# CHAPTER 6

# AIRCRAFT POWER PLANTS

## INTRODUCTION

All naval aircraft are engine driven. The early engines were all reciprocating engines. Today, almost all are jet propulsion engines. Therefore, this chapter covers only jet propulsion engines.

The jet propulsion principle is the basic concept for the gas turbine engine. This principle is not a new concept. Sea creatures use jet propulsion to propel themselves through the water. The Egyptians built the first reaction engine around 250 BC. Between 1700 and 1930, technical achievements in engineering, manufacturing, and metallurgy made the reaction principle applicable to the development of the gas turbine engine for jet propulsion. In 1939, the Germans flew the first aircraft powered by a gas turbine engine, followed by the British in 1941, and the Americans in 1942. During World War II, Germany was the only nation to fly a gas turbine-propelled aircraft in actual combat.

There are four types of jet propulsion engines: the rocket, the ramjet, the pulsejet, and the gas turbine engine. Of these, the gas turbine engine powers almost all naval aircraft. There are four types of gas turbine engines: the turbojet, the turbofan, the turboprop, and the turboshaft. The turbojet and turbofan engines use thrust directly. The turboprop and turboshaft engines use thrust to deliver torque (turning power) to an airplane propeller or a helicopter rotor. Regardless of the type, the purpose of an engine is to develop thrust. This chapter will give you basic information on jet propulsion engines.

## JET PROPULSION ENGINES

**LEARNING OBJECTIVE**: Recognize the basic operating principles for the four types of jet propulsion engines, and identify the components and functions of each type of engine.

A jet propulsion engine projects a column of air to the rear at extremely high speeds. The resulting thrust pushes the aircraft in the opposite (or forward) direction. Jet propulsion engines are grouped into four main types:

1. Rocket. These are jet propulsion systems that do not use atmospheric air.
2. Ramjet. The ramjet operates as a continuous thermal duct or athodyd.
3. Pulsejet. The pulsejet operates as an intermittent impulse duct.
4. Gas turbine. The gas turbine engine operates as a continuous turbine-compressor unit.

### ROCKET ENGINES

The rocket uses a form of jet propulsion that differs in basic ways from thermal gas turbine systems. The rocket does not draw air from the outside to fuel the combustion process. It carries with it both the fuel and the oxidizer for combustion. This is a disadvantage for atmospheric flight, but it is the only way at present to fuel flight outside the earth's atmosphere. The rocket is a true jet reaction unit. A brief examination of its functions clarifies the reaction principle by which all thermal jet units operate.

If you burn a hydrocarbon (compound containing only hydrogen and carbon) in a closed container (fig. 6-1), the heat of the burning fuel is released, causing the trapped gases to expand rapidly. Because the container has a closed volume, the temperature and pressure rises and is uniformly distributed (balanced) in all directions. Since the force of the rising pressure cannot be released and is balanced, the container does not move.

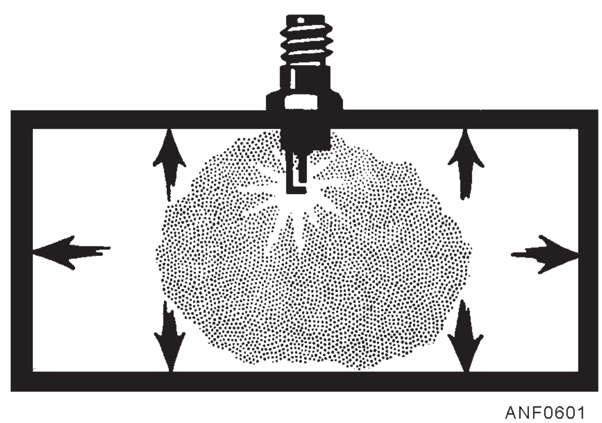


**Figure 6-1.—Combustion in a closed container.**

When you burn fuel in a container that has an opening (or nozzle) at one end, expanding gases rush out of the nozzle at a high velocity, as shown in figure 6-2. Releasing internal pressure at the nozzle end of the container leaves an unbalanced pressure at the other end. **The released pressure moves the container in the direction opposite to that of the escaping gases. This is the basic operating principle for all jet engines**. Obviously, propulsion depends solely on internal conditions. The container does not "push against" external air. In fact, a complete vacuum would produce even greater force.

The jet propulsion engine operates like a toy balloon. Newton's third law of motion explains this operation. This law states "for every acting force there is an equal and opposite reacting force." Inflate a balloon. The air pressure inside the balloon, which is stretching the skin, is greater than the pressure outside the balloon. If the stem is tied closed, the inside air pushes in all directions and the balloon will not move. Place the balloon in a vacuum and release the stem. The escaping air has nothing to push against, but the balloon will move in a direction away from the stem, just as it does in a normal atmosphere.

Releasing the stem removes a section of skin on the side of the balloon against which the air has been pushing. On the side directly opposite the stem, however, the air continues to push on an equal area of skin. The continued push of air on this area causes the balloon to move in the direction away from the stem.

The *acting force* that Newton's third law refers to is the acceleration of the escaping air from the rear of the balloon. The reaction to this acceleration is a force in the opposite direction. In addition, the amount of force acting on the balloon is the product of the mass of air being accelerated times the acceleration of that air. Since the forces always occur in pairs, we can say that if a certain force is needed to accelerate a mass rearward, the reaction to this force is thrust in the opposite direction (force = thrust, as shown in figure 6-3).

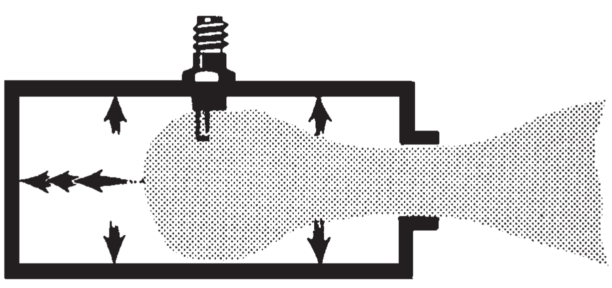


**Figure 6-2.—Principle of jet propulsion.**

## RAMJET ENGINES

The ramjet is often described as a flying stovepipe. It is the simplest of all power plants that use atmospheric air to support combustion.

A ramjet is an appropriately shaped duct, tapered at both ends, in which fuel is injected and burned at a constant pressure, as shown in figure 6-4. Except for the possibility of fuel pumps or other accessories, there are no moving parts.

The air inlet diffuser of the ramjet engine is designed to convert the velocity energy of the entering air into static pressure. This is commonly known as *ram*. During the inlet process, fuel is injected into the airstream, where it is well mixed with the air so that it will burn readily. At about the point of highest pressure in the engine, combustion is initiated and the fuel-air mixture is burned. The gases of combustion and the heated air expand, thus air is ejected from the exit nozzle at a much higher velocity than it had when it entered the engine. This change in the velocity of the entering and departing air results in the thrust.

## PULSEJET ENGINES

The pulsejet engine is a member of the athodyd (aero-thermodynamic-duct) family, since it does not have a compressor or a turbine.

The pulsejet engine differs from the ramjet in that the inlet duct is sealed with a disc that incorporates flapper valves. The purpose of the flapper valves is to provide the required air intake system, seal the high-pressure gases in the combustion chamber, and prevent their escape out the inlet duct during the combustion cycle. A pulsejet engine consists essentially of a diffuser, an air valve bank (automatic or

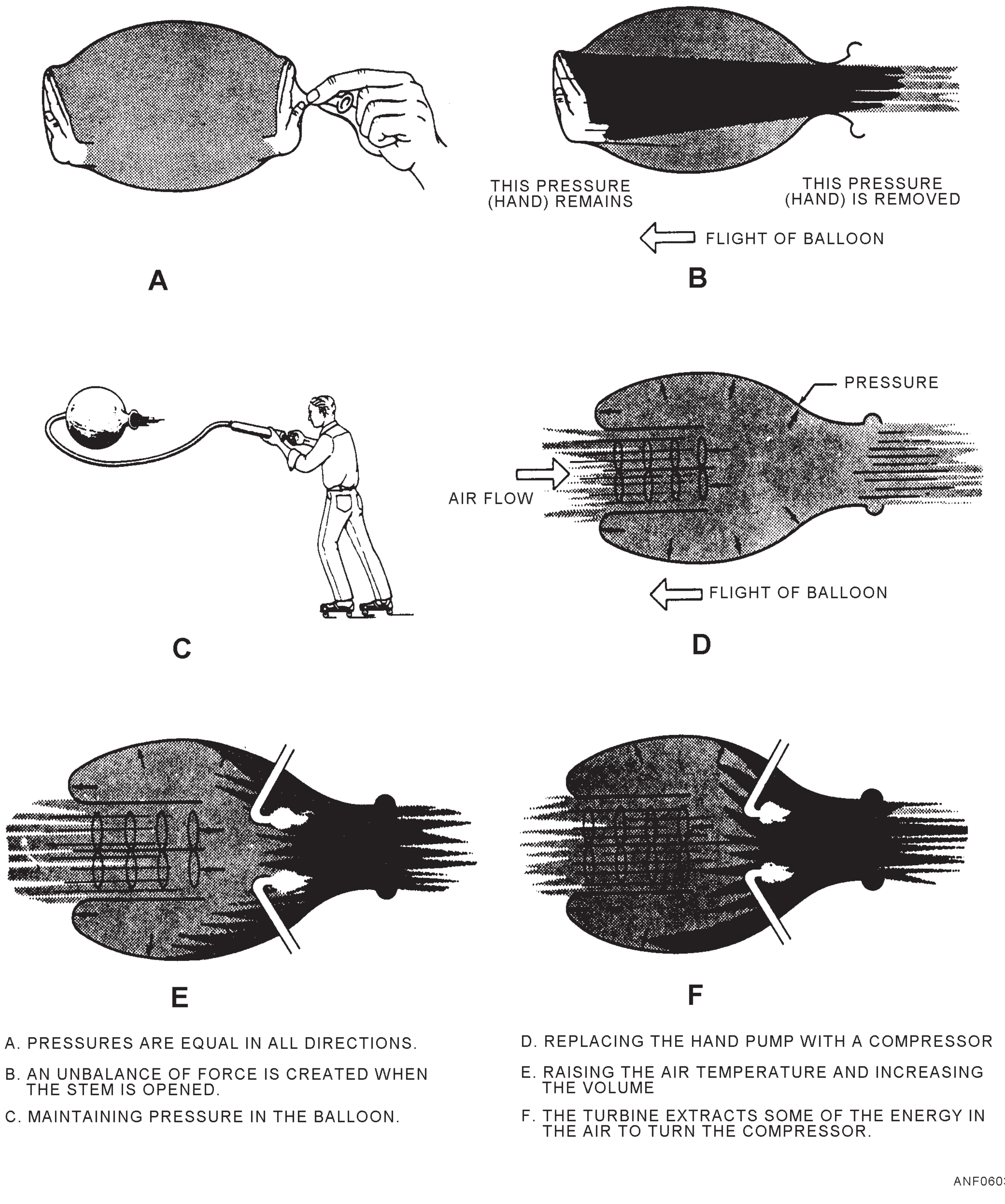


**Figure 6-3.—Balloon as a jet engine.**

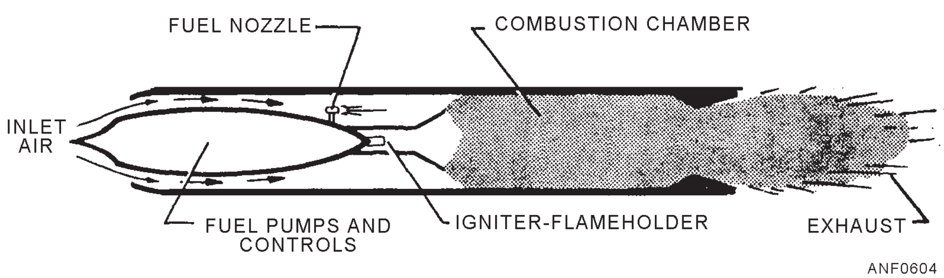


**Figure 6-4.—The ramjet engine.**

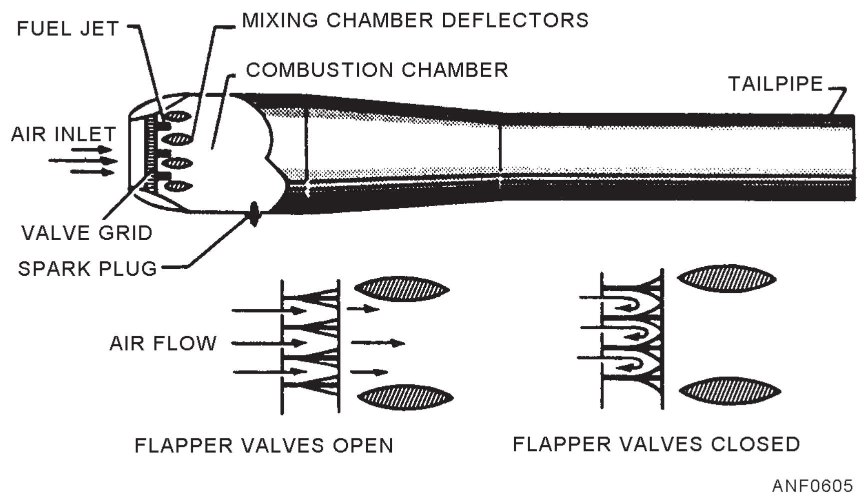


**Figure 6-5.—The pulsejet engine.**

mechanical), a combustion chamber, and a tailpipe or exit nozzle, as shown in figure 6-5.

While the ramjet will deliver no static thrust, the pulsejet engine can produce static thrust. However, the thrust developed under static conditions is not sufficient to enable a pulsejet aircraft or guided missile to take off under its own power, at least not on conventional runways. Consequently, missiles or other devices powered by pulsejet engines must be boosted to self-sustaining flight speeds by catapults or rockets.

Possible applications for the pulsejet engine, other than for powering pilotless military weapons, include flight research, powering helicopters by attaching small pulsejet engines to the rotor blade tips, and emergency power plants for small aircraft and gliders.

## GAS TURBINE ENGINES

As stated earlier, there are four types of gas turbine engines: turbojet, turboprop, turboshaft, and turbofan. Each of these engines is briefly discussed in the following paragraphs.

### Turbojet Engines

There are over 40 different Navy models of the turbojet engine. The A-6 and T-2 are examples of aircraft that use this direct thrust engine. The turbojet engine consists of five major components: an inlet duct, a compressor, a combustion chamber (or chambers), a turbine (or turbines), and an exhaust cone assembly, as shown in figure 6-6.

**INLET DUCT**.—The inlet duct is an opening in the front of the aircraft that allows outside (ambient) air to enter the engine. The compressor compresses the incoming air and delivers it to the combustion (or burner) section. In the combustion chamber, fuel is sprayed into and mixed with the compressed air. An igniter then ignites the fuel-air mixture. The burning mixture continues to burn in the presence of the proper fuel-air mixture. The fuel-air mixture burns at a relatively constant pressure. Only about 25 percent of the air is used in the combustion process. The rest of the air (75 percent) is mixed with the combustion products (exhaust) for cooling before the gases enter the turbine section.

The turbine section extracts and uses a major portion of the energy in the gas stream to turn the compressor and accessories. After leaving the turbine, the remaining pressure forces the hot gases through the engine exhaust duct at very high speeds. The air that

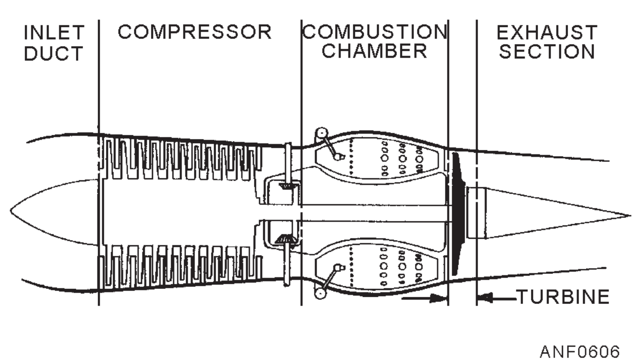


**Figure 6-6.—Five major components of the turbojet.**

entered the inlet is now expelled at a much higher speed than when it entered. This causes the engine thrust.

**COMPRESSOR**.—The axial-flow compressor is made up of a series of rotating blades and a row of stationary stator vanes, as shown in figure 6-7. A row of rotating blades and stator vanes is called a stage. The entire compressor is made up of a series of alternating rotor blade and stator vane stages.

You recall that the compressor provides high-pressure air to the combustion chamber (or chambers). The compressor delivers outside air (ambient) to the inlet section and passes this air through the inlet guide vanes. In turn, the inlet guide vanes deflect the air in the direction of compressor rotation. The rotating blades arrest the airflow and pass it to a set of stationary stator vanes. The air is again deflected and picked up by another set of rotating blades, and so on through the compressor. The pressure of the air increases each time it passes through a set of rotors and stators because the areas of the rotors and stators get smaller, as shown in figure 6-8.

One development in the axial-flow engine is the *split spool* compressor. This compressor (fig. 6-9) uses two rotors of nine and seven stages, respectively. An assigned wheel drives each rotor of the axial three-stage

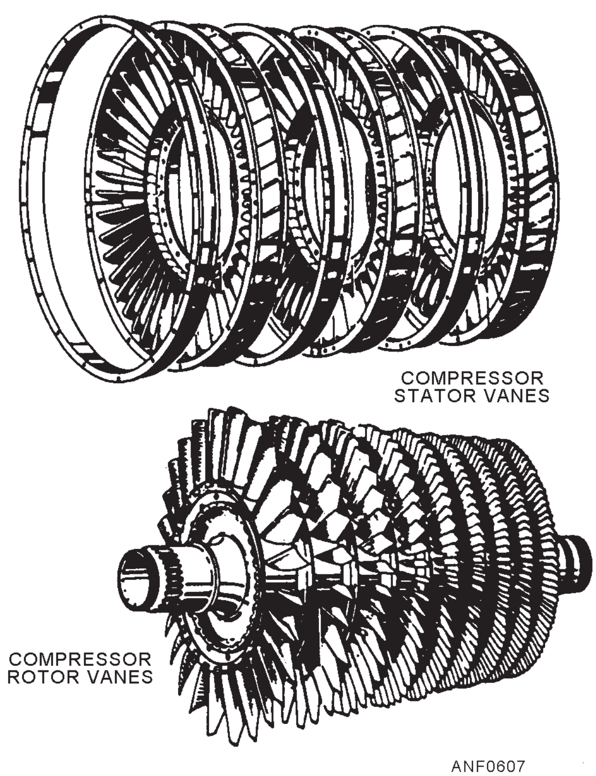


**Figure 6-7.—Stator and rotor components of an axial-flow compressor.**

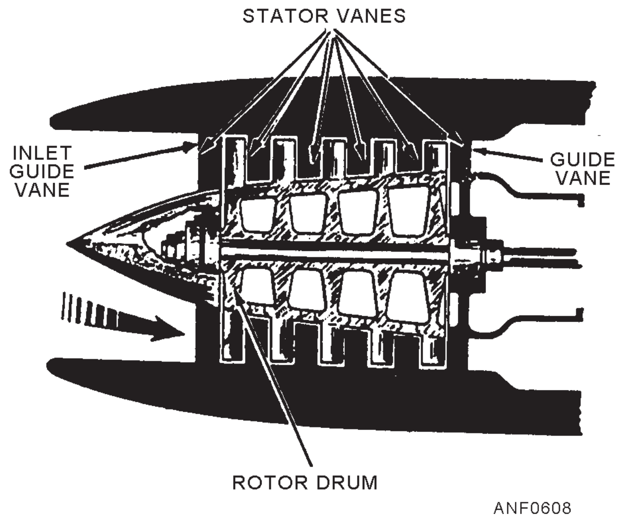


**Figure 6-8.—Five-stage compressor.**

turbine assembly. This configuration makes possible high compressor pressure ratios, which are necessary for efficient high-altitude operations.

Another development was necessary to eliminate compressor stall in turbojet engines. The axial compressor, especially with fixed blading, was subject to stalling. Compressor stall was normally caused by a breakdown of the airflow through a few stages of the compressor. Compressor stall could progress until the complete unit stalled.

There are two methods to eliminate compressor stall. The compressor bleed-air system and the variable vane system. The compressor bleed-air system bleeds off approximately 10 percent of the front compressor discharge air. It reduces the amount of air available to the rear compressor. This provides a surge-free operation throughout the critical speeds of the engine. The variable vane system changes the position of the inlet guide vanes and the stator vanes to avoid compressor stall. This action maintains the velocity of the air (and the angle at which it strikes the blades) within acceptable limits for low airflow conditions. It also permits high airflow with a minimum of restriction.

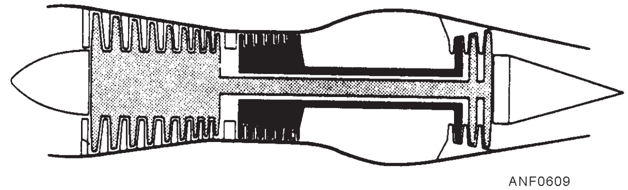


**Figure 6-9.—Dual rotor turbine for split spool compressor.**

**COMBUSTION CHAMBER**.—The efficiency and performance of a turbine power unit depend on the type of combustion system used. The basic requirements for a satisfactory system are a high rate of burning, minimum pressure drop, small bulk, and light weight. The system must be consistent in operation over a wide range of loads and altitudes, with no tendency to flood with fuel or suffer *combustion blowout*. Combustion blowout is a flame failure, and it is primarily a problem in high-altitude operation. Starting must be easy and positive, both on the ground and in the air. Combustion must be complete to avoid formation of carbon deposits.

Fuel enters the front of the burner as an atomized spray or in a prevaporized form. Air flows in around the fuel nozzle and through the first row of combustion air holes in the liner. Air near the burner nozzle stays close to the front liner wall for cooling and cleaning purposes. Air entering through opposing liner holes mixes rapidly with the fuel to form a combustible mixture. Air entering the forward section of the liner recirculates and moves upstream against the fuel spray. During combustion, this action permits rapid mixing and prevents flame blowout by forming a low-velocity stabilization zone. This zone acts as a continuous pilot for the rest of the burner. Air entering the downstream part of the liner provides the correct mixture for combustion. This air also creates the intense turbulence necessary for mixing the fuel and air and for transferring energy from the burned to the unburned gases.

Since an engine usually has two igniter plugs, cross ignition tubes are necessary in the can and can-annular types of burners. These tubes allow burning to start in the other cans or inner liners. Axial-flow engines use either an annular or the can-annular (fig. 6-10) type of combustion chamber. The igniter plug is usually located in the upstream reverse flow region of the burner. After ignition, the flame quickly spreads to the primary (combustion) zone. This zone contains the correct proportion of air to completely burn the fuel. If all the air flowing through the engine were mixed with the fuel at this point, the mixture would be outside the combustion limits for the fuel normally used. Therefore, only about one-third to one-half of the air is allowed to enter the combustion zone of the burner. About 25 percent of the air actually takes part in the combustion process.

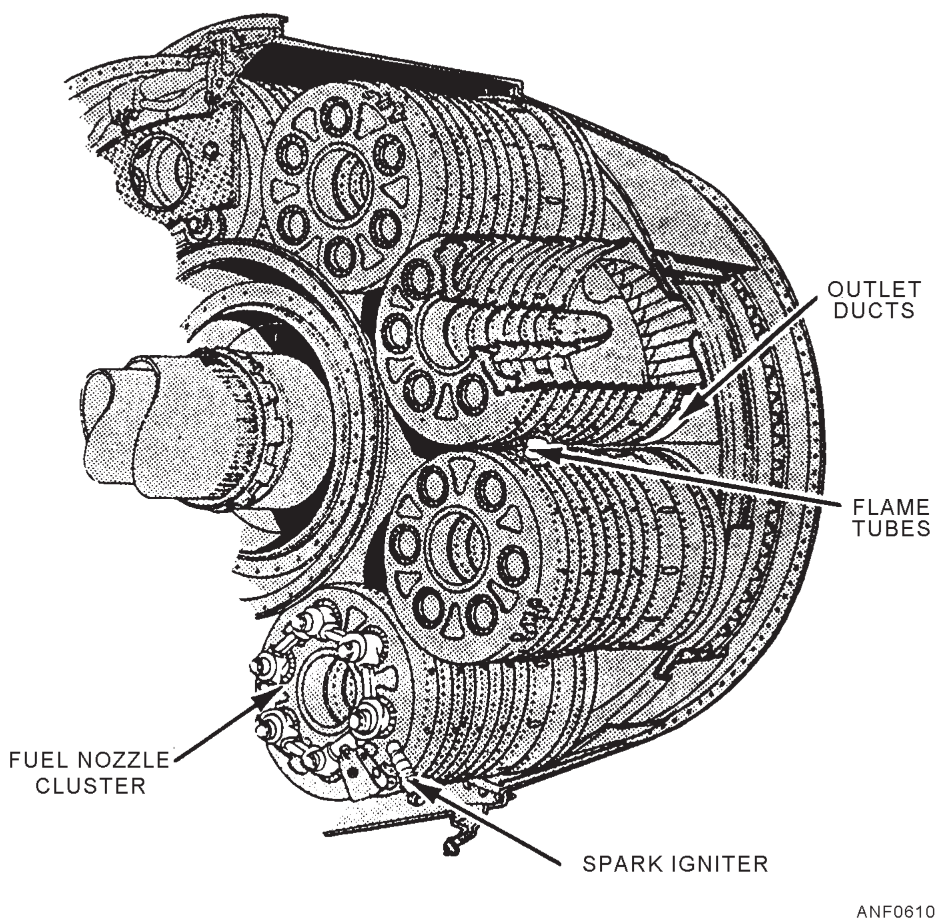


**Figure 6-10.—Can-annular combustion chamber components and arrangements.**

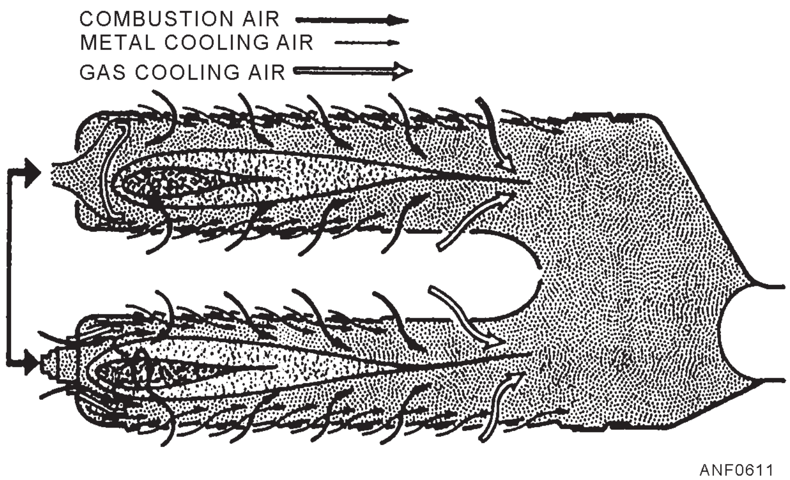


**Figure 6-11.—Airflow through a can-annular chamber.**

Gases that result from the combustion process have temperatures of approximately 3,500˚F (1,900˚C). Before entering the turbine, these gases must be cooled to about half this value. The design of the turbine and the materials used in its makeup determine the temperature to which the gases must be cooled. Secondary air, which enters through a set of relatively large holes located toward the rear of the liner, dilutes and cools the hot gases. The liner must also be protected from the high temperatures of combustion. This is usually done by cool air introduced at several different places along the liner. The cool air forms an insulating blanket between the hot gases and the metal walls, as shown in figure 6-11.

**TURBINE**.—The turbine assembly drives the compressor and accessories by extracting some of the energy and pressure from the combustion gases. In a typical jet engine, about 75 percent of the power produced internally is used to drive the compressor. The remaining 25 percent produces the necessary thrust.

The turbine consists of a nozzle assembly and a rotating blade assembly. The hot gases from the combustion chamber flow through the turbine nozzle assembly and are directed against the rotating turbine disk blades. The rotating blade assembly (turbine rotor) is made up of a steel shaft and disk. High-temperature alloy blades are locked into grooves cut in the periphery of the disk. The entire turbine rotor is statically and dynamically balanced. In some units, the turbine compressor rotors are mounted on the same shaft. In other units they are mounted on separate shafts that are connected during assembly.

The nozzle assembly consists of the nozzle guide vanes and the stator ring/shroud ring, as shown in figure 6-12. The guide vanes are made up of high-temperature alloy. They are fitted into or welded to the stator ring/shroud.

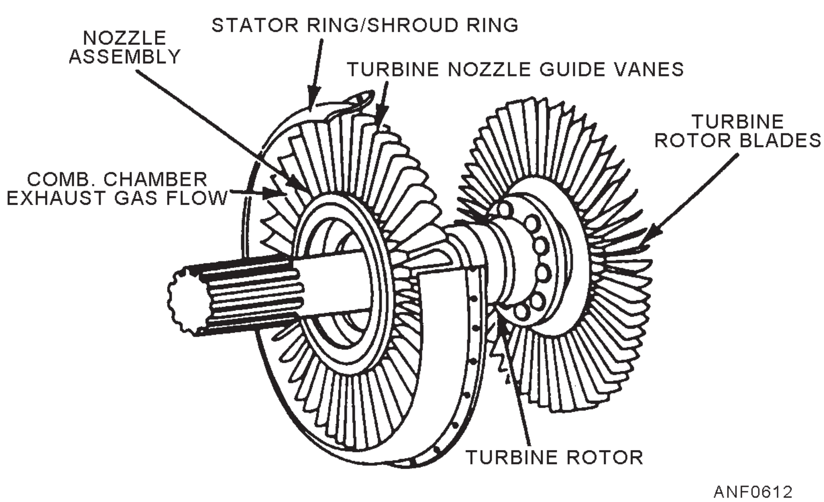


**Figure 6-12.—Turbine rotor and nozzle.**

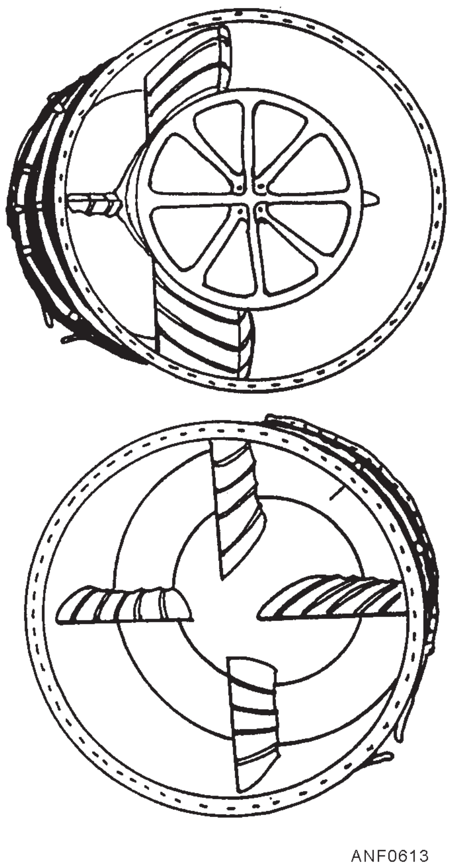


**Figure 6-13.—Typical exhaust cone assembly.**

**EXHAUST CONE ASSEMBLY**.—The exhaust cone (fig. 6-13), attached to the rear of the turbine assembly, is a tapered, cylinder-shaped outlet for the gases. The cone eliminates turbulence in the emerging jet, thereby giving maximum velocity.

The inner cone is usually attached to the outer cone by streamlined vanes called brace assemblies. The exhaust cone itself is usually made of stainless steel sheets, reinforced at each end with stainless steel flanges. As much heat energy as possible is kept within the exhaust cone. A covering of layers of aluminum foil or other material acts as insulation for the cone.

**Turboprop Engines**

There are numerous models of the turboprop engine. The P-3 and E-2 aircraft are examples of aircraft that use turboprop engines.

The turboprop engine was developed to provide the power requirements for aircraft of greater size, carrying capacity, range, and speed. The turboprop engine is capable of developing 2 1/2 horsepower per pound of weight.

The turboprop converts most of its gas-energy into mechanical power to drive the compressor, accessories, and a propeller. The additional turbine stages needed to drive the extra load of a propeller create the low-pressure, low-velocity gas stream. A small amount of jet thrust is obtained from this gas stream.

The turboprop engine (fig. 6-14) consists of three major assemblies: the power section, the torquemeter assembly, and the reduction gear assembly. The propeller assembly mounts on the reduction gear assembly to provide aircraft thrust.

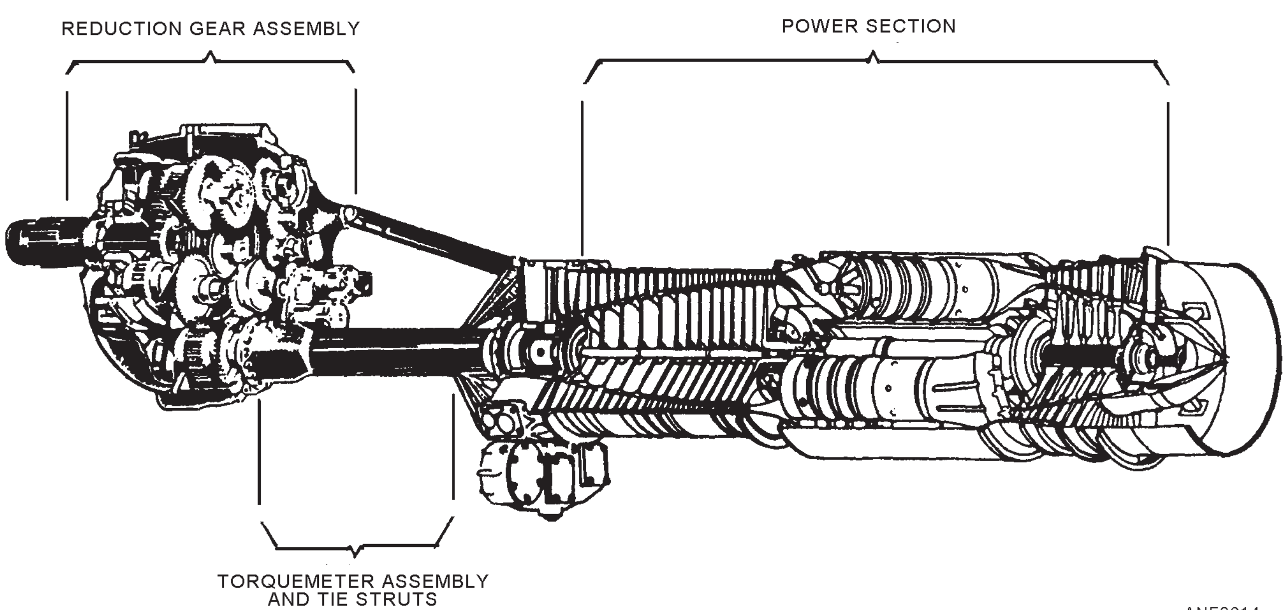


**Figure 6-14.—T56 turboprop engine.**

**POWER SECTION**.—The power section consists of an axial-flow compressor, a combustion chamber, a multi-stage turbine, and an exhaust section. The last two stages of the turbine are used to drive the propeller using the torquemeter assembly and the reduction gear assembly.

**TORQUEMETER ASSEMBLY**.—The torquemeter assembly electronically measures the torsional deflection (twist). Torsional deflection occurs in the power transmitting shaft that connects the power section to the reduction gear assembly. This torsional deflection is recorded as horsepower.

**REDUCTION GEAR ASSEMBLY**.—The reduction gear assembly reduces the engine rpm within the range of efficient propeller rpm. The ratio on some installations is as high as 12 or 13 to 1. This large reduction ratio is necessary because the gas turbine must operate at a very high rpm to produce power efficiently. This engine operates at a constant rpm. The propeller blade angle changes for an increase or decrease in power while the engine rpm remains the same.

The typical propeller assembly for a turboprop engine (fig. 6-15) consists of a front and rear spinner assembly, a hub-mounted bulkhead assembly, the dome assembly, four blades, an afterbody fairing assembly, and a propeller control assembly. The propeller assembly converts the power developed by the engine into thrust as efficiently as possible under all operating conditions.

### Turboshaft Engines

There are many different models of this type of engine. The H-46 and H-53 helicopters are examples of aircraft that use this engine.

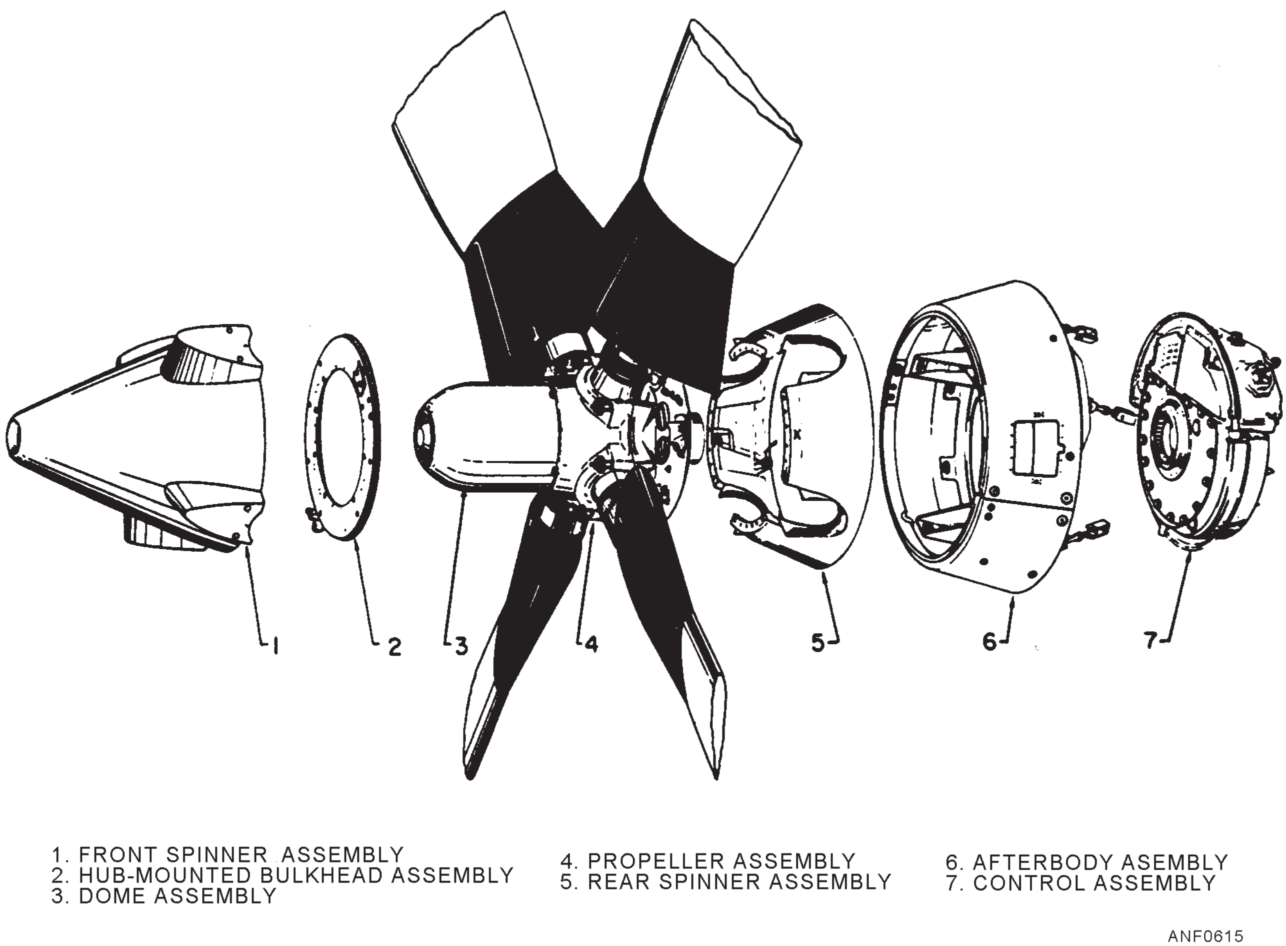


**Figure 6-15.—Propeller assembly and associated parts.**

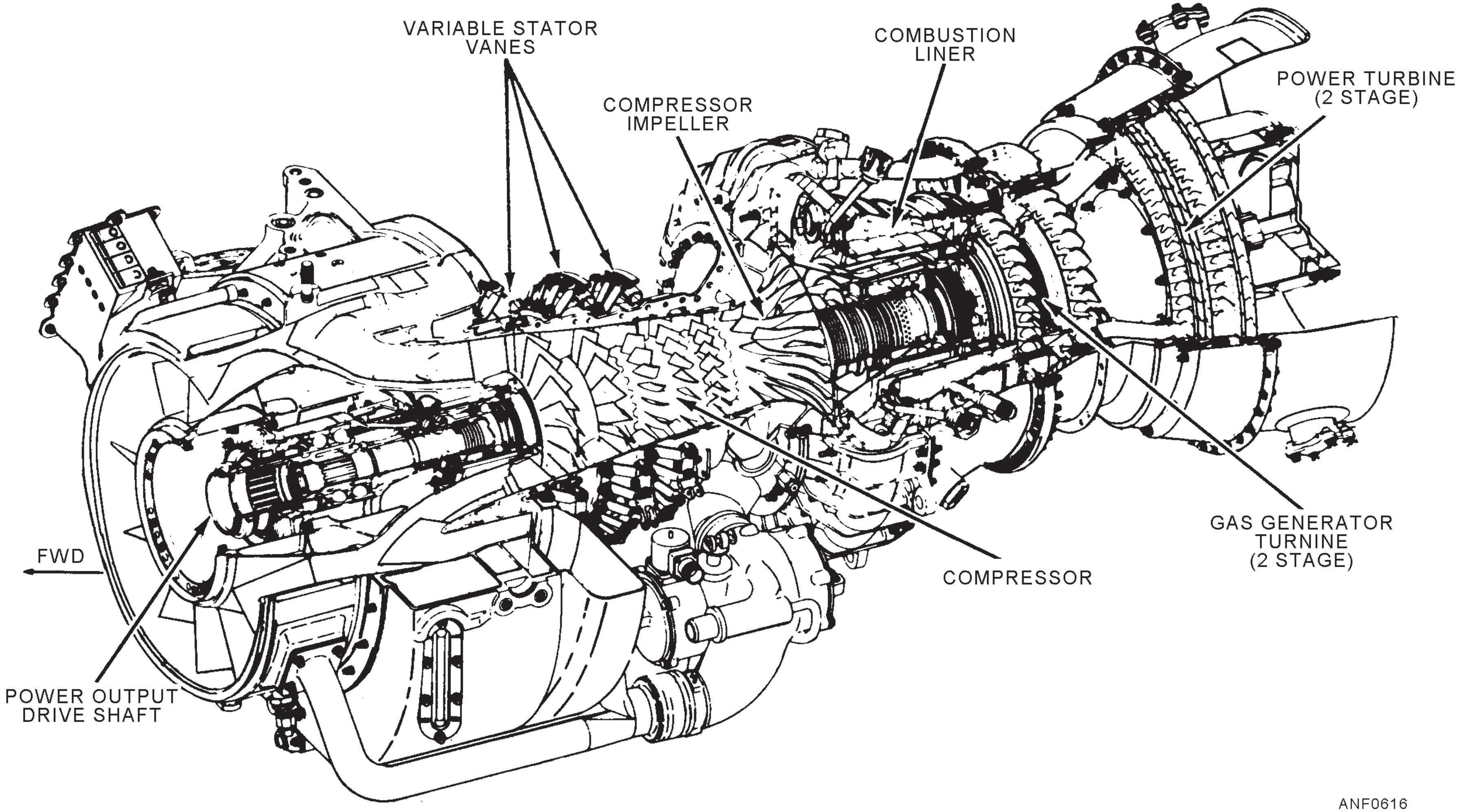


**Figure 6-16.—Turboshaft gas turbine engine.**

Turboshaft engines have a high power-to-weight ratio and are widely used in helicopters. Figure 6-16 shows a typical turboshaft engine.

This engine is an axial-flow turboshaft engine incorporating the free turbine principle. It is comprised of a compressor, combustor, gas generator turbine, and power turbine. The engine is equipped with a control system that modulates fuel flow to maintain constant power turbine output speed for a given speed selector setting in the governed range. This system maintains the selected speed by automatically changing the fuel flow to increase or decrease gas generator speed. The pilot determines the speed by positioning the power lever. The control system provides automatic protection against compressor stall, turbine overtemperature, overspeed of either turbine assembly, and combustion flameout.

An emergency throttle system is provided for use in case of fuel control failure. A starter, mounted at the nose of the engine, drives the gas generator rotor and engine accessories for engine starting. The engine is installed with its nose facing forward and supported by engine mounts bolted to the aircraft fuselage. Air is supplied to the engine through the inlet air duct, located inside the right-hand side door of the center nacelle. An alternate air door is attached to the duct by a hinge. Air is supplied through the alternate air door when an insufficient amount of air comes into the engine through the main air duct. The engine is installed so that with the nacelle removed, all accessories and components can be easily reached and maintained.

### Turbofan Engines

There are also many different models of this type of engine. The S-3, AV-8, and F/A-18 are examples of aircraft that use this engine.

The turbofan engine (fig. 6-17) is similar to the turboprop, except a fan replaces the turboprop propeller. One basic operational difference between the two engines is the airflow. The fan is inside a cowling, and as a result the airflow through the fan is unaffected by the aircraft's speed. These factors eliminate loss of operational efficiency at high speeds, which limits the maximum airspeed of propeller-driven (turboprop) aircraft.

The turbofan engine has a duct-enclosed fan mounted at the front or rear of the engine. The fan runs at the same speed as the compressor, or it may be mechanically geared down. An independent turbine located to the rear of the compressor drive turbine may also drive the fan.

The fan draws in more air than the compressor of a turbojet engine because of the larger area of the inlet. Because the larger amount of air is compressed and accelerated by the fan, the air completely bypasses the burner and turbine sections of the engine and exits through the fan exit ducts. Since the air is not heated by burning fuel to obtain thrust, the turbofan engine has lower fuel consumption. To develop thrust, the turbofan engine accelerates a large amount of air at a relatively low velocity, which improves its propulsion efficiency.

Compared to the turbojet, the turbofan engine has a low engine noise level. The low noise level results from the lower gas velocity as it exits the engine tailpipe. One reason for the decreased velocity is an additional turbine stage in the engine. This additional turbine stage extracts power from the exhaust gases to drive the fan.

The aircraft powered by a turbofan engine has a shorter takeoff distance and produces more thrust during climb than a turbojet of approximately the same size. This extra thrust allows the turbofan aircraft to take off at a much higher gross weight.

### Gas Turbine Engine Component Controls, Systems, And Sections

In addition to the five major components discussed as part of the turbojet engine, there are numerous controls, systems, and sections that are common to all four types of gas turbine engines. Among the more important of these are the fuel control, lubrication system, ignition system, and accessory section.

**FUEL CONTROL.—**Depending upon the type of engine and the performance expected of it, fuel controls may vary in complexity. They may range from simple valves to automatic computing controls containing hundreds of intricate, highly machined parts.

The pilot of a gas turbine powered aircraft does not directly control the engine. The pilot's relation to the power plant corresponds to that of the bridge officer on a ship. The bridge officer obtains engine response by relaying orders to an engineer below deck, who, in turn, actually moves the throttle of the engine.

Modern fuel controls are divided into two basic groups, hydromechanical and electronic. The controls sense some or all of the following engine operating variables:

1. Pilot's demands (throttle position)

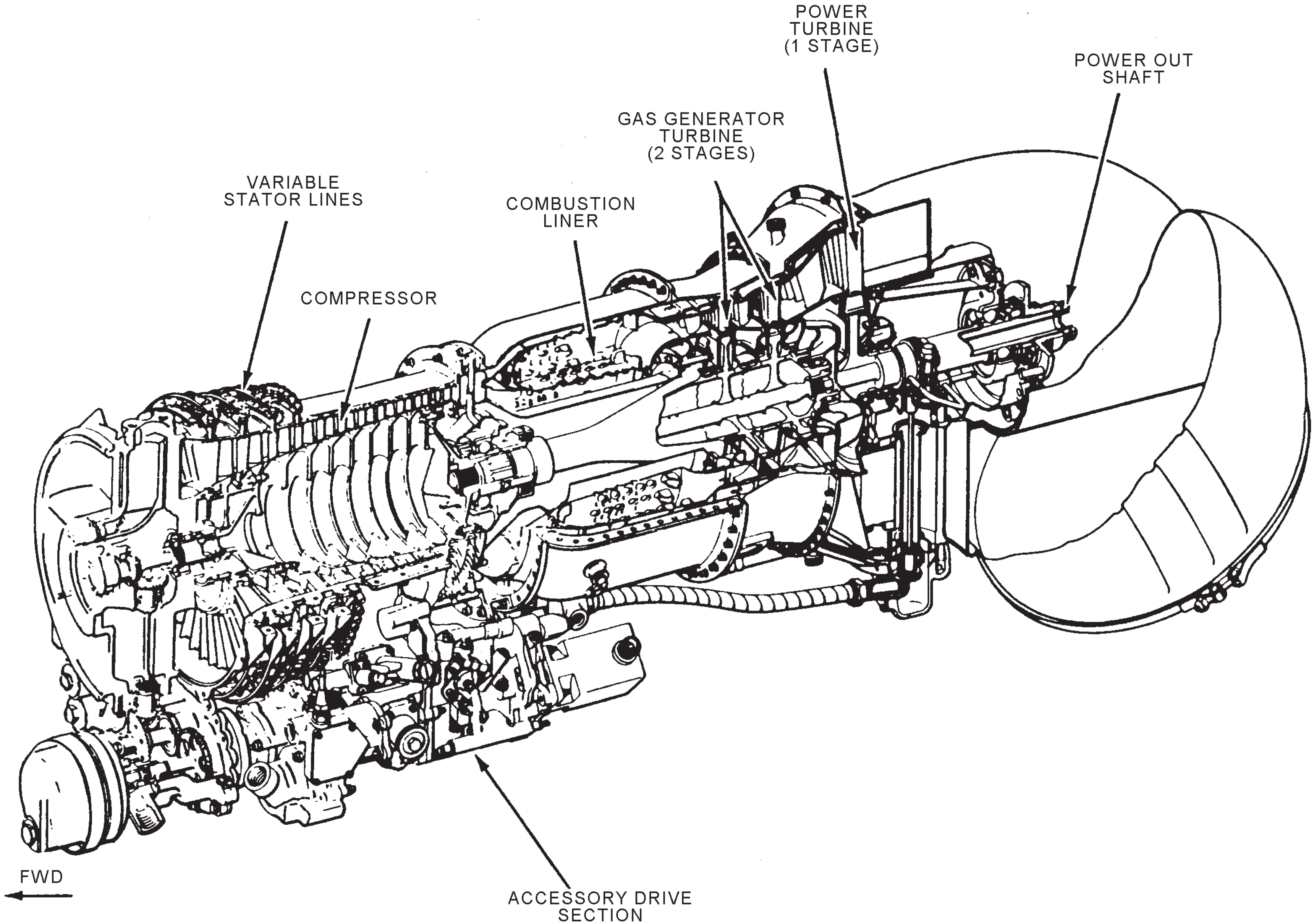


**Figure 6-17.—Turbofan engine.**

2. Compressor inlet temperature
3. Compressor discharge pressure
4. Burner pressure
5. Compressor inlet pressure
6. RPM
7. Turbine temperature

The more sophisticated fuel controls sense even more operating variables.

The fuel control is the *heart* of the gas turbine engine fuel system. This complex device schedules fuel flow to the engine combustion chamber. It automatically provides fuel flow as dictated by the operating conditions of the engine (temperature, pressures, altitude, throttle position, etc.).

The fuel control combines the inputs of throttle position, compressor discharge pressure, compressor inlet temperature, and engine speed to produce the fuel flow to operate the engine. The fuel control governs the engine speed by controlling fuel flow. Fuel flow variations are limited to ensure fast stall-free acceleration and deceleration. During throttle bursts, the fuel control also postpones the initiation of the afterburner operation (if installed) to achieve the fastest possible acceleration.

**LUBRICATION SYSTEM**.—The oil lubrication systems of modern gas turbine engines vary in design and plumbing. However, most systems have units that perform similar functions. In a majority of cases, a pressure pump or system furnishes oil to lubricate and cool several parts of the engine. A scavenging system returns the oil to the tank for reuse. Overheating is a problem in gas turbine engines. Overheating is more severe after the engine stops than while it is running. Oil flow, which normally cools the bearings, stops. The heat stored in the turbine wheel now raises the temperature of the bearings much higher than when the engine was running. The oil moves heat away from these bearings to prevent overheating. Most systems include a heat exchanger to cool the oil. Many systems have pressurized sumps and a pressurized oil tank. This equipment ensures a constant head pressure to the pressure lubrication pump to prevent pump cavitation at high altitudes.

Oil consumption is relatively low in a gas turbine engine compared to a piston-type engine. Oil consumption in the turbine engine primarily depends upon the efficiency of the seals. However, oil can be lost through internal leakage, and, in some engines, by malfunctioning of the pressurizing or venting system. Oil sealing is very important in a jet engine. Any wetting of the blades or vanes by oil vapor causes accumulation of dust or dirt. Since oil consumption is so low, oil tanks are made small to decrease weight and storage problems.

The main parts of the turbine requiring lubrication and cooling are the main bearings and accessory drive gears. Therefore, lubrication of the gas turbine engine is simple. In some engines the oil operates the servomechanism of fuel controls and controls the position of the variable-area exhaust nozzle vanes.

Because each engine bearing gets its oil from a metered or calibrated opening, the lubrication system is known as the calibrated type. With few exceptions, the lubricating system is of the dry sump design. This design carries the bulk of the oil in an airframe or engine-supplied separate tank. In the wet sump system, the oil is carried in the engine itself. All gas turbine engine lubrication systems normally use synthetic oil.

Figure 6-18 shows components that usually make up the dry sump oil system of a gas turbine engine.

**IGNITION SYSTEM**.—Modern gas turbine engines use high voltage and a spark of high heat intensity. The high-energy, capacitor-discharge type of ignition system provides both high voltage and an exceptionally hot spark. This system assures ignition of the fuel-air mixture at high altitudes.

There are two types of capacitor discharge ignition systems. The high-voltage and the low-voltage systems with dc or ac input. The high-voltage system produces a double spark. The double spark is a high-voltage component. This component ionizes (makes conductive) the gap between the igniter plug electrodes so that the high- energy, low-voltage component may follow. In the low-voltage system, the spark is similar to the high-voltage system, but uses a self-ionizing igniter plug.

**WARNING**

Because of the high power in these ignition systems, you must be careful to prevent a lethal electrical shock from capacitors. Always avoid contact with leads, connections, and components until the capacitors have been grounded and are fully discharged.

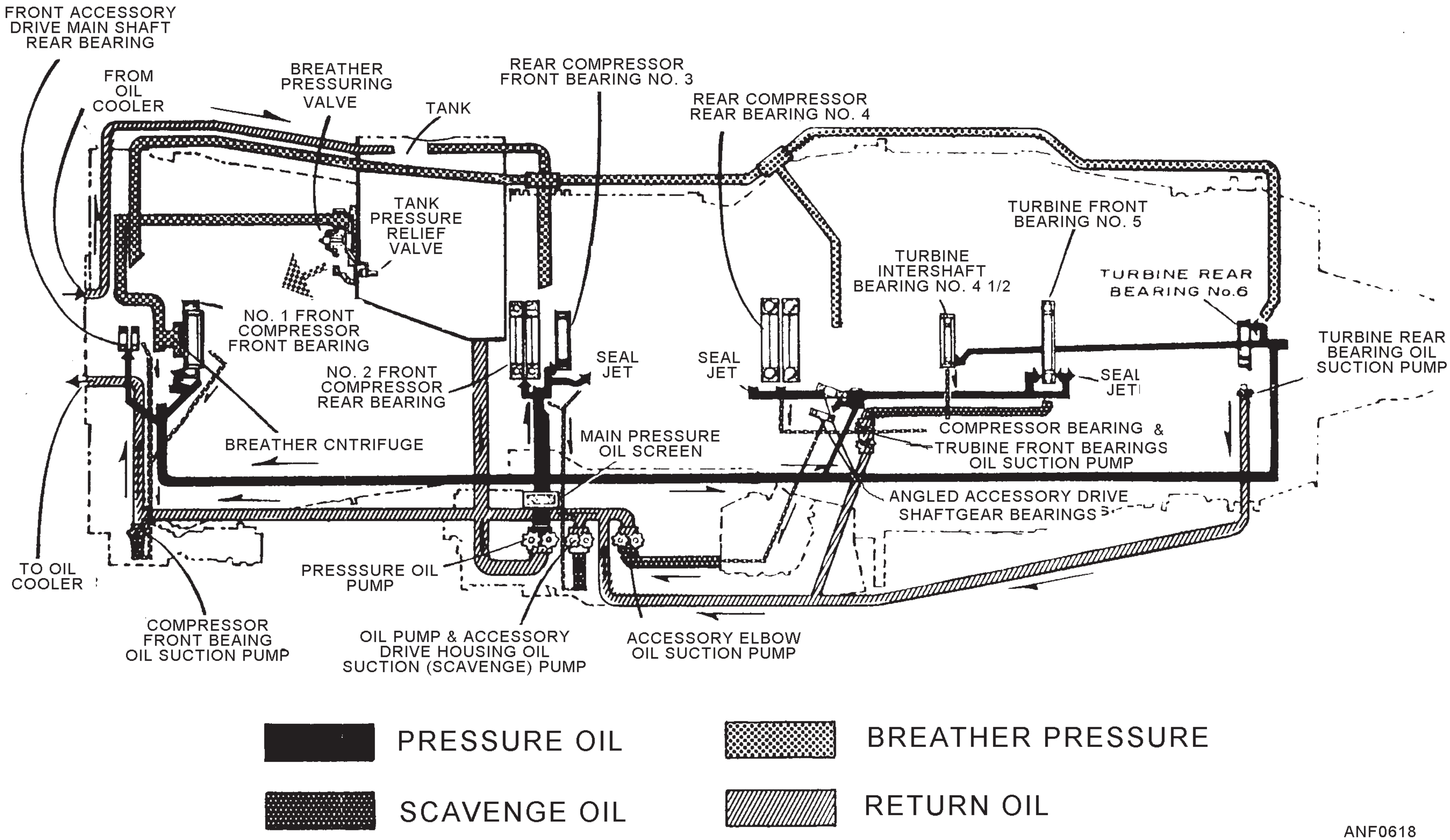


**Figure 6-18.—Dry sump oil system.**

Figure 6-19 shows a typical spark igniter.

**ACCESSORY SECTION**.—The accessory section of the gas turbine engine is usually mounted beneath the compressor section. This section contains an accessory drive gearbox, a housing (case), and provisions for mounting the engine-driven accessories (constant speed drive transmission, fuel and oil pumps, and electrical and tachometer generators, etc.). In gas turbine engines with air turbine starters, the starter is mounted on the forward face of the accessory gearbox. The accessory gearbox also includes many of the gas turbine engine's internal lubrication system components.

*Q6-1. What are the four types of jet propulsion engines?*

*Q6-2. Describe the basic operating principle for all jet engines.*

*Q6-3. The law that states "for every acting force there is an equal and opposite reacting force" describes how air escaping from the rear of a balloon propels the balloon in the opposite direction. What law does this illustrate?*

*Q6-4. What is the simplest power plant that uses atmospheric air to support combustion?*

*Q6-5. What jet engine doesn't have either a compressor or a turbine and can't take off under its own power?*

*Q6-6. What are the four types of gas turbine engines?*

*Q6-7. What are the five major components of a turbojet?*

*Q6-8. What are the three major assemblies of the turboprop engine?*

*Q6-9. Turboshaft engines are normally found on what type of aircraft?*

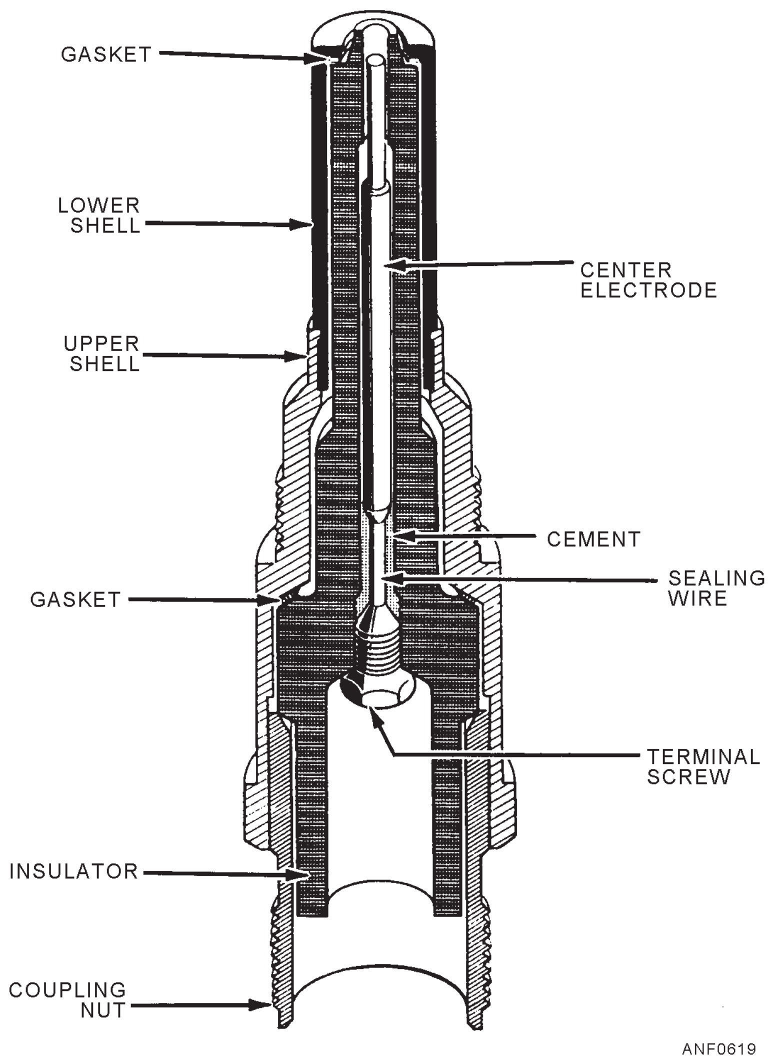


**Figure 6-19.—Spark igniter.**

*Q6-10. What is the major difference between a turboshaft and a turbofan engine?*

*Q6-11. What is the* ***heart*** *of the gas turbine fuel system?*

*Q6-12. List some of the engine-operating variables that are sensed by modern fuel controls.*

*Q6-13. What are the two main parts of a turbine that need lubrication?*

*Q6-14. In most lubricating systems, a pressure pump or system provides oil that lubricates and cools. What system returns the oil to the tank for reuse?*

*Q6-15. What is the difference between low- and high-voltage capacitor discharge ignition systems?*

*Q6-16. Where is the accessory section of the gas turbine engine usually mounted?*

## THE BRAYTON CYCLE

**LEARNING OBJECTIVE**: Recognize the Brayton cycle and its application to gas turbine and jet engines.

A cycle is a process that begins with certain conditions and ends with those same conditions. The Brayton Cycle is illustrated in figure 6-20. Note that in the gas turbine engine, each cycle is not only performed continuously, but also by a separate component designed for its particular function.

Since all of the events are going on continuously, we can say that all gas turbine engines work on an open cycle. Figure 6-20 compares the cycles of operation of a piston-type (reciprocating) engine and a gas turbine engine. The piston-type engine produces power by intermittent combustion. The gas turbine engine produces power continuously.

*Q6-17. What is the Brayton cycle?*

## ENGINE IDENTIFICATION

**LEARNING OBJECTIVE**: Identify the two engine designation systems to include symbols, numbers, indicators, and special designators.

Presently two engine designation systems identify aircraft power plants. One system is described in Air

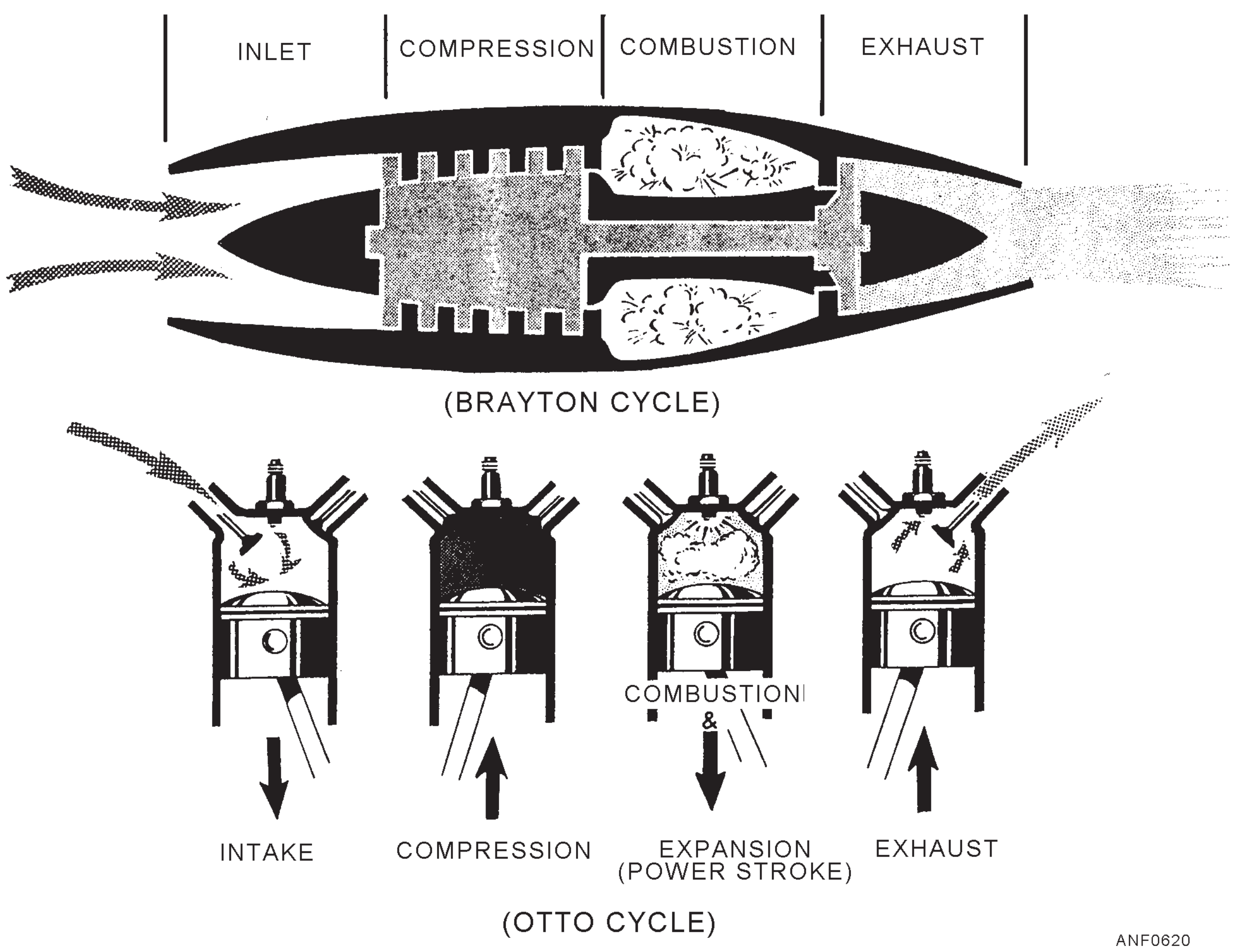


**Figure 6-20.—A comparison of turbojet and reciprocating engine cycles.**

Table 6-1.—Aircraft Letter Symbols and Engine Types

| SYMBOL | ENGINE TYPE |
|---|---|
| R | Internal combustion, air-cooled, radial engine (reciprocating) |
| J | Aviation gas turbine (turbojet engine) |
| T | Aviation gas turbine (turboprop and turboshaft engines) |
| TF | Turbofan engine |
| PJ | Pulsejet engine |
| RJ | Ramjet engine |

Force-Navy Aeronautical (ANA) Bulletin No. 306M. The other system, MIL-STD-1812 designation system, includes all newly developed (Air Force, Army, and Navy) gas turbine engines.

These designation systems use standard symbols to represent the types and models of engines now used in military aircraft.

## ANA BULLETIN NO. 306M DESIGNATION SYSTEM

The following paragraph describes the ANA Bulletin No. 306M designation system. This system has no provisions for Army designation. T56-A-14 is an example of this systems designation number.

### Type Symbols

The first part of the designation system is a letter (or letters) that indicates each basic engine type. Table 6-1 shows the letter symbols that identify engine types.

A number follows the first letter symbol. The using armed service assigns the number used in conjunction with the letter symbol as follows:

- The number 30 for the Navy. The Navy has even numbers.
- The number 31 for the Air Force. The Air Force has odd numbers.

The designation of odd or even numbers does not restrict the use of the engine to the sponsoring service. Aircraft engines, regardless of type designation, are used by various services, depending on their applicability for a particular aircraft. In some instances, engines are made interchangeable for a particular airframe.

### Manufacturer's Symbol

The second part of the designation is a dash and a letter symbol that indicates the engine manufacturer. Some of the manufacturers are listed in table 6-2.

Table 6-2.—Engine Manufacturers

| MANUFACTURER SYMBOL | MANUFACTURER |
|---|---|
| AD | Allison Division, General Motors Corp. |
| BA | Bell Aircraft Company |
| CA | Continental Aviation and Engineering Corp. |
| CP | United Aircraft of Canada Ltd. |
| GA | AiResearch Division, Garrett Corp. |
| GE | General Electric Company |
| LA | Lockheed Aircraft Company |
| LD | Lycoming Division, Avco Corp. |
| MD | McDonald-Douglas, Aircraft Company |
| PW | Pratt and Whitney Aircraft Division, United Aircraft Corp. |
| RR | Rolls Royce, Ltd. |
| WA | Curtis-Wright Corp |
| WE | Westinghouse Electric Company |

Special manufacturer's symbols may be assigned when two manufacturers are jointly producing an engine. In these instances, the manufacturer's symbol is one letter from each of the manufacturers' symbols.

### Model Numbers

The third part of the designation is a dash and a number indicating the model number.

- Navy numbers begin with 2, and they continue with consecutive even numbers. All even model numbers are assigned to engines approved by the Naval Air Systems Command.
- Air Force numbers begin with 1 and continue with consecutive odd numbers.

Each engine design has only one type and model designation for both the Air Force and Navy. For example, the Navy may wish to use an engine that has Air Force-approved type and model numbers. The Navy may use those numbers without change, provided there are no engine changes. If the Air Force wants to use a Navy-approved type engine, but requires minor engine production changes, the Air Force must use the Navy type designation. The Air Force then assigns its own model designation (which begins with the number 1 and progresses with consecutive odd numbers) to the modified engine, regardless of the Navy model number. This model number is actually a modification number. It tells which service made the last production change to the engine for a particular aircraft application.

### Special Designations

The letter X or Y preceding the basic designation signifies a special designation.

The prefix letter X is a basic engine designation signifying the experimental and service test of a particular engine. This prefix letter is removed after tests prove the engine can perform as it should under all operating conditions.

The prefix letter Y indicates a Restricted Service designation. It indicates that the engine will not, or is not expected to, perform satisfactorily under all operating conditions. It is applied to an engine with a specific function or that has completed a 150-hour qualification test only. Upon satisfactorily completing the qualification testing, the Y designation is dropped. The engine is then approved for installation in a production aircraft.

The following is an example of a complete ANA Bulletin No. 306M engine designation number:

**T56-A-14**

- T—Turboprop
- 56—Navy developed
- A—Allison
- 14—Navy model

The ANA Bulletin No. 306M designation system is effective until each engine manufactured before the introduction of MIL-STD-1812 is modified or deleted from service.

## MIL-STD-1812 DESIGNATION SYSTEM

This engine designation system is made up of three-digit numerals and model numbers. It is used on all newly developed gas turbine engines. Existing engines receive a new three-digit model number whenever there are major changes in engine configuration or design. In most instances the old two-digit indicator will be retained. The MIL-STD-1812 engine designation system applies to all the armed services—Air Force, Navy, and the Army.

The complete designation system has three parts—the type indicator, the manufacturer's indicator, and the model indicator. Special designations in this system are the same as those discussed under the ANA Bulletin No. 306M system (X or Y preceding the basic designation).

### Type Indicator

The first part is the type indicator. It consists of the type letter symbol and the type numeral. Letter type symbols are shown in table 6-3:

**Table 6-3.—Engine Type Indicator**

| INDICATOR | ENGINE TYPE |
|---|---|
| J | Turbojet |
| T | Turboprop/Turboshaft |
| F | Turbofan |

The type numerals and type letter symbol are assigned consecutively by each of the services. The numerals begin as follows:

- 100—Air Force
- 400—Navy
- 700—Army

### Model Indicator

The third part is the model indicator. It is a dash and a model number, or a dash and a model number with a suffix letter.

Each configuration of the engine has an assigned model number. Each of the services assigns a block of numbers that are used consecutively.

- 100—Air Force
- 400—Navy
- 700—Army

**NOTE**: If one service uses another services' designated engines, the designation remains the same unless a model change is required. Only in this case will the model indicator change to indicate the engine has been modified.

F401-PW-400 is an example of a MIL-STD-1812 engine designation.

- F Turbofan
- 401 Second Navy turbofan in designation system
- PW Pratt and Whitney Aircraft Division, United Aircraft Corporation
- 400 First Navy model of this particular engine

*Q6-18. What are the two engine designation systems used to identify aircraft power plants?*

*Q6-19. What does the letter X or Y preceding the basic designation signify?*

*Q6-20. What are the three parts of the MIL-STD-1812 designation system?*

*Q6-21. F401-PW-400 is an example of what engine designation system?*

## POWER PLANT SAFETY PRECAUTIONS

**LEARNING OBJECTIVE**: Recognize power plant safety precautions that apply to the intake ducts, exhaust area, and engine noise.

Operational readiness of a maximum number of aircraft power plants is necessary if naval aviation is to successfully perform its mission. Keeping aircraft and power plants in top operating condition is the principal function of naval aviation maintenance personnel. This maintenance work must be performed without injury to personnel.

Every person connected with power plant maintenance is responsible for discovering and eliminating unsafe work practices. In the following section, we will discuss a few standard safety precautions. You must follow these precautions to prevent injury to yourself or others working on or near aircraft jet engines.

### INTAKE DUCTS

The air intake ducts of operating jet engines are an extreme hazard to personnel working near the aircraft. Ducts are also a hazard to the engine itself if the area around the front of the aircraft is not kept clear of debris. The air intake duct develops enough suction to pull an individual, or hats, eye glasses, etc., into the intake. The hazard is obviously greatest during maximum power settings. Protective screens for the ducts are part of the aircraft's ground-handling equipment. These screens must be installed prior to all maintenance turnups.

### EXHAUST AREA

Jet engine exhausts create many hazards to personnel. The two most serious hazards are the high temperature and the high velocity of the exhaust gases from the tailpipe. High temperatures are present several hundred feet from the tailpipe. The closer you get to the aircraft, the higher the exhaust temperatures and the greater the danger.

When a jet engine is starting, sometimes excess fuel will accumulate in the tailpipe. When this fuel ignites, long flames shoot out of the tailpipe at very high velocity. You will want to stay clear of this danger at all times.

## ENGINE NOISE

Jet engine noise can cause temporary or permanent hearing loss. Hearing loss occurs when your unprotected ear is exposed to high sound intensities for excessive periods of time. The higher the sound level, the less time it takes to damage your hearing. Without ear protection, persons exposed to sound intensities above 140 dB (decibels) for any length of time may suffer serious hearing damage. You must wear proper ear protection at all times. You should wear **double** hearing protection when working around turning aircraft.

As an Airman, you must be familiar with all aircraft general safety precautions as well as those peculiar to your squadron. The life you save may be your own.

*Q6-22. What device must be installed before all maintenance turnups?*

*Q6-23. List the two most serious hazards when working around engine exhausts?*

*Q6-24. Why should you wear ear protectors when working around jet engines?*

## SUMMARY

In this chapter, you have been introduced to jet and gas turbine engines. You have learned basic operating principles and how various parts of these engines operate.

# ASSIGNMENT 6

Textbook Assignment: "Aircraft Power Plants," chapter 6, pages 6-1 through 6-20.

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6-1. In 250 B.C., the first reaction engine was built by what group of people?

1. Romans
2. Egyptians
3. Greeks
4. Babylonians

6-2. Naval aircraft jet propulsion engines may be identified by what total number of categories?

1. One
2. Two
3. Three
4. Four

6-3. The gas turbine engine powers almost all Navy aircraft.

1. True
2. False

6-4. Rocket engines carry their own oxidizer for combustion for what primary reason?

1. For travel above the atmosphere
2. For travel within the atmosphere
3. To take the place of hydrogen
4. To take the place of carbon

6-5. Jet propulsion engine operations can be explained by which of the following laws of motion?

1. Newton's first
2. Newton's second
3. Newton's third
4. Newton's fourth

6-6. When the stem of an inflated balloon is released, what action causes the balloon to move forward?

1. The force of the escaping air
2. The low-pressure area against the front of the balloon
3. The pressure from inside the balloon pushing against the outside air
4. The pressure of the air on the inside of the balloon directly opposite the open stem

6-7. A basic gas turbine engine consists of what total number of major sections?

1. Six
2. Five
3. Three
4. Four

6-8. Most of the air taken into the combustion chamber of a jet engine is used for what purpose?

1. Compression
2. Propulsion
3. Combustion
4. Cooling

6-9. A compressor stage consists of what row(s) of blades or vanes?

1. Rotating blades only
2. Stator vanes only
3. Rotating blades and stator vanes
4. Three or more rows of rotating blades and stator vanes

6-10. In a compressor, the air pressure increases each time it passes through a set of rotors and stators for which of the following reasons?

1. The areas of the rotors and stators gets larger
2. The areas of the rotors and stators gets smaller
3. The spool area of the stators increases
4. The spool area of the rotors increases

6-11. Since the initial appearance of the split-spool compressor engine, the potential thrust of today's engines has been boosted considerably. These compressors are driven individually by what means?

1. The turbine assembly
2. Separate wheels of the turbine assembly
3. The rotor assembly
4. The stator assembly

6-12. Compressor stalls may be eliminated by using which of the following systems?

1. Rotor vane and stator vane system
2. Inlet guide vane and stator vane system
3. Front and rear compressor system
4. Compressor bleed-air system and variable vane system

6-13. Which of the following is NOT a basic requirement for a satisfactory and efficient combustion chamber system?

1. Light weight
2. A minimum pressure drop
3. A high rate of burning
4. Can-annular design

6-14. Fuel is introduced into the combustion chamber at what location?

1. Back of the combustion chamber
2. Top of the combustion chamber
3. Front of the combustion chamber
4. Bottom of the combustion chamber

6-15. A gas turbine engine normally has provisions for what total number of igniter plugs in the combustion chamber?

1. One
2. Two
3. Three
4. Four

6-16. The flame from the chambers containing the igniter plugs is spread to the remaining chambers through what design feature?

1. Guide vanes
2. Drilled holes
3. Flame tubes/cross ignition tubes
4. Louvers

6-17. What percent of the air in the combustion chamber actually takes part in the combustion process?

1. 25%
2. 35%
3. 45%
4. 55%

6-18. Secondary air is used in the combustion chamber for what purpose?

1. To dilute and cool the hot gases
2. To help the combustion process
3. To drive the compressor
4. To drive the turbine

6-19. What function does the turbine assembly serve?

1. It develops exhaust gas power
2. It reduces the speed of the compressor
3. It increases the turbine gas temperatures
4. It drives the compressor

6-20. The flowing gases from the combustion chamber of a turbojet engine act directly against what engine component?

1. Impeller
2. Compressor
3. Turbine disk blades
4. Auxiliary equipment

6-21. Turbine blades are normally made from what material alloy?

1. Copper
2. Aluminum
3. Magnesium
4. Steel

6-22. What is the function of the inner cone in the exhaust section?

1. To eliminate exhaust gas turbulence
2. To direct air to the outer exhaust cone
3. To give support to the exit guide vanes
4. To cool the turbine wheel

6-23. The inner cone is attached to the outer cone by what means?

1. Copper alloy tubes
2. Streamlined vanes called brace assemblies
3. Stainless steel sheets
4. Tapered cylinder-shaped brackets

6-24. The exhaust cone is made from what material?

1. Aluminum alloy
2. Stainless steel sheets
3. High-temperature alloy
4. Low-temperature alloy

6-25. What material is used to insulate the cone?

1. High-temperature alloy
2. Copper sheets
3. Aluminum alloy sheets
4. Aluminum foil

6-26. The turboprop engine is capable of developing what maximum horsepower per pound of weight?

1. 1/2 hp
2. 1 1/2 hp
3. 2 hp
4. 2 1/2 hp

6-27. A turboprop engine has what total number of major assemblies?

1. One
2. Two
3. Three
4. Four

6-28. What component of the power section of a turboprop engine provides the power that drives the propeller?

1. Turbine
2. Combustion chamber
3. Compressor
4. Exhaust

6-29. Torsional deflection in a turboprop engine is an indication of what variable?

1. Temperature
2. Horsepower
3. Pressure
4. Rpm

6-30. What is the function of the reduction gear assembly?

1. To change the propeller blade angle to a variable rpm
2. To provide a constant rpm unit for propeller operation
3. To reduce the engine rpm to within the range of efficient propeller rpm
4. To provide higher propeller rpm than the engine provides

6-31. What is the basic function of the propeller assembly?

1. To efficiently develop thrust
2. To drive the reduction gearbox assembly
3. To drive the compressor section
4. To efficiently develop rpm

6-32. Turboshaft engines are currently being used on which of the following types of aircraft?

1. Fighters
2. Attack
3. Transport
4. Helicopters

6-33. Which of the following types of gas turbine engines operates on the free turbine principle?

1. Turboprop
2. Turboshaft
3. Turbofan
4. Turbojet

6-34. During all operations of the turboshaft engine, automatic protection is provided for which of the following malfunctions?

1. Turbine overspeed, compressor stall, combustion flame-out, and turbine overtemperature
2. Compressor overspeed, turbine stall, turbine overtemperature, and combustion flame-out
3. Combustion flame-out, turbine under temperature, turbine overspeed, and compressor stall
4. Turbine underspeed, compressor stall, combustion flame-out, and turbine overtemperature

6-35. Operation of the turbofan engine is similar to which of the following gas turbine engines?

1. Turboshaft
2. Turbojet
3. Turboprop
4. Turbopulse

6-36. The turbofan engine has a low rate of fuel consumption.

1. True
2. False

6-37. A turbofan powered aircraft that is approximately the same size as a turbojet aircraft is capable of accomplishing which of the following tasks?

1. Handling higher gross weight at takeoff
2. Producing more thrust during climb
3. Using shorter takeoff distance
4. Each of the above

6-38. What factor causes the low noise level of the turbofan engine?

1. The enclosed fan, which is driven at the engine's speed
2. The high velocity of compressed air that passes through the burner and turbine sections
3. The increased thrust from the use of the afterburner
4. The low gas velocity coming out of the tailpipe

6-39. What are the two basic groups of modern fuel control systems?

1. Pneumatic and pressure
2. Hydromechanical and electronic
3. Automatic and manual
4. Pressure and mechanical

6-40. What is considered to be the "heart" of a gas turbine engine fuel system?

1. Fuel control
2. Fuel cell pumps
3. Fuel cross-feed valves
4. Fuel shutoff valve

6-41. Which of the following inputs does the fuel control system combine to operate a gas turbine engine?

1. Fuel flow, compressor pressure, turbine speed, and temperature
2. Combustion, ignition, altitude, fuel flow, and acceleration
3. Engine speed, altitude, exhaust temperature, and throttle position
4. Throttle position, compressor discharge pressure, engine speed, and compressor inlet temperature

6-42. What lubrication system returns engine oil back to the oil tank for reuse?

1. Pressure pump system
2. Wet sump system
3. Scavenge system
4. Pressurized sump system

6-43. The purpose of a pressurized oil tank in the lubricating system of a gas turbine engine is to prevent pump cavitation under what condition?

1. High altitude
2. Engine start
3. Low altitude
4. Engine stop

6-44. The lubricating system used on a gas turbine engine is, with few exceptions, always the dry sump design.

1. True
2. False

6-45. What type of oil is used in all gas turbine engine lubrication systems?

1. Synthetic oil
2. Petroleum-based oil
3. Animal fat-based oil
4. Mineral-based oil

6-46. What type of ignition system has been universally accepted for use in a gas turbine engine?

1. Low spark, capacitor
2. High capacitor, low spark
3. High energy, capacitor
4. Low capacitor, low energy

6-47. To avoid a lethal electrical shock from the ignition system, which of the following components must be grounded before maintenance work can be started?

1. Resistors
2. Igniter plugs
3. Spark plugs
4. Capacitors

6-48. The accessory section is usually mounted to what section on a gas turbine engine?

1. Turbine section
2. Combustion section
3. Compressor section
4. Exhaust section

6-49. The term used to describe a process that begins with certain conditions and ends with those same conditions is known as "Brayton Cycle."

1. True
2. False

6-50. The MIL-STD-1812 designation system has no provision for what branch of the armed forces?

1. Navy
2. Army
3. Air Force
4. Coast Guard

IN ANSWERING QUESTIONS 6-51 THROUGH 6-53, REFER TO TABLE 6-1.

6-51. What aircraft letter symbol identifies a turbojet engine?

1. RJ
2. R
3. J
4. T

6-52. What aircraft letter symbol identifies a turboshaft engine?

1. R
2. J
3. T
4. TF

6-53. What aircraft letter symbol identifies a turbofan engine?

1. R
2. J
3. T
4. TF

6-54. Following the first letter symbol identifying the engine type, a number appears to identify the service that uses the engine(s). Which of the following numbers represents an Air Force engine?

1. 20
2. 30
3. 31
4. 40

IN ANSWERING QUESTIONS 6-55 THROUGH 6-58, REFER TO TABLE 6-2 IN THE TEXT.

6-55. The manufacturer's symbol BA identifies which aircraft engine manufacturer?

1. Allison Division, General Motors Corporation
2. General Electric Company
3. Bell Aircraft Company
4. McDonald–Douglas Aircraft Company

6-56. What engine manufacturer's symbol identifies the Lockheed Aircraft Company?

1. LA
2. LD
3. AD
4. GA

6-57. The manufacturer's symbol PW identifies which aircraft engine manufacturer?

1. Rolls Royce, Ltd.
2. Westinghouse Electric Company
3. AiResearch Division, Garrett Corporation
4. Pratt and Whitney Aircraft Division

6-58. What engine manufacturer's symbol identifies the Curtis-Wright Corporation?

1. WE
2. WA
3. PW
4. MD

6-59. When two manufacturers' are jointly producing an engine, the symbol is one letter from each manufacturer's symbols.

1. True
2. False

6-60. The third part or section of the engine designation consists of a dash and a number indicating the model number. The Navy model number begins with 2 and continues with consecutive even numbers.

1. True
2. False

6-61. Under special engine designations, what prefix letter is assigned to experimental and service test engines?

1. W
2. X
3. Y
4. Z

6-62. Under special engine designations, what prefix letter is assigned to restricted service engines?

1. W
2. X
3. Y
4. Z

6-63. Normally the restricted service designation for an engine is dropped after completion of what total number of qualifying test hours?

1. 50 hr
2. 100 hr
3. 150 hr
4. 200 hr

6-64. The MIL-STD-1812 engine designation system is made up of what total number of parts or sections?

1. One
2. Two
3. Three
4. Four

6-65. The Air Force, Navy, and Army are assigned a block of engine configuration model numbers that are used consecutively.

1. True
2. False

6-66. What series or block of engine configuration model numbers are assigned to the Navy?

1. 100
2. 400
3. 700

6-67. Which of the following characters identifies the type of engine in the designation number F401–PW–400?

1. F
2. 401
3. PW
4. 400

6-68. Which of the following characters identifies the engine manufacturer in the designation number F401–PW–400?

1. F
2. 401
3. PW
4. 400

6-69. Which of the following personnel is/are responsible for trying to discover and eliminate unsafe work practices?

1. Commanding officer
2. Maintenance officer
3. Work center supervisor
4. All hands

6-70. The greatest hazard of working near the aircraft intake ducts occurs during which of the following operations?

1. Engine start
2. Engine stop
3. Maximum power
4. Minimum power

6-71. Serious hearing damage may occur to unprotected ears if the dB (decibel) level is greater than what maximum level?

1. 140 dB
2. 120 dB
3. 110 dB
4. 100 dB