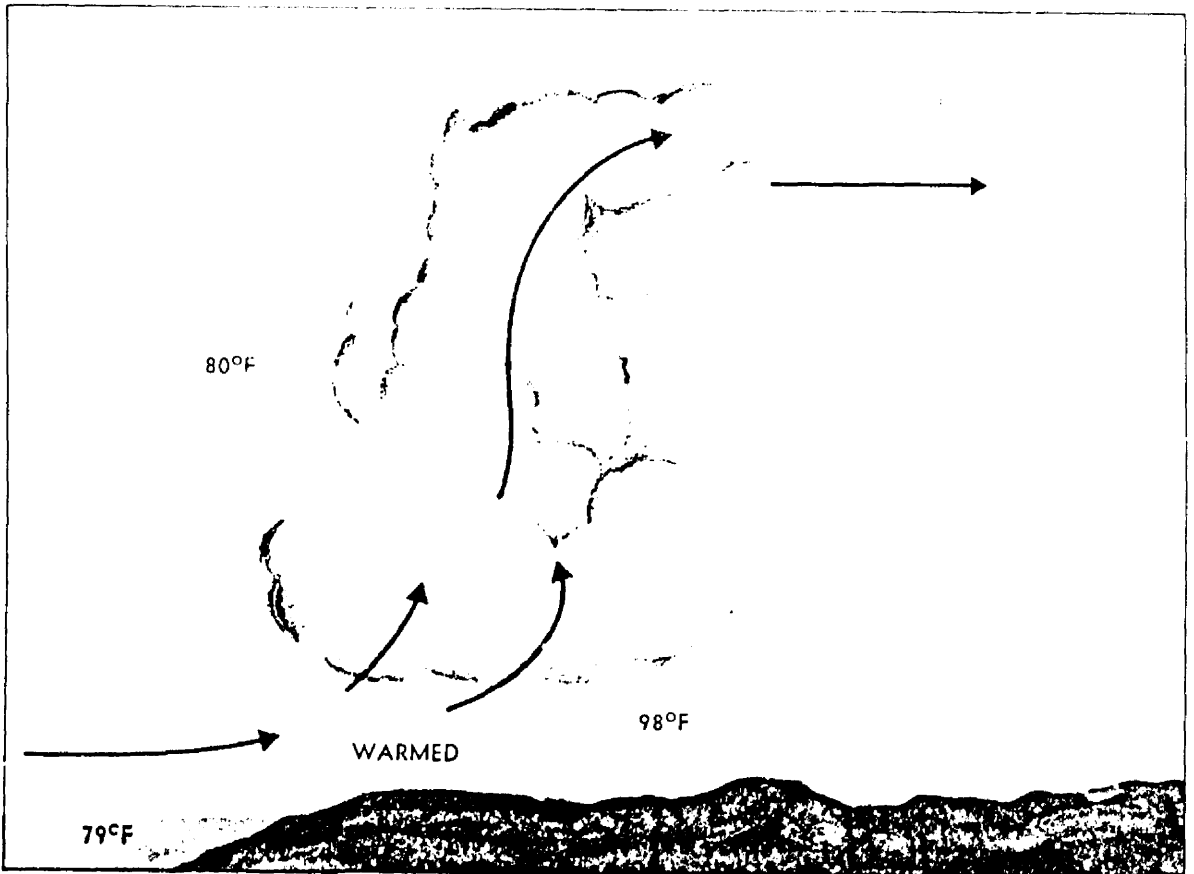


FIGURE 6. Temperature differences create air movement and, at times, cloudiness.

with height. Inversions may also occur at any altitude when conditions are favorable. For example, a current of warm air aloft overrunning cold air

near the surface produces an inversion aloft. Figure 7 diagrams temperature inversions both surface and aloft. Inversions are common in the stratosphere.

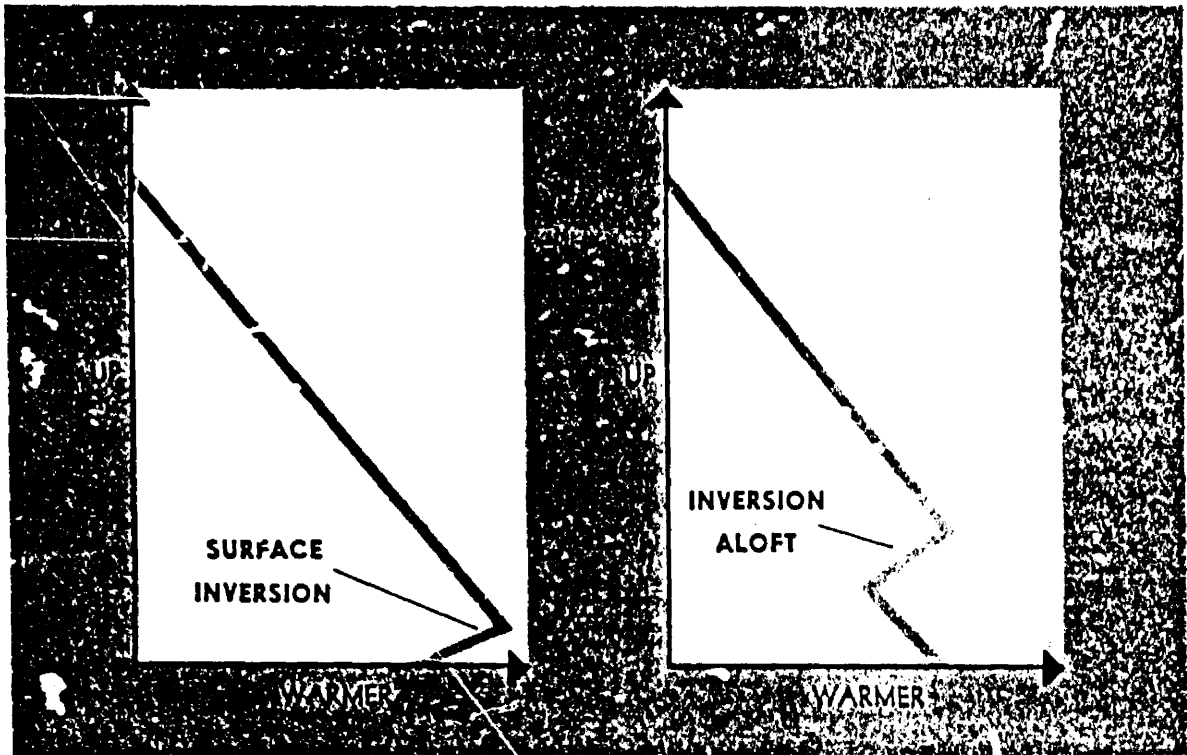
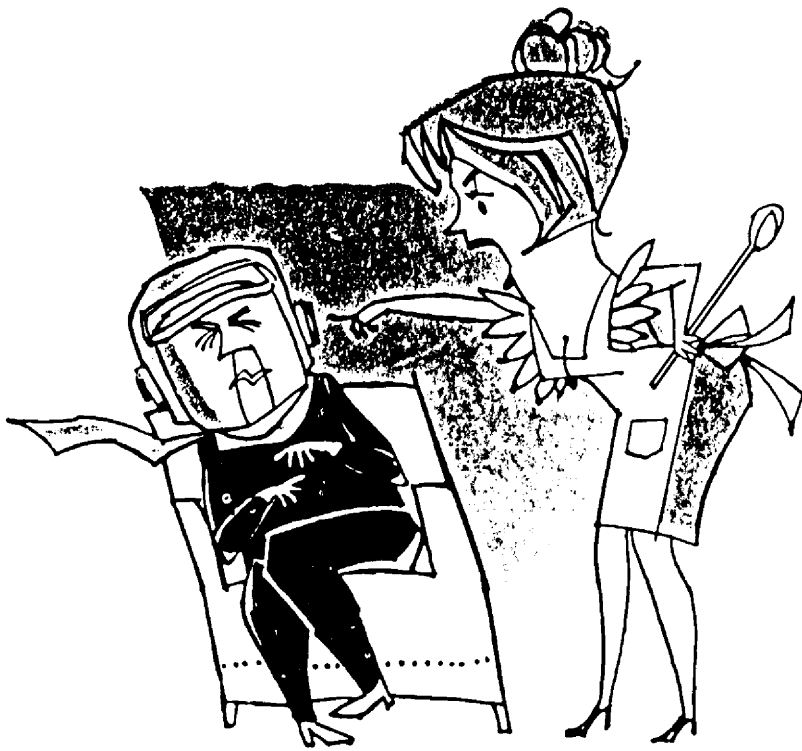


FIGURE 7. Inverted lapse rates or "inversions." A lapse rate is a decrease of temperature with height. An inversion is an increase of temperature with height, i.e., the lapse rate is inverted. Shown here are a surface inversion and an inversion aloft.

## IN CLOSING

Temperature affects aircraft performance and is critical to some operations. Following are some operational pointers to remember, and most of them are developed in later chapters:

1. The aircraft thermometer is subject to inaccuracies no matter how good the instrument and its installation. Position of the aircraft relative to the sun can cause errors due to radiation, particularly on a parked aircraft. At high speeds, aerodynamical effects and friction are basically the causes of inaccuracies.
2. High temperature reduces air density and reduces aircraft performance (chapter 3).
3. Diurnal and topographical temperature variations create local winds (chapter 4).
4. Diurnal cooling is conducive to fog (chapter 5).
5. Lapse rate contributes to stability (chapter 6), cloud formation (chapter 7), turbulence (chapter 9), and thunderstorms (chapter 11).
6. An inversion aloft permits warm rain to fall through cold air below. Temperature in the cold air can be critical to icing (chapter 10).
7. A ground based inversion favors poor visibility by trapping fog, smoke, and other restrictions into low levels of the atmosphere (chapter 12).



## Chapter 3

# ATMOSPHERIC PRESSURE AND ALTIMETRY

When you understand pressure, its measurement, and effects of temperature and altitude on

pressure, you can more readily grasp the significance of pressure and its application to altimetry.

### ATMOSPHERIC PRESSURE

Atmospheric pressure is the force per unit area exerted by the weight of the atmosphere. Since air is not solid, we cannot weigh it with conventional scales. Yet, Toricelli proved three centuries ago that he could weigh the atmosphere by balancing it against a column of mercury. He actually measured pressure converting it directly to weight.

### MEASURING PRESSURE

The instrument Toricelli designed for measuring pressure is the barometer. Weather services and the aviation community use two types of barometers in measuring pressure—the mercurial and aneroid.



## The Mercurial Barometer

The mercurial barometer, diagrammed in figure 8, consists of an open dish of mercury into which we place the open end of an evacuated glass tube. Atmospheric pressure forces mercury to rise in the tube. At stations near sea level, the column of mercury rises on the average to a height of 29.92 inches or 760 millimeters. In other words, a column of mercury of that height weighs the same as a column of air having the same cross section as the column of mercury and extending from sea level to the top of the atmosphere.

Why do we use mercury in the barometer? Mercury is the heaviest substance available which remains liquid at ordinary temperatures. It permits the instrument to be of manageable size. We could

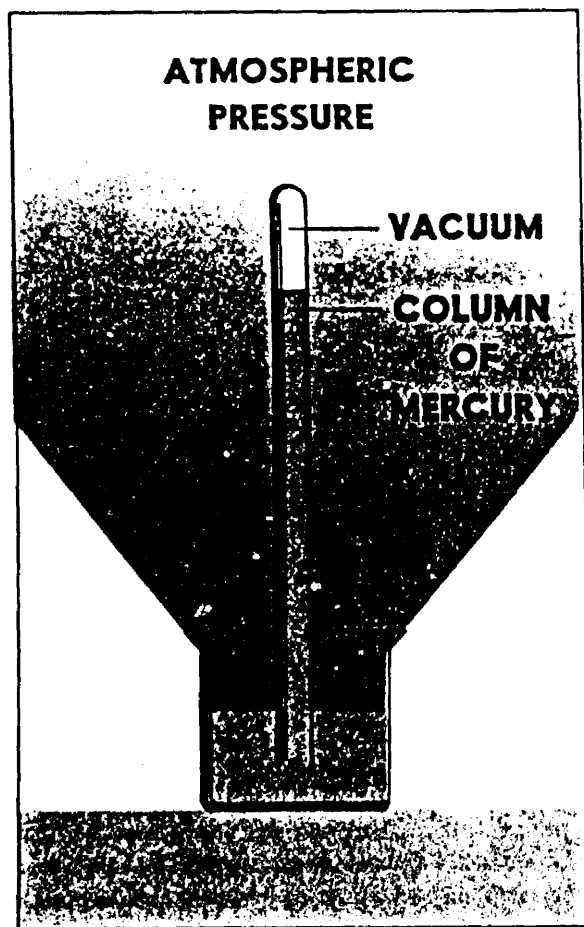


FIGURE 8. The mercurial barometer. Atmospheric pressure forces mercury from the open dish upward into the evacuated glass tube. The height of the mercury column is a measure of atmospheric pressure.

use water, but at sea level the water column would be about 34 feet high.

## The Aneroid Barometer

Essential features of an aneroid barometer illustrated in figure 9 are a flexible metal cell and the registering mechanism. The cell is partially evacuated and contracts or expands as pressure changes. One end of the cell is fixed, while the other end moves the registering mechanism. The coupling mechanism magnifies movement of the cell driving an indicator hand along a scale graduated in pressure units.

## Pressure Units

Pressure is expressed in many ways throughout the world. The term used depends somewhat on its application and the system of measurement. Two popular units are "inches of mercury" or "millimeters of mercury." Since pressure is force per unit area, a more explicit expression of pressure is "pounds per square inch" or "grams per square centimeter." The term "millibar" precisely expresses pressure as a force per unit area, one millibar being a force of 1,000 dynes per square centimeter. The millibar is rapidly becoming a universal pressure unit.

## Station Pressure

Obviously, we can measure pressure only at the point of measurement. The pressure measured at a station or airport is "station pressure" or the actual pressure at field elevation. We know that pressure at high altitude is less than at sea level or low altitude. For instance, station pressure at Denver is less than at New Orleans. Let's look more closely at some factors influencing pressure.

## PRESSURE VARIATION

Pressure varies with altitude and temperature of the air as well as with other minor influences which we neglect here.

## Altitude

As we move upward through the atmosphere, weight of the air above becomes less and less. If we carry a barometer with us, we can measure a decrease in pressure as weight of the air above decreases. Within the lower few thousand feet of the troposphere, pressure decreases roughly one inch for each 1,000 feet increase in altitude. The higher we go, the slower is the rate of decrease with height.

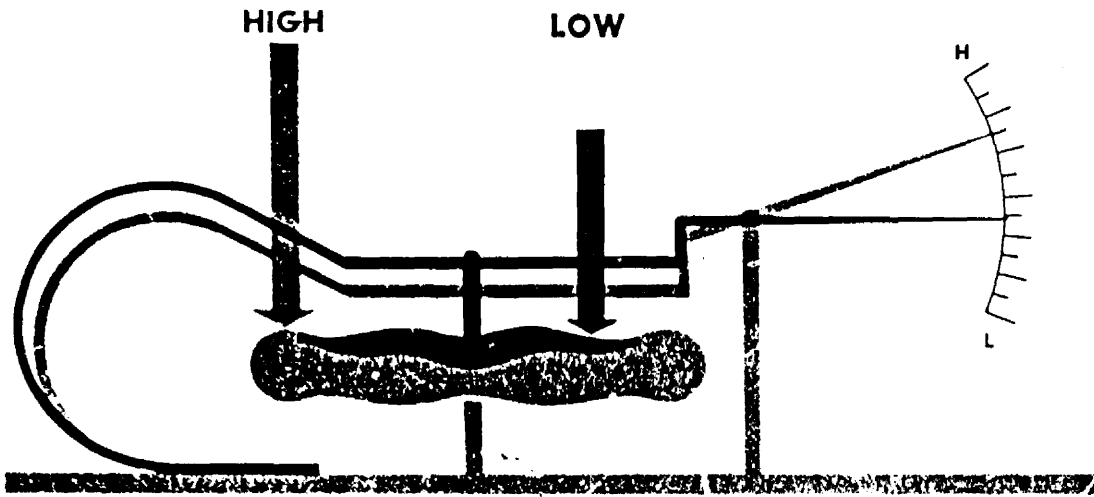


FIGURE 9. The aneroid barometer. The aneroid consists of a partially evacuated metal cell, a coupling mechanism, and an indicator scale. The cell contracts and expands with changing pressure. The coupling mechanism drives the indicator along a scale graduated in pressure units.

Figure 10 shows the pressure decrease with height in the standard atmosphere. These standard altitudes are based on standard temperatures. In the real atmosphere, temperatures are seldom standard, so let's explore temperature effects.

### Temperature

Like most substances, air expands as it becomes warmer and shrinks as it cools. Figure 11 shows three columns of air—one colder than standard, one at standard temperature, and one warmer than standard. Pressure is equal at the bottom of each column and equal at the top of each column. Therefore, pressure decrease upward through each column is the same. Vertical expansion of the warm column has made it higher than the column at standard temperature. Shrinkage of the cold column has made it shorter. Since pressure decrease is the same in each column, the *rate of decrease* of pressure with height in warm air is less than standard; the rate of decrease of pressure with height in cold air is greater than standard. You will soon see the importance of temperature in altimetry and weather analysis and on aircraft performance.

### Sea Level Pressure

Since pressure varies with altitude, we cannot readily compare station pressures between stations at different altitudes. To make them comparable, we must adjust them to some common level. Mean sea level seems the most feasible common reference. In figure 12, pressure measured at a 5,000-foot station is 25 inches; pressure increases about 1 inch for each 1,000 feet or a total of 5 inches. Sea level pressure is approximately 25 + 5 or 30 inches. The weather observer takes temperature and other effects into account, but this simplified example explains the basic principle of sea level pressure reduction.

We usually express sea level pressure in millibars. Standard sea level pressure is 1013.2 millibars, 29.92 inches of mercury, 760 millimeters of mercury, or about 14.7 pounds per square inch. Figures 23 and 24 in chapter 4 show world-wide averages of sea level pressure for the months of July and January. Pressure changes continually, however, and departs widely from these averages. We use a sequence of weather maps to follow these changing pressures.

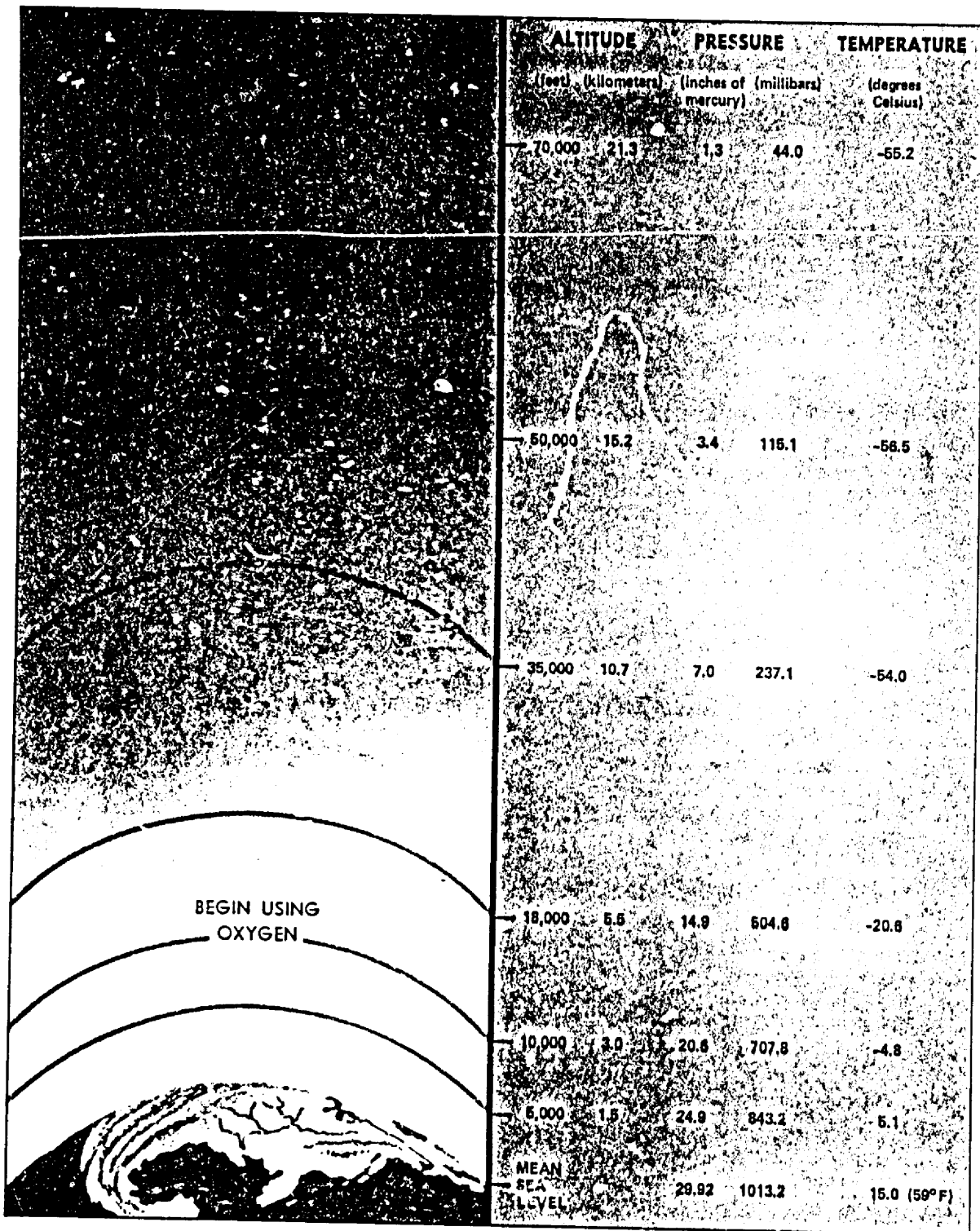
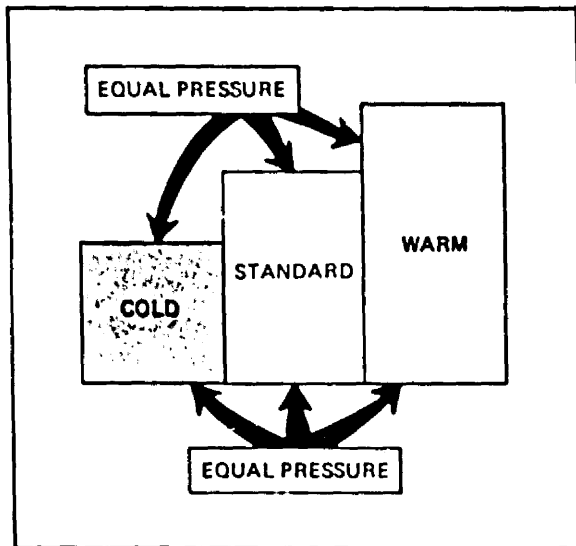


FIGURE 10. The standard atmosphere. Note how pressure decreases with increasing height; the rate of decrease with height is greatest in lower levels.



**FIGURE 11.** Three columns of air showing how decrease of pressure with height varies with temperature. Left column is colder than average and right column, warmer than average. Pressure is equal at the bottom of each column and equal at the top of each column. Pressure decreases most rapidly with height in the cold air and least rapidly in the warm air.

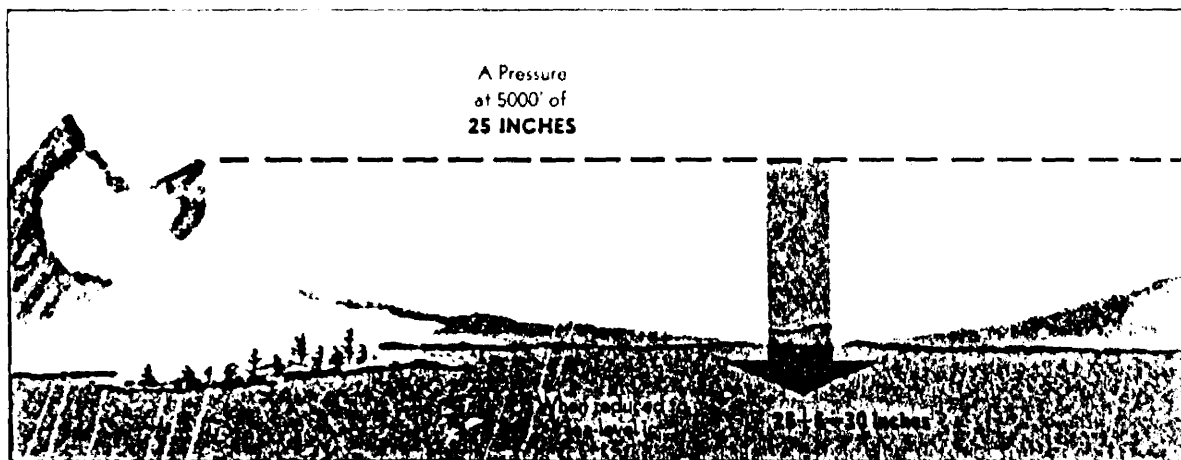
### Pressure Analyses

We plot sea level pressures on a map and draw lines connecting points of equal pressure. These lines of equal pressure are *isobars*. Hence, the surface map is an *isobaric analysis* showing identi-

able, organized pressure patterns. Five pressure systems are shown in figure 13 and are defined as follow:

1. **LOW**--a center of pressure surrounded on all sides by higher pressure; also called a cyclone. Cyclonic curvature is the curvature of isobars to the left when you stand with lower pressure to your left.
2. **HIGH**--a center of pressure surrounded on all sides by lower pressure, also called an anticyclone. Anticyclonic curvature is the curvature of isobars to the right when you stand with lower pressure to your left.
3. **TROUGH**--an elongated area of low pressure with the lowest pressure along a line marking maximum cyclonic curvature.
4. **RIDGE**--an elongated area of high pressure with the highest pressure along a line marking maximum anticyclonic curvature.
5. **COL**--the neutral area between two highs and two lows. It also is the intersection of a trough and a ridge. The col on a pressure surface is analogous to a mountain pass on a topographic surface.

Upper air weather maps reveal these same types of pressure patterns aloft for several levels. They also show temperature, moisture, and wind at each level. In fact, a chart is available for a level within a few thousand feet of your planned cruising altitude. AVIATION WEATHER SERVICES lists the approximate heights of upper air maps and shows details of the surface map and each upper air chart.



**FIGURE 12.** Reduction of station pressure to sea level. Pressure increases about 1 inch per 1,000 feet from the station elevation to sea level.

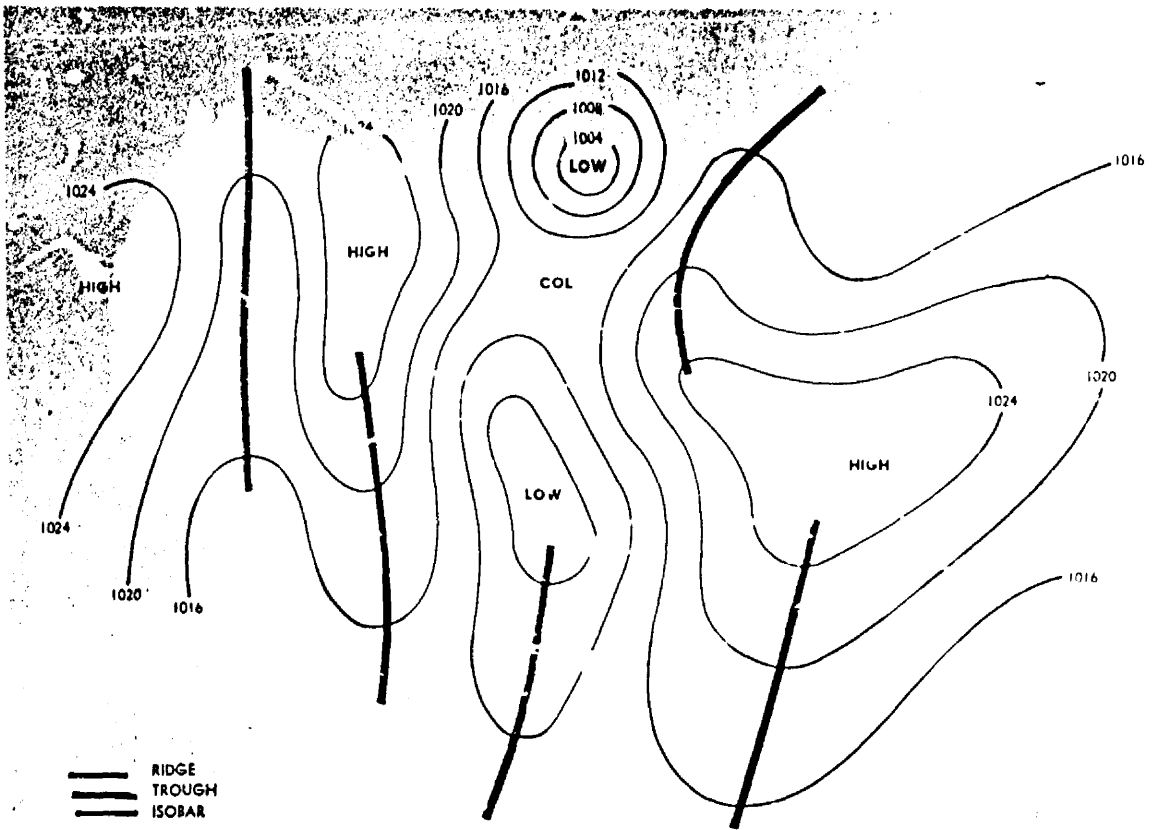


FIGURE 13. Pressure systems.

Chapter 4 of this book ties together the surface chart and upper air charts into a three-dimensional picture.

An upper air map is a *constant pressure analysis*. But, what do we mean by "constant pressure"? Constant pressure simply refers to a specific pressure. Let's arbitrarily choose 700 millibars. Everywhere above the earth's surface, pressure decreases with height; and at some height, it decreases to this constant pressure of 700 millibars. Therefore, there is a "surface" throughout the atmosphere at which pressure is 700 millibars. We call this the 700-millibar constant pressure surface. However, the *height* of this surface is *not* constant. Rising pressure pushes the surface upward into highs and ridges. Falling pressure lowers the height of the surface into lows and troughs. These systems migrate continuously as "waves" on the pressure surface. Remember that we chose this constant pressure surface arbitrarily as a reference. It in no way defines any discrete boundary.

The National Weather Service and military weather services take routine scheduled upper air observations—sometimes called soundings. A balloon carries aloft a radiosonde instrument which consists of miniature radio gear and sensing elements. While in flight, the radiosonde transmits data from which a specialist determines wind, temperature, moisture, and height at selected pressure surfaces.

We routinely collect these observations, plot the heights of a constant pressure surface on a map, and draw lines connecting points of equal height. These lines are *height contours*. But, what is a height contour?

First, consider a topographic map with contours showing variations in elevation. These are height contours of the terrain surface. The Earth surface is a fixed reference and we contour variations in its height.

The same concept applies to height contours on a constant pressure chart, except our reference is a

*constant pressure surface.* We simply contour the heights of the pressure surface. For example, a 700-millibar constant pressure analysis is a contour map of the heights of the 700-millibar pressure surface. While the contour map is based on variations in height, these variations are small when compared to flight levels, and for all practical purposes, you may regard the 700-millibar chart as a weather map at approximately 10,000 feet or 3,048 meters.

A contour analysis shows highs, ridges, lows, and troughs aloft just as the isobaric analysis shows such systems at the surface. What we say concerning

pressure patterns and systems applies equally to an isobaric or a contour analysis.

Low pressure systems quite often are regions of poor flying weather, and high pressure areas predominantly are regions of favorable flying weather. A word of caution, however—use care in applying the low pressure-bad weather, high pressure-good weather rule of thumb; it all too frequently fails. When planning a flight, gather *all* information possible on expected weather. Pressure patterns also bear a direct relationship to wind which is the subject of the next chapter. But first, let's look at pressure and altimeters.

## ALTIMETRY

The altimeter is essentially an aneroid barometer. The difference is the scale. The altimeter is graduated to read increments of height rather than units of pressure. The standard for graduating the altimeter is the standard atmosphere.

### ALTITUDE

Altitude seems like a simple term; it means height. But in aviation, it can have many meanings.

#### True Altitude

Since existing conditions in a real atmosphere are seldom standard, altitude indications on the altimeter are seldom actual or true altitudes. *True altitude is the actual or exact altitude above mean sea level.* If your altimeter does not indicate true altitude, what does it indicate?

#### Indicated Altitude

Look again at figure 11 showing the effect of mean temperature on the thickness of the three columns of air. Pressures are equal at the bottoms and equal at the tops of the three layers. Since the altimeter is essentially a barometer, altitude indicated by the altimeter at the top of each column would be the same. To see this effect more clearly, study figure 14. Note that in the warm air, you fly at an altitude higher than indicated. In the cold air, you are at an altitude lower than indicated.

Height indicated on the altimeter also changes with changes in surface pressure. A movable scale on the altimeter permits you to adjust for surface pressure, but you have no means of adjusting the instrument for mean temperature of the column of

air below you. *Indicated altitude is the altitude above mean sea level indicated on the altimeter when set at the local altimeter setting.* But what is altimeter setting?

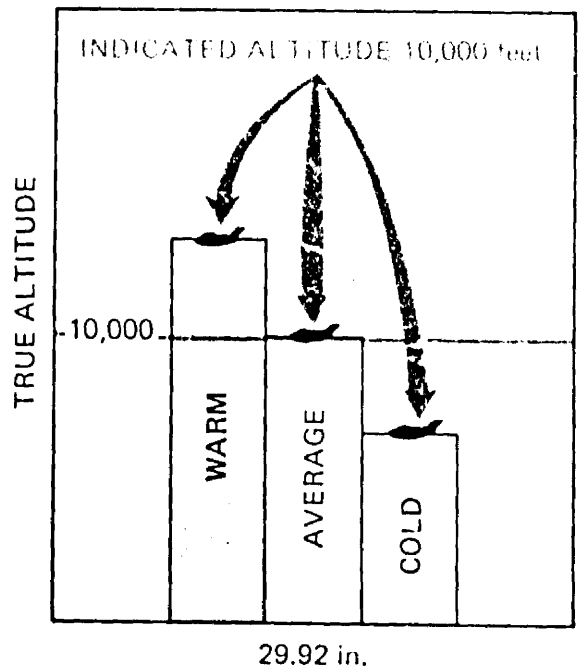


FIGURE 14. Indicated altitude depends on air temperature below the aircraft. Since pressure is equal at the bases and equal at the tops of each column, indicated altitude is the same at the top of each column. When air is colder than average (right), the altimeter reads higher than true altitude. When air is warmer than standard (left), the altimeter reads lower than true altitude.

## Altimeter Setting

Since the altitude scale is adjustable, you can set the altimeter to read true altitude at some specified height. Takeoff and landing are the most critical phases of flight; therefore, airport elevation is the most desirable altitude for a true reading of the altimeter. *Altimeter setting is the value to which the scale of the pressure altimeter is set so the altimeter indicates true altitude at field elevation.*

In order to ensure that your altimeter reading is compatible with altimeter readings of other aircraft in your vicinity, keep your altimeter setting current. Adjust it frequently in flight to the altimeter setting reported by the nearest tower or weather reporting station. Figure 15 shows the trouble you can encounter if you are lax in adjusting your altimeter in flight. Note that as you fly from high pressure to low pressure, you are lower than your altimeter indicates.

Figure 16 shows that as you fly from warm to cold air, your altimeter reads too high—you are lower than your altimeter indicates. Over flat terrain this lower than true reading is no great problem; other aircraft in the vicinity also are flying indicated

rather than true altitude, and your altimeter readings are compatible. If flying in cold weather over mountainous areas, however, you must take this difference between indicated and true altitude into account. You must know that your true altitude assures clearance of terrain, so you compute a correction to indicated altitude.

## Corrected (Approximately True) Altitude

If it were possible for a pilot always to determine mean temperature of the column of air between the aircraft and the surface, flight computers would be designed to use this mean temperature in computing true altitude. However, the only guide a pilot has to temperature below him is free air temperature at his altitude. Therefore, the flight computer uses outside air temperature to correct indicated altitude to approximate true altitude. *Corrected altitude is indicated altitude corrected for the temperature of the air column below the aircraft, the correction being based on the estimated departure of the existing temperature from standard atmospheric temperature.* It is a close approximation to true altitude and is labeled *true altitude* on flight computers. It is close enough to

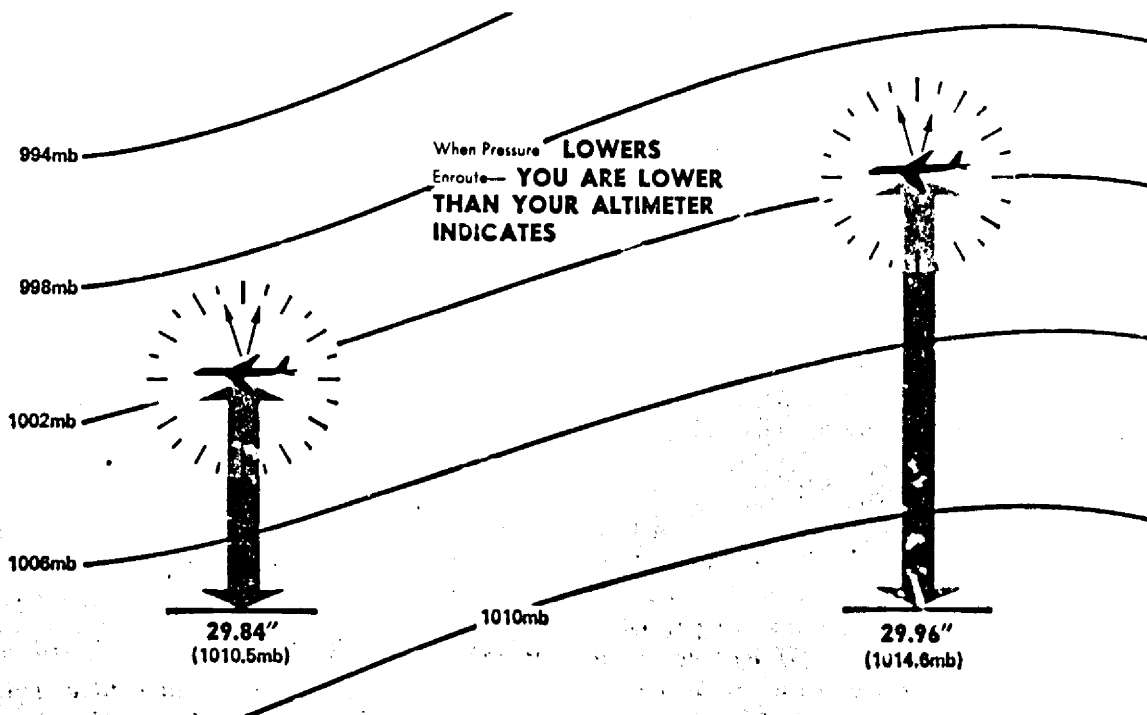


FIGURE 15. When flying from high pressure to lower pressure without adjusting your altimeter, you are losing true altitude.

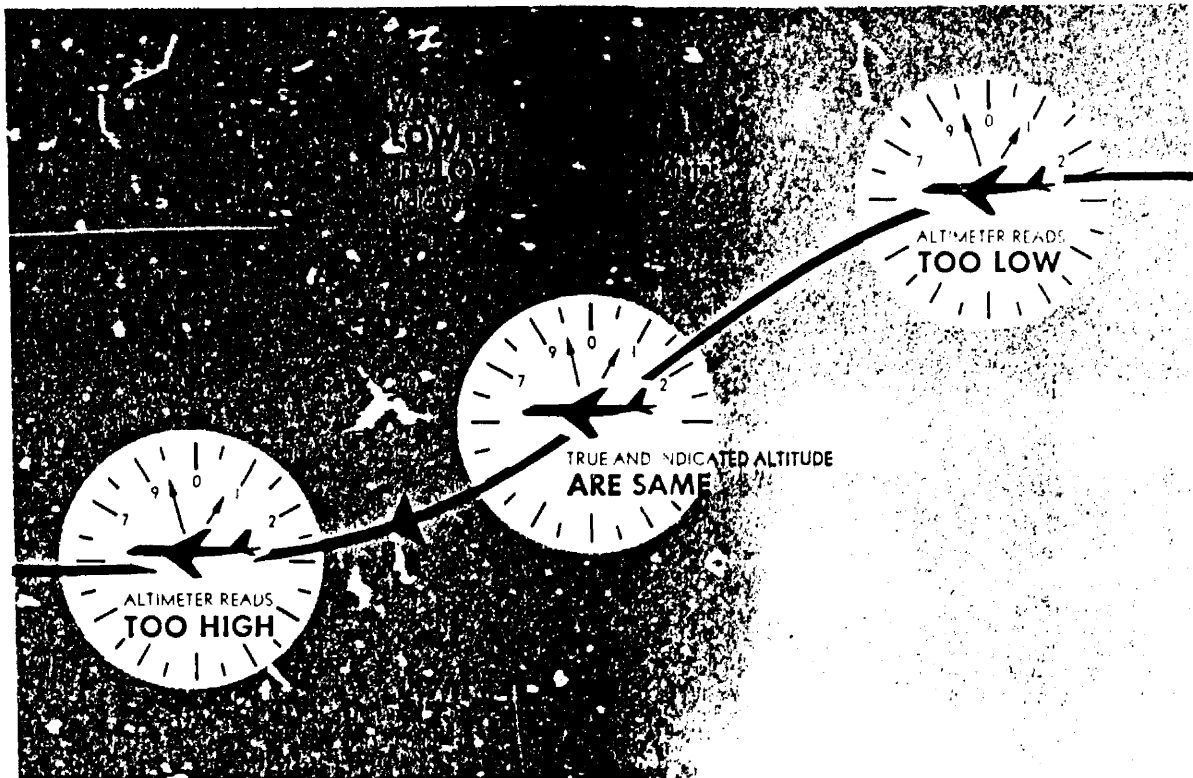


FIGURE 16. Effect of temperature on altitude. When air is warmer than average, you are higher than your altimeter indicates. When temperature is colder than average, you are lower than indicated. When flying from warm to cold air at a constant indicated altitude, you are losing true altitude.

true altitude to be used for terrain clearance provided you have your altimeter set to the value reported from a nearby reporting station.

Pilots have met with disaster because they failed to allow for the difference between indicated and true altitude. In cold weather when you must clear high terrain, take time to compute true altitude.

FAA regulations require you to fly indicated altitude at low levels and pressure altitude at high levels (at or above 18,000 feet at the time this book was printed). What is pressure altitude?

### Pressure Altitude

In the standard atmosphere, sea level pressure is 29.92 inches of mercury or 1013.2 millibars. Pressure falls at a fixed rate upward through this hypothetical atmosphere. Therefore, in the standard atmosphere, a given pressure exists at any specified altitude. *Pressure altitude is the altitude in the standard atmosphere where pressure is the same as where you are.* Since at a specific pressure altitude, pressure is everywhere the same, a constant pres-

sure surface defines a constant pressure altitude. When you fly a constant pressure altitude, you are flying a constant pressure surface.

You can always determine pressure altitude from your altimeter whether in flight or on the ground. Simply set your altimeter at the standard altimeter setting of 29.92 inches, and your altimeter indicates pressure altitude.

A conflict sometimes occurs near the altitude separating flights using indicated altitude from those using pressure altitude. Pressure altitude on one aircraft and indicated altitude on another may indicate altitude separation when, actually, the two are at the same true altitude. All flights using pressure altitude at high altitudes are IFR controlled flights. When this conflict occurs, air traffic controllers prohibit IFR flight at the conflicting altitudes.

### DENSITY ALTITUDE

What is density altitude? *Density altitude simply is the altitude in the standard atmosphere where air density is the same as where you are.* Pressure,



temperature, and humidity determine air density. On a hot day, the air becomes "thinner" or lighter, and its density where you are is equivalent to a higher altitude in the standard atmosphere—thus the term "high density altitude." On a cold day, the air becomes heavy; its density is the same as that at an altitude in the standard atmosphere lower than your altitude—"low density altitude."

Density altitude is not a height reference; rather, it is an index to aircraft performance. Low density altitude increases performance. *High density altitude* is a real hazard since it *reduces aircraft performance*. It affects performance in three ways. (1) It reduces power because the engine takes in less air to support combustion. (2) It reduces thrust because the propeller gets less grip on the light air

or a jet has less mass of gases to spit out the exhaust. (3) It reduces lift because the light air exerts less force on the airfoils.

You cannot detect the effect of high density altitude on your airspeed indicator. Your aircraft lifts off, climbs, cruises, glides, and lands at the prescribed indicated airspeeds. But at a specified indicated airspeed, your true airspeed and your groundspeed increase proportionally as density altitude becomes higher.

The net results are that high density altitude lengthens your takeoff and landing rolls and reduces your rate of climb. Before lift-off, you must attain a faster groundspeed, and therefore, you need more runway; your reduced power and thrust add a need for still more runway. You land at a

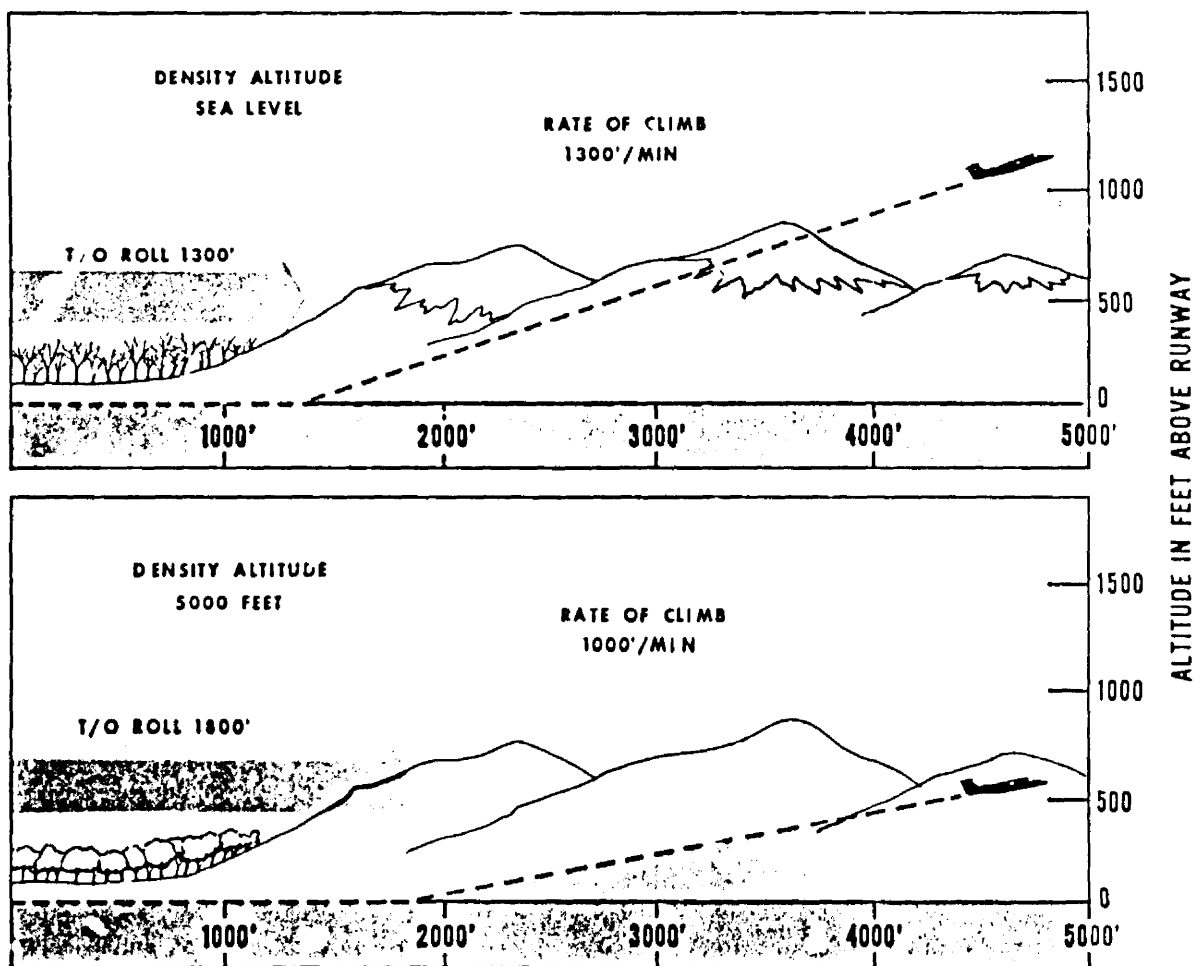


FIGURE 17. Effect of density altitude on takeoff and climb. High density altitude lengthens takeoff roll and reduces rate of climb.

faster groundspeed and, therefore, need more room to stop. At a prescribed indicated airspeed, you are flying at a faster true airspeed, and therefore, you cover more distance in a given time which means climbing at a more shallow angle. Add to this the problems of reduced power and rate of climb, and you are in double jeopardy in your climb. Figure 17 shows the effect of density altitude on takeoff distance and rate of climb.

High density altitude also can be a problem at cruising altitudes. When air is abnormally warm, the high density altitude lowers your service ceiling. For example, if temperature at 10,000 feet pressure altitude is 20° C, density altitude is 12,700

feet. (Check this on your flight computer.) Your aircraft will perform as though it were at 12,700 indicated with a normal temperature of -8° C.

To compute density altitude, set your altimeter at 29.92 inches or 1013.2 millibars and read pressure altitude from your altimeter. Read outside air temperature and then use your flight computer to get density altitude. On an airport served by a weather observing station, you usually can get density altitude for the airport from the observer. Section 16 of AVIATION WEATHER SERVICES has a graph for computing density altitude if you have no flight computer handy.

## IN CLOSING

Pressure patterns can be a clue to weather causes and movement of weather systems, but they give only a part of the total weather picture. Pressure decreases with increasing altitude. The altimeter is an aneroid barometer graduated in increments of altitude in the standard atmosphere instead of units of pressure. Temperature greatly affects the rate of pressure decrease with height; therefore, it influences altimeter readings. Temperature also determines the density of air at a given pressure (density altitude). Density altitude is an index to aircraft performance. Always be alert for departures of pressure and temperature from normals and compensate for these abnormalities.

Following are a few operational reminders:

1. Beware of the low pressure-bad weather, high pressure-good weather rule of thumb. It frequently fails. Always get the *complete* weather picture.
2. When flying from high pressure to low pressure at constant indicated altitude and without adjusting the altimeter, you are losing true altitude.
3. When temperature is colder than standard, you are at an altitude *lower* than your altimeter indicates. When temperature is warmer than standard, you are *higher* than your altimeter indicates.
4. When flying cross country, keep your altimeter setting current. This procedure assures more positive altitude separation from other aircraft.

5. When flying over high terrain in cold weather, compute your true altitude to ensure terrain clearance.
6. When your aircraft is heavily loaded, the temperature is abnormally warm, and/or the pressure is abnormally low, compute density altitude. Then check your aircraft manual to ensure that you can become airborne from the available runway. Check further to determine that your rate of climb permits clearance of obstacles beyond the end of the runway. This procedure is advisable for any airport regardless of altitude.
7. When planning takeoff or landing at a high altitude airport regardless of load, determine density altitude. The procedure is especially critical when temperature is abnormally warm or pressure abnormally low. Make certain you have sufficient runway for takeoff or landing roll. Make sure you can clear obstacles beyond the end of the runway after takeoff or in event of a go-around.
8. Sometimes the altimeter setting is taken from an instrument of questionable reliability. However, if the instrument can cause an error in altitude reading of more than 20 feet, it is removed from service. When altimeter setting is estimated, be prepared for a possible 10- to 20-foot difference between field elevation and your altimeter reading at touchdown.