Concept: Pressure

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1. Definition and Introduction

Pressure fundamentally ascribed to the momentum flowing across a given surface per unit time, per unit area of the surface. It is a scalar, in that it acts in all directions. However, the force due to pressure acting on a given area of a surface is taken as being directed towards the surface, and perpendicular (or normal) to the surface. Pressure is expressed in newtons per square meter (pascals), in pounds per square foot (psf), or in pounds per square inch (psi). The pressure of the atmosphere at standard sea level at a temperature of 288.15 Kelvins is 101,325 pascals, or 14.7 psi. This is called 1 atmosphere on Earth. Mercury and water barometers have become such familiar devices that pressure is also expressed in inches of water, inches or millimeters of mercury whose weight can be supported by a given pressure, or in torrs.

In liquids and gases, hydrostatic pressure at a given level is attributed to the force of gravity acting on the ocean and atmosphere above that level. The pressure experienced at a given level is that needed to support the weight (gravitational force) per unit area of all of the liquid or gas above that level. Thus the pressure drops as one goes up in the atmosphere from sea level, and increases as one goes down into water from sea level. In other words, the pressure at 1 kilometer below sea-level is roughly 1 million Newtons per square meter. Sea-level standard atmospheric pressure on Earth is 101320 Newtons per square meter (Pascals).

Pressure in gases is related to the density and temperature through the Thermal Equation of State, most usually seen in its form as the Perfect Gas Law. Here the pressure is expressed as the product of the density, the gas constant and the absolute temperature, the gas constant being the universal gas constant divided by the molecular weight of the gas. The term "perfect" refers to the fact the gas constant is constant over the range of values of temperate and density considered. This usually means that there is no change in the mean molecular weight, or in other words, no dissociation of recombination of the gas. Most gas conditions encountered in aerospace gas dynamics satisfy the condition that intermolecular forces are negligibly small in relating pressure to density and temperature. This is because the density is low enough, or the temperature high enough, to ensure that molecules are not packed close enough to feel short-range attractive or repulsive forces, except during collisions. On the other hand, high pressure applications, usually encountered in chemical engineering, may have low enough temperature and high enough density so that intermolecular forces have to be considered. The Van Der Waal Equation of state takes into account the short-range intermolecular forces.

2. Pressure in Moving Fluids

When an object moves through a liquid or gas, the pressure acting at a given point on the body depends on the speed of motion of the fluid relative to the object. At the front of the object, the fluid is pushed along at the same speed as the body, or in other words, the fluid coming at the object stagnates there. The pressure developed at this point is called the stagnation pressure. In the case of objects moving slower than the speed of sound, the stagnation pressure is obtained as the pressure reached when fluid moving at that speed is brought to rest. It is composed of the static pressure and the dynamic pressure. The static pressure is the pressure in the fluid far away from the moving body, for example, the atmospheric pressure. The dynamic pressure is the part due to motion. Where the speed of motion of the object, or equivalently, the speed of the freestream coming at the object, is less than about 30 percent of the speed of sound, the dynamic pressure, often called "q" is given by the product of the half the density and the square of the freestream speed. For speeds above 30 percent of the speed of sound, the change in density accompanying the rise in pressure is over 5 percent, and the pressure change must be calculated using the thermodynamic relations for a compression process performed with no losses, or an isentropic process. For speeds above that of sound, a shock will form ahead of the stagnation point, and some of the stagnation pressure is lost across the shock. The entropy also increases.

2.1. Pressure Coefficient

The pressure coefficient of C_p is given by the difference of the pressure at a given point from the freestream static pressure, normalized by the freestream dynamic pressure. Thus at the stagnation point in a low-speed flow, the C_p is 1.0, while at a point that experiences the freestream static pressure, the value is zero. Regions where the pressure coefficient is negative are called suction regions.

3. Measurement of Pressure

Pressure ranges from the near-vacuum of Space and the very small amplitudes at the threshold of hearing, to the pressures int he depths of the ocean, and in the shock waves of thermonuclear fusion explosions. Barometry started as the science of measuring the pressure of the atmosphere. Derived from the Greek words for "heavy" or "weight" (baros) and "measure" (metron), it is now used to describe any measurement of gas pressure. Pressure is expressed in units of force per unit area. Thus methods to measure pressure often measure the force acting per unit area of a sensor, or the effects of that force.

Initial weather forecasting barometers measured This Torricelli barometer is an absolute pressure instrument, used in weather forecasting. It measures the height of a liquid column that the pressure of air would support, with a vacuum at the closed top end of a vertical tube. Atmospheric pressure is obtained as the product of the height, the density of the barometric liquid, and the acceleration due to gravity at the Earth's surface. The aneroid barometer uses a partially evacuated box whose spring-loaded sides expand or contract depending on the atmospheric pressure, driving a clock-like mechanism to show the pressure on a circular dial. Carried on mountaineering, ballooning, and mining expeditions, it measured altitude by the change in atmospheric pressure. A barograph is an aneroid barometer adapted to graph the variation of pressure with time. The rate of change of pressure helps weather forecasters to predict the strength of approaching storms.

The term "manometer" derives from the Greek word manos, meaning "sparse," and denotes an instrument used to measure the pressure relative to a known pressure. A U-tube manometer measures the difference from a reference pressure using the level difference between the liquid in the legs of the U-tube connected to a known pressure source and to the pressure of interest. The Pitot-static tubes used to measure flow velocity in wind tunnels were initially connected to water or mercury manometers. Inclined tube manometers were used to increase the sensitivity of the instrument in measuring small pressure differences amounting to fractions of an inch of water.

In 1643, Evangelista Torricelli (1608-1647) showed that atmospheric pressure would support the weight of approximately 35 feet of water column leaving a vacuum above that in a closed tube, and that this height would change with the weather. Later Torricelli barometers used liquid mercury to reduce the size of the column and thus make such instruments more practical. The technology of pressure measurement has evolved gradually since then, with the aneroid barometer demonstrating the reliability of deflecting a diaphragm. Electrical means of measuring the amount of deflection used strain gages on a diaphragm and directly measured the strain. Later methods used the change in capacitance due to the changing gap between two charged plates. Piezoresistive materials expanded the ability of miniaturized strain gage sensors to measure high pressures changing at high frequency. Miniaturized solid-state sensors using micro electromechanical system (MEMS) technology provide alternatives today. These are suitable for high amplitudes and frequencies, such as those encountered in shock waves and explosions, and transonic or supersonic wind tunnel tests.Pressure-sensitive paints are enabling increasingly sensitive and faster-responding measurements of varying pressure with very fine spatial resolution. Condenser microphones are used in acoustic measurements.