CHAPTER TWO

Atmospheric Mechanics of Winds, Clouds and Moisture, and Atmospheric Stability

200. INTRODUCTION

This chapter introduces the student to the concepts associated with large- and small-scale wind systems, the relationship between atmospheric temperature, moisture content, major cloud types, and their effects on flight, as well as the various terms and requirements used to describe atmospheric stability and instability.

Additionally, it covers a wide range of topics basic to the understanding of weather phenomena. After an introduction to the meteorological station model, used in this chapter mainly to show wind direction in diagrams, we build upon the pressure basics presented in Chapter One to determine why winds blow in the particular direction that they do. To keep our analysis as simple as possible, we will focus only on winds in the Northern Hemisphere. Since winds and some forces in the Southern Hemisphere are a mirror image, discussing both patterns at this stage would unnecessarily complicate things for a first-time introduction to weather.

The next topic covered is atmospheric moisture. Since most weather hazards have something to do with moisture, it is important to understand how air becomes saturated, and how this will affect the formation of clouds, fog, and precipitation. In fact, the two main types of precipitation match up with two types of clouds. Clouds are classified according to the altitude of their bases, and this chapter covers four major types of cloud. Eventually (and usually more often than desired) all aviators will fly into clouds and thus an understanding of cloud composition and activity will be essential to this course.

Cloud types can be a visual signal of atmospheric stability or instability. These two conditions can be a further indication to meteorologists as well as to aircrew regarding the various weather and flight conditions that may be encountered. There can be great differences in the expected weather found between stable and unstable conditions, each with their own particular hazards to flight. Consequently, knowing the relationships between atmospheric stability and flight conditions could prove invaluable to an aviator.

201. LESSON TOPIC LEARNING OBJECTIVES

Terminal Objective: Partially supported by this lesson topic:

2.0 Upon completion of this unit of instruction, student aviators and flight officers will demonstrate knowledge of meteorological theory enabling them to make intelligent decisions when confronted with various weather phenomena and hazards.

Enabling Objectives: Completely supported by this lesson topic:

2.12 Explain the term pressure gradient.

2.13 Explain Coriolis force and its apparent effect on wind.
2.14 Explain and identify gradient winds with respect to the isobars around high and low pressure systems in the Northern Hemisphere.

2.15 Define Buys Ballot’s Law.

2.16 Explain and identify the surface wind direction with respect to the gradient winds in a high and low-pressure system in the Northern Hemisphere.

2.17 Describe the jet stream.

2.18 Describe sea breezes and land breezes.

2.19 Describe valley and mountain winds.

2.20 Define saturation, dew point temperature, dew point depression, and relative humidity.

2.21 State the relationships between saturation, air temperature, dew point temperature, and dew point depression necessary for the formation of clouds, fog, and precipitation.

2.22 Describe the three characteristics of precipitation.

2.23 Describe the types of precipitation.

2.24 Identify the four principal cloud groups.

2.25 Identify the weather conditions associated with various clouds and types of precipitation.

2.26 Describe atmospheric stability, instability, and neutral stability.

2.27 Describe the four types of lifting.

2.28 Identify the flight conditions associated with a stable and unstable atmosphere including cloud type, turbulence, precipitation, visibility, winds, and icing.

202. REFERENCES

Weather for Air Crews, AFH 11-203, Volume 1, Chapters 2, 5, 6, and 9

203. STUDY ASSIGNMENT

Review Chapter Two and answer the Study Questions.

204. WINDS

Understanding the causes of wind and wind direction is essential to the safe operation of an aircraft. Takeoffs and landings are best performed into a headwind, whereas landing with a
strong crosswind can be dangerous, to say the least. Additionally, the circulation of air brings about changes in weather by transporting water vapor. Therefore, wind plays an important role in the formation of fog, clouds, and precipitation.

So how does one determine the wind direction? Wind direction is always expressed in terms of the direction from which it is blowing. This convention holds throughout the world--civilian or military, weather or navigation, aviation or sailing--wind always blows from a particular direction. Thus, it would be best for a student to master this particular concept as early as possible in a career where wind is an everyday concern.

There are many different ways weather phenomenon, such as wind, are annotated on charts or in print. One of these methods is the use of a station model.

205. STATION MODELS

Some weather charts display the information gathered from individual weather stations through the use of the station model, shown in Figure 2-1. This model begins with a circle (or a square for automated stations) at the center to represent the location of the station that issued the weather report. Around the station symbol, data describing wind, temperatures, weather, and pressures are displayed in a pictorial shorthand (Figure 2-2) to provide the maximum amount of data in a minimum of space.

![Figure 2-1 Station Model Explanation](image)

Another noticeable feature of the station model is a line coming out of the circle indicating the wind direction. Since the station models are aligned for ease of reading, north is at the top of the
Therefore, in Figure 2-1, the winds are from the northwest. At the end of this stick are any numbers of barbs, which come in three shapes, to indicate the wind speed. A long barb represents 10 knots, short barbs are 5 knots, and pennants are 50 knots.

The numbers to the left of the station symbol indicate the temperature (top left) and dew point (bottom left). In between the temperature and dew point, there may be a symbol from Figure 2-2 representing the present weather at the station. Additionally, the circle (or square) may be filled in to represent the amount of sky covered by clouds, in eighths. An empty circle means clear skies, while a fully darkened circle indicates a completely overcast sky (also from Figure 2-2).

<table>
<thead>
<tr>
<th>AUTOMATED SKY CONDITION</th>
<th>MANUAL SKY CONDITION</th>
<th>PRESENT WEATHER</th>
<th>PRESENT TENDENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>🌧️ OR 🌧️</td>
<td>CLEAR</td>
<td>⬠ RAIN</td>
<td>RISING, THEN FALLING (+)</td>
</tr>
<tr>
<td>🌧️ OR 🌧️</td>
<td>1/8 TO 6/8 INCLUSIVE/SCATTERED</td>
<td>⬠ RAIN SHOWERS</td>
<td>RISING AND STEADY (+)</td>
</tr>
<tr>
<td>🌧️ OR 🌧️</td>
<td>6/8 TO 7/8 INCLUSIVE/BROKEN</td>
<td>⬠ DRIZZLE</td>
<td>RISING (+)</td>
</tr>
<tr>
<td>🌦️ OR 🌦️</td>
<td>8/8 (OVERCAST)</td>
<td>⬠ SNOW</td>
<td>FALLING, THEN RISING (+)</td>
</tr>
<tr>
<td>🌧️ OR 🌧️</td>
<td>SKY OBSCURED OR PARTIALLY OBSCURED</td>
<td>⬠ SQUALL</td>
<td>STEADY</td>
</tr>
<tr>
<td>🌧️ OR 🌧️</td>
<td>DATA MISSING</td>
<td>⬠ FREEZING GRIZZLE</td>
<td>FALLING, THEN STEADY (-)</td>
</tr>
<tr>
<td>🌧️ OR 🌧️</td>
<td>FREEZING RAIN</td>
<td>⬠ FREEZING DUST</td>
<td>FALLING (-)</td>
</tr>
<tr>
<td>🌧️ OR 🌧️</td>
<td>DUST DEVIL</td>
<td>⬠ SNOW SHOWERS</td>
<td>RISING, THEN FALLING (-)</td>
</tr>
<tr>
<td>🌧️ OR 🌧️</td>
<td>SMOKE</td>
<td>⬠ HAIL</td>
<td>HIGHER THAN 2 HOURS AGO</td>
</tr>
<tr>
<td>🌧️ OR 🌧️</td>
<td>Haze</td>
<td>BLOWING SNOW</td>
<td>LOWER THAN 2 HOURS AGO</td>
</tr>
</tbody>
</table>

Figure 2-2 Major Station Model Symbols

The right-hand side of the station model describes the pressure at the station. On the top right, there will be three digits to represent the sea level pressure (SLP) in millibars and tenths. Since SLP will always be somewhere around 1000 millibars, the hundreds digit (and thousands, if present) is dropped, and the decimal point is also omitted. Thus, depicted pressures beginning with large numbers (such as a 9) really start with a hidden “9” and pressures beginning with small numbers (such as a 1) actually have a “10” in front of them. Below the current SLP is the pressure tendency over the last three hours, beginning with a (+) or (-) sign to denote an overall rise or fall, and then the value of that total pressure change. After this notation is a set of two
connected line segments graphically showing the pressure change over those three hours, as indicated on the right-hand side of Figure 2-2.

206. LARGE SCALE WIND PATTERNS

Now that we have discussed station models, it may be easier to understand how pressure and wind fit together by imagining how a surface analysis chart is constructed (Figure 2-3). While most of these are built automatically by computer, picture a meteorologist at the National Weather Service starting with a U.S. map covered only with station models. The first thing he/she would do is to start playing “connect the dots” by finding stations with the same pressures, and drawing isobars between them (as discussed in Chapter One). These isobars are drawn, as a standard, with four millibars of space between each line, and they are labeled accordingly. At this point, it would become clear where the low and high-pressure systems are located, and he/she could draw either a big red “L” or a blue “H” to signify these locations. Finally, he/she could draw other symbols, such as fronts and troughs, as needed, depending on the chart type. We now have enough of a picture to move onward in the discussion of winds.

Notice the winds in Figure 2-3 are moving in generally the same direction in the areas between each of the pressure systems. If you look closely, you may even notice the winds are moving almost parallel to the isobars, in most situations. After enough observation, you may also recognize a pattern of air circulation around high- and low-pressure systems. In fact, each of these characteristics is a result of pressure differences causing the air to circulate in a consistent pattern: parallel (or almost parallel) to isobars, clockwise around high pressure, and counterclockwise around low pressure. Next, we will discuss why winds blow in this fashion.
Pressure Gradients

The spacing of isobars indicates the rate of pressure change over a horizontal distance. In Figure 2-4, the isobars are more closely spaced to the east than they are to the west, indicating that pressure changes more rapidly on the eastern side. The rate of pressure change in a direction perpendicular to the isobars (horizontal distance) is called the pressure gradient and this isobar spacing represents the size of the pressure gradient force (PGF). The PGF is steep or strong, when isobars are close together and is shallow or weak, when the isobars are far apart; the steeper the gradient, the stronger the winds. The PGF is the initial movement of air from high pressure to low pressure, thus it is the initiating force for wind.
Atmospheric circulation moves air in mainly two ways: ascending and descending currents. When the air descends, the downward force against the Earth creates a high-pressure system on the surface. The air then can only spread out and diverge, moving across the surface of the Earth, producing the horizontal flow of air known as wind. Likewise, air moving upward away from the Earth, results in a low at the surface and tries to converge toward the center of the low, also producing wind.

However, the wind cannot and does not blow straight out of a high into a low. These motions are the result of the pressure gradient force (Figure 2-5).
Gradient Winds

While the pressure gradient force causes air to flow from high- to low-pressure across the isobar pattern, another force acts upon the wind to determine its direction. The Coriolis force, created by the Earth’s rotation, diverts the air to the right—regardless of whether the air is near a high- or low-pressure system. The result of these two forces is the gradient winds, which flow perpendicular to the pressure gradient force. This means gradient winds flow parallel to the isobars (Figure 2-6) and results in circulation flowing clockwise around highs and counterclockwise around lows. Finally, gradient winds are found above 2000 feet AGL.

Surface Winds

When we consider winds below 2000 feet AGL, we cannot ignore the role of surface friction in the analysis of wind direction. Surface friction reduces the speed of the wind, which causes a reduction in the Coriolis force. This results in a different set of forces that must be balanced: the PGF, Coriolis force, and friction. When the new balance of forces is reached, the air blows at an angle across the isobars from high pressure to low pressure. This angle varies as a result of the type of terrain, but for our purposes, we will assume a 45° angle (Figure 2-7). Another way to think of this effect is that the Coriolis force still tries to turn the wind to the right, from its initial intended direction of the PGF, but it does not turn to the right quite as much as with gradient winds. Thus, surface winds still move clockwise around highs, and counterclockwise around lows, but since they blow across the isobars at a 45° angle, they also have a component of motion that moves air out of the high pressure and into the low. Thus, given a gradient wind we can calculate the appropriate surface winds as shown in Figure 2-8.
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**Figure 2-7** Surface Winds are Deflected Across Isobars Towards Lower Pressure

<table>
<thead>
<tr>
<th>Gradient:</th>
<th>N</th>
<th>E</th>
<th>S</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface:</td>
<td>NW</td>
<td>NE</td>
<td>SE</td>
<td>SW</td>
</tr>
</tbody>
</table>

**Figure 2-8** Surface Winds Relates to Gradient Wind Above It

**Buys Ballot’s Law, A Rule Of Thumb**

A rule of thumb to help remember the direction of the wind in relation to a pressure system is Buys Ballot’s Law. This law states that if the wind is at your back, the area of lower pressure will be to your left. When standing on the Earth’s surface, the low will be slightly forward or directly left because the winds flow across the isobars.

**Movement of Pressure Systems and Large Scale Wind Patterns**

Weather in the Temperate Zone (which includes the U.S.) and farther north changes almost constantly with the passage of highs and lows. These migrating systems move from west to east with the prevailing westerly winds. They are accompanied by wind shifts, and with some exceptions, large and rapid changes in temperature and broad areas of precipitation. These systems furnish the most significant means of heat transfer between high and low latitudes.

**The Jet Stream**

Wind speeds generally increase with height through the troposphere, reaching a maximum near the tropopause, and often culminating in the jet stream. The jet stream is a narrow band of strong winds of 50 knots or more that meanders vertically and horizontally around the hemisphere in wave-like patterns. The jet streams (polar and subtropical) have a profound influence on weather patterns.
These winds average about 100 to 150 knots but may reach speeds in excess of 250 knots (Figure 2-9). Since the jet stream is stronger in some places than in others, it rarely encircles the entire hemisphere as a continuous river of wind. More frequently, it is found in segments from 1000 to 3000 miles in length, 100 to 400 miles in width, and 3000 to 7000 feet in depth.

The average height of jet stream winds is about 30,000 feet MSL, but they can be above or below this level depending on the latitude and the season. During the winter, the position of the jet stream is further south, the core rises to higher altitudes, and its speed is faster than in the summer.

The existence of jet streams at operational altitudes requires additional aircrew flight planning consideration. The greater headwind component for westbound aircraft will increase fuel consumption and may require additional alternate landing fields along the route. Wind shear associated with the jet stream may also cause turbulence, forcing the aircrew to change altitude or course.

**Local Winds**

The term “local,” in the case of wind systems, applies to areas whose sizes range from tens of miles across, to long, geographically thin areas. The local wind systems created by mountains, valleys, and water masses are superimposed on the general wind systems and may cause significant changes in the weather.
Sea and Land Breezes

The differences in the specific heat of land and water cause land surfaces to warm and cool more rapidly than water surfaces through insolation and terrestrial radiation. Therefore, land is normally warmer than the ocean during the day and colder at night. This difference in temperature is more noticeable during the summer and when there is little horizontal transport of air in the lower levels of the atmosphere. In coastal areas, this difference of temperature creates a tendency for the warmer, less dense air to rise, and the cooler, denser air to sink, which produces a pressure gradient. During the day, the pressure over the warm land becomes lower than over the colder water. The cool air over the water moves toward the lower pressure, replacing the warm air over the land that moved upward. The resulting onshore wind, blowing from the sea, is called a sea breeze, with speeds sometimes reaching 15 to 20 knots (Figure 2-10).

At night, the circulation is reversed so that the air movement is from land to sea, producing an offshore wind called the land breeze (Figure 2-10). The sea breezes are usually stronger than the land breezes, but they seldom penetrate far inland. Land and sea breezes are shallow in depth, and should be considered during takeoff and landing near large lakes and oceans.
Mountain and Valley Winds

In the daytime, mountain slopes are heated by the Sun’s radiation, and in turn, they heat the adjacent air through conduction. This air usually becomes warmer than air farther away from the slope at the same altitude and, since warmer air is less dense, it begins to rise (Figure 2-10). It cools while moving away from the warm ground, increasing its density. It then settles downward, towards the valley floor, completing a pattern of circulation. This downward motion forces the warmer air near the ground up the mountain and since it is then flowing from the valley, it is called a valley wind.
At night, the air in contact with the mountain slope is cooled by outgoing terrestrial radiation and becomes more dense than the surrounding air. As the denser air flows downhill, from the top of the mountain, it is called the mountain wind, and a circulation opposite to the daytime pattern forms.

These winds are of particular importance for light aircraft, helicopter, and low-level operations. In mountainous areas where the performance of some fixed-wing aircraft or helicopters is marginal, the location of mountain and valley winds can be critical.

**Atmospheric Moisture**

Moisture is water in any of its three states: solid, liquid, or gas. As water changes from one state to another, it releases (or absorbs) heat to (or from) the atmosphere. For example, when water in the atmosphere freezes, it releases heat into the air, and the air becomes warmer. Air can hold only a certain amount of water depending on the air temperature. The higher the temperature, the more water vapor the air can hold (Figure 2-13). The air reaches saturation when it contains the maximum amount of water vapor for that temperature.

![Figure 2-13 Dots Illustrate the Increased Water Vapor Capacity of Warmer Air](image)

The dew point temperature \( (T_D) \) is the temperature at which saturation occurs. The dew point is a direct indication of the amount of moisture present in the air. The higher the dew point, the greater chances for clouds, fog, or precipitation.

If there is a difference between the air temperature and the dew point temperature, this is known as the dew point depression or dew point spread, and the dew point will always be the lower of the two. The dew point can never be higher than the air temperature, only equal to or less than. This spread provides a good indication of how close the atmosphere is to the point of saturation. When the dew point depression reaches about 4°F, the air is holding close to the maximum amount of water vapor possible. If this spread continues to decrease, moisture will begin to condense from the vapor state to the liquid or solid state and become visible. This visible moisture can form dew or frost on exposed surfaces, fog near the ground, or clouds higher in the atmosphere.
atmosphere. Saturation occurs when the dew point and the air temperature are equal. This can occur either by raising the dew point (evaporation) or lowering the air temperature (cooling).

Another measure of atmospheric moisture is the relative humidity (RH), which is the percent of saturation of the air. The air can become saturated (RH = 100%) by one of two ways. If the air is cooled, the falling air temperature decreases the dew point spread closer to zero, while the RH rises closer to 100%. If evaporation occurs, this adds moisture to the atmosphere, increasing the dew point, which again lowers the dew point spread and increases the RH. Once the dew point spread reaches 4°F, the RH will be 90%, and the water vapor will begin to condense into fog or clouds. Any further cooling or evaporation will produce precipitation, as there will be more water present in the air than it can hold.

207. CHARACTERISTICS AND TYPES OF PRECIPITATION

The characteristics and types of precipitation reveal information about various atmospheric processes. The nature of precipitation may give a clue about a cloud’s vertical and horizontal structure or indicate the presence of another cloud deck aloft. The three characteristics of precipitation are:

1. Showers - Characterized by a sudden beginning and ending, and abruptly changing intensity and/or sky conditions. Showers are associated with cumuliform clouds.

2. Continuous - Also known as steady (not showery). Intensity changes gradually, if at all. Continuous or steady precipitation is associated with stratiform clouds.

3. Intermittent - Stops and restarts at least once during the hour. Intermittent precipitation may be showery or steady, and therefore may be associated with cumuliform or stratiform clouds.

Precipitation takes many forms. A few of the more common types of precipitation are mentioned here.

1. Drizzle – Very small droplets of water that appear to float in the atmosphere.

2. Freezing drizzle – Drizzle that freezes on impact with objects.

3. Rain – Precipitation in the form of water droplets that are larger than drizzle and fall to the ground.

4. Freezing rain – Rain that freezes on impact with objects.

5. Hail or graupel – A form of precipitation composed of irregular lumps of ice that develop in severe thunderstorms, consisting of alternate opaque and clear layers of ice in most cases. Water drops, which are carried upward by vertical currents, freeze into ice pellets, start falling, accumulate a coating of water, and are carried upward again, causing the water to freeze. A
repetition of this process increases the size of the hailstone. It does not lead to the formation of structural ice, but it can cause structural damage to aircraft.

6. Ice pellets or sleet – Small translucent and irregularly shaped particles of ice. They form when rain falls through air with temperatures below freezing. They usually bounce when hitting hard ground and make a noise on impact. Ice pellets do not produce structural icing unless mixed with super-cooled water.

7. Snow – White or translucent ice crystals, usually of branched hexagonal or star-like form that connect to one another forming snowflakes. When condensation takes place at temperatures below freezing, water vapor changes directly into minute ice crystals. A number of these crystals unite to form a single snowflake. Partially melted, or “wet” snow, can lead to structural icing.

8. Snow grains – Very small white, opaque grains of ice. When the grains hit the ground, they do not bounce or shatter. They usually fall in small quantities from stratus-type clouds, never as showers.

Precipitation, depending on the type and intensity, affects aviation in many ways:

Visibility in light rain or drizzle is somewhat restricted. In heavy rain or drizzle, it may drop to a few hundred feet. Rain or drizzle streaming across a windscreen further restricts forward visibility. Snow can greatly reduce visibility and can lead to a total lack of forward vision.

Very heavy rain falling on a runway may cause hydroplaning. During hydroplaning, the tires are completely separated from the runway surface by a thin film of water. Tire traction becomes negligible and the wheels may stop rotating. The tires now provide no braking capability and do not contribute to directional control of the aircraft. Loss of control may result.

If there is enough wet snow on the runway, it tends to pile up ahead of the tires during takeoff. This creates sufficient friction to keep the aircraft from reaching rotation speed and becoming airborne.

Heavy rain ingested into the engines of a jet or turboprop aircraft in flight can cause power loss or even flameout.

Hail can cause serious damage to any aircraft, but so can rain if it is penetrated at very high speed.

Clouds

Clouds may be defined as the visible manifestation of weather. With some knowledge of the weather conditions that cause clouds to develop, a pilot can get an excellent picture of the weather environment and can make a reasonable forecast of the weather conditions to follow. The most important element in the formation of clouds is water vapor.
General Theory of Clouds

Clouds are condensed water vapor, consisting of water droplets or ice crystals. They form when the air becomes saturated either by being cooled to the dew point or through the addition of moisture. Most clouds are the result of cooling from some lifting process, such as surface heating. The excess moisture condenses on minute particles in the atmosphere, thus forming droplets.

Condensation Nuclei

Water vapor requires a surface on which to condense. An abundance of microscopic solid particles, called condensation nuclei, are suspended in the air and provide condensation surfaces. Condensation nuclei consist of dust, salt crystals from the sea, acid salts from industrial waste, ash and soot from volcanoes and forest fires, rock particles from wind erosion, and organic matter from forests and grass lands. The most effective condensation nuclei are the various salts since they can induce condensation even when air is almost, but not completely, saturated.

208. TYPES OF CLOUDS

Clouds provide visible evidence of the atmosphere’s motions, water content, and degree of stability and are therefore weather signposts in the sky. They can be numerous, widespread, form at very low levels, or show extensive vertical development.

Knowledge of principal cloud types helps the aircrew member when being briefed to visualize expected weather conditions. Additionally, knowledge of cloud types helps the pilot recognize potential weather hazards in flight. Clouds are classified according to their appearance, form, and altitude of their bases, and may be divided into four groups:

1. Low clouds, ranging from just above the surface to 6500 feet AGL.
2. Middle clouds with bases between 6500 and 20,000 feet AGL.
3. High clouds with bases usually above 16,000 feet AGL.
4. Special clouds with extensive vertical development.

The height of the cloud base, not the top, determines the classification. A cloud with a base at 5000 feet AGL and a top at 8000 feet AGL is classified as a low cloud. Each group is subdivided by appearance. There are two principal cloud forms:

1. Cumuliform – A lumpy, billowy cloud with a base showing a definite pattern or structure.
2. Stratiform – A cloud with a uniform base, formed in horizontal, sheet-like layers.
Low Clouds

Cloud bases in this category range from just above the surface to 6500 feet AGL (Figure 2-14). Low clouds are mainly composed of water droplets. The low clouds have no special prefix attached to their name. However, if the word nimbo or nimbus appears, beware, these clouds are producing violent or heavy precipitation.

Nimbostratus, a stratiform cloud, produces heavy steady precipitation.

Low clouds frequently present serious hazards to flying. The most serious hazard is the proximity of the cloud base to the surface of the Earth. Some of the low cloud types hide hills, making a collision with the terrain a very real danger, and visibility within low clouds is very poor. Low clouds may also hide thunderstorms. If the clouds are at or below freezing temperatures, icing may result. Icing accumulates faster in low clouds since they are generally denser than middle and high clouds. Turbulence varies from none to moderate. Expect turbulence in and below the clouds. Precipitation from low clouds is generally light rain or drizzle.
Middle Clouds

In this category, cloud bases form between 6500 and 20,000 feet AGL. The names of the middle clouds will contain the prefix alto- (Figure 2-15). They are composed of ice crystals, water droplets, or a mixture of the two.

A special cloud, altocumulus, produces continuous rain, snow, or ice pellets. The cloud base will extend down to about 1000 feet AGL and fog is often present. Expect poor visibility and low ceilings with very slow clearing.

![Figure 2-15 Altocumulus Clouds](image)

Visibility in middle clouds varies depending on cloud density from 1/2 mile to a few feet. Turbulence may be encountered in middle clouds. Frequently these clouds are dark and turbulent enough to make formation flying difficult. Icing is common due to the presence of super-cooled water droplets. Rain, rain and snow mixed, or snow can be encountered in thick middle clouds.

Virga is rain or snow that evaporates before reaching the ground and may be encountered below these clouds.

High Clouds

In this category, cloud bases average 20,000 to 40,000 feet AGL. The names of the high clouds will contain the prefix cirro- or the word cirrus (Figure 2-16).

High clouds have little effect on flying except for moderate turbulence and limited visibility associated with dense jet stream cirrus. Since high clouds are composed mostly of ice crystals,
they have no precipitation and do not constitute an icing hazard. Severe or extreme turbulence is often found in the anvil cirrus of thunderstorms.

![Figure 2-16 Cirrus Clouds](image)

**Special Clouds with Extensive Vertical Development**

This category consists of towering cumulus and cumulonimbus clouds. The base of these clouds is found at the low to middle cloud heights and their tops extend through the high cloud category. Figure 2-17 shows cumulonimbus clouds.

![Figure 2-17 Cumulonimbus Clouds](image)
Towering cumulus are clouds nearing the thunderstorm stage. They can produce heavy rain showers and moderate turbulence in and near the cloud. Icing is common above the freezing level.

Cumulonimbus clouds are thunderstorm clouds. A cumulonimbus cloud is sometimes referred to as a “CB.” Cumulonimbus is an exceedingly dangerous cloud, with numerous hazards to flight such as severe to extreme turbulence, hail, icing, lightning, and other hazards discussed in Chapter Four. Figure 2-18 summarizes the weather conditions found in the various types of clouds.

### Cloud Groups

<table>
<thead>
<tr>
<th></th>
<th>High Clouds</th>
<th>Middle Clouds</th>
<th>Low Clouds</th>
<th>Clouds with Extensive Vertical Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility</td>
<td>Good to Fair</td>
<td>1/2 mile to a few feet</td>
<td>A few feet</td>
<td>A few feet</td>
</tr>
<tr>
<td>Icing</td>
<td>None to Light</td>
<td>None to Moderate</td>
<td>None to Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>Turbulence</td>
<td>None to Light</td>
<td>None to Moderate</td>
<td>None to Moderate</td>
<td>Severe</td>
</tr>
</tbody>
</table>

**Figure 2-18  Cloud Families**

### 209. ATMOSPHERIC STABILITY

One of the most important meteorological considerations to a pilot is stability. Atmospheric stability is one of the primary determinants of weather encountered in flight. In some cases, a pilot may be able to determine if stable or unstable conditions exist along the route of flight.

There are three conditions of stability: stable, neutral stable, and unstable. We will consider each of these individually by observing a ball inside a bowl. If the ball is displaced, and tends to return to its original position, the ball is said to be stable (Figure 2-19).

**Figure 2-19 Stable**
If a ball on a flat table is displaced, it will tend to remain in its new position and is said to be neutrally stable (Figure 2-20). It will not have a tendency to return to its original position or move away from its final position.

![Figure 2-20 Neutrally Stable](image)

Now, consider an inverted bowl with a ball balanced on top. Once the ball is displaced, it will tend to move away from its original position, never to return, and the ball is said to be in an unstable condition (Figure 2-21).

![Figure 2-21 Unstable](image)

In weather, parts or parcels of an air mass become displaced through one of four lifting methods. The temperature of the surrounding air determines the stability of a quantity of air after it is lifted. Lifted air that is colder than the surrounding air settles when the lifting action is removed, since it is denser. This indicates a stable condition. Lifted air that is warmer than the surrounding air continues to rise when the lifting action is removed because it is less dense. This indicates an unstable condition. This lifted air that continues to rise has reached the point of free convection, which occurs when the lifted air rises with no external lifting force, due only to the parcel’s warmer temperature. Lifted air having the same temperature as the surrounding air after it is lifted will simply remain at the point where the lifting action was removed. This is an example of a neutrally stable atmosphere. If the air behaves in one of these three ways, then we can say the atmosphere has the same condition of stability (Figure 2-22).
210. METHODS OF LIFTING

The four methods of lifting are convergence, frontal, orographic, and thermal (Figure 2-23). Convergence of two air masses, or parts of a single air mass, force the air upward because it has nowhere else to go. Because of the shape of cold fronts, as they move through an area, they will lift the air ahead of the cold air mass. Orographic lifting is a term indicating the force of the wind against a mountainside pushes the air upward. Thermal lifting, also known as convective lifting, is caused when cool air is over a warm surface and it is heightened by intense solar heating on a clear day.

211. STABILITY AND FLIGHT CONDITIONS

Cloud types are helpful in identifying conditions of stability or instability. Cumuliform clouds develop with unstable conditions and stratiform clouds develop with stable conditions (Figure 2-24), assuming sufficient moisture exists for cloud development.
Figure 2-24  Clouds in Stable and Unstable Air

There are a significant number of flight conditions associated with atmospheric stability, as depicted in Figure 2-25. If one or more of these conditions is encountered, the stability of the atmosphere can be easily determined, and other flight conditions can be predicted. Thus, understanding the relationships among stability and flight conditions provides aircrew with a key that unlocks many of the mysteries of weather phenomena.

<table>
<thead>
<tr>
<th>Flight Conditions</th>
<th>Stable Atmosphere</th>
<th>Unstable Atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud type</td>
<td>Stratus</td>
<td>Cumulus</td>
</tr>
<tr>
<td>Turbulence</td>
<td>Smooth</td>
<td>Rough</td>
</tr>
<tr>
<td>Visibility</td>
<td>Poor</td>
<td>Good (outside clouds)</td>
</tr>
<tr>
<td>Winds</td>
<td>Steady</td>
<td>Gusty</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Steady</td>
<td>Showery</td>
</tr>
<tr>
<td>Icing</td>
<td>Rime</td>
<td>Clear</td>
</tr>
<tr>
<td>Air mass</td>
<td>Warm</td>
<td>Cold</td>
</tr>
<tr>
<td>Front</td>
<td>Warm</td>
<td>Cold</td>
</tr>
</tbody>
</table>

Figure 2-25  Atmospheric Stability and Flight Conditions

Being able to recognize the stability of the air while flying will help prepare you for the various flight conditions you are experiencing. When encountering a change in weather conditions—apart from what was briefed—the relationships in Figure 2-25 can also be a guide to understanding the different options available and to making better decisions for avoiding weather hazards. Here are some additional “signs in the sky” that indicate stable air: temperature inversions, low fog and stratus, and rising air temperature while climbing. Thunderstorms, showers, towering clouds, dust devils, and rapidly decreasing air temperature while climbing all indicate unstable atmospheric conditions.
STUDY QUESTIONS

1. Which one of the following types of isobar spacing would indicate a weak pressure gradient force?
   a. Narrow
   b. Deep
   c. Wide
   d. Tight

2. Which one of the following types of pressure gradients would indicate the presence of strong winds?
   a. Steep
   b. Low pressure
   c. Weak
   d. Shallow

3. The initial movement of air toward a low-pressure area is caused by the_____________.
   a. pressure gradient force
   b. Coriolis force
   c. centrifugal force
   d. force of friction

4. Coriolis force directs air __________, with respect to its initial direction of motion.
   a. vertically
   b. to the left
   c. horizontally
   d. to the right

5. According to Buys Ballot's law, if I have a head wind the area of lower pressure is_______.
   a. to my right
   b. to my left
   c. straight ahead
   d. aft

6. The forces that determine the wind direction in the atmosphere are weakened at the Earth’s surface by the_____________.
   a. pressure gradient force
   b. Coriolis force
   c. centrifugal force
   d. force of friction
7. Gradient winds move parallel to the isobars above 2000 feet AGL because they are not affected by the ________________.
   a. pressure gradient force
   b. Coriolis force
   c. centrifugal force
   d. force of friction

8. The surface wind, when compared with the gradient wind, is of ________________.
   a. lesser speed and blows parallel to the isobars
   b. lesser speed and blows across the isobars toward low pressure
   c. greater speed and blows across the isobars toward high pressure
   d. greater speed and blows across the isobars toward low pressure

9. In the Northern Hemisphere, the wind blows ________________.
   a. from low to high pressure
   b. clockwise around a low
   c. counterclockwise around a low
   d. perpendicular to the isobars

10. Gradient winds blow parallel to the isobars because of the ________________.
    a. Coriolis force
    b. frictional force
    c. centrifugal force
    d. wind force

11. The sea breeze blows from the ______ to the ______ during the ______, and the land breeze blows from the ______ to the ______ during the ______.
    a. water, land, day; water, land, night
    b. land, water, day; land, water, night
    c. land, water, day; water, land, night
    d. water, land, day; land, water, night

12. ___________ and water vapor must be present in the atmosphere for precipitation to occur.
    a. Carbon dioxide
    b. Condensation nuclei
    c. Wind
    d. Nitrogen
13. When air contains the maximum moisture possible for a given temperature, the air is _________.

14. The temperature to which air must be cooled to become saturated is called the __________________.

15. Which one of the following conditions could produce fog, clouds, or precipitation?
   a. Dew point spread of 5°C
   b. Warm air over cold water.
   c. RH of 0%
   d. RH of 100%

16. Stratiform clouds are associated with (stable/unstable) flight conditions.

17. At which altitude could an altostratus cloud be found?
   a. 5000 feet MSL
   b. 5000 feet AGL
   c. 10,000 feet AGL
   d. 25,000 feet AGL

18. Cumulonimbus clouds typically produce which type of precipitation?
   a. Drizzle
   b. Light steady
   c. Heavy showers
   d. Fog

19. Nimbostratus clouds will produce ____________ precipitation.
   a. heavy showery
   b. light showery
   c. heavy steady
   d. light steady

20. __________ defines air with the same temperature as the surrounding air.
   a. Unstable
   b. Neutrally stable
   c. Stable
   d. Displaced
21. Which one of the following correctly lists the four methods of lifting?
   a. Convergence, frontal, orographic, and thermal
   b. Convergence, subsidence, orographic, and thermal
   c. Convergence, convection, adiabatic, and katabatic
   d. Divergence, subsidence, frontal, and convective

22. If lifted air is warmer than the surrounding air, then _________ clouds will form resulting in _________ flight conditions.

23. If stratus clouds are present, which of the following flight conditions could be expected?
   a. Rough turbulence, good visibility, showery precipitation, and clear icing
   b. Smooth flight, good visibility, steady winds, and no precipitation
   c. Poor visibility, steady winds, continuous precipitation, and rime icing
   d. Smooth flight, turbulent flight, good visibility, and showery precipitation

24. Which one of the following types of clouds could be produced by unstable conditions?
   a. Cirrus
   b. Cumulonimbus
   c. Stratus
   d. Nimbostratus