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**AERODYNAMICS of FLIGHT - Keys**

Adapted from: https://www.courses.netc.navy.mil/courses/14014A/14014A\_ch3.pdf

Aerodynamics is the study of the forces that let an aircraft fly. These forces can be understood by the physical laws of aerodynamics, which include Newton's laws of motion and the Bernoulli principle

**LAWS OF MOTION**

Motion is the act or process of changing place or position. Simply put, motion is movement. An object may be **in motion in relation** to one object and **motionless in relation** to another. For example, a person sitting in an aircraft flying at 200 mph is at rest or motionless in relation to the aircraft. However, the person is in motion in relation to the air or the earth. Air has no force or power other than pressure when it's motionless. When air is moving, its force becomes apparent. A moving object in motionless air has a force exerted on it as a result of its own motion. It makes no difference in the effect whether an object is moving in relation to the air or the air is moving in relation to the object. The following information explains some basic laws of motion.

**Newton's First Law of Motion**

For an aircraft to fly, a force must be applied to it. It would remain at rest without an outside force. Once the aircraft is moving, another force must act on it to bring it to a stop. It would continue in motion without an outside force. This willingness of an object to remain at rest or to continue in motion is referred to as *inertia*.

**Newton's Second Law of Motion**

The second law of motion states that if an object moving with uniform speed is acted upon by an external force, the change of motion (acceleration) will be directly proportional to the amount of force and inversely proportional to the mass of the object being moved. A heavier aircraft will accelerate more slowly than a lighter aircraft when an equal force is applied.

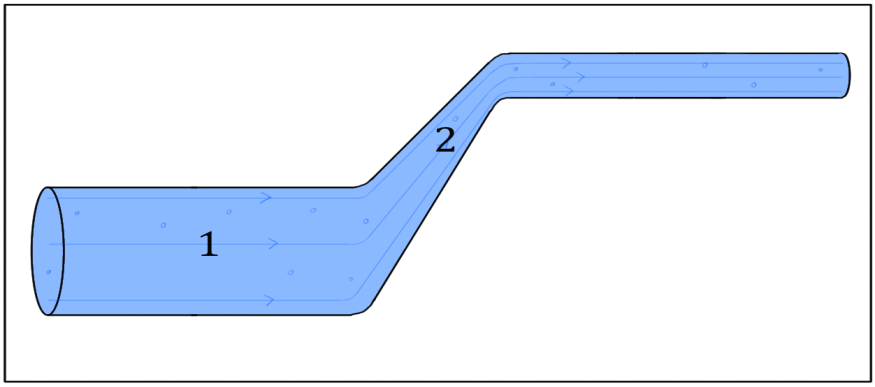
**Newton's Third Law of Motion**

The third law of motion (action and reaction) states that for every action (force) there is an equal and opposite reaction (force). This law can be demonstrated with a balloon. If you inflate a balloon with air and release it without securing the neck, as the air is expelled the balloon moves in the opposite direction of the air rushing out of it.

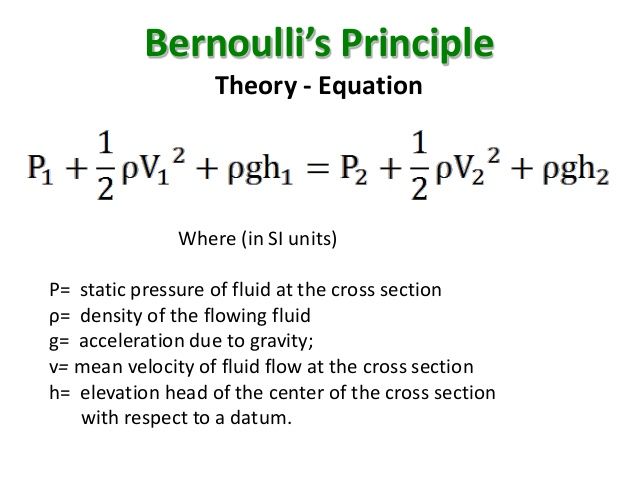
**BERNOULLI'S PRINCIPLE**

Bernoulli's principle states that when a fluid flowing through a tube reaches a constriction or narrowing of the tube, the speed of the fluid passing through the constriction increases and its pressure decreases.

Bernoulli's equation is essentially a more general and mathematical form of Bernoulli's principle that also takes into account changes in gravitational potential energy. We won’t derive this equation due to time issues. Bernoulli's equation relates the pressure, speed, and height of any two points (1 and 2, **Figure 1**) in a steady streamline flowing fluid of density *ρ*.

**Figure 1:** diagram showing a particular choice of two points (1 and 2) in a fluid – drawn by the Author.

Bernoulli's equation is usually written as follows

We should note here that Bernoulli's principle is contained within Bernoulli's equation. If we start with the equation above, and assume that there is no change in the height of the fluid, *ρgh* cancel if we subtract them from both sides. This simplified formula highlights Bernoulli's principle since if the speed v of a fluid is larger in a given region of streamline flow, the pressure P must be smaller in that region (which is Bernoulli's principle).

**FORCES ACTING ON AN AIRCRAFT**

Once an aircraft leaves the ground, it is acted upon by four aerodynamic forces; thrust, drag, lift and weight. Understanding how these forces work and knowing how to control them with the use of power and flight controls are essential to flight.

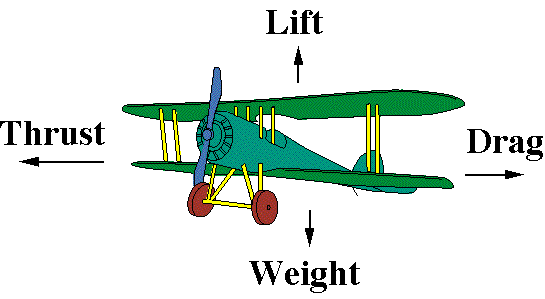
They are defined as follows:

• **Thrust**—the forward force produced by the power plant/propeller or rotor. It opposes or overcomes the force of drag. As a general rule, it acts parallel to the longitudinal axis. However, this is not always the case, as explained later.

• **Drag**—a rearward, retarding force caused by disruption of airflow by the wing, rotor, fuselage, and other protruding objects. Drag opposes thrust and acts rearward parallel to the relative wind.

• **Weight**—the combined load of the aircraft itself, the crew, the fuel, and the cargo or baggage. Weight pulls the aircraft downward because of the force of gravity. It opposes lift and acts vertically downward through the aircraft’s center of gravity (CG).

• **Lift**—opposes the downward force of weight, is produced by the dynamic effect of the air acting on the airfoil, and acts perpendicular to the flightpath through the center of lift.



**Figure 2:** forces on an aircraft. Source: https://commons.wikimedia.org/wiki/File:Forces2.gif