MODULE 08

FOR B1 & B2 CERTIFICATION

BASIC AERODYNAMICS

Aviation Maintenance Technician Certification Series

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REVISION LOG

VERSION	EFFECTIVE DATE	DESCRIPTION OF CHANGE
001	2015 01	Module Creation and Release
002	2016 07	Format Update and Minor Content Revisions
003	2018 07	Refined content sequencing to Appendix 1.

Version 003 - The following content was added for clarity:

Sub-Module 02 Free Stream Air Flow, Wash-In/Wash-Out

Sub-Module 03 Steady State Flight; High Speed Aerodynamics; Helicopter Aerodynamics

Sub-Module 04 Passive and Active Stability

BASIC AERODYNAMICS

SUB-MODULE 01
PHYSICS OF THE ATMOSPHERE

SUB-MODULE 02
AERODYNAMICS

SUB-MODULE 03
THEORY OF FLIGHT

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SUB-MODULE 04
FLIGHT STABILITY AND DYNAMICS

8.1 - PHYSICS OF THE ATMOSPHERE

BASIC AERODYNAMICS

Three topics that are directly related to the manufacture, operation, and repair of aircraft are: aerodynamics, aircraft assembly, and rigging. Each of these subject areas, though studied separately, eventually connect to provide a scientific and physical understanding of how an aircraft is prepared for flight. A logical place to start with these three topics is the study of basic aerodynamics. By studying aerodynamics, a person becomes familiar with the fundamentals of aircraft flight.

Aerodynamics is the study of the dynamics of gases. The interaction between a moving object and the atmosphere is the primary interest in this module. The movement of an object and its reaction to the air flow around it can be seen when watching water passing the bow of a ship. The major difference between water and air is that air is compressible and water is incompressible. The action of the airflow over a body is a large part of the study of aerodynamics. Some common aircraft terms, such as rudder, hull, water line, and keel beam, were borrowed from nautical terms.

Many textbooks have been written about the aerodynamics of aircraft flight. It is not necessary for an airframe and powerplant technician to be as knowledgeable as an aeronautical design engineer about aerodynamics. The technician must be able to understand the relationships between how an aircraft performs in flight and its reaction to the forces acting on its structural parts. Understanding why aircraft are designed with particular types of primary and secondary control systems and why the surfaces must be aerodynamically smooth becomes essential when maintaining today's complex aircraft.

The theory of flight should be described in terms of the laws of flight because what happens to an aircraft when it flies is not based upon assumptions, but upon a series of facts. Aerodynamics is a study of laws which have been proven to be the physical reasons why an airplane flies. The term aerodynamics is derived from the combination of two Greek words: "aero," meaning air, and "dyne," meaning force of power. Thus, when "aero" joins "dynamics" the result is "*aerodynamics*"; the study of objects in motion through the air and the forces that produce or change such motion.

Aerodynamically, an aircraft can be defined as an object traveling through space that is affected by the changes in atmospheric conditions. To state it another way, aerodynamics covers the relationships between the aircraft, relative wind, and atmosphere.

PHYSICS OF THE ATMOSPHERE

Before examining the fundamental laws of flight, several basic facts must be considered. An aircraft operates in the air. Therefore, those properties of air that affect the control and performance of an aircraft must be understood.

The air in the earth's atmosphere is composed mostly of nitrogen and oxygen. Air is considered a fluid because it fits the definition of a substance that has the ability to flow or assume the shape of the container in which it is enclosed. If the container is heated, pressure increases; if cooled, the pressure decreases. The weight of air is heaviest at sea level where it has been compressed by all of the air above. This compression of air is called atmospheric pressure.

PRESSURE

Atmospheric pressure is usually defined as the force exerted against the earth's surface by the weight of the air above that surface. Weight is force applied to an area that results in pressure. Force (F) equals area (A) times pressure (P), or $F = AP$. Therefore, to find the amount of pressure, divide area into force ($P = F/A$). 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 1-1***)

Atmospheric pressure is measured with an instrument called a barometer, composed of mercury in a tube that records atmospheric pressure in inches of mercury (Hg). (***Figure 1-2***)

The standard measurement in aviation altimeters and U.S. weather reports has been "Hg". However, worldwide weather maps and some non-U.S., manufactured aircraft instruments indicate pressure in millibars (mb), an SI metric unit.

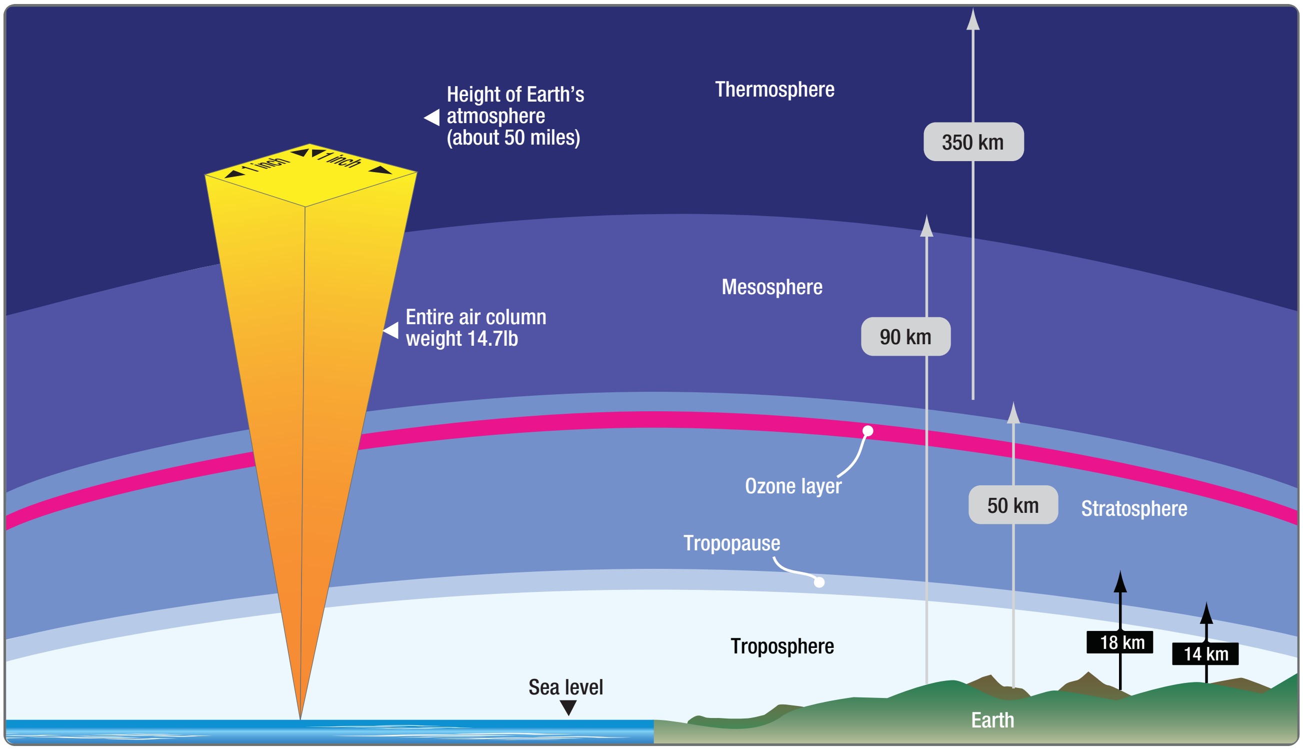

Figure 1-1. The weight exerted by a 1 square inch column of air stretching from sea level to the top of the atmosphere is what is measured when it is said that atmospheric pressure is equal to 14.7 pounds per square inch.

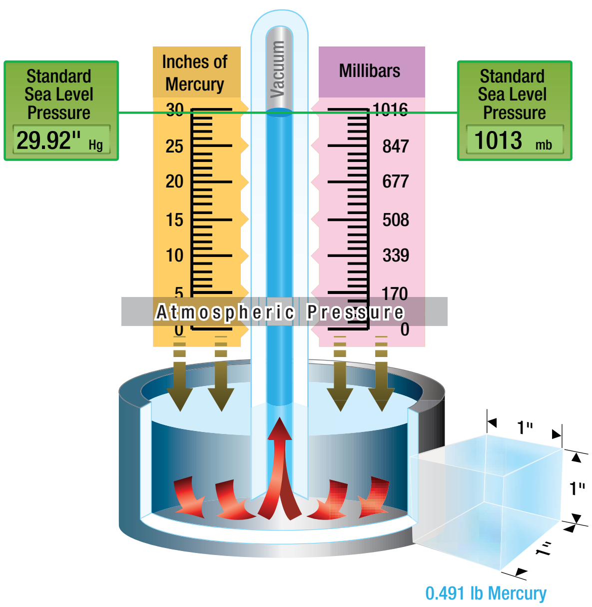

Figure 1-2. Barometer used to measure atmospheric pressure.

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 1-3***)

Atmospheric pressure decreases with increasing altitude. The simplest explanation for this is that the column of air that is weighed is shorter. How the pressure changes for a given altitude is shown in ***Figure 1-4***. The decrease

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 1-3. Various equivalent representations of atmospheric pressure at sea level.

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 an identical container, 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.

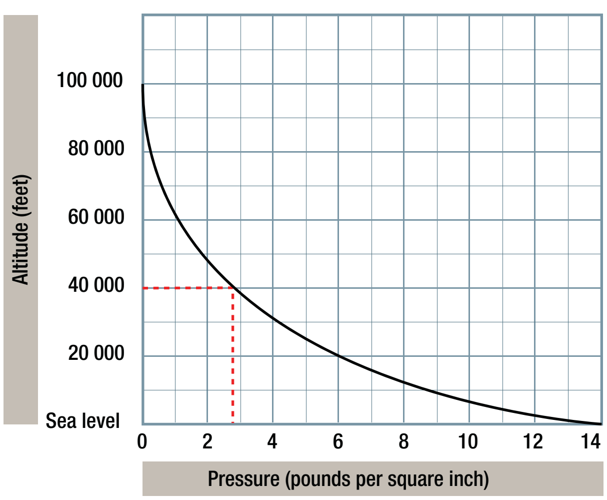

Figure 1-4. Atmospheric pressure decreasing with altitude. At sea level the pressure is 14.7 psi, while at 40 000 feet, as the dotted lines show, the pressure is only 2.72 psi.

HUMIDITY

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 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 troposphere is the lowest layer of the atmosphere. On average, it ranges from the earth's surface to about 38 000 feet above it. Over the poles, the troposphere extends to only 25 000 - 30 000 feet and, at the equator, it may extend to around 60 000 feet. This oblong nature of the troposphere is illustrated in ***Figure 1-5***.

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.

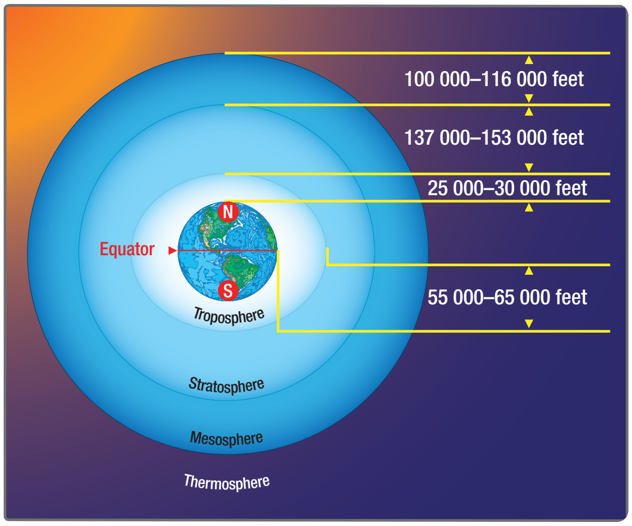

Figure 1-5. The troposphere extends higher above the earth's surface at the equator than it does at the poles.

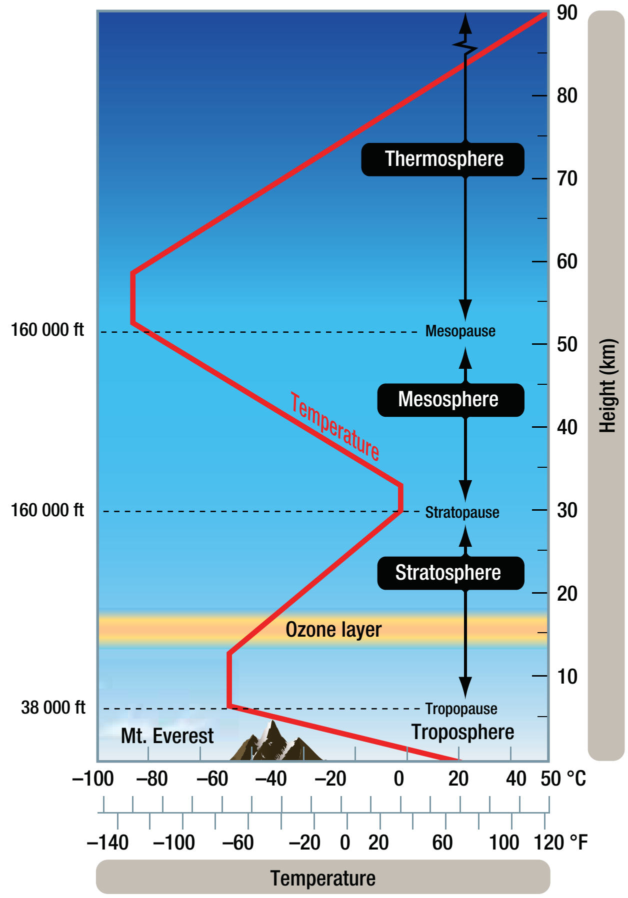

Figure 1-6. The atmospheric layers with temperature changes depicted by the red line.

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 (Ultraviolet) rays. Some civilian flights and numerous military flights occur in the stratosphere. ***Figure 1-6*** diagrams the temperature variations in different layers of the atmosphere.

As stated, density varies inversely with temperature or, as temperature increases, air density decreases. This phenomenon explains why on very warm days, aircraft takeoff performance decreases. The air available for combustion is less dense. Air with low density contains less total oxygen to combine with the fuel.

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. International Civil Aviation Organization (ICAO), International Organization for Standardization (ISO), and various governments establish and publish the values known as the International Standard Atmosphere. (***Figure 1-7***)

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
1000	55.4	13	14.17	977.16	0.002309	1.19
2000	51.9	11	13.66	941.82	0.002242	1.15
3000	48.3	9.1	13.17	908.11	0.002176	1.12
4000	44.7	7.1	12.69	874.94	0.002112	1.09
5000	41.2	5.1	12.05	843.07	0.002049	1.06
6000	37.6	3.1	11.78	812.2	0.001988	1.02
7000	34	1.1	11.34	781.85	0.001928	0.99
8000	30.5	-0.9	10.92	752.91	0.001869	0.96
9000	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 1-7. The International Standard Atmosphere.