

Flight Training Fundamentals – Principles of Flight

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This is a continuing series of the Pilot's Handbook of Aeronautical Knowledge series for flight training students. The handbook is published by the Federal Aviation Administration and provides basic knowledge for the flight student who is learning to fly as well as pilots seeking advanced pilot certification. Here are some important parts from Chapter 3 – Principles of Flight – that explains Atmospheric Pressure and Theories in the Production of Lift. This section describes atmospheric pressure.

Introduction

The atmosphere is an envelope of air that surrounds the Earth and rests upon its surface. It is as much a part of the Earth as the seas or the land, but air differs from land and water as it is a mixture of gases. It has mass, weight, and indefinite shape. The atmosphere is composed of 78 percent nitrogen, 21 percent oxygen, and 1 percent other gases, such as argon or helium. Some of these elements are heavier than others. The heavier elements, such as oxygen, settle to the surface of the Earth, while the lighter elements are lifted up to the region of higher altitude. Most of the atmosphere's oxygen is contained below 35,000 feet altitude.

Air, like fluid, is able to flow and change shape when subjected to even minute pressures because it lacks strong molecular cohesion. For example, gas completely fills any container into which it is placed, expanding or contracting to adjust its shape to the limits of the container.

Atmospheric Pressure

Although there are various kinds of pressure, pilots are mainly concerned with atmospheric pressure. It is one of the basic factors in weather changes, helps to lift an aircraft, and actuates some of the important flight instruments. These instruments are the altimeter, airspeed indicator, vertical speed indicator, and manifold pressure gauge.

Air is very light, but it has mass and is affected by the attraction of gravity. Therefore, like any other substance, it has weight, and because of its weight, it has force. Since it is a fluid substance, this force is exerted equally in all directions, and its effect on bodies within the air is called pressure.

Under standard conditions at sea level, the average pressure exerted by the weight of the atmosphere is approximately 14.70 pounds per square inch (psi) of surface, or 1,013.2 millibars (mb). Its thickness is limited; therefore, the higher the altitude, the less air there is above. For this reason, the weight of the atmosphere at 18,000 feet is one-half what it is at sea level. The pressure of the atmosphere varies with time and location. Due to the changing atmospheric pressure, a standard reference was developed. The standard atmosphere at sea level is a surface temperature of 59 °F or 15 °C and a surface pressure of 29.92 inches of mercury ("Hg), or 1,013.2 mb.

A standard temperature lapse rate is one in which the temperature decreases at the rate of approximately 3.5 °F or 2 °C per thousand feet up to 36,000 feet which is approximately -65 °F or -55 °C. Above this point, the temperature is considered constant up to 80,000 feet. A standard pressure lapse rate is one in which pressure decreases at a rate of approximately 1 "Hg per 1,000 feet of altitude gain to 10,000 feet. The International Civil Aviation Organization (ICAO) has established this as a worldwide standard, and it is often referred to as International Standard Atmosphere (ISA) or ICAO Standard Atmosphere. Any temperature or pressure that differs from the standard lapse rates is considered nonstandard temperature and pressure.

Since aircraft performance is compared and evaluated with respect to the standard atmosphere, all aircraft instruments are calibrated for the standard atmosphere.

Pressure Altitude

Pressure altitude is the height above a standard datum plane (SDP), which is a theoretical level where the weight of the atmosphere is 29.92 "Hg (1,013.2 mb) as measured by a barometer. An altimeter is essentially a sensitive barometer calibrated to indicate altitude in the standard atmosphere. If the altimeter is set for 29.92 "Hg SDP, the altitude indicated is the pressure altitude. As atmospheric pressure changes, the SDP may be below, at, or above sea level. Pressure altitude is important as a basis for determining airplane performance, as well as for assigning flight levels to airplanes operating at or above 18,000 feet.

The pressure altitude can be determined by either of two methods:

1. Setting the barometric scale of the altimeter to 29.92 and reading the indicated altitude.
2. Applying a correction factor to the indicated altitude according to the reported altimeter setting.

Density Altitude

SDP is a theoretical pressure altitude, but aircraft operate in a nonstandard atmosphere and the term density altitude is used for correlating aerodynamic performance in the nonstandard atmosphere. Density altitude is the vertical distance above sea level in the standard atmosphere at which a given density is to be found. The density of air has significant effects on the aircraft's performance because as air becomes less dense, it reduces:

- Power because the engine takes in less air.
- Thrust because a propeller is less efficient in thin air.
- Lift because the thin air exerts less force on the airfoils.

Density altitude is pressure altitude corrected for nonstandard temperature. As the density of the air increases (lower density altitude), aircraft performance increases and conversely as air density decreases (higher density altitude), aircraft performance decreases. A decrease in air density means a high density altitude; an increase in air density means a lower density altitude. Density altitude is used in calculating aircraft performance, because under standard atmospheric conditions, air at each level in the atmosphere not only has a specific density, its pressure altitude and density altitude identify the same level.

The computation of density altitude involves consideration of pressure (pressure altitude) and temperature. Since aircraft

performance data at any level is based upon air density under standard day conditions, such performance data apply to air density levels that may not be identical with altimeter indications. Under conditions higher or lower than standard, these levels cannot be determined directly from the altimeter.

Density altitude is determined by first finding pressure altitude, and then correcting this altitude for nonstandard temperature variations. Since density varies directly with pressure, and inversely with temperature, a given pressure altitude may exist for a wide range of temperature by allowing the density to vary. However, a known density occurs for any one temperature and pressure altitude. The density of the air has a pronounced effect on aircraft and engine performance.

Regardless of the actual altitude at which the aircraft is operating, it will perform as though it were operating at an altitude equal to the existing density altitude.

Air density is affected by changes in altitude, temperature, and humidity. High density altitude refers to thin air while low density altitude refers to dense air. The conditions that result in a high density altitude are high elevations, low atmospheric pressures, high temperatures, high humidity, or some combination of these factors. Lower elevations, high atmospheric pressure, low temperatures, and low humidity are more indicative of low density altitude.

Effect of Pressure on Density

Since air is a gas, it can be compressed or expanded. When air is compressed, a greater amount of air can occupy a given volume. Conversely, when pressure on a given volume of air is decreased, the air expands and occupies a greater space. At a lower pressure, the original column of air contains a smaller mass of air. The density is decreased because density is directly proportional to pressure. If the pressure is doubled, the density is doubled; if the pressure is lowered, the density is lowered. This statement is true only at a constant temperature.

Effect of Temperature on Density

Increasing the temperature of a substance decreases its density. Conversely, decreasing the temperature increases the density. Thus, the density of air varies inversely with temperature. This statement is true only at a constant pressure. In the atmosphere, both temperature and pressure decrease with altitude, and have conflicting effects upon density. However, the fairly rapid drop in pressure as altitude is increased usually has the dominating effect. Hence, pilots can expect the density to decrease with altitude.

Effect of Humidity (Moisture) on Density

The preceding paragraphs refer to air that is perfectly dry. In reality, it is never completely dry. The small amount of water vapor suspended in the atmosphere may be almost negligible under certain conditions, but in other conditions humidity may become an important factor in the performance of an aircraft. Water vapor is lighter than air; consequently, moist air is lighter than dry air. Therefore, as the water content of the air increases, the air becomes less dense, increasing density altitude and decreasing performance. It is lightest or least dense when, in a given set of conditions, it contains the maximum amount of water vapor.

Humidity, also called relative humidity, refers to the amount of water vapor contained in the atmosphere, and is expressed as

a percentage of the maximum amount of water vapor the air can hold. This amount varies with temperature. Warm air holds more water vapor, while colder air holds less. Perfectly dry air that contains no water vapor has a relative humidity of zero percent, while saturated air, which cannot hold any more water vapor, has a relative humidity of 100 percent. Humidity alone is usually not considered an important factor in calculating density altitude and aircraft performance, but it does contribute.

As temperature increases, the air can hold greater amounts of water vapor. When comparing two separate air masses, the first warm and moist (both qualities tending to lighten the air) and the second cold and dry (both qualities making it heavier), the first must be less dense than the second. Pressure, temperature, and humidity have a great influence on aircraft performance because of their effect upon density. There are no rules of thumb that can be easily conveyed but the affect of humidity can be determined using online formulas.

We will continue this series from time to time. You can read the entire Pilot's Handbook of Aeronautical Knowledge and even print it out by visiting the [Federal Aviation Administration's website](#).
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