MODULE 15

FOR B1 CERTIFICATION

# GAS TURBINE ENGINE

## Aviation Maintenance Technician Certification Series

COMPLIANT WITH EASA PART 66/147

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# WELCOME

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# REVISION LOG

| VERSION | EFFECTIVE DATE | DESCRIPTION OF CHANGE |
|---|---|---|
| 01 | 2016 01 | Module Creation and Release |
| 02 | 2016 08 | Module Revisions |
| 03 | 2017 11 | Format Updates |
| 04 | 2019 01 | Fine tuned Sub-Module content sequence based on Appendix-A. Updated layout and styling. Enhanced or modified content within the following Sub-Modules listed below. |
| | | Sub-Module 01 Definition of Energy; Constructional Arrangements |
| | | Sub-Module 02 Operating Principles; EPR Measurement, Engine Ratings |
| | | Sub-Module 03 Ice Protection |
| | | Sub-Module 04 Air Flow Control; Compressor Ratio |
| | | Sub-Module 05 Operation of Combustion Chambers |
| | | Sub-Module 06 Turbine Blade Operation |
| | | Sub-Module 09 Spectrometric Oil Analysis |
| | | Sub-Module 12 Turbine Engine Cooling; Bearing Chamber Seal; Anti-icing |
| | | Sub-Module 13 Starter System Safety |
| | | Sub-Module 14 Fuel Flow Indication |
| | | Sub-Module 15 Operation and Application; Afterburner Systems |
| | | Sub-Module 16 Reduction Gears; Engine Control; Overspeed Devices |
| | | Sub-Module 17 Drive Systems |
| | | Sub-Module 19 Cowling C-ducts; Control Cables |
| | | Sub-Module 21 Health and Trend Monitoring; FOD |
| | | Sub-Module 22 Fuel System Preservation |

## GAS TURBINE ENGINE



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# 15.1 - FUNDAMENTALS

## TURBINE ENGINE FUNDAMENTALS

A discussion of turbine engines begins with some of the basic physics behind turbine engine operation.

### ENERGY

Energy is typically defined as something that gives us the capacity to perform work. As individuals, saying that we feel full of energy is probably indicating that we can perform a lot of work. Energy can be classified as one of two types: either potential or kinetic. (***Figure 1-1***)

#### *Potential Energy*

Potential energy is defined as being energy at rest, or energy that is stored. Potential energy may be classified into three groups: (1) that due to position, (2) that due to distortion of an elastic body, and (3) that which produces work through chemical action.

Water in an elevated reservoir, and an airplane raised off the ground sitting on jacks are examples of the first group; a stretched bungee cord on a Piper Tri-Pacer or compressed spring are examples of the second group; and energy in aviation gasoline, food, and storage batteries are examples of the third group.

To calculate the potential energy of an object due to its position, as in height, the following formula is used:

$$\text{Potential Energy} = \text{Weight} \times \text{Height}$$
$$PE = 450\,000 \text{ lb} \times 4 \text{ ft}$$
$$PE = 1\,800\,000 \text{ ft-lbs}$$

A calculation based on this formula will produce an answer that has units of foot-pounds (ft-lbs) or inch-pounds (in-lbs), which are the same units that apply to work. Work, which is covered later in this chapter, is described as a force being applied over a measured distance, with the force being pounds and the distance being feet or inches. It can be seen that potential energy and work have a lot in common.

*Example:*
*A Boeing 747 weighing 450 000 pounds needs to be raised 4 feet in the air so maintenance can be done on the landing gear. How much potential energy does the airplane possess because of this raised position?*

As mentioned previously, aviation gasoline possesses potential energy because of its chemical nature.

Gasoline has the potential to release heat energy, based on its British thermal unit (BTU) content. One pound of aviation gas contains 18 900 BTU of heat energy, and each BTU is capable of 778 ft-lbs of work. So if we multiply 778 by 18 900, we find that one pound of aviation gas is capable of 14 704 200 ft-lbs of work. Imagine the potential energy in the completely serviced fuel tanks of an airplane.

#### *Kinetic Energy*

Kinetic energy is defined as being energy in motion. An airplane rolling down the runway or a rotating flywheel on an engine are both examples of kinetic energy. Kinetic energy has the same units as potential energy, namely foot-pounds or inch-pounds.

Figure 1-1. Potential energy is the water being held back by the dam. Kinetic energy is the water released from the dam.

To calculate the kinetic energy for something in motion, the following formula is used:

$$Kinetic\ Energy = \tfrac{1}{2}\ Mass \times Velocity^2$$

To use the formula, we will show the mass as weight divided by gravity (weight ÷ gravity) and the velocity of the object will be in feet per second. This is necessary to end up with units in foot-pounds.

*Example:*
*A Boeing 777 weighing 600 000 lbs is moving down the runway on its takeoff roll with a velocity of 200 fps. How many foot-pounds of kinetic energy does the airplane possess?*

$$Kinetic\ Energy = \tfrac{1}{2}\ Mass \times Velocity^2$$
$$Kinetic\ Energy = \tfrac{1}{2} \times (600\ 000 \div 32.2) \times 200^2$$
$$KE = 372\ 670\ 807\ ft\text{-}lb$$

## NEWTON'S LAWS OF MOTION

The physic laws originated by Sir Isaac Newton are particularly applicable to operation of turbine engines.

### *Newton's First Law*

*Objects at rest tend to remain at rest and objects in motion tend to remain in motion at the same speed and in the same direction, unless acted on by an external force.*

When a magician snatches a tablecloth from a table and leaves a full setting of dishes undisturbed, he is not displaying a mystic art; he is demonstrating the principle of inertia. Inertia is responsible for the discomfort felt when an airplane is brought to a sudden halt in the parking area and the passengers are thrown forward in their seats. Inertia is a property of matter. This property of matter is described by Newton's first law of motion.

### *Newton's Second Law*

*When a force acts upon a body, the momentum of that body is changed. The rate of change of momentum is proportional to the applied force.*

Bodies in motion have the property called momentum. A body that has great momentum has a strong tendency to remain in motion and is therefore hard to stop. For example, a train moving at even low velocity is difficult to stop because of its large mass. Newton's second law applies to this property.

Based on Newton's second law, the formula for calculating thrust is derived, which states that force equals mass times acceleration:

$$(F = MA)$$

Mass equals weight divided by gravity, and acceleration equals velocity final minus velocity initial divided by time. Putting all these concepts together, the formula for thrust is:

$$Force = \frac{Weight\ (Velocity\ Final - Velocity\ Initial)}{Gravity\ (Time)}$$

$$F = \frac{W\ (Vf - Vi)}{Gt}$$

*Example:*
*A turbojet engine is moving 150 lbs of air per second through the engine. The air enters going 100 fps and leaves going 1 200 fps. How much thrust, in pounds, is the engine creating?*

$$F = \frac{W\ (Vf - Vi)}{Gt}$$

$$F = \frac{150\ (1\ 200 - 100)}{32.2\ (1)}$$

$$F = 5\ 124\ lb\ of\ thrust$$

### *Newton's Third Law*

*For every action there is an equal and opposite reaction.*

Newton's third law of motion is often called the law of action and reaction. This means that if a force is applied to an object, the object will supply a resistive force exactly equal to and in the opposite direction of the force applied. It is easy to see how this might apply to objects at rest. For example, as a man stands on the floor, the floor exerts a force against his feet exactly equal to his weight. But this law is also applicable when a force is applied to an object in motion.

Forces always occur in pairs. The "acting force" means the force one body exerts on a second body, and reacting force means the force the second body exerts on the first.

When an aircraft propeller pushes a stream of air backward with a force of 500 lbs, the air pushes the blades forward with a force of 500 lbs. This forward force causes the aircraft to move forward. A turbofan engine exerts a force on the air entering the inlet duct, causing it to accelerate out the fan duct and the tailpipe. The air accelerating to the rear is the action, and the force inside the engine that makes it happen is the reaction, also called thrust.

## BERNOULLI'S PRINCIPLE

Bernoulli's principle explains the action of a liquid flowing through the varying cross-sectional areas of tubes. In ***Figure 1-2*** a tube is shown in which the cross-sectional area gradually decreases to a minimum diameter in its center section. A tube constructed in this manner is called a "venturi". Where the cross sectional area is decreasing, the passageway is referred to as a *converging duct*. As the passageway starts to spread out, it is referred to as a *diverging duct*. As a fluid flows through the venturi tube, at A, B, and C are positioned to register the velocity and the static pressure of the liquid. The venturi in ***Figure 1-2*** is used to illustrate Bernoulli's principle, which states:

> *The static pressure of a fluid (liquid or gas) decreases at points where the velocity of the fluid increases, provided no energy is added to nor taken away from the fluid.*

The velocity of the air is kinetic energy and the static pressure of the air is potential energy. In the wide section of the venturi (***points A and C of Figure 1-2***), the liquid moves at low velocity, producing a high static pressure, as indicated by the pressure gauge. As the tube narrows in the center, it must contain the same volume of fluid as the two end areas. In this narrow section, the liquid moves at a higher velocity, producing a lower pressure than that at points A and C, as indicated by the velocity gauge reading high and the pressure gauge reading low.

Bernoulli's principle is important in understanding how some of the systems used in aviation work, including how the wing of an airplane generates lift or why the inlet duct of a turbine engine on a subsonic airplane is diverging in shape. Key to Bernoulli's principle is that the total pressure of the airflow remains the same while static pressure varies due to negotiation of the curvature of a venturi or wing. As the static pressure of the fluid decreases to move over the curved surface, dynamic pressure increases, expressed as an equation:

*Total Pressure = Static Pressure + Dynamic Pressure*

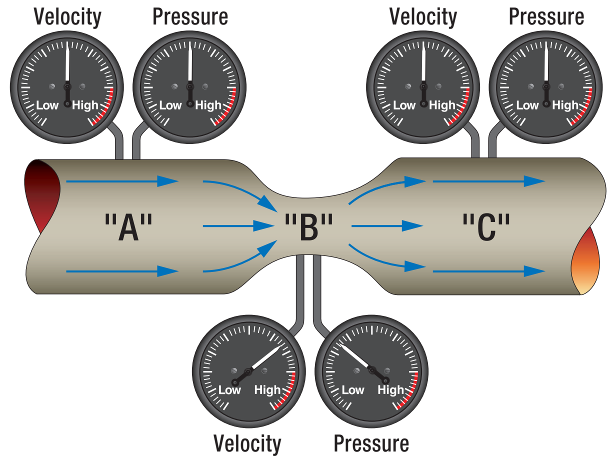

Figure 1-2. Bernoulli's principle and a venturi.

## BOYLE'S & CHARLES' LAW

Boyle's Law states that when the temperature of a gas is kept constant and the pressure increased, its volume is decreased proportionately. In reverse; when a gas is at a constant temperature and pressure decreases, volume increases. (***Figure 1-3***)

By itself Boyle's Law is of little use because in practice air is not compressed at a constant temperature. Although if we use Boyle's Law in combination with Charles' Law, it becomes more useful. Charles' Law states that if air is heated at a constant pressure, the change in volume will vary with the change in temperature. Therefore, the volume of a mass of gas at constant pressure is proportional to the temperature of the gas (air). So, the product of the pressure and volume of the air through each stage within a turbine engine is proportional to the temperature of the air at the stage.

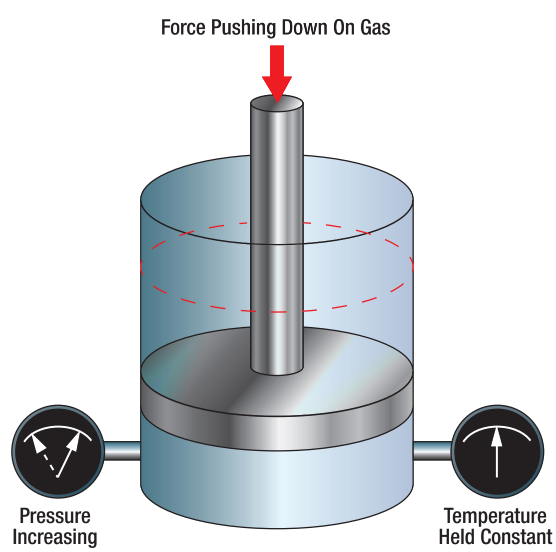

Figure 1-3. Boyle's law example.

During compression, as work is done to increase pressure and decrease volume, there is a corresponding rise in temperature. During combustion, the addition of fuel to burn with the air increases the pressure and there is a corresponding increase in volume. During exhaust, there is a decrease in the pressure and temperature of the gas with an additional increase in volume. (***Figure 1-4***)

## THE BRAYTON CYCLE

The Brayton cycle is the name given to the thermodynamic cycle of a gas turbine engine to produce thrust. This is a variable volume constant-pressure cycle of events and is commonly called the constant-pressure cycle. A more recent term is "continuous combustion cycle." The four continuous and constant events are intake, compression, expansion (includes power), and exhaust. These cycles are discussed as they apply to a gas turbine engine. (***Figure 1-5)***

In the intake cycle, air enters at ambient pressure and at a constant volume. It leaves the intake at an increased pressure and a decrease in volume. At the compressor section, air is received from the intake at an increased pressure, slightly above ambient, and a slight decrease in volume. Air enters the compressor where it is compressed. It leaves the compressor with a large increase in pressure and decrease in volume, created by the mechanical action of the compressor. The next step, expansion, takes place in the combustion chamber by burning fuel, which expands the air by heating it. The pressure remains relatively constant, but a marked increase in volume takes place. The expanding gases move rearward through the turbine assembly and are converted from velocity energy to mechanical energy by the turbine. The exhaust section, which is a convergent duct, converts the expanding volume and decreasing pressure of the gases to a final high velocity. The force created inside the engine to keep this cycle continuous has an equal and opposite reaction (thrust) to move the aircraft forward.

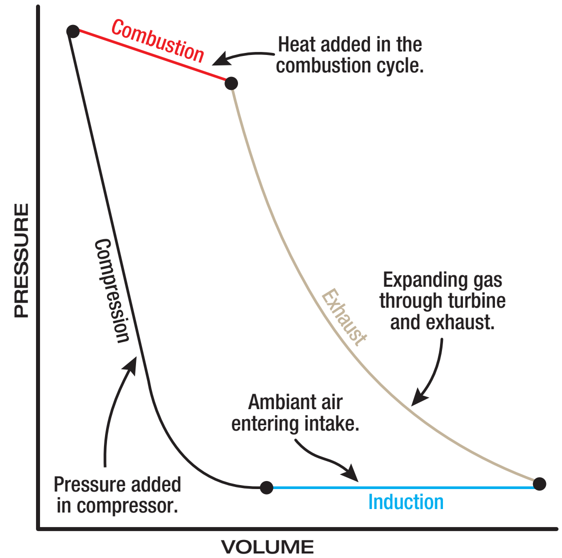

Figure 1-4. Pressure/volume relationship.

Bernoulli's principle (whenever a stream of any fluid has its velocity increased at a given point, the pressure of the stream at that point is less than the rest of the stream) is applied to gas turbine engines through the design of convergent and divergent air ducts. The convergent duct increases velocity and decreases pressure. The divergent duct decreases velocity and increases pressure. The convergent principle is usually used for the exhaust nozzle. The divergent principle is used in the compressor and diffuser where the air is slowing and pressurizing.

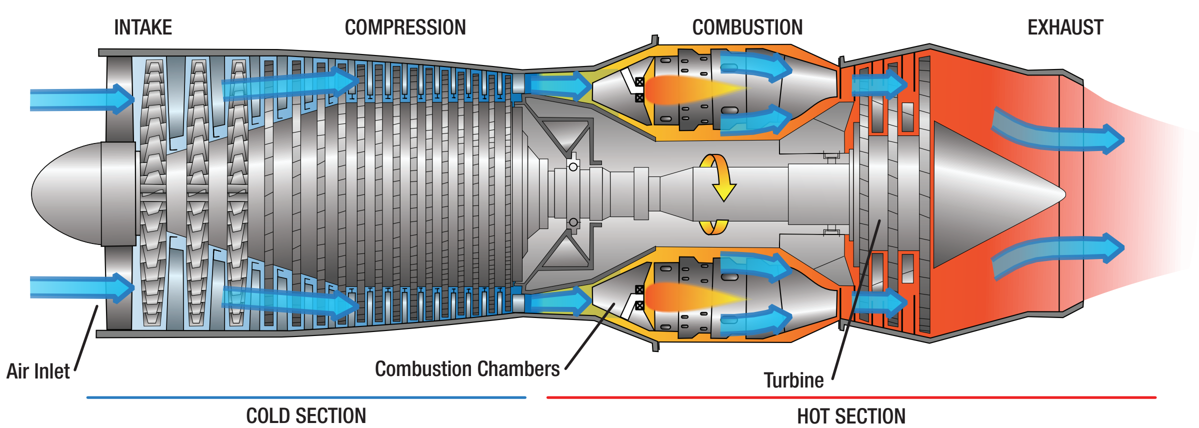

Figure 1-5. The Brayton Cycle.