Figure 8-2. Analog instruments embedded in a glass cockpit for redundancy (Cessna Sky Hawk).

Figure 8-3. Engine instruments centered on the cockpit front instrument panel for easy viewing by both co-pilot and pilot (Boeing 737 aircraft).

ENGINE INSTRUMENTS

The center position of the cockpit front panel is generally occupied by engine instrumentation. The central location (***Figure 8-3***) facilitates both the pilot and copilot to monitor critical engine parameters. Multiengine aircraft generally use a single gauge for a particular engine parameter which displays information for all engines through the use of multiple pointers on the same dial face, whereas in some cases, a single gauge is used to display a certain engine parameter separately for every engine.

NAVIGATION INSTRUMENTS

The Navigation instruments are those that contribute information used by the pilot to guide the aircraft along a definite course. This group includes compasses of various kinds, some of which incorporate the use of radio signals to define a specific course while flying the aircraft en route from one airport to another. Other navigational instruments are designed specifically to direct the pilot's approach to landing at an airport (***Figure 8-4***). Traditional navigation instruments include a clock and a magnetic compass. Along with the airspeed indicator and wind information, these can be used to calculate navigational progress. Radios and instruments sending locating information via radio waves have replaced these manual efforts in modern aircraft. Global position systems (GPS) use satellites to pinpoint the location of the aircraft via geometric triangulation. This technology is built into some aircraft instrument packages for navigational purposes.

THE ATMOSPHERE

The Earth's atmosphere is a layer of gas that is held on by gravity, which prevents objects and particles flying off into space. The Earth atmosphere has a mass of about 5 × 1018 kg, three quarters of which is within about 11 km (6.8 miles; 36 000 ft) of the surface. From

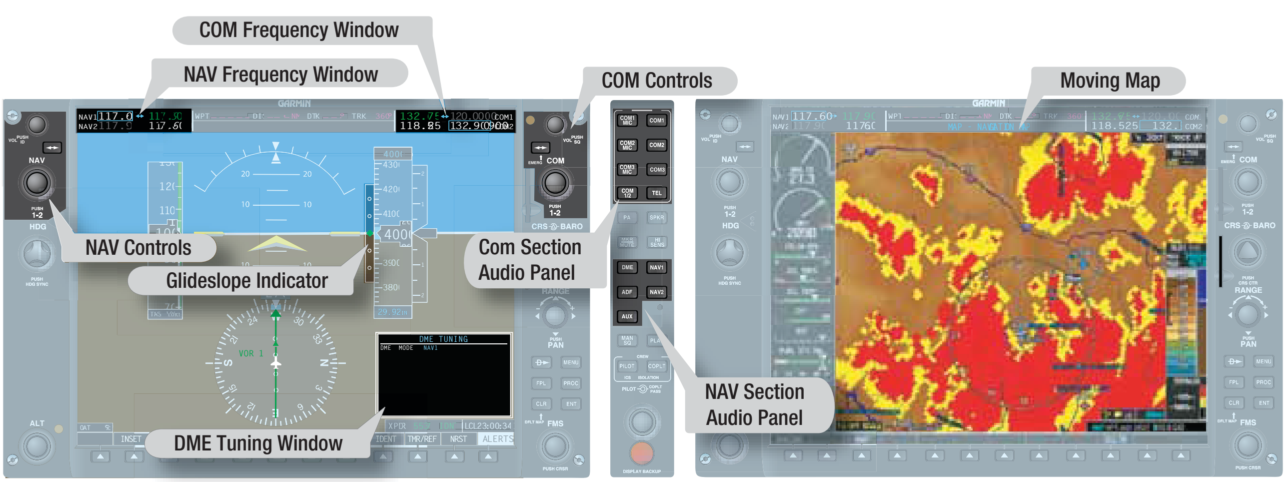

Figure 8-4. The composition of the Earth's atmosphere.

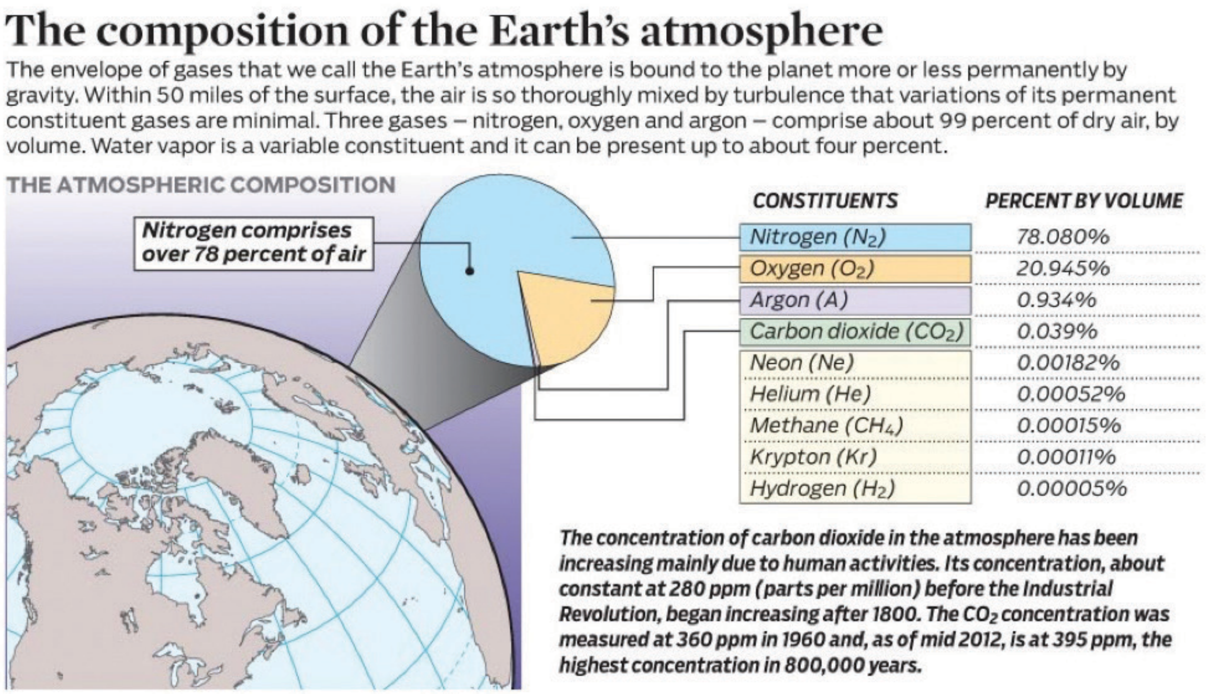

Figure 8-5. The composition of the Earth's atmosphere.

that point the atmosphere gets increasingly thin and eventually becomes space at an indistinct point around 100 km above sea level.

CHARACTERISTICS OF THE ATMOSPHERE

Salient characteristics of the atmosphere are measured in pressure, density, humidity and temperature. These values are not fixed and vary immensely depending on time and geographical location.

PRESSURE

Atmospheric pressure is the weight of the column of gas directly above a certain point. Atmospheric pressure decreases, the higher the measurement is taken off the ground, due to the smaller column of gas remaining above. A column of air (one square inch) extending from sea level to the top of the atmosphere weighs approximately 14.7 pounds; therefore, atmospheric pressure is stated in pounds per square inch (psi). Thus, atmospheric pressure at sea level is 14.7 psi (***Figure 8-6***). Atmospheric pressure is measured with an instrument shown in ***Figure 8-7***, called a barometer, composed of mercury in a tube that records atmospheric pressure in inches of mercury ("Hg). The standard measurement in aviation altimeters and U.S. weather reports has been "Hg. However, world-wide weather maps and some non-U.S. manufactured aircraft instruments indicate pressure in millibars (mb), an SI metric unit. Aviators often interchange references to atmospheric pressure between linear displacement (e.g., inches of mercury) and units of force (e.g., psi).

Over the years, meteorology has shifted its use of linear displacement representation of atmospheric pressure to units of force. The unit of force nearly universally used today to represent atmospheric pressure in meteorology is the hectoPascal (hPa). A Pascal is a SI metric unit that expresses force in Newtons per square meter. A hectoPascal is 100 Pascals. 1 013.2 hPa is equal to 14.7 psi which is equal to 29.92 "Hg (***Figure 8-8***). Pressure variation with increasing altitude is shown in ***Figure 8-9***. As depicted in the graph, the decrease in pressure is a rapid one and, at 50 000 feet, the atmospheric pressure has dropped to almost one-tenth of the sea level value. As an aircraft ascends, atmospheric pressure drops, the quantity of oxygen decreases, and temperature drops. These changes in altitude affect an aircraft's performance in such areas as lift and engine horsepower. The effects of temperature, altitude, and density of air on aircraft performance are covered in the following paragraphs.

DENSITY

Density is weight per unit of volume. Since air is a mixture of gases, it can be compressed. If the air in one container is under half as much pressure as an equal amount of air in

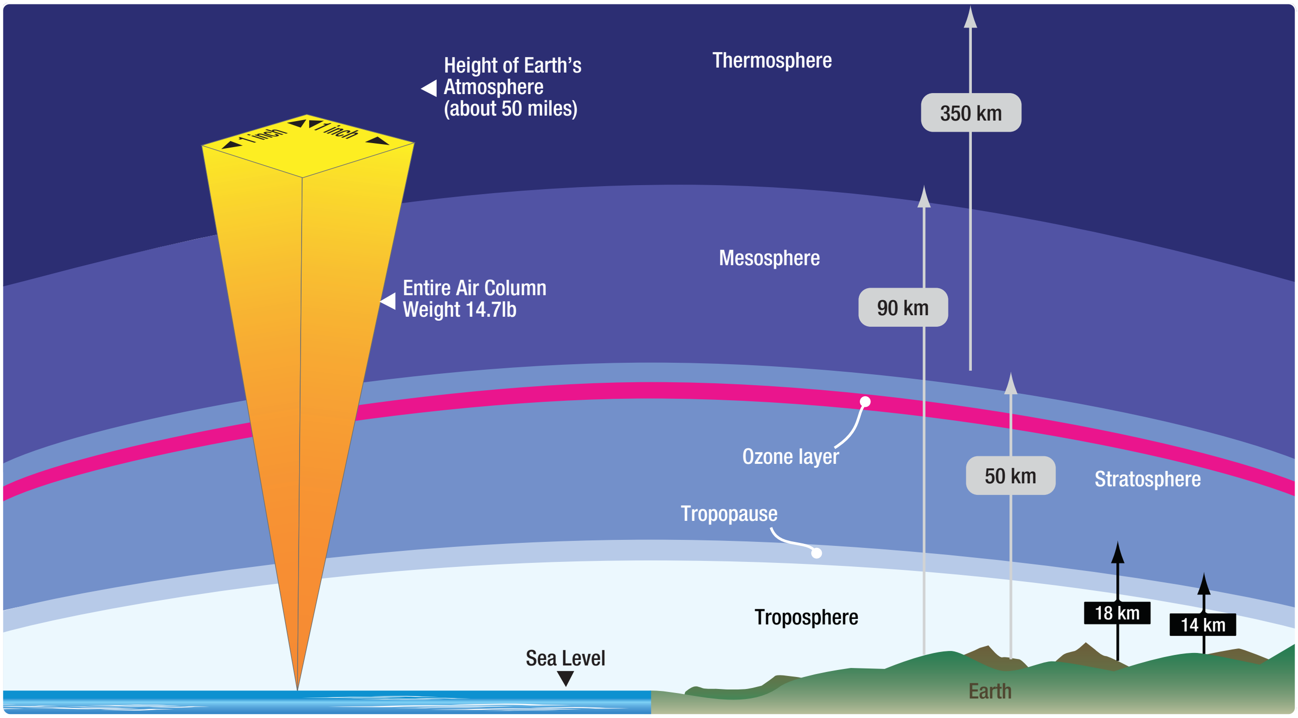

Figure 8-6. The weight exerted by a 1 square inch column of air stretching from sea level to the top of the atmosphere is what is measured when it is said that atmospheric pressure is equal to 14.7 psi.

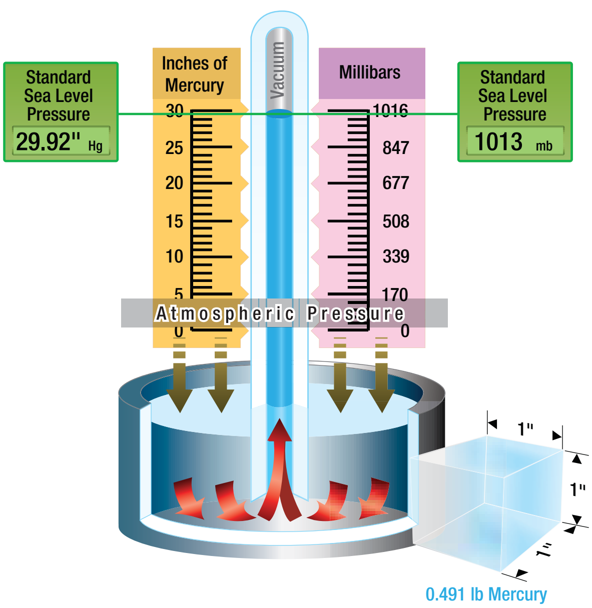

Figure 8-7. Temperature variation with increasing altitude in various atmospheric layers.

an identical container, the air under the greater pressure weighs twice as much as that in the container under lower pressure. The air under greater pressure is twice as dense as that in the other container. For the equal weight of air, that which is under the greater pressure occupies only half the volume of that under half the pressure.

The density of gases is governed by the following rules:

1. Density varies in direct proportion with the pressure.
2. Density varies inversely with the temperature. Thus, air at high altitudes is less dense than air at low altitudes, and a mass of hot air is less dense than a mass of cool air. Changes in density affect the aerodynamic performance of aircraft with the same horsepower. An aircraft can fly faster at a high altitude where the air density is low than at a low altitude where the density is greater. This is because air offers less resistance to the aircraft when it contains a smaller number of air particles per unit of volume.

HUMIDITY

Humidity is the amount of water vapor in the air. The maximum amount of water vapor that air can hold varies with the temperature. The higher the temperature of the air, the more water vapor it can absorb.

1. Absolute humidity is the weight of water vapor in a unit volume of air.
2. Relative humidity is the ratio, in percent, of the moisture actually in the air to the moisture it would hold if it were saturated at the same temperature and pressure.

Assuming that the temperature and pressure remain the same, the density of the air varies inversely with the

Atmospheric Pressure

Standard atmospheric pressure at sea level is also known as 1 atmosphere, or 1 atm. The following measurements of standard atmospheric pressure are all equal to each other.

1 atm (atmosphere)	=	14.7 psi (prounds per square inch)	=	29.92 in Hg (inches of mercury)	=	1013.2 hPa (or 101325 newtons per square meters)	=	1013.2 mb (millibars)	=	760 mm Hg (millimeters of mercury)

Figure 8-8. Various equivalent representations of atmospheric pressure at sea level.

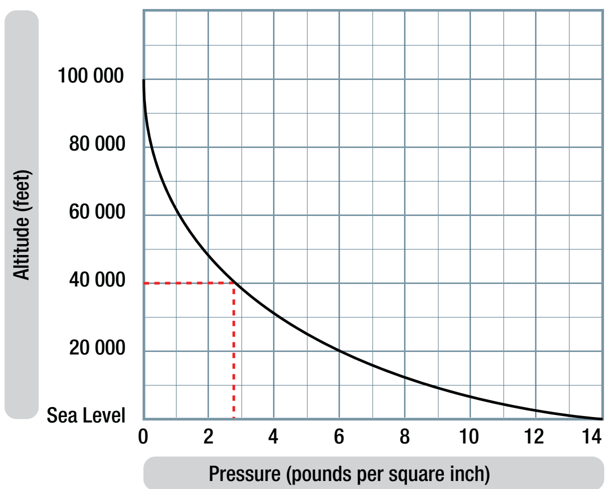

Figure 8-9. Atmospheric pressure decreasing with altitude. At sea level the pressure is 14.7 psi, while at 40 000 feet, as the dotted lines show, the pressure is only 2.72 psi.

humidity. On damp days, the air density is less than on dry days. For this reason, an aircraft requires a longer runway for takeoff on damp days than it does on dry days. By itself, water vapor weighs approximately five eighths as much as an equal amount of perfectly dry air. Therefore, when air contains water vapor, it is not as heavy as dry air containing no moisture.

TEMPERATURE AND ALTITUDE

Temperature variations in the atmosphere are of concern to aviators. Weather systems produce changes in temperature near the earth's surface. Temperature also changes as altitude is increased. The variation in temperature with increasing altitude in while crossing various layers of the atmosphere is illustrated in ***Figure 8-10***.

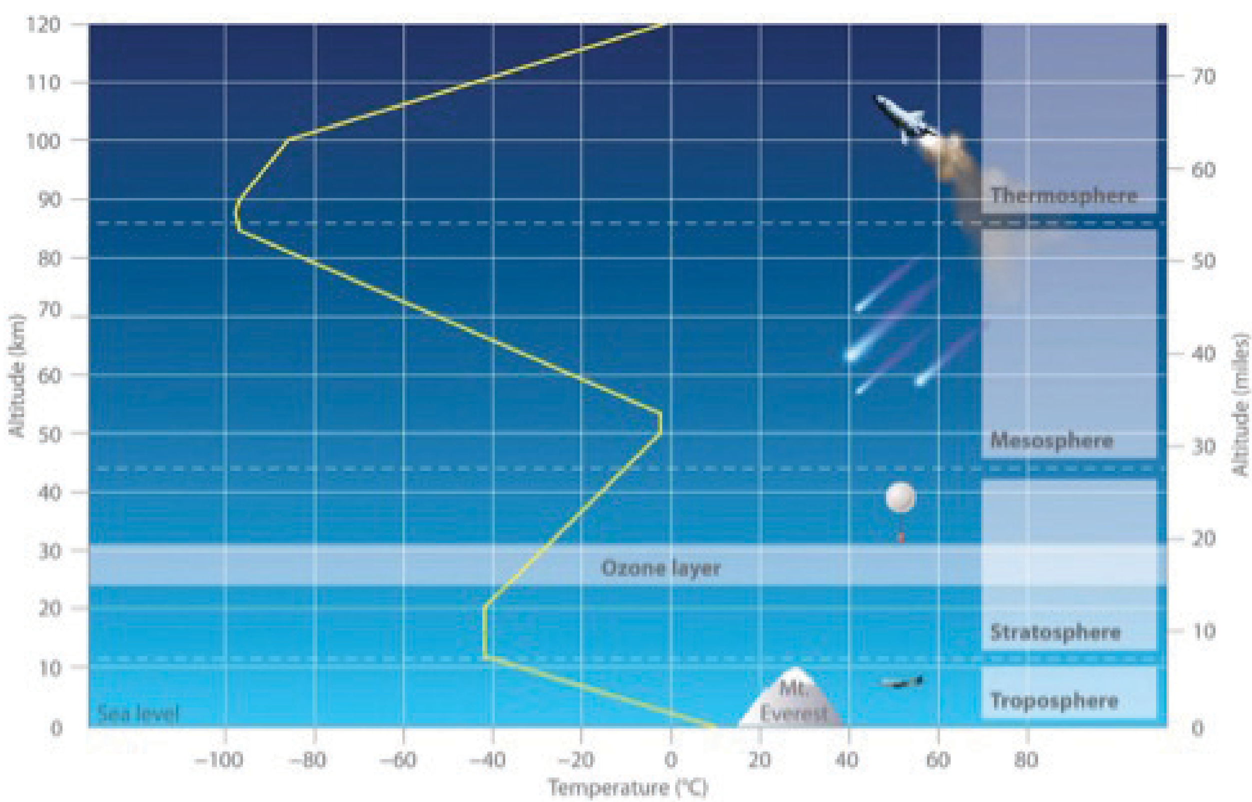

Figure 8-10. Temperature variation with increasing altitude in various atmospheric layers.

Most civilian aviation takes place in the troposphere in which temperature decreases as altitude increases. The rate of change is somewhat constant at about –2 °C or –3.5 °F for every 1 000 feet of increase in altitude. The upper boundary of the troposphere is the Tropopause. It is characterized as a zone of relatively constant temperature of –57 °C or –69 °F. Above the Tropopause lies the Stratosphere. Temperature increases with altitude in the Stratosphere to near 0 °C before decreasing again in the Mesosphere, which lies above it. The stratosphere contains the ozone layer that protects the earth's inhabitants from harmful UV rays. Some civilian lights and numerous military lights occur in the stratosphere.

INTERNATIONAL STANDARD ATMOSPHERE

The atmosphere is never at rest. Pressure, temperature, humidity, and density of the air are continuously changing. To provide a basis for theoretical calculations, performance comparisons and instrumentation parity, standard values for these and other characteristic of the atmosphere have been developed. ICAO, ISO, and various governments establish and publish the values known as the International Standard Atmosphere (***Figure 8-11***).

In a theoretical example, where the real atmosphere was the same as ISA, the sea level temperature would be 15° C. Ascending 154m would drop the temperature by 1° C. The temperature drops 6.5° C per 1 000 m, up about to 11 000 m. Similarly, pressure would be 1 013 hPa at sea level. Every 8m of ascension would decrease the pressure by 1 hPa. This ratio of pressure difference to vertical distance is called the vertical 'baric gradient'. The ratio is constant in low atmospheric layers, but the baric gradient decreases higher up. While in the real world atmosphere surfaces are wavy, they are represented on maps as lines parallel to sea level. These lines are called isobars and are usually depicted 4 millibars apart.

PRESSURE MEASURING DEVICES AND SYSTEMS

A number of instruments inform the pilot of the aircraft's condition and flight situations through the measurement of pressure. Pressure measurements on an aircraft are related to control and operation of aircraft engines, ancillary/environmental systems like hydraulic, pneumatic, air conditioning and oxygen, while other pressure instruments specialize in air data measurements or aerodynamic flight planning parameters (speeds, altitudes), a category known as Anemo-Barometric systems (***Figure 8-12***).

ALTITUDE	TEMPERATURE		PRESSURE		DENSITY	
Feet	°F	°C	psi	hPa	slug/ft³	kg/m³
Sea Level	59	15	14.67	1013.53	0.002378	1.23
1 000	55.4	13	14.17	977.16	0.002309	1.19
2 000	51.9	11	13.66	941.82	0.002242	1.15
3 000	48.3	9.1	13.17	908.11	0.002176	1.12
4 000	44.7	7.1	12.69	874.94	0.002112	1.09
5 000	41.2	5.1	12.05	843.07	0.002049	1.06
6 000	37.6	3.1	11.78	812.2	0.001988	1.02
7 000	34	1.1	11.34	781.85	0.001928	0.99
8 000	30.5	-0.9	10.92	752.91	0.001869	0.96
9 000	26.9	-2.8	10.5	724.28	0.001812	0.93
10 000	23.3	-4.8	10.11	697.06	0.001756	0.9
15 000	5.5	-14.7	8.3	571.82	0.001496	0.77
20 000	-12.3	-24.6	6.75	465.4	0.001267	0.65
25 000	-30.2	-34.5	5.46	376.01	0.001066	0.55
30 000	-48	-44.4	4.37	301.3	0.000891	0.46
35 000	-65.8	-54.3	3.47	238.42	0.000738	0.38
40 000	-69.7	-56.5	2.72	187.54	0.000587	0.3
45 000	-69.7	-56.5	2.15	147.48	0.000462	0.24
50 000	-69.7	-56.5	1.68	115.83	0.000362	0.19

Figure 8-11. The International Standard Atmosphere.