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Fundamentals of Gas Turbine Engines

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CHAPTER 1

GAS TURBINE ENGINE FUNDAMENTALS

This chapter will help you understand the history and development of gas turbine engines (GTEs). It will help you become familiar with the basic concepts used by GTE designers, follow discussions of how the Brayton cycle describes the thermodynamic processes in a GTE, and learn how various conditions and design limitations affect GTE performance. How a GTE develops and uses hot gases under pressure is also thoroughly discussed in this chapter. After reading this chapter, you should have the basic knowledge to be able to describe the principal components of GTEs and their construction, the GTE auxiliary systems, and also be familiar with the nomenclature related to GTEs and GTE technology. A more in-depth coverage of the individual systems and components for the General Electric LM2500 GTE will be discussed in chapter 2 of this TRAMAN. To refresh your memory about the different laws and principles discussed in this chapter, refer to NAVEDTRA 10563, volume 1, chapter 4.

HISTORY AND BACKGROUND

Until recent years, GTE technology and jet engine technology have overlapped a great deal. The same people have worked in both fields, and the same sciences have been applied to both types of engines. In the past, the jet engine has been used more as a part of aviation. The GTE has been used for electric generation, ship propulsion, and even experimental automobile propulsion. Many operational turbine power plants use a derivative of an aircraft jet engine as a gas generator (GG). When used as such, the engine must be modified by the addition of a power turbine (PT) and reduction gearing to complete the plant.

In nature, the squid was using jet propulsion long before scientists thought of it. Examples of

the reaction principle (Newton's third law) existed in early history. However, practical application of the reaction principle occurred only recently. This delay is due to the slow progress of technical achievement in engineering, fuels, and metallurgy (the science of metals).

Hero, a scientist in Alexandria, Egypt, who lived between the first and third centuries A.D., described what is considered to be the first jet engine (the aeolipile). This device (fig. 1-1) is mentioned in sources dating back as far as 250 B.C., and many sources credit Hero as the inventor.

History records several examples of other scientists using the principle of expanding gases to perform work. Among these were inventions

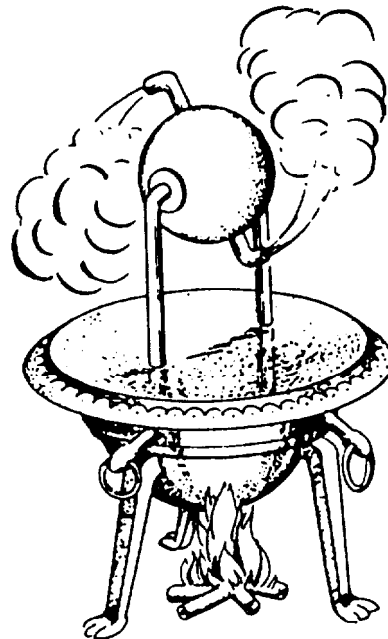


Figure 1-1.—Hero's aeolipile.

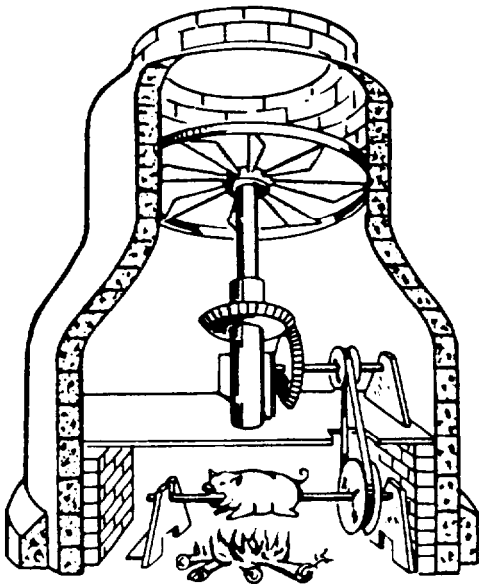


Figure 1-2.—da Vinci's chimney jack.

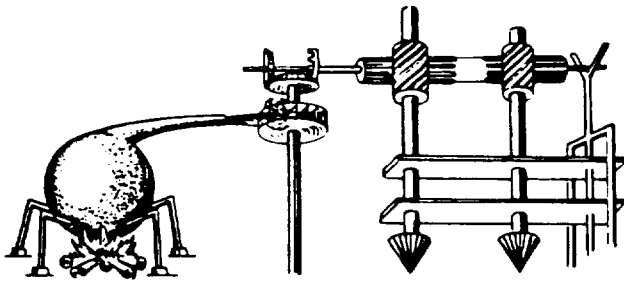


Figure 1-3.—Branca's jet turbine.

of Leonardo da Vinci (around 1500 A.D.) (fig. 1-2) and Giovanni Branca (in 1629) (fig. 1-3).

In the 1680s Sir Isaac Newton described the laws of motion (discussed in GSE3/GSM3, volume 1, chapter 4). All devices that use the theory of jet propulsion are based on these laws. Newton's steam wagon is an example of the reaction principle (fig. 1-4).

In 1791 John Barber, an Englishman, submitted the first patent for a design that used the thermodynamic cycle of the modern GTE. This design was also suggested for jet propulsion.

TWENTIETH-CENTURY DEVELOPMENT

The patented application for the GTE as we know it today was submitted in 1930 by another



Figure 1-4.—Newton's steam wagon.

Englishman, Sir Frank Whittle. His patent was for a jet aircraft engine. Whittle used his own ideas along with the contributions of other scientists. After several failures, he came up with a working GTE.

American Development

The United States did not go into the GTE field until 1941. General Electric was then awarded a contract to build an American version of the British-designed Whittle aircraft engine. The engine and airframe were both built in 1 year. The first jet aircraft was flown in this country in October 1942.

In late 1941 Westinghouse Corporation was awarded a contract to design and build the first all-American GTE. Their engineers designed the first axial-flow compressor and annular combustion chamber. Both of these ideas, with minor changes, are the basis for most modern gas turbines in use today.

Marine Gas Turbine Engine

Using a GTE to propel a ship goes back to 1937 when a Pescara free piston gas engine was used experimentally with a GTE. The free piston engine, or gasifier (fig. 1-5), is a form of diesel engine. It uses air cushions instead of a crankshaft to return the pistons. It was an effective producer of pressurized gases. The German navy used it in their submarines during World War II as an air compressor. In 1953 the French placed in service two small vessels powered by a free piston engine/GTE combination. In 1957 the liberty ship *William Patterson* went into service on a transatlantic run. It had six free piston engines driving two turbines.

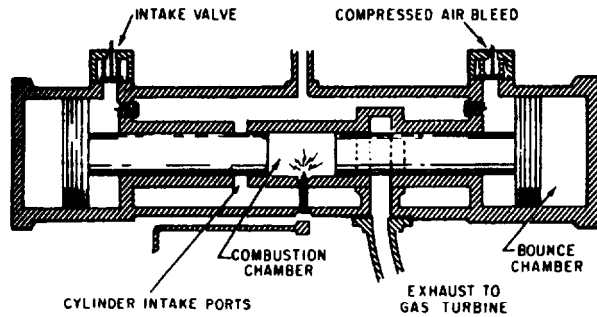


Figure 1-5.—Free piston engine.

At that time applications of the use of a rotary gasifier to drive a main propulsion turbine were used. The gasifier (used as a compressor) was usually an aircraft jet engine or turboprop front end. In 1947 the Motor Gun Boat 2009 of the British navy used a 2500-hp GTE. In 1951 the tanker *Auris*, in an experimental application, replaced one of four diesel engines with a 1200-hp GTE. In 1956 the gas turbine ship *John Sergeant* had a very efficient installation. It gave a fuel consumption rate of 0.523 pounds per hp/hr. The efficiency was largely due to use of a regenerator, which recovered heat from the exhaust gases.

By the late 1950s the marine GTE was becoming widely used, mostly by European navies. All the applications used a dual main propulsion system, combining the gas turbine plant with another conventional form of propulsion machinery. The GTE was used for high-speed operation. The conventional plant was used for cruising. The most common arrangements were the combined diesel and gas (CODAG) or the combined diesel or gas (CODOG) systems. Diesel engines give good cruising range and reliability, but they have a disadvantage when used in antisubmarine warfare. Their low-frequency sounds travel great distances through water. This makes them easily detected by passive sonar. Steam turbines have been combined to reduce low-frequency sound in the combined steam and gas (COSAG) configuration like those used on the British *County* class destroyers. The COSAG configuration requires more personnel to operate. Also they do not have the long range of the diesel combinations. Another configuration that has been successful is the combined gas or gas (COGOG), such as used on the British 42. These ships use the 4,500-hp Tyne GTE for cruising and the Rolls

Royce Olympus, a 28,000-hp engine, for high-speed situations.

The U.S. Navy entered the marine gas turbine field with the *Asheville* class patrol gunboats. These ships have the CODOG configuration with two diesel engines for cruising and a General Electric LM1500 GTE for high-speed operations. The Navy has now designed and is building destroyers, frigates, cruisers, hovercraft, and patrol hydrofoils that are entirely propelled by GTEs. This is a result of the reliability and efficiency of the new GTE designs.

ADVANTAGES AND DISADVANTAGES

The GTE, when compared to other types of engines, offers many advantages. Its greatest asset is its high power-to-weight ratio. This has made it, in the forms of turboprop or turbojet engines, the preferred engine for aircraft. Compared to the gasoline piston engine, the GTE operates on cheaper and safer fuels. The relatively vibration-free operation of the GTE, compared with reciprocating engines, has made it even more desirable in aircraft. Less vibration reduces strain on the airframe. In a warship, the lack of low-frequency vibration of GTEs makes them preferable to diesel engines because there is less noise for a submarine to pick up at long range. Modern production techniques have made GTEs more economical in terms of horsepower-per-dollar on initial installation. Their increasing reliability makes them a cost-effective alternative to steam turbine or diesel engine installation. In terms of fuel economy, modern marine GTEs can compete with diesel engines and they may even be superior to boiler/steam turbine plants that are operating on distillate fuel.

The GTEs do have a few disadvantages. Since they are high-performance engines, many parts are under high stress. Improper maintenance and lack of attention to details of the maintenance procedures will impair engine performance and may lead to engine failure. A **pencil mark** on a compressor turbine blade can cause failure of the part. Most GTE propulsion control systems are very complex and require the monitoring of numerous operating conditions and parameters. The control systems must react quickly to turbine operating conditions to avoid casualties to the equipment. In shipboard installations special soundproofing is necessary because GTEs produce high-pitched noises that can damage the human ear. The turbine takes in large quantities of air

that may contain substances or objects that can harm it. Also, the large amount of air used by a GTE requires large intake and exhaust ducting, which takes up much valuable space on a small ship. This adds to the complexity of the installation and makes access for maintenance more difficult.

From a tactical standpoint, the GTE has two major drawbacks. The first is the large amount of exhaust heat produced by the engines. Most current antiship missiles are heat-seekers. Therefore, the infrared (IR) signature of a GTE is an easy target. Countermeasures, such as exhaust gas cooling and IR decoys, have been developed to reduce this problem.

The second tactical disadvantage is the requirement for depot maintenance and repair of major casualties. On the whole, the turbines are too complex to overhaul in place. They must be removed and replaced by rebuilt engines if any major casualties occur. However, this problem is reduced by the design of the system. A GTE on a frigate, cruiser, or destroyer can be changed out in about 4 days if crane service and a replacement engine are available. A GTE on a hovercraft can be changed out in 8 hours. Gas turbine ships can operate or be repaired to the same standards as their steam- or diesel-driven counterparts.

FUTURE TRENDS

As improved materials and designs permit operation at higher combustion temperatures and pressures, GTE efficiency will increase. Even now, GTE main propulsion plants offer fuel economy and installation costs comparable to diesel engines. Initial costs are lower than equivalent steam plants that burn distillate fuels. These improvements have made GTEs the best choice for nonnuclear propulsion of naval ships up to, and including, an underway replenishment ship in size.

At present, marine GTEs use derivatives of aircraft jet engines for GGs. These are slightly modified for use in a marine environment, particularly in respect to corrosion resistance. As marine GTEs become more widely used, specific designs for ships may evolve. These compressors may be heavier and bulkier than aircraft engines and take advantage of regenerators to permit greater efficiency.

The high power-to-weight ratios of GTEs permit the development of high-performance craft, such as the hovercraft and the hydrofoil, the patrol combatant missile the patrol

combatant (PG), and the landing craft, air cushion (LCAC). These crafts are capable of high speed, can carry formidable weapons systems, and are being seen in increasing numbers in our fleet. In civilian versions, hydrofoils have served for many years to transport people on many of the world's waterways. Hovercraft are being used more and more as carriers of people. They are capable of speeds up to 100 knots. If beach gradients are not too steep, they can reach points inland over virtually any type of terrain.

GAS TURBINE ENGINE THEORY

Two elements are required for proper operation of a GTE. One is expressed by Newton's third law (action/reaction). The other is the convergent-divergent process (or Bernoulli's principle). Convergent means coming closer together, as the inner walls of a tube that is narrowing. Divergent means moving away from each other, as the inner walls of a tube that flares outward. The venturi of an automobile carburetor is a common example of Bernoulli's principle and the convergent-divergent process. Before we discuss GTE construction and design, we will discuss a little more on cycles and theory.

THEORETICAL CYCLES

A cycle is a process that begins with certain conditions, progresses through a series of additional conditions, and returns to the original conditions. The basic GTE cycle is named for the Boston engineer, George Brayton, who proposed it in the late nineteenth century.

The Brayton cycle is one in which combustion occurs at constant pressure. In GTEs, specific components are designed to perform each function of the cycle separately. These functions are intake, compression, combustion, expansion, and exhaust. Refer to figure 1-6 as we explain the Brayton cycle graphically.

- **Intake**—At point A, air enters the inlet at atmospheric pressure and ambient temperature.
- **Compression**—As the air passes through the compressor, it increases in pressure and temperature and decreases in volume (line A-B).
- **Combustion**—At point B, combustion occurs at constant pressure while the addition of heat causes a sharp increase in volume (line B-C).

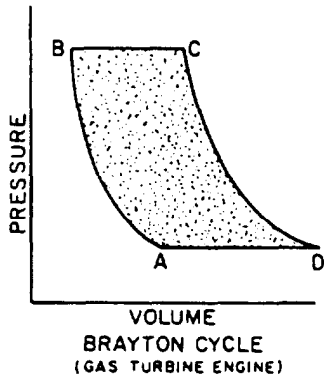


Figure 1-6.—The Brayton cycle.

- **Expansion**—The gases at constant pressure and increased volume enter the turbine and expand through it. As the gases pass through the turbine rotor, the rotor turns kinetic energy into mechanical energy. The expanding size of the passages causes further increase in volume and a sharp decrease in pressure and temperature (line C-D).

- **Exhaust**—The gases are released through the stack with a large drop in volume and at constant pressure (line D-A).

The cycle is continuous and repetitive in a GTE. The functions occur simultaneously throughout the system.

OPEN, SEMICLOSED, AND CLOSED CYCLES

Most internal-combustion engines operate on an open engine cycle. This means the working fluid is taken in, used, and discarded. The GTEs you will encounter in the Navy operate on the open cycle. In the open cycle all the working fluid passes through the engine only once. The open cycle offers the advantages of simplicity and light weight.

Some GTEs operate on a semiclosed cycle. They use a regenerator, such as used on the *John Sergeant*. The regenerator simply transfers the heat from the turbine exhaust gas to the compressor discharge gas before that gas has energy externally supplied (ahead of the combustor).

The third classification of cycles is the closed cycle, in which energy is added externally. The

closed cycle has been called the “natural” cycle for the GTE because it allows use of any fuel, including nuclear, as an energy source. The typical ship’s steam plant is an example of a closed cycle system.

BASIC GTE OPERATION THEORY

The following is a description of a practical demonstration of how a GTE operates. Refer to figure 1-7 as you read the description.

A balloon full of air (view A) does nothing unless the trapped air is released. When the air is released, it escapes rearward, causing the balloon to move forward (Newton’s third law) (view B).

If you could devise a way to keep the balloon constantly full of air, it would continue to move forward (view C) as long as the air is allowed to escape from it.

If you place a fan or pinwheel in the escaping airstream, the pressure energy and velocity energy will cause the fan to rotate. Then you can use the escaping air to do work (view D).

Now, if you replace the balloon with a firmly mounted tube or container and keep it filled with air from a fan located in the air opening and driven by an external source, you could use the discharge air to turn a fan at the rear to do work (view E).

If you add fuel and allow combustion to occur (view F), the volume of air and the velocity with which it passes over the exhaust fan are greatly increased (Charles’s law). The horsepower the fan will produce is also increased. The continuous pressure created by the inlet fan, or compressor, prevents the hot gases from going forward.

Now, if you attach a shaft to the compressor and extend it back to a turbine wheel, you have a simple GTE (view G). It can supply power to run its own compressor and still provide enough power to do useful work. It could drive a generator or propel a ship.

By comparing view H with view G, you can see that a GTE is very similar to the balloon

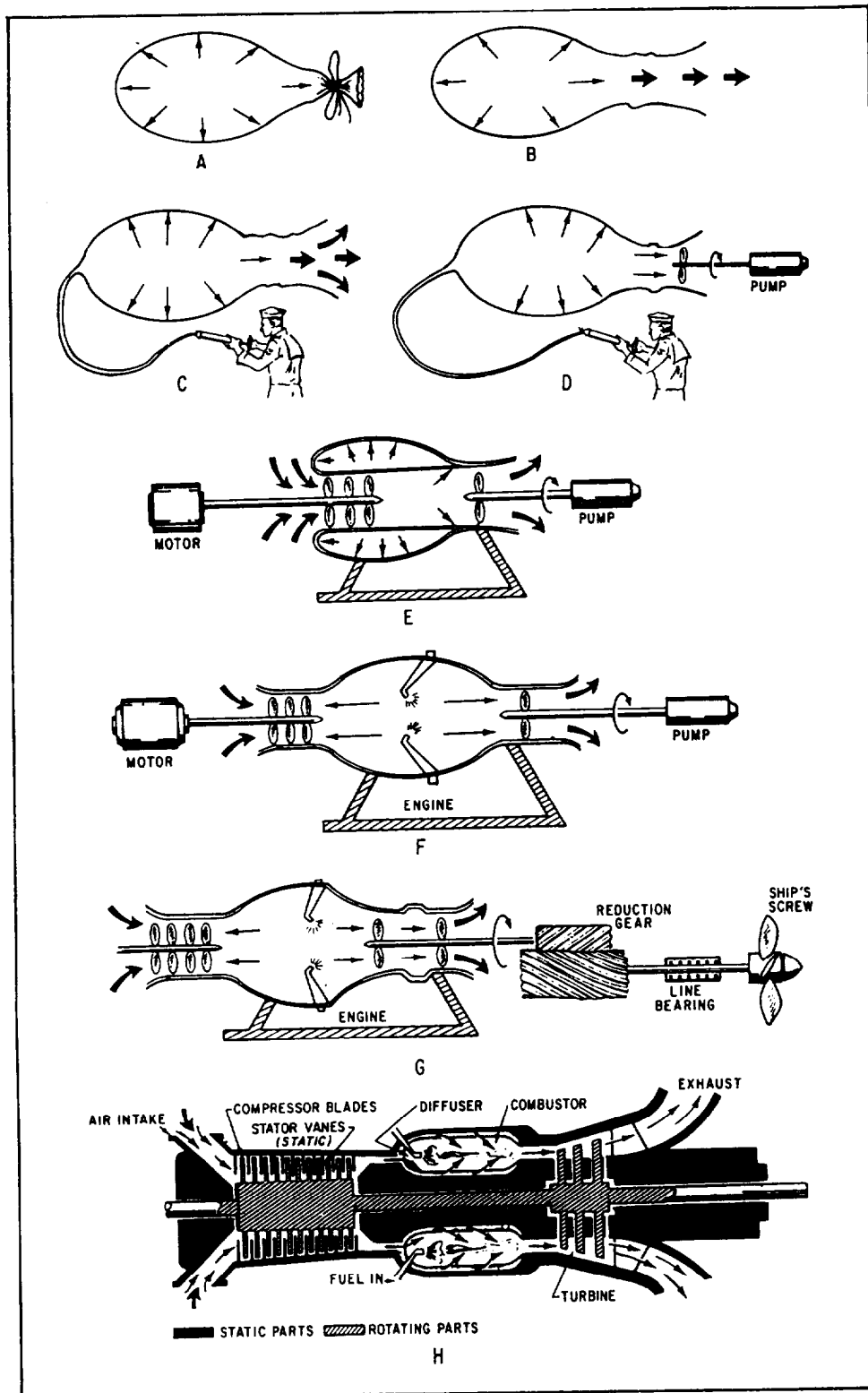


Figure 1-7.—Practical demonstration of GTE operations.

discussed earlier. A review of the gas turbine process is detailed as follows:

1. Air is taken in through the air inlet duct by the compressor. There it is raised in pressure and discharged into the combustion chamber (or combustor).
2. Fuel is admitted into the combustion chamber by the fuel nozzle(s). The fuel-air mixture is ignited by an igniter(s) (not shown) and combustion occurs.
3. The hot and rapidly expanding gases are directed aft through the turbine rotor assembly. There, thermal and kinetic energy are converted into mechanical energy. The gases are then directed out through the exhaust duct.

CONVERGENT-DIVERGENT PROCESS

Several pressure, volume, and velocity changes occur within a GTE during operation. The convergent-divergent process is an application of Bernoulli's principle. (If a fluid flowing through a tube reaches a constriction or narrowing of the tube, the velocity of the fluid flowing through the constriction increases and the pressure decreases. The opposite is true when the fluid leaves the constriction; velocity decreases and pressure increases.) Boyle's law and Charles's law (discussed in NAVEDTRA 10563, volume 1, chapter 4) also come into play during this process. Refer to figure 1-8 as we apply these laws to the GTE.

Air is drawn into the front of the compressor. The rotor is so constructed that the area decreases toward the rear. This tapered construction gives a convergent area (area A).

Between each rotating stage is a stationary stage or stator. The stator partially converts high velocity to pressure and directs the air to the next set of rotating blades.

Because of its high rotational speed and the aerodynamic shape of its blades, the rotor increases the velocity of the air. Each pair of rotor and stator blades constitutes a pressure stage. Both a pressure increase and a reduction in volume occurs at each stage (Boyle).

This process continues at each stage until the air charge enters the diffuser (area B). There is a short area in the diffuser where no further changes take place. As the air charge approaches the end of the diffuser, you will notice that the opening flares (diverges) outward. At this point, the air loses velocity and increases in volume and pressure. The velocity energy has become pressure energy, while pressure through the diffuser has remained constant. The reverse of Bernoulli's principle and Boyle's law has taken place. The compressor continuously forcing more air through this section at a constant rate maintains constant pressure. Once the air is in the combustor, combustion takes place at constant pressure. After combustion there is a large increase in the volume of the air and combustion gases (Charles's law).

The combustion gases go rearward to area C. This occurs partially by velocity imparted by the

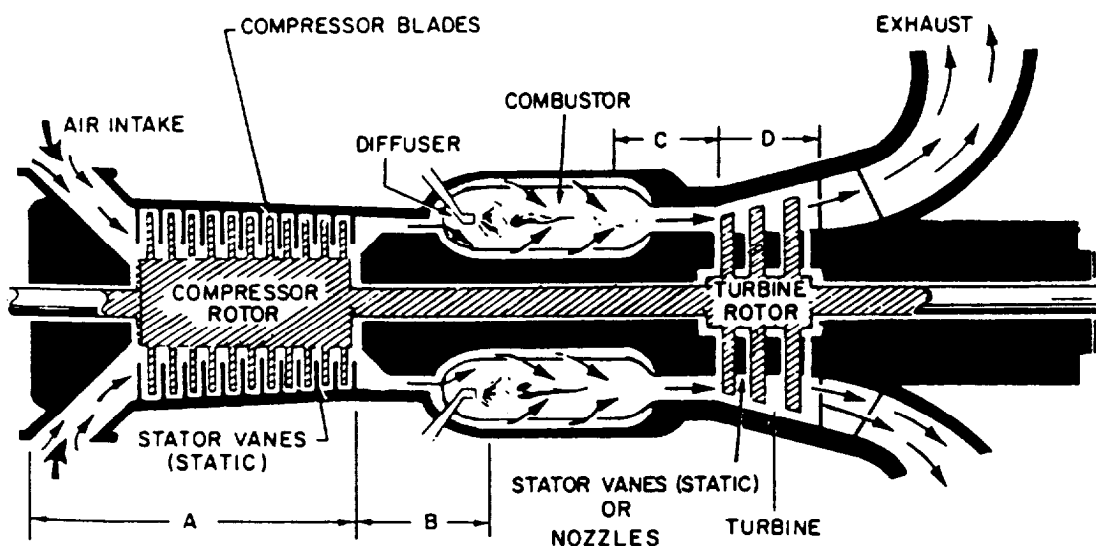


Figure 1-8.—Convergent-divergent process.

compressor and partially because area C is a lower pressure area. The end of area C is the turbine nozzle section. Here you will find a decrease in pressure and an increase in velocity. The high-velocity, high-temperature, low-pressure (LP) gases are directed through the inlet nozzle to the first stage of the turbine rotor (area D). The high-velocity, high-temperature gases cause the rotor to rotate by transferring velocity energy and thermal energy to the turbine blades. Area D is a divergent area. Between each rotating turbine stage is a static stage or nozzle. The nozzles perform the same function as the stators in the compressor.

A turbine nozzle is a stator ring with a series of vanes. The vanes direct the combustion gases uniformly and at the proper angle to the turbine blades. The passages between the vanes are designed as diverging nozzles. Each succeeding stage imparts velocity to the gases as they pass through the nozzle. Each nozzle converts heat and pressure energy into velocity energy by controlling the expansion of the gas.

Each stage of the turbine is larger than the preceding one. The drop in pressure is quite rapid; consequently, each stage must be larger to use the energy of a lower pressure, lower temperature, and larger volume of gas.

Atmospheric air is raised in pressure and velocity and lowered in volume in area A by the compressor. Each stage can only compress air about 1.2 times. In the turbine rotor (area D), the gases give up thermal and pressure energy and

increase in volume through three stages. (If this did not happen rapidly, back pressure from area D would cause area C to become choked.) The gases in the combustor would back up into the compressor. There they would disrupt airflow and cause a condition known as surge, or compressor stall. This condition can destroy an engine in a matter of seconds. Surge will be explained later in our discussion of axial-flow compressors.

The gases from the last turbine stage enter the exhaust duct where they are sent to the atmosphere. The leading portion of the exhaust duct is part of a divergent area. Further divergence reduces the pressure and increases the volume of the warm gases and aids in lowering the velocity. The exhaust gases enter the atmosphere at or slightly above atmospheric pressure. This depends on the length and size of the exhaust duct.

Refer to figure 1-6 and compare the graph and the actual operation of the cycle. Air enters the intake at constant pressure (point A). It is compressed as it passes through the compressor (line A-B in fig. 1-6 and area A in fig. 1-8). Between the end of area B and the beginning of area C in figure 1-8, combustion occurs and volume increases (fig. 1-6, line B-C). As the gases pass through area D (fig. 1-8), the gases expand with a drop in pressure and an increase in volume (fig. 1-6, line C-D). The gases are discharged to the atmosphere through the exhaust duct at constant pressure (fig. 1-6, line D-A and fig. 1-8, exhaust). At this point, you should have the basic knowledge of how a simple gas turbine works.

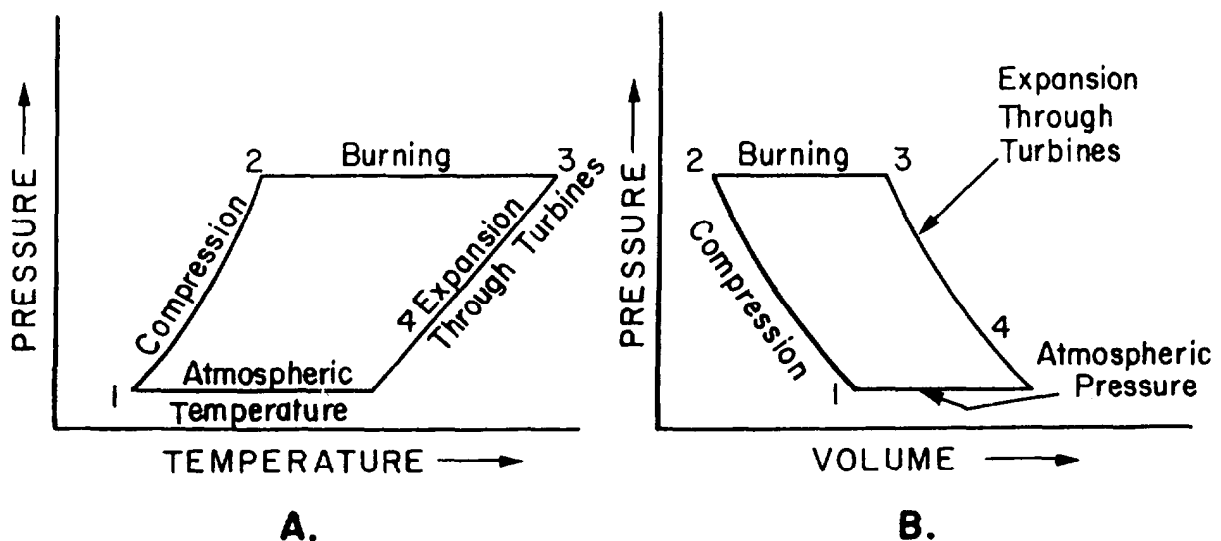


Figure 1-9.—GTE pressure-temperature-volume relationship.

ADIABATIC COMPRESSION

In an adiabatic stage change, no transfer of heat to or from the system occurs during the process. Theoretically, in the ideal GTE, the air enters the compressor and is compressed adiabatically. In many real processes, adiabatic changes can occur when the process is performed rapidly. Since heat transfer is relatively slow, any rapidly performed process can approach an adiabatic state. Compression and expansion of working fluids are often achieved almost adiabatically. This is the case in today's GTEs.

Figure 1-9 is a schematic representation of a stationary simple GTE. It uses two graphs to show the pressure-temperature-volume relationships at various process states. The major components of the GTE are the compressor for the process from 1 to 2, the combustor for the process from 2 to 3, and the turbine for the process from 3 to 4. The heat rejection process from 4 to 1, which completes the cycle, is carried out by exhausting the hot gas and allowing it to mix with the atmosphere.

In an initial simplified analysis, the compressor is taken to include the inlet nozzle and ducting and any exit diffuser leading to the combustor. Thus, for the compressor inlet condition (point 1), the air being drawn from the surroundings has zero velocity, ambient temperature, and ambient pressure. For the exit condition (point 4), the air has zero velocity at some elevated pressure and temperature that are measured. View A of figure 1-9 depicts a pressure-temperature graph for a simple GTE, while view B depicts a pressure-volume graph. The distance between adjacent numbers on each of the diagrams represents an event of the combustion cycle. A combustion cycle includes compression of air, burning of the compressed air and fuel mixture, expansion of gases, and removal of gases. By comparing the numerical points on both graphs (point 1 to 2 on view A with point 1 to 2 on view B), you can get a better understanding of the pressure-temperature-volume relationship of a simple GTE.

During operation the work produced by the compressor turbine rotor is almost the same amount as the work required by the compressor. The mass flow available to the compressor turbine is about the same as the mass flow handled by the compressor. This allows the heat of compression to be about the same value as the heat of expansion. Allowances are made for

factors such as bleed air, pressure of fuel added, and heat loss to turbine parts.

As the high-temperature, high-pressure (HP) gases enter the turbine section, they expand rapidly. Relatively little change in the temperature of the gases occurs. The net power available from the turbine is the difference between the turbine-developed power and the power required to operate the compressor.

FACTORS AFFECTING ENGINE PERFORMANCE

Many factors, such as aerodynamics and thermodynamics, have a direct effect on efficient GTE performance. In this chapter we will discuss only two common factors, the effect of ambient temperatures and the effect of compressor cleanliness. As a gas turbine technician, you will be concerned with these in your daily operation of the GTE.

Effect of Ambient Temperature

In discussions of temperature effects on GTEs, you will often hear the term *Navy standard day*. This term refers to a theoretical condition seldom duplicated except in some permanent test situations and is used only as a reference or standard. A standard day is indicated by the following conditions at sea level: barometric pressure—29.92 Hg, humidity (water vapor pressure)—0.00 Hg, and temperature—59°F. Operation of engines above or below 50°F will proportionally affect engine power output by as much as 15 or 20 percent.

The power and efficiency of a GTE are affected by both outside and inside variables. Air has volume that is directly affected by its temperature. As the temperature decreases, the volume of air for a given mass decreases and its density increases. Consequently, the mass weight of the air increases, causing the engine to operate more efficiently. This happens because less energy is needed to achieve the same compression at the combustion chambers. Also, cooler air causes lower burning temperatures. The resulting temperatures extend turbine life. For example, a propulsion GTE is operating at 100 percent GG speed with 100 percent PT speed. The ambient (external air) temperature is 70°F. If the temperature were increased to 120°F, the volume of air required would increase. The mass weight would decrease. Since the amount of fuel added is limited by the inlet temperature the turbine will

withstand, the mass weight flow cannot be achieved; the result is a loss of net power available for work. The plant may be able to produce only 90 to 95 percent of its rated horsepower.

On the other hand, if the ambient temperature were to drop to 0°F, the volume of air (mass) required would decrease. However, the mass weight would increase. Since the mass weight is increased and heat transfer is better at higher pressure, less fuel is needed to increase volume. This situation produces quite an efficient power plant. It has a GG speed of 85 to 90 percent and a PT speed of 100 percent. In a constant speed engine, the differences in temperature will show up on exhaust gas temperature. In some cases, it will show up on the load the engine will pull. For instance, on a hot day of 120°F, the engine on a 300-kW generator set may be able to pull only 275 kW. This is due to limitations on exhaust or turbine inlet temperature. On a day with 0°F ambient temperature, the same engine will pull 300 kW. It can have an exhaust or turbine inlet temperature that is more than 100°F, lower than average. Here again, less fuel is needed to increase volume and a greater mass weight flow. In turn, the plant is more efficient.

Effect of Compressor Cleanliness

Another factor that will have a great effect on performance is the condition of the compressor. A clean compressor is essential to efficiency and reliability. During operation at sea, the compressor takes in a high volume of salt-contaminated air. Salt buildup is relatively slow in the compressor and will occur more on the stator vanes and the compressor case than on rotating parts. Centrifugal force tends to sling salt contaminants off the rotor blades.

Any oil ingested into the engine coats the compressor with a film and will rapidly increase contamination of the compressor. The film traps any dust and other foreign matter suspended in the air. The dust and dirt absorb more oil, which traps more dirt, and so forth. If left unattended, the buildup of contamination (either oil or salt) will lead to a choking of the compressor and a restricted airflow. This restricted airflow will require the main fuel to schedule more fuel to produce an equivalent horsepower. The combustion gas temperatures will rise until loss of power, and damage to the turbine may result. Contamination, if not controlled, can induce a surge condition in the compressor during engine start. It will also reduce the life of the compressor

and turbine blading through corrosion of the engine parts.

TYPES OF GAS TURBINE ENGINES

The different types of GTEs all use the same basic principles already discussed. A GTE is classified by its construction (the type of compressor, combustor, or shaft system used). The compressor may be either centrifugal or axial type. The combustor may be annular, can-annular, or can type. The type of shaft used on a GTE may be either single shaft, split shaft, or twin spool. These classifications will be discussed in the following paragraphs.

CLASSIFICATION BY COMPRESSOR TYPE

The compressor takes in atmospheric air and compresses it to a pressure of several atmospheres. A GTE may be classified by compressor type, based on the direction of the flow of air through the compressor. The two principal types of compressors are the centrifugal flow and the axial flow. The centrifugal-flow compressor draws in air at the center or eye of the impeller and accelerates it around and outward. In the axial-flow compressor, the air is compressed while continuing its original direction of flow (parallel to the axis of the compressor rotor).

Centrifugal Compressor

The centrifugal compressor is usually located between the accessory section and the combustion section. The basic compressor section consists of an impeller, diffuser, and compressor manifold. The diffuser is bolted to the manifold. Often the entire assembly is referred to as the diffuser. For ease of understanding, we will discuss each unit separately.

The impeller may be either single entry or dual entry (fig. 1-10). The main differences between the single-entry and dual-entry impeller are the size of the impeller and the ducting arrangement. The single-entry impeller permits convenient ducting directly to the inlet vanes. The dual-entry impeller uses a more complicated ducting to reach the rear side of the compressor. Single-entry impellers are slightly more efficient in receiving air, but they must be of greater diameter to provide sufficient airflow. This increases the overall diameter of the engine.

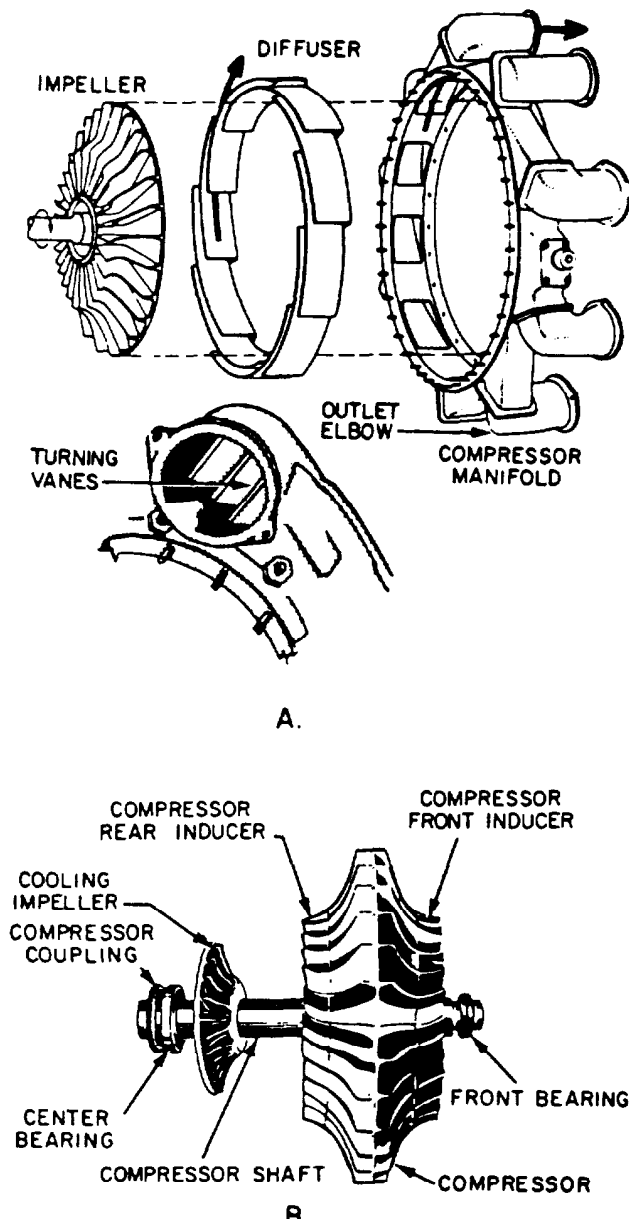


Figure 1-10.—Centrifugal compressors. A. Single entry. B. Dual entry.

Dual-entry impellers are smaller in diameter and rotate at higher speeds to ensure a sufficient airflow. Most modern GTEs use the dual-entry compressor to reduce engine diameter. Because the air must enter the engine at almost right angles to the engine axis, a plenum chamber is required for dual-entry compressors. The air must surround the compressor at a positive pressure before entering the compressor to ensure an undisturbed flow.

PRINCIPLES OF OPERATION.—The compressor draws in the air at the hub of the impeller and accelerates it radially by centrifugal force through the impeller. It leaves the impeller at a high velocity and a low pressure and flows through the diffuser (fig. 1-10, view A). The diffuser converts the high-velocity, LP air to low-velocity, HP air. The compressor manifold diverts the flow of air from the diffuser (an integral part of the manifold) into the combustion chambers.

CONSTRUCTION.—In a centrifugal compressor the manifold has one outlet port for each combustion chamber. The outlet ports are bolted to an outlet elbow on the manifold (fig. 1-10, view A). The outlet ports ensure that the same amount of air is delivered to each combustion chamber. Each outlet port elbow contains from two to four turning vanes to change the airflow from radial to axial flow and to reduce air pressure losses by presenting a smooth turning surface.

The impeller is usually made from a forged aluminum alloy that is heat-treated, machined, and smoothed for minimum flow restriction and turbulence. Some types of impellers are made from a single forging, while in other types the inducer vanes are separate pieces that are welded in place.

Centrifugal compressors may achieve efficiencies of 80 to 84 percent at pressure ratios of 2.5:1 to 4:1 and efficiencies of 76 to 81 percent at pressure ratios of 4:1 to 10:1.

Some advantages of centrifugal compressors are as follows:

- Rugged, simple in design
- Relatively light in weight
- Develop high-pressure ratio per stage

Some disadvantages of centrifugal compressors are as follows:

- Large frontal area
- Lower efficiency than axial-flow compressors
- Difficulty in using two or more stages due to the air loss that occurs between stages and seals

Axial-Flow Compressors

The purpose of the axial compressor is the same as the centrifugal compressor. They both

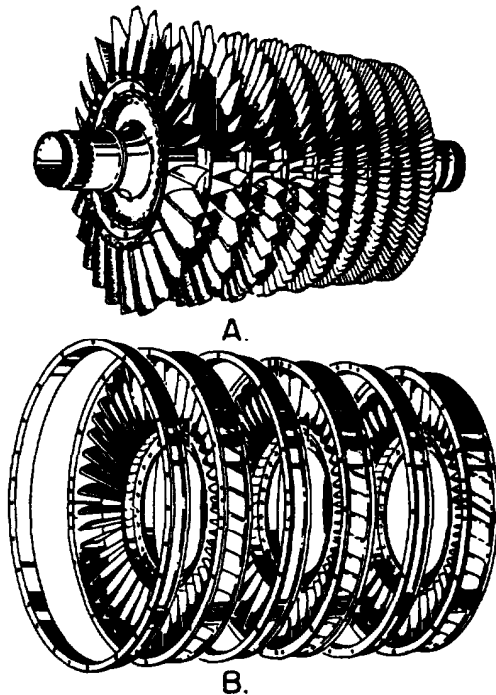


Figure 1-11.—Components of an axial-flow compressor.
A. Rotor. B. Stator.

take in ambient air and increase its velocity and pressure. The air is then discharged through the diffuser into the combustion chamber.

The two main elements of an axial-flow compressor are the rotor and the stator (fig. 1-11). The rotor has fixed blades which force the air rearward much like an aircraft propeller. Behind each rotor is a stator which directs the air rearward to the next rotor. Each consecutive pair of rotor and stator blades constitutes a pressure stage.

The action of the rotor at each stage increases compression and velocity of the air and directs it rearward. By virtue of this increased velocity, energy is transferred from the compressor to the air in the form of velocity energy. The stators at each stage act as diffusers, partially converting this high velocity to pressure.

The number of stages required in a compressor is determined by the amount of air and total pressure rise required by the GTE. The greater the number of stages, the higher the compression ratio. Most present-day engines have 8 to 16 stages.

COMPRESSOR CONSTRUCTION.—The rotor and stators are enclosed in the compressor case. Today's GTEs use a case that is horizontally divided into upper and lower halves. The halves are bolted together with fitted bolts and dowel pins located at various points for casing alignment. This ensures proper casing half alignment. Other assemblies can then be bolted to either end of the compressor case.

On some older design engines, the case is a one-piece cylinder open on both ends. The one-piece compressor case is simpler to manufacture, but any repair or detailed inspection of the compressor rotor requires engine removal and delivery to a shop. At the shop it is disassembled for inspection or repair of the rotor or stator. On

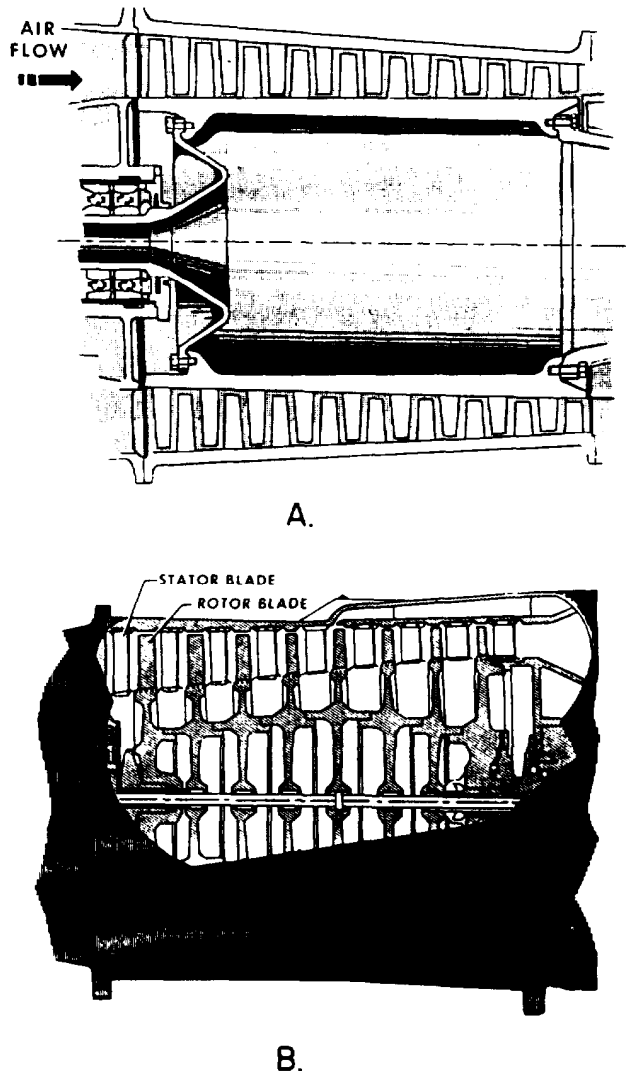
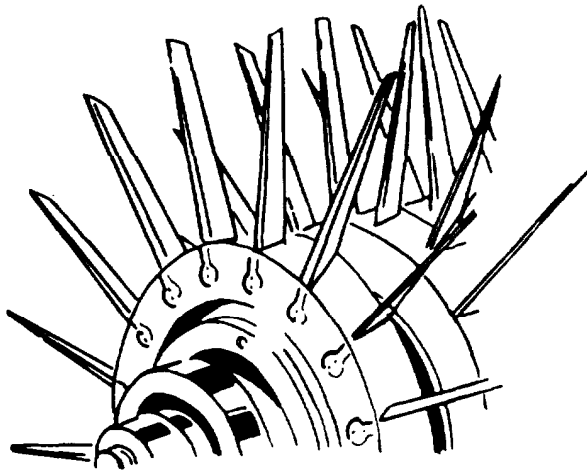


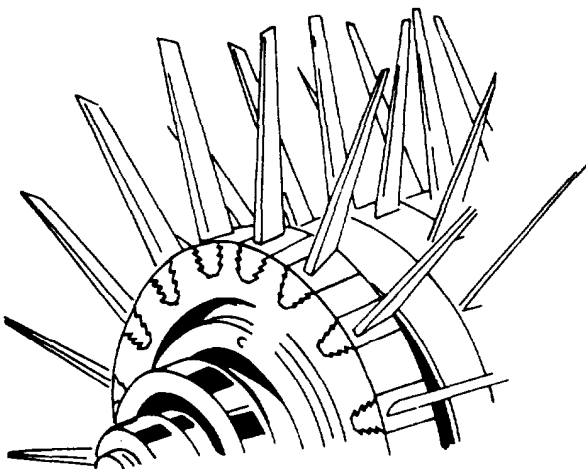
Figure 1-12.—Compressor rotors. A. Drum type. B. Disk type.

engines with the split case, either the upper or lower case can be removed, allowing the engine to remain in place for maintenance and inspection.

The compressor case is usually made of aluminum or steel. The material used will depend on the engine manufacturer, the weight requirements of the engine, and the accessories attached to the case. The compressor case may have external connections made as part of the case. These connections are normally used as bleed air ports to aid in the prevention of stalls during starting and acceleration or at low-speed operation.



A. BULB TYPE



B. FIR-TREE TYPE

Figure 1-13.—Rotor blades.

The two main types of axial compressor rotors are the drum type and the disk type.

Drum Type.—The drum-type rotor (fig. 1-12, view A) consists of rings that are flanged to fit one against the other. The entire assembly may then be held together by through bolts (often called tie bolts). The drum is one diameter over its full length. The blades and stators vary in their radial length from the front to the rear of the assembly. The compressor case tapers accordingly. This type of construction is satisfactory for low-speed compressors where centrifugal stresses are low.

Disk Type.—The disk-type rotor (fig. 1-12, view B) consists of a series of disks of increasing diameter which are machined from forgings and shrunk fit over a steel shaft. Another method of rotor construction is to machine the disks and shaft from a single aluminum forging and bolt steel stub shafts on the front and rear of the assembly. The stub shafts provide bearing support surfaces and splines for joining the turbine shaft. The blades decrease in length from entry to discharge. This is due to a progressive reduction in the annular working space (drum to casing) toward the rear. The working space decreases because the rotor disk diameter increases. The disk-type rotors are used almost exclusively in all present-day, high-speed engines.

COMPRESSOR BLADING.—Each stage of an axial compressor has a set of rotor and stator blades. Stator blades may also be referred to as vanes. The construction of these blades is important to efficient operation of a GTE.

Rotor Blades.—The rotor blades are usually made of aluminum, titanium, or stainless or semistainless steel. Methods of attaching the blades in the rotor disk rims vary. They are commonly fitted into the disks by either the bulb or the fir-tree type of roots (fig. 1-13, views A and B). The blades are then locked with grub-screws, lockwires, pins, or keys.

Compressor blade tips are reduced by cutouts, which are referred to as blade profiles. Some manufacturers use a ring (usually called a shroud) that acts as a spacer for the stators. The shroud can also act as a wear surface when the blade tips come into contact with the ring. This rubbing of blade tips maintains the close tolerances necessary to maintain the efficiency of the compressor and the profiles prevent serious damage to the blade or housing.

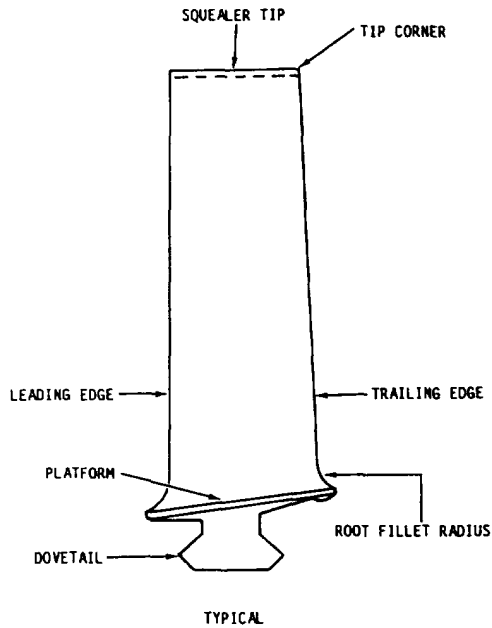


Figure 1-14.—Blade with squealer tip.

Another method of maintaining minimum clearance is to metal-spray the case and stators. Thin squealer tips on the blades and vanes (fig. 1-14) contact the sprayed material. The abrasive action of the blade tip cuts into the sprayed material, thus obtaining minimum clearance.

The primary causes of rubbing are an excessively loose blade or a malfunction of a compressor support bearing. This causes the compressor rotor to drop.

Large compressors have loose-fitting blades on the first several stages. These move during acceleration to minimize vibration while passing through critical speed ranges. Once up to speed, centrifugal force locks the blades in place and little or no movement occurs. Movement of the blades also occurs during rundown. On a clean engine some of the blades may have as much as 1/4-inch radial movement, which can cause a tinkling sound during rundown.

Large compressor rotors have long blades on the first stage. They have a wing tip on the blade faces called a midspan platform (fig. 1-15). The platform gives some radial support to the blades during acceleration. This midpoint support is needed because of the length and amount of movement of the blades.

Stators.—The stator vanes project radially toward the rotor axis and fit closely on either side of each stage of the rotor. The function of the stators is twofold: (1) they receive air from the air inlet duct or from each preceding stage of the rotor and deliver the air to the next stage or to combustors at a workable velocity and pressure; (2) they control the direction of air to each rotor stage to obtain the maximum compressor blade efficiency. The stator vanes are made of alloys with corrosion- and erosion-resistant qualities. Frequently, the vanes are shrouded by a band of suitable material to simplify the fastening problem. The outer shrouds are secured to the inner wall of the compressor case by radial retaining screws.

Some manufacturers machine a slot in the outer shrouds and run a long, thin key the length of the compressor case. The key is held in place by retaining screws to prevent the stators from turning within the case. This method is used when a one-piece compressor case is slid over the compressor and stator assembly.

Each pair of vanes in a stator acts as a diffuser. They use the divergent principle: the outlet of the vane area is larger than the inlet. In this diverging area, the high-velocity, LP air from the preceding rotor stage is converted to a low-velocity, HP airflow and directed at the proper angle to the next rotor stage. The next rotor stage will restore the air velocity that was lost because of the pressure rise. The next stator will give a further pressure rise. This process continues for each stage in the compressor.

A pressure rise of about 1.2 times the preceding stage is about as much as a single stage can handle. Higher pressure rises result in higher diffusion rates with excessive turning angles. This causes excessive air instability and low efficiency.

Preceding the first stage compressor blades is a row of vanes known as inlet guide vanes (IGVs). The function of the IGVs varies somewhat, depending on the size of the engine and the air-inlet construction. On smaller engines the air inlet is not totally in line with the first stage of the rotor. The IGVs straighten the airflow and direct it to the first-stage rotor. On large engines the IGVs are variable and move with the variable stators. The variable IGVs on large engines direct the airflow at the proper angle to reduce drag on the first-stage

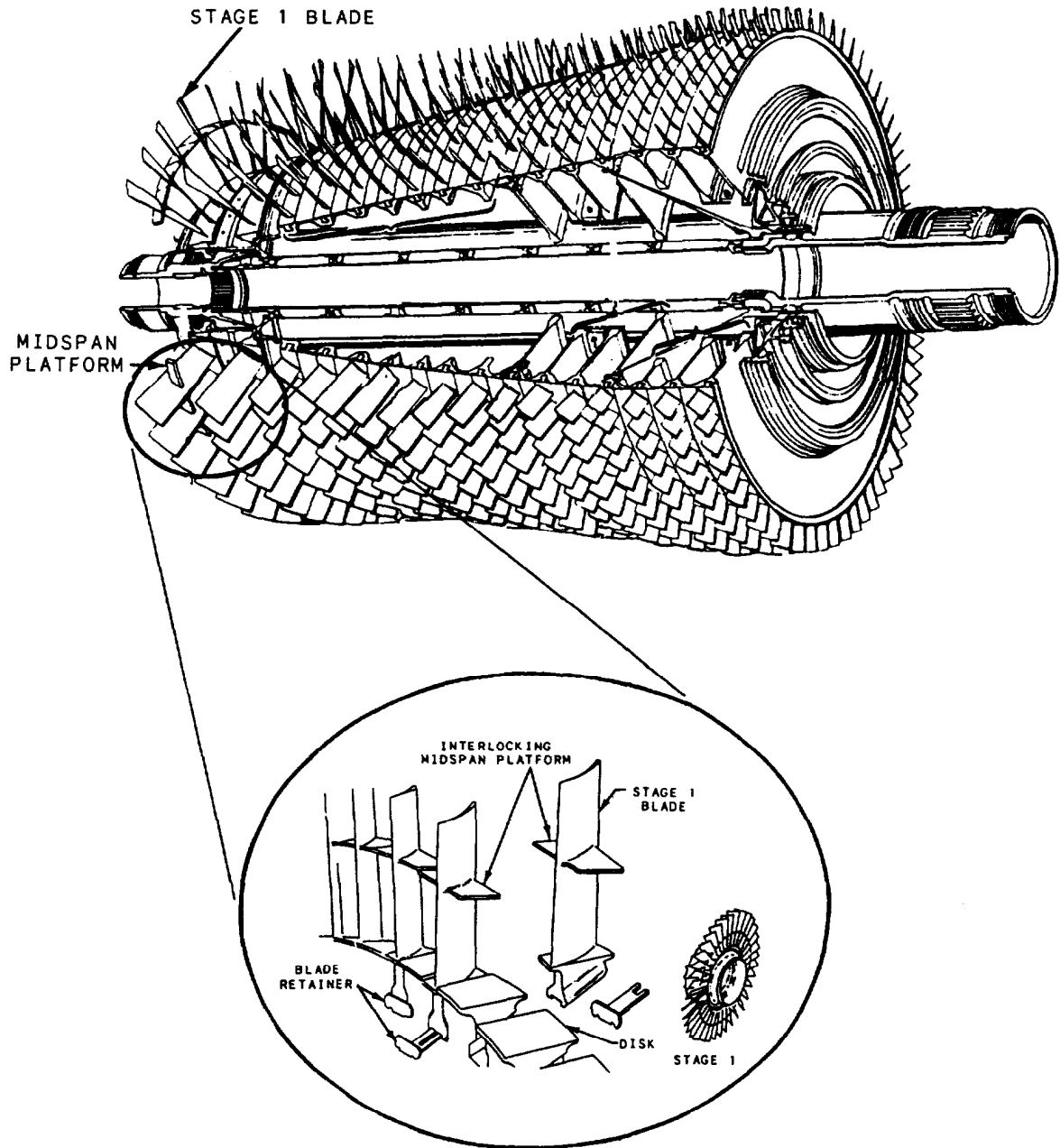


Figure 1-15.—Large engine compressor rotor with midspan platforms.

rotor. Variable IGVs achieve the same purposes as variable stator vanes (VSVs).

Some GTEs have moveable, or variable, stators. The position of the variable stators is determined by compressor inlet temperature (CIT) and engine power requirements. They are moved by mechanical linkages that are connected to, and controlled by, the fuel-control governor. Variable stators have two purposes. First, they are

positioned at various angles, depending on compressor speed, to ensure the proper angle of attack of the air in the compressor blades. Varying the stator angle helps to maintain maximum compressor efficiency over the operating speed range of the engine. This is important in variable-speed engines, such as those used for main propulsion. Second, the variable stators on large engines greatly reduce incidences of

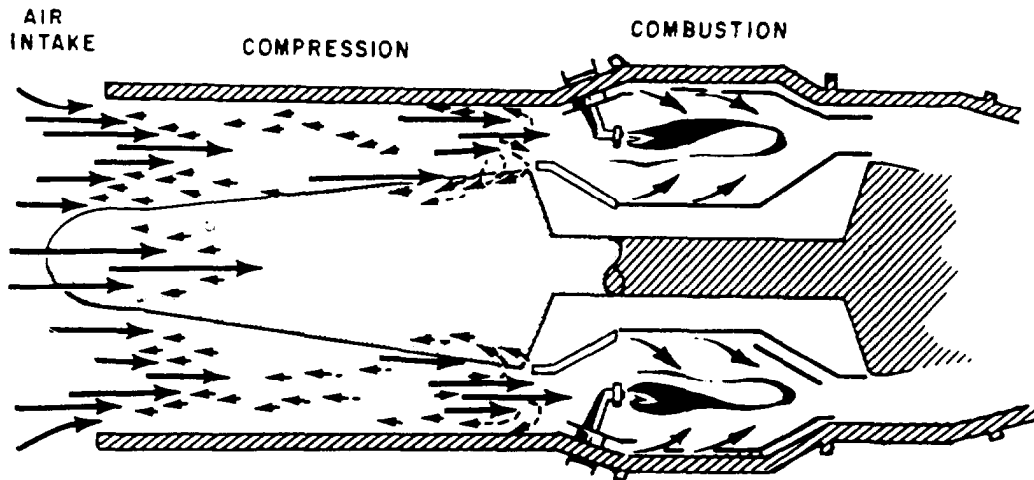


Figure 1-16.—Compressor surge.

compressor surge. Surge (fig. 1-16) results when the airflow stalls across the compressor blades; that is, air is not smoothly compressed into the combustion and turbine section. Stalling may occur over a few blades or a section of some stages. If enough flow is interrupted, pressure may surge back through the compressor. This occurrence can be minor or very severe with damage to the turbine resulting. If severe disturbance occurs, all the air in the combustor may be used for combustion instead of only the primary air. This would result in a lack of cooling air (secondary) that may cause extreme temperatures which burn the combustor and turbine section. We will discuss primary and secondary air systems later in this chapter.

By a change in the angle of the stators and use of bleed valves, smooth airflow through the compressor is ensured.

Constant-speed engines, such as those used to drive generators, normally do not use variable stators. They are designed to operate at 100 percent rpm all the time. Proper fuel scheduling and use of bleed air valves are used to reduce the probability of compressor surge in these engines.

CLASSIFICATION BY COMBUSTION CHAMBER DESIGN

The combustion chamber is the component in which the fuel-air mixture is burned. The

combustion chamber consists of a casing, a perforated inner shell, a fuel nozzle, and a device for initial ignition (igniter). The number of combustion chambers used in a GTE varies widely; as few as one and as many as 16 combustion chambers have been used in one GTE. The combustion chamber is the most efficient component of a GTE. The three types of combustion chambers are the (1) can, (2) annular, and (3) can-annular. The can-type chamber is used primarily on engines that have a centrifugal compressor. The annular and can-annular types are used on axial-flow compressors.

Can Chamber

The can-type combustion chamber has individual liners and cases mounted around the axis of the engine. Each chamber (fig. 1-17) contains a fuel nozzle. This arrangement makes removing a chamber easy, but it is a bulky arrangement and makes a structurally weak engine. The outer casing is welded to a ring that directs the gases into the turbine nozzle. Each of the casings is linked to the others with a short tube. This arrangement ensures that combustion occurs in all the burners during engine start. Inside each of these tubes is a flame tube that joins an adjacent inner liner.

Annular Chamber

The annular-type combustion chamber is probably one of the most popular combustion

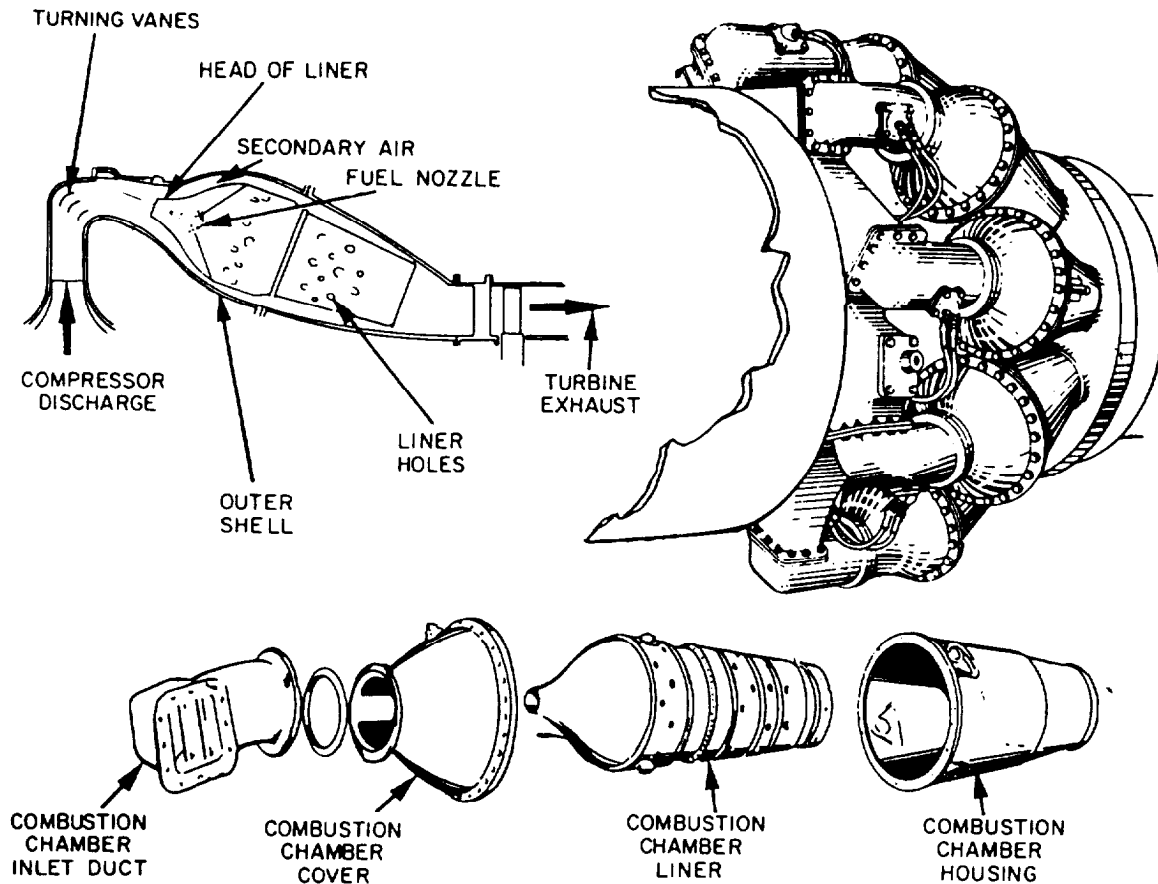


Figure 1-17.—Can-type combustion chamber.

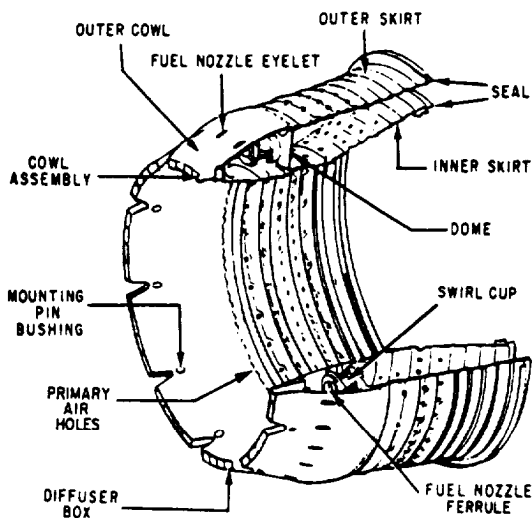


Figure 1-18.—Annular-type combustion chamber.

systems in use. The construction consists of a housing and liner the same as the can type (fig. 1-18).

The difference between the two is in the liner. On large engines, the liner consists of an undivided circular shroud extending all the way around the outside of the turbine shaft housing. A large one-piece combustor case covers the liner and is attached at the turbine section and diffuser section.

The dome of the liner has small slots and holes to admit primary air. They also impart a swirling motion for better atomization of fuel. There are holes in the dome for the fuel nozzles to extend through into the combustion area. The inner and outer liners form the combustion space. The outer liner keeps flame from contacting the combustor case. The inner liner prevents flame from contacting the turbine shaft housing.

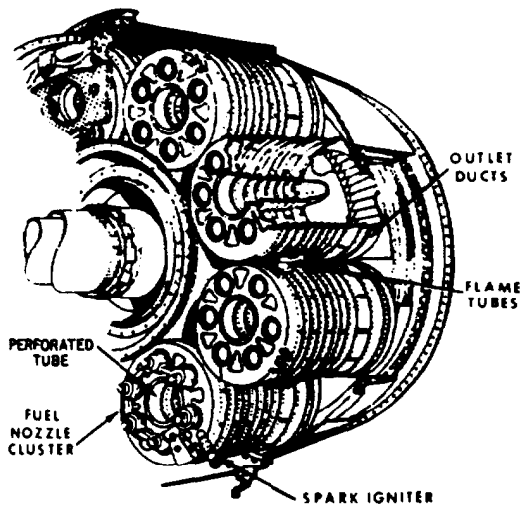


Figure 1-19.—Can-annular type of combustion chamber.

Large holes and slots are located along the liners. They (1) admit some cooling air into the combustion space to help cool the hot gases to a safe level, (2) center the flame, and (3) admit the balance of air for combustion.

The annular-type combustion chamber is a very efficient system that minimizes bulk and can be used most effectively in limited space. There are some disadvantages. On some engines, the liners are one piece and cannot be removed without engine disassembly. Also, engines that use a one-piece combustor dome must be disassembled to remove the dome.

Can-Annular Chamber

The can-annular type of combustion chamber combines some of the features of both the can and the annular burners. The can-annular type of chamber design is a result of the split-shaft compressor concept. Problems were encountered with a long shaft and with one shaft within the other. Because of these problems, a chamber was designed to perform all the necessary functions.

In the can-annular type of chamber, individual cans are placed inside an annular case. The cans are essentially individual combustion chambers (fig. 1-19) with concentric rings of perforated holes to admit air for cooling. On some models each can has a round perforated tube that runs down the middle of the can. The tube carries additional air, which enters the can through the perforations to provide more air for combustion and cooling. The effect is to permit more burning per inch of can length than could otherwise be done.

Fuel nozzle arrangement varies from one nozzle in each can to several nozzles around the perimeter of each can. The cans have an inherent resistance to buckling because of their small diameter. Each can has two holes that are opposite each other near the forward end of the can. One hole has a collar called a flame tube. When the cans are assembled in the annular case, these holes and their collars form open tubes. The tubes are between adjacent cans so a flame passes from one can to the next during engine starting.

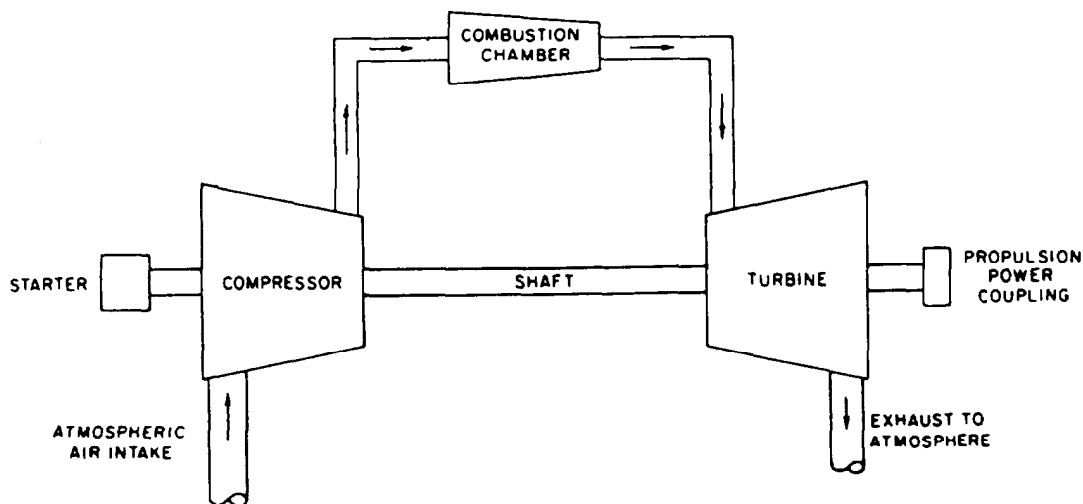


Figure 1-20.—Single-shaft engine.

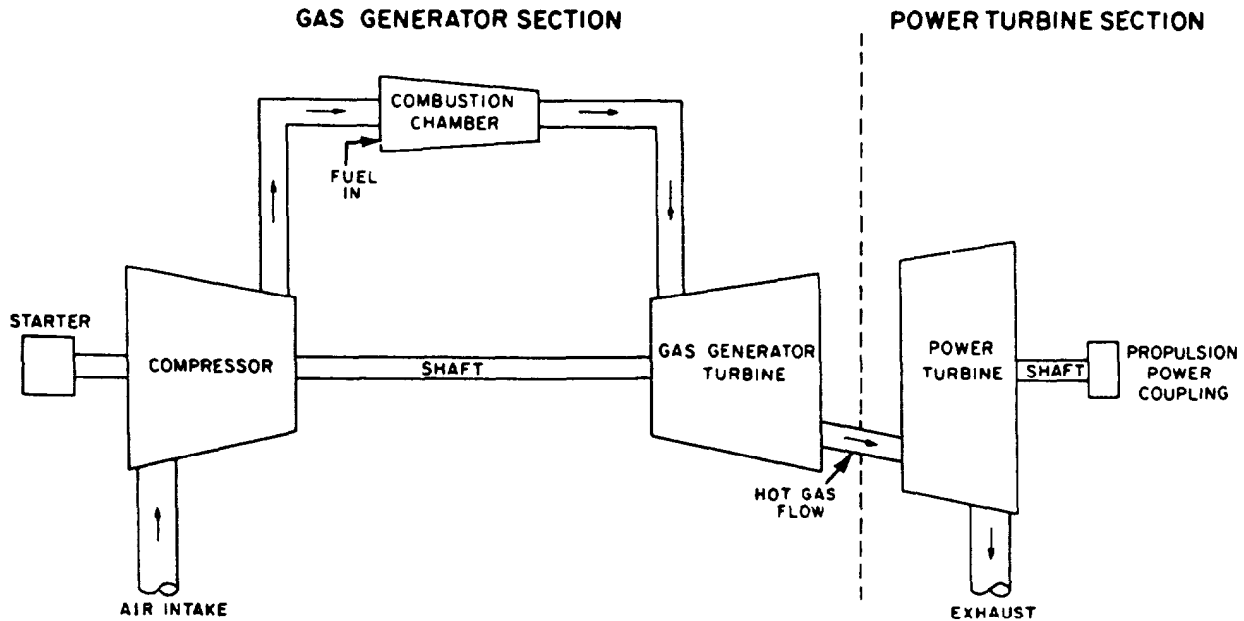


Figure 1-21.—Split-shaft engine.

The short length of the can-annular type of chamber provides minimal pressure drop of the gases between the compressor outlet and the flame area. The relatively cool air in the annular outer can reduces the high temperatures of the inner cans. This air blanket keeps the outer shell of the combustion section cooler. Maintenance on the burners is simple. You can remove and inspect any number of burners just by sliding the case back.

CLASSIFICATION BY TYPE OF SHAFTING

Several types of GTE shafts are used. These are single shaft, split shaft, and twin spool. Of these, the single shaft and split shaft are the most common in use in naval vessels. The twin-spool shaft is currently used for marine military application only on the U.S. Coast Guard *Hamilton* class cutters, which use the Pratt-Whitney FT-4 twin-spool GTE.

In current U.S. Navy service, the single-shaft engine is used primarily for driving ship's service generators. The split-shaft engine is used for main propulsion, as a variety of speed ranges is encountered.

Figure 1-20 is a block diagram of a single-shaft GTE. In the engine shown, the power output shaft

is connected directly to the same turbine rotor that drives the compressor. Usually, a speed decreaser or reduction gear is located between the rotor and the power output shaft. A mechanical connection still exists throughout the engine.

In the split-shaft engine (fig. 1-21), no mechanical connection exists between the GG turbine and the PT. In this type of engine, the output speed is varied by variation of the generator speed. Also, under certain conditions, the GG can run at a reduced rpm and still provide maximum PT rpm. The reduced rpm greatly improves fuel economy and also extends the life of the GG turbine. The starting torque required is lowered because the PT, reduction gears, and output shaft are stationary until the GG reaches approximate idle speed. Another feature of the multishaft marine propulsion plant is the GG rotates only one way. One design (clockwise rotation or counterclockwise rotation) of the GG can be used on either shaft and still allow the PT to rotate either way. This is done by changing the PT wheel and nozzles. The arrangement shown in figure 1-21 is typical for propulsion GTEs aboard today's ships.

The twin-spool type of GTE is sometimes referred to as a multistage GTE. It has two separate compressors and two separate turbine

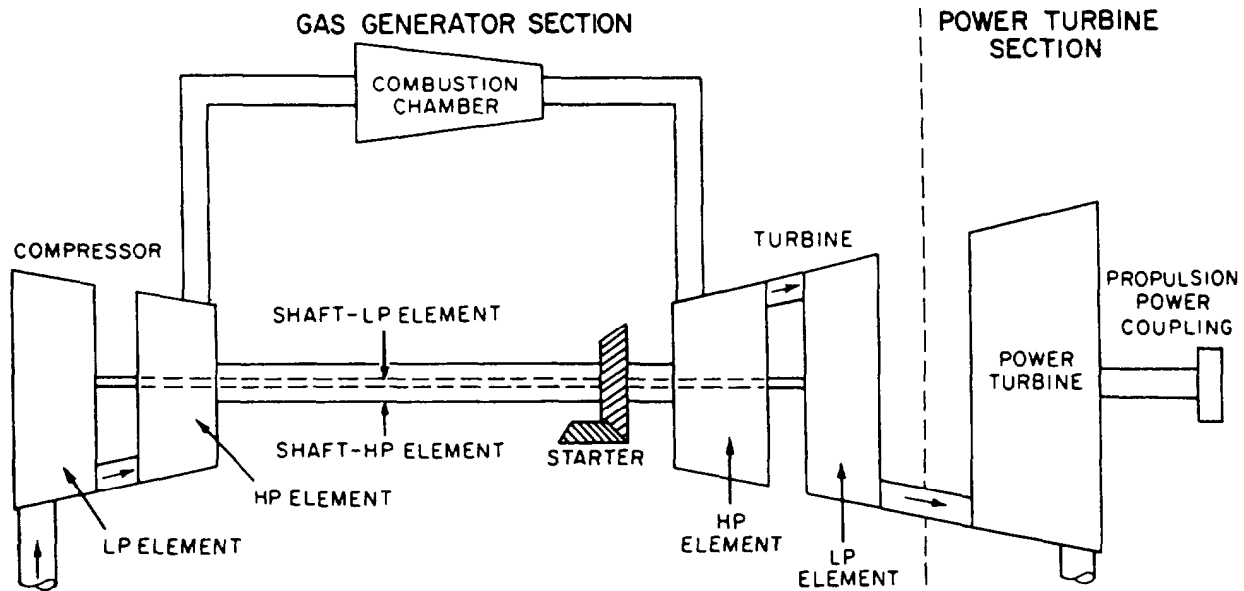


Figure 1-22.—Twin-spool engine.

rotors. They are referred to as LP compressor and turbine rotor and HP compressor and turbine rotor (fig. 1-22). The LP compressor and turbine are connected by a shaft. The shaft runs through the hollow shaft that connects the HP turbine to the HP compressor. The starter drives the HP assembly during engine start. The PT functions the same as in the split-shaft engine. A larger volume of air can be handled as compared to a single- or split-shaft engine. The increase in overall dimensions and complexity makes the engine less desirable for ship's propulsion than the split-shaft engine, as this type of engine has more moving parts.

TURBINE ASSEMBLIES

The GTEs are not normally classified by turbine type. However, we will discuss turbines now so you will have knowledge of their construction before we describe the General Electric LM2500 GTE in the next chapter.

In theory, design, and operating characteristics, the turbines used in GTEs are similar to those used in steam plants. The GTE differs from the steam turbine chiefly in (1) the type of blading material used, (2) the means provided for cooling the turbine shaft bearings, and (3) the lower ratio of blade length to wheel diameter.

The designations GG and PT are used to differentiate between the turbines. The GG

turbine powers the GG and accessories. The PT powers the ship's propeller through the reduction gear and shafting. Refer to figures 1-21 and 1-22 as we discuss these turbines.

Gas Generator Turbine

The turbine that drives the compressor of a GTE is located aft of the combustion chamber outlet. The turbine consists of two basic elements, the stator or nozzle, and the rotor. A cutaway view of a stator element is shown in figure 1-23; a rotor element is shown in figure 1-24.

TURBINE STATORS.—The stator element of the turbine section is known by a variety of names. The most common are turbine nozzle vanes and turbine guide vanes. In this text, turbine statos are usually referred to as nozzles. The turbine nozzle vanes are located directly aft of the combustion chambers and immediately forward of, and between, the turbine wheels.

Turbine nozzles have a twofold function. First, the nozzles prepare the mass flow for harnessing of power through the turbine rotor. This occurs after the combustion chamber has introduced the heat energy into the mass airflow and delivered it evenly to the nozzles. The stationary vanes of the turbine nozzles are contoured and set at a certain angle. The spaces between the vanes form several small nozzles that discharge the gas as extremely high-speed jets. The

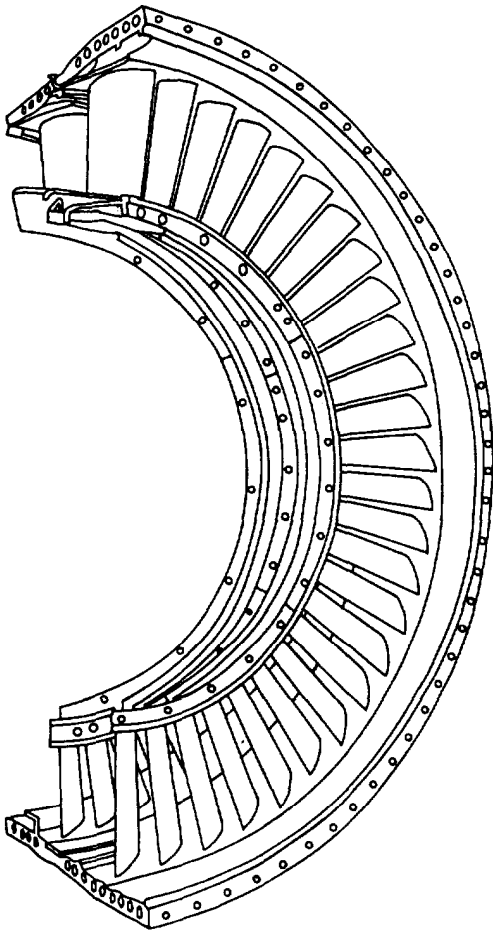


Figure 1-23.—Cutaway view of a turbine stator.

nozzle converts a varying portion of the heat and pressure energy to velocity energy. The velocity energy can then be converted to mechanical energy through the rotor blades.

The turbine nozzle functions to deflect the gases to a specific angle in the direction of turbine wheel rotation. The gas flow from the nozzle must enter the turbine blade passageway while it is still rotating, making it essential to aim the gas in the general direction of turbine rotation.

The turbine nozzle assembly has an inner shroud and an outer shroud between which are fixed the nozzle vanes. The number of vanes varies with different types and sizes of engines. Figure 1-25 shows typical turbine nozzle assemblies.

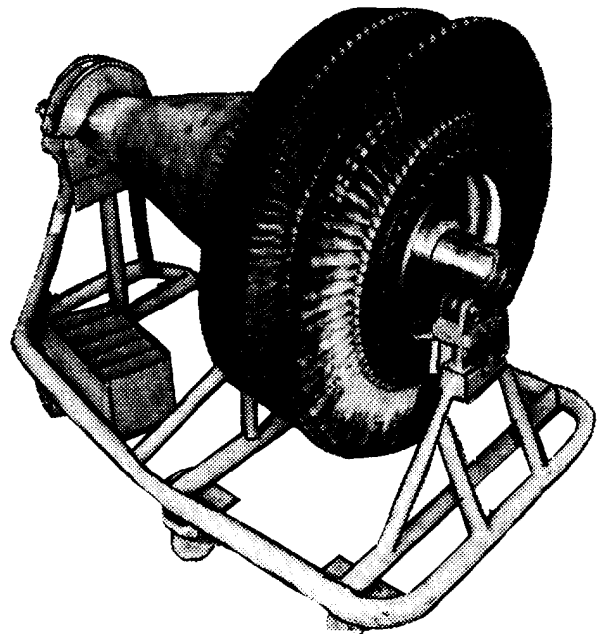


Figure 1-24.—Turbine rotor elements.

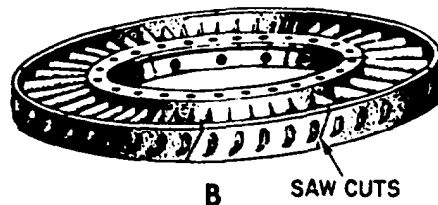
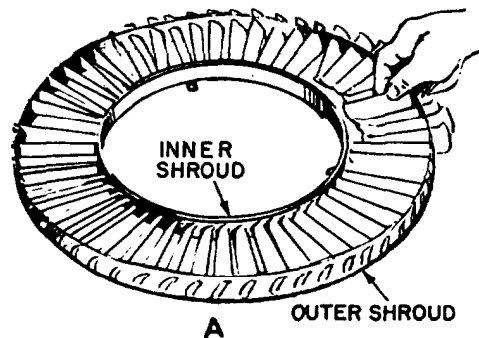


Figure 1-25.—Turbine nozzle assemblies. A. Loose-fitting vanes. B. Welded vanes.

All turbine nozzles must be constructed to allow for thermal expansion, because rapid temperature variances could cause distortion or warping of the metal components. Thermal expansion of turbine nozzles is allowed by one of several construction methods.

In one method the vanes are assembled loosely in the supporting inner and outer shrouds (fig. 1-25, view A). Each of the vanes fits into a contoured slot in the shrouds. The slots conform with the airfoil shape of the vanes. These slots are slightly larger than the vane to give a loose fit. For further support the inner and outer shrouds are encased by an inner and an outer support ring. This adds strength and rigidity to the turbine nozzle. These supports also permit removal of the nozzle vanes as a unit; otherwise, the vanes could fall out of the shrouds as the shrouds are removed.

Another method to allow for thermal expansion is to fit the vanes into inner and outer shrouds. In this method the vanes are welded or riveted into position (fig. 1-25, view B). Either the inner or the outer shroud ring is cut into segments to provide for thermal expansion. The saw cuts dividing the segments will allow enough expansion to prevent stress and warping of the vanes.

The basic types of construction of nozzles are the same for all types of turbines. The turbine nozzles are made of high-strength steel to withstand the direct impact of the hot, HP, high-velocity gases from the combustor. The nozzle vanes must also resist erosion from the high-velocity gases passing over them.

If the inlet gas temperature could be increased by about 750°F, almost a 100 percent increase in specific horsepower could be achieved. Nozzles can not stand up for long to these higher temperatures. Many different methods of increasing nozzle endurance have been tried over the years. One method that was tried was to coat the nozzle with ceramic. Higher temperatures were achieved, but the different expansion rates of the steel and the ceramic caused the coating to break away after several hours of operation. Experiments are still being conducted, even so far as to use an entirely ceramic nozzle.

Another means of withstanding high temperatures is to use newly developed alloys. However, the extreme costs of the alloys prohibit commercial production of such nozzles. Still another method, in wide use today in large engines, is to use air-cooled nozzle vanes. Compressor bleed air is fed through passages to the turbine, where it

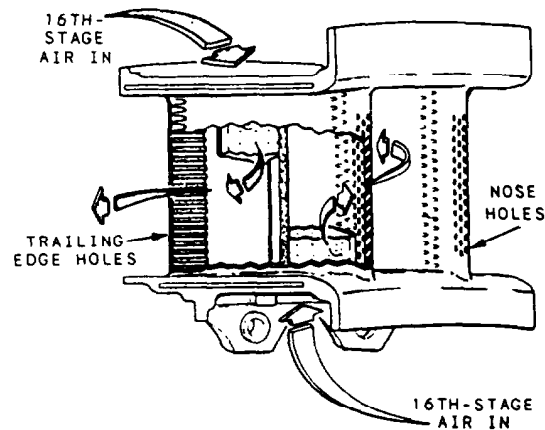


Figure 1-26.—First-stage GG turbine nozzle cooling.

is directed to the nozzle. The air cools both the turbine (discussed later) and the nozzle. The nozzle may also be cooled by air admitted from the outer perimeter of the nozzle ring. The method of getting the air in is determined by the manufacturer.

The nozzle vanes are made with many small holes or slots on the leading and trailing edges (fig. 1-26). Air is forced into the nozzle and out through the slots and holes. The vane is cooled as the air passes through. The air is discharged into the hot gas stream, passing through the remainder of the turbine section and out the exhaust duct.

Figure 1-27 shows temperature comparisons of a nonair-cooled vane and an air-cooled vane. Cooling air is used primarily in the HP turbine section and not in the LP section. By the time the gases reach the LP turbine section, the temperature of the gases is at an acceptable level. In the LP turbine section, metals in current use will last for a long time.

TURBINE ROTORS.—The rotor element of the turbine consists of a shaft and bladed wheel(s). The wheel(s) is attached to the main power transmitting shaft of the GTE. The jets of combustion gas leaving the vanes of the stator element act upon the turbine blades, making them rotate. The turbine wheel can rotate in a speed range of about 3,600 to 42,000 rpm. These high rotational speeds impose severe centrifugal loads on the turbine wheel. At the same time, the high temperatures (1050° to 2300°F) result in a lowering of the strength of the material. The engine speed and temperature must be controlled to keep turbine operation within safe limits.

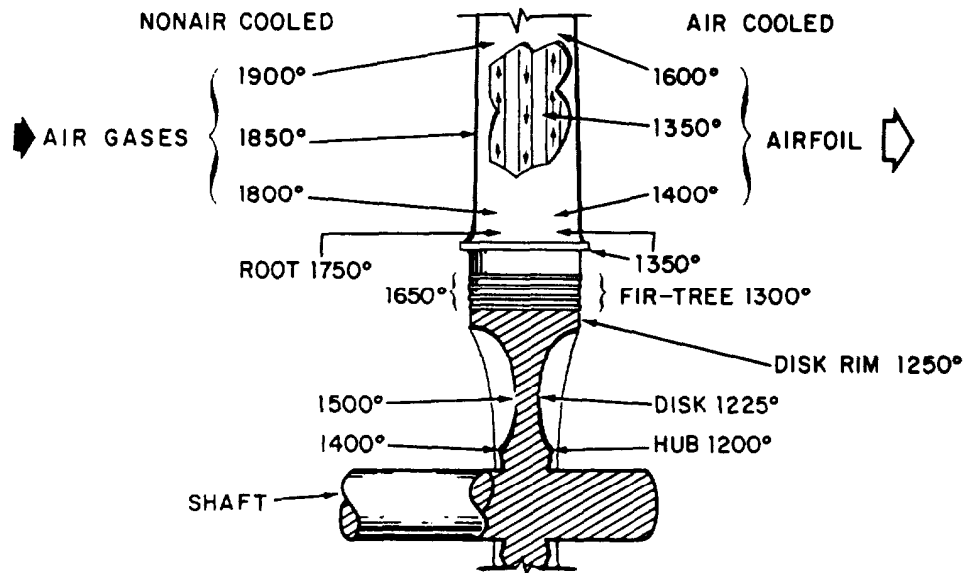


Figure 1-27.—Cooling comparisons between a nonair-cooled vane and an air-cooled vane.

The turbine wheel is a dynamically balanced unit consisting of blades attached to a rotating disk. The disk in turn is attached to the rotor shaft of the engine. When in an unbladed form, we refer to this section of the unit as the turbine disk. The portion of the unit consisting of the turbine blades is called the turbine wheel. The disk acts as an anchoring component for the turbine blades. This enables the blades to transmit to the rotor shaft the energy they extract from the exhaust gases.

The disk rim is exposed to the hot gases passing through the blades and absorbs considerable heat from these gases. In addition, because the rim also absorbs heat from the turbine blades by conduction, the disk rim temperatures are higher than the temperatures of the remote inner portion of the disk. As a result of these temperature gradients, thermal stresses are added to the stresses caused by rotation.

Various means are provided to relieve these stresses. One way is to incorporate an auxiliary fan, which is usually rotor-shaft driven, somewhere ahead of the disk. This will force cooling air back into the face of the disk. Another method of relieving the thermal stresses of the disk is by the method of blade installation. By notching the disk rims to conform with the blade root design, the disk is made able to retain the turbine blades. This space provided by the notches allows for thermal expansion of the disk.

The turbine shaft is usually made from low-alloy steel. It must be capable of absorbing high torque loads, such as exerted when a heavy axial-flow compressor is started. The methods of connecting the shaft to the turbine disk vary. One method used is welding. The shaft is welded to the disk, which has a butt or protrusion provided for the joint. Another method is by bolting. This method requires that the shaft have a hub that matches a machined surface on the disk face. The bolts then are inserted through holes in the shaft hub. They are anchored in tapped holes in the disk. Of the two methods, the latter is more common.

The turbine shaft must have some means for joining the compressor rotor hub. This is usually accomplished by a splined cut on the forward end of the shaft. The spline fits into a coupling device between the compressor and the turbine shafts. If a coupling is not used, the splined end of the turbine shaft fits into a splined recess in the compressor rotor hub. The centrifugal compressor engines use the splined coupling arrangement almost exclusively. Axial compressor engines may use either of these methods.

Various ways of attaching turbine blades are in use today. Some ways are similar to the way compressor blades are attached. The most satisfactory method used is the fir-tree design

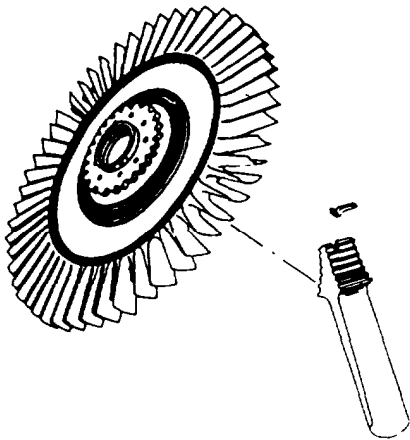


Figure 1-28.—Turbine blade with fir-tree design and tab lock method of blade retention.

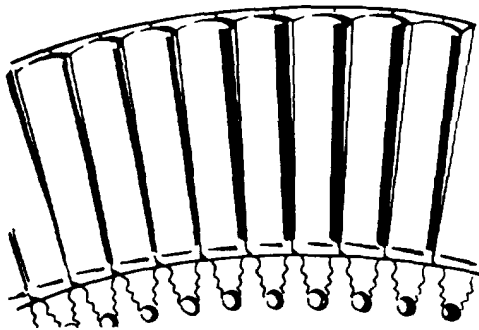


Figure 1-29.—Riveting method of turbine blade retention.

shown in figure 1-28. The blades are retained in their respective grooves by a variety of methods. Some of the more common methods are pinning, locking tabs, riveting, and retaining rings. Figure 1-29 shows a typical turbine wheel using riveting for blade retention.

Turbine blades may be either forged or cast, depending on the metal they are made of. Turbine blades are usually machined from individual forgings. Various materials are used in the forging. Speed and operating temperatures are important factors in deciding what materials go into the turbine blades.

Large engines use an air-cooled blading arrangement on the GG turbine (fig. 1-30). Compressor discharge air is constantly fed through passages along the forward turbine shaft between a spacer and the shaft. A thermal shield directs the cooling air along the face of the disk to cool the disk. The shield is between the first- and second-stage turbine wheels. The air is then directed through slots in the fir-tree portion of the disk, into slots in the blade fir-tree. The air then goes up through holes in the blades to cool the blades (fig. 1-31).

Cooling of the turbine wheel and blades reduces thermal stresses on the rotating members. The turbine nozzles are also air-cooled. By cooling the stationary and rotating parts of the turbine section, higher turbine inlet temperatures are permissible. The higher temperatures allow for more power, a more efficient engine, and longer engine life.

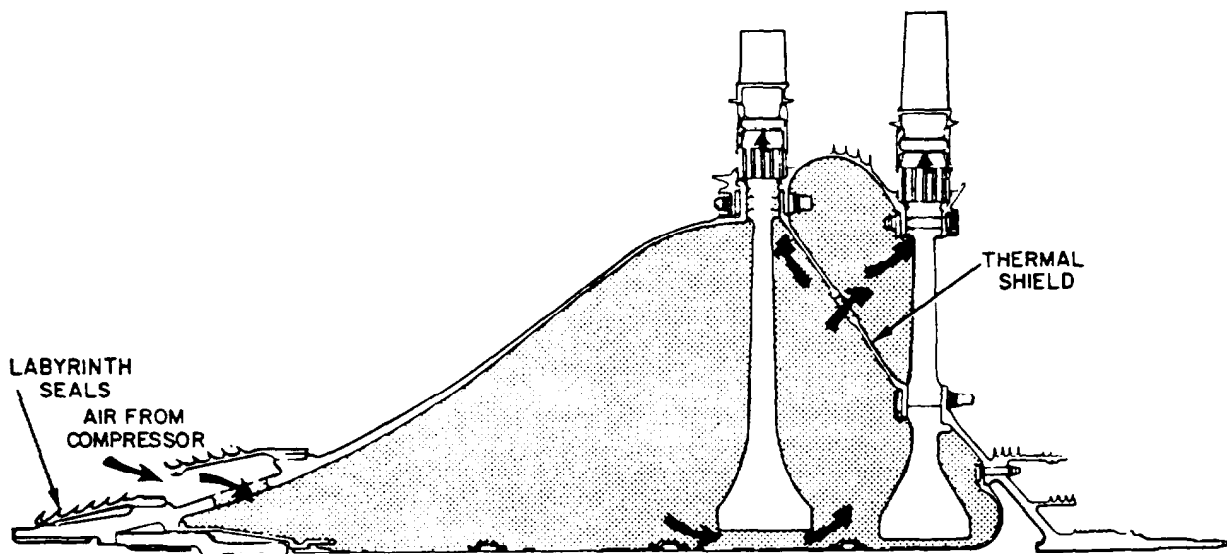


Figure 1-30.—GG turbine rotor cooling airflow.

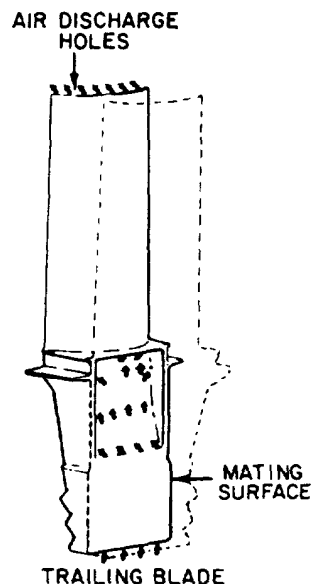


Figure 1-31.—GG turbine rotor blade cooling.

Power Turbines

The PT (fig. 1-32) is a multistage turbine located behind the GG turbine. The two turbines have no mechanical connection between them. The PT is connected to a reduction gear through a clutch mechanism. Either a controllable reversible pitch (CRP) propeller or a reverse gear is used to change the direction of the ship.

Power turbines are used to extract the remaining energy from the hot combustion gases. They extract this energy in the following three ways, depending upon engine application:

1. The aircraft power turbine is designed so the turbine extracts only enough energy from the gases to run the compressor and accessories.
2. In the solid-wheel turbine (used primarily in small GTEs), as much energy as possible is extracted from the gases to turn the turbine. The turbine provides power for the compressor, accessories, and the airplane propeller or the ship's generator. These engines are designed to run at 100 percent specified rpm all the time. The location of the mechanical connection between the turbine wheel and the reduction gear on the compressor front shaft depends on the design of the installation. Normally, a ship's service generator cannot be disconnected from its GTE except by disassembly. This setup is used for generators to prevent slippage between the engine and the generator.

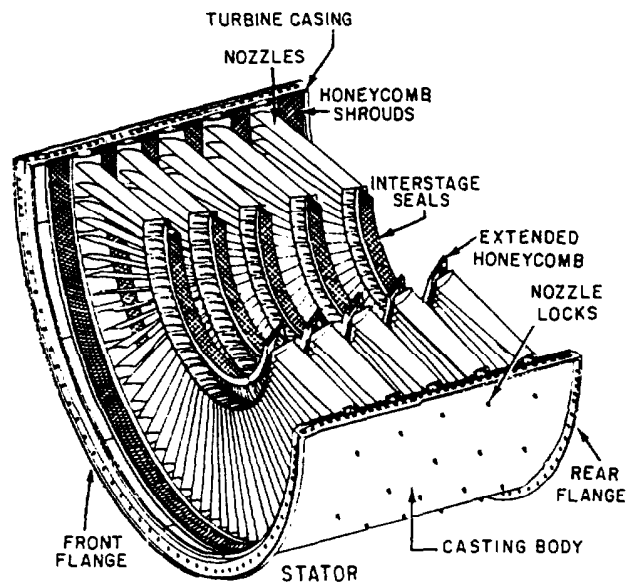
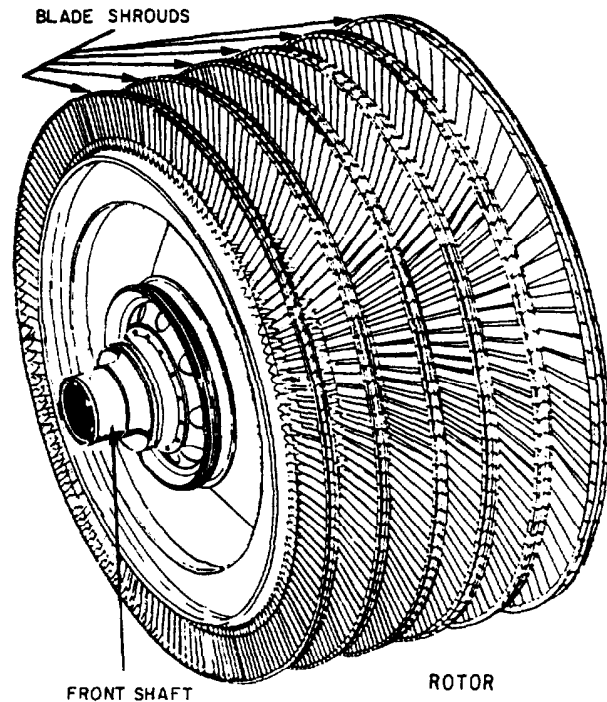


Figure 1-32.—Typical power turbine.

3. Marine propulsion engines use a combination of the previously mentioned two turbine types. The GG has a single- or multiple-stage HP rotor that drives the compressor and accessories and an LP turbine to transmit power to the ship's propeller via the reduction gear and shafting.

Some ships that have two sets of engines use counterrotating PTs. For example, PTs on one main propeller shaft rotate clockwise while the PTs on the other shaft rotate counterclockwise. The GG rotates in the same direction for both sets of engines. The blade angle of the wheel and the nozzles in the PT section determine the directional rotation of the PT. On large ships where different length propeller shafts are permitted, the engine(s) can be mounted to the other end of the reduction gear. This allows for counterrotation of the propellers without changing PT rotation.

You can control the output speed of the PT by varying the GG speed. Since only a portion of the energy is used to drive the compressor, the plant can be operated very efficiently. For example, on a cold day you can have 100 percent power turbine rpm with 80 to 90 percent gas generator rpm. The operating temperature variables discussed earlier in this chapter account for this situation.

The PT is constructed much like the GG turbine. The main differences are (1) the absence of vane and blade cooling air and (2) interlocking shroud tips on the PT blades to reduce vibration. Honeycomb shrouds in the turbine case mate with the blade shrouds to provide a gas seal. They also protect the case from the high-temperature gas. Two popular methods of blade retention are the bulb and the dovetail. These methods were discussed earlier in this chapter.

MAIN BEARINGS

The main bearings have the critical function of supporting the main engine rotor. For the most part, the number of bearings necessary for proper engine support is decided by the length and weight of the engine rotor. The length and weight are directly affected by the type of compressor used in the engine. Naturally a split-spool axial compressor will require more support than a simple centrifugal compressor engine. The minimum number of bearings required will be three, while some of the later models of split-spool axial compressor engines will require six or more.

While some engines use sleeve bearings, the GTE rotors are usually supported by either ball or roller bearings. In general, ball or roller antifriction bearings are preferred for the following reasons:

- They offer little rotational resistance.
- They facilitate precision alignment of rotating elements.

- They are relatively inexpensive.
- They may be easily replaced.
- They can withstand high momentary overloads.
- They are simple to cool, lubricate, and maintain.
- They can accommodate both radial and axial loads.
- They are relatively resistant to elevated temperatures.

The main disadvantages of ball or roller antifriction bearings are their vulnerability to foreign matter damage and their tendency to fail without appreciable warning.

Usually the bearings are positioned on the compressor or turbine shaft to absorb any axial (thrust) loads or radial loads. The ball bearings are designed to absorb the thrust loads, and the roller bearings are used to support the radial loads because they present a larger working surface.

The elements of a typical ball or roller bearing assembly include a bearing support housing, which must be strongly constructed and supported to carry the radial and axial loads of the rapidly rotating rotor. The bearing housing usually contains oil seals to prevent the oil from leaking from its normal path of flow. The housing also delivers lube oil to the bearing, usually through spray nozzles.

On modern engines, the bearing is mounted in a sump. The bearing sump has a line through which the lube oil is scavenged back to the sump. The bearing sump is also vented to prevent either a pressure or vacuum. The vent goes either to the atmosphere or to an air-oil separator.

GAS TURBINE ENGINE AUXILIARY SYSTEMS

Up to this point, we have pointed out the physical features and functions of a typical GTE. In this section we will point out the basics of the required auxiliary systems being used on most GTEs of today's Navy. The systems are not discussed in any order of importance. We will give you a broad overview of the systems, which include the air systems, the fuel oil system, the accessory drive system, the lubrication system, the starting systems, and the spark igniter system.

AIR SYSTEMS

Air is used for many different functions on the GTE. The terms *primary airflow* and *secondary airflow* designate the major systems. Figure 1-33 (At the end of this chapter) shows the LM2500 GTE airflow. See page 1-34 for an overall view and pages 1-35 through 1-37 for details. Although the following discussion on air systems is generic, we are using the LM2500 system discussed in chapter 2 as our example. For a better understanding of primary airflow and secondary airflow, use this figure in conjunction with the following discussion. You should also use this figure when studying the bleed air system in chapter 2 of this manual.

Primary Airflow

The GG compressor draws air from the ship's inlet plenum. After being compressed, the primary air enters the combustion section, where some of it is mixed with fuel, and the mixture is burned. The remainder of the primary air is used for centering the flame in the combustor and cooling some parts of the GG turbine. The primary air becomes part of the hot combustion gases. Some of the energy in the hot combustion gas is used to turn the GG turbine rotor, which is coupled to, and turns, the compressor rotor. Upon leaving the GG turbine section, the gas

passes into the PT section. Most of the remaining energy is extracted by the PT rotor, which drives the high-speed, flexible-coupling shaft. The shaft provides the power for the ship's drive system. The gas exits from the PT through the turbine rear frame and passes into the exhaust duct and out through the ship's exhaust.

Secondary Airflow

Secondary air is the source of bearing pressure seal air and bleed air for cooling. Bleed air has numerous other uses. We will not attempt to describe them all because each type of engine has its own peculiarities.

Secondary air is taken from the compressor ahead of the combustor stage. Secondary air is bled from various pressure stages on the compressor due to different pressure requirements at different points in the engine. Occasionally it is bled from the combustor outer case. The air is fed internally through passages to bearing cavities and seals, and it also cools the GG turbine and nozzles. On some engines the air is piped externally to seals where shafts extend outside a housing, such as a reduction gear.

Seal air is used in the GTE air seals, which are of two types: labyrinth/honeycomb, used in the sump and turbine areas, and fishmouth, used in the combustor and turbine midframe (fig. 1-34).

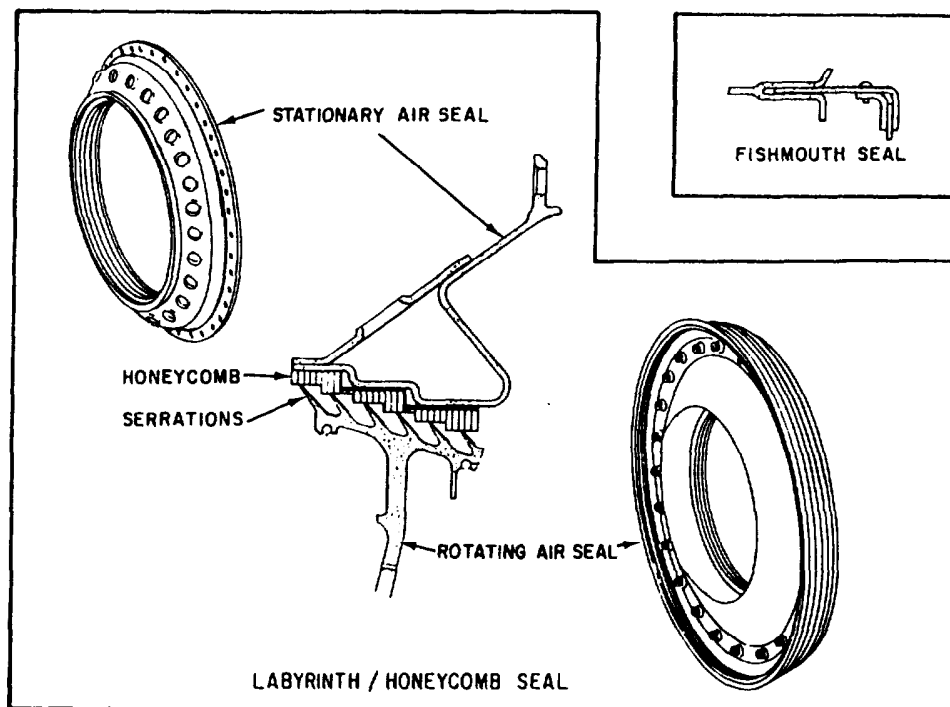


Figure 1-34.—Typical air seals.

The labyrinth/honeycomb seal combines a rotating seal having a serrated surface with a stationary seal having a honeycomb surface. The serrations cut into the honeycomb to maintain close tolerances over a large temperature range. The fishmouth seals are sheet metal, circular, stationary, interlocking seals used to prevent excessive leakage of hot combustion gas from the primary airflow.

FUEL OIL SYSTEM

The fuel oil system has a number of functions. Primarily, it provides filtered, pressurized, and accurately metered fuel for combustion. While doing this, it controls the power output of the GG, which in turn determines the amount of power delivered by the engine from the PT. Additionally, the fuel system may provide pressurized fuel as a hydraulic medium to actuate the fuel controls. In some engines it controls the angle of the variable compressor stator vanes.

All fuel systems are not alike, but they all have certain elements in common. For example, they must have a fuel pump, a fuel control, a pressurizing valve or its equivalent, a fuel manifold, and fuel nozzles or vaporizers. The fuel pump capacity is great enough to perform any required hydraulic functions in addition to providing combustion fuel. Excess fuel is bypassed in the fuel control and returned to the LP side of the pump. Pressure in excess of the capability of this bypass is dumped by a relief valve in the pump assembly. The fuel pump and fuel control are usually assembled together and mounted on the gearbox.

ACCESSORY DRIVE SYSTEM

A popular misconception exists that the GTE has only one moving part because the turbine and the compressor are on the same rotating shaft. This is not true. A GTE requires a starting device (which is usually a moving part), some kind of control mechanism, and power takeoffs to drive other components, such as the lube oil and fuel pumps. The accessory drive section of the GTE takes care of these various accessory functions. The primary function of the accessory drive section is to provide space for the mounting of the accessories required for the operation and control of the engine. The accessory drive section also serves as an oil reservoir and/or sump and houses the accessory drive gears and reduction gears.

The gear train of the accessory drive is driven by the engine rotor through an accessory drive shaft coupling. The reduction gearing within the case provides suitable drive speeds for each engine accessory or component. Because the operating rpm of the rotor is so high, the accessory reduction gear ratios are relatively high. The accessory drives are supported by ball bearings assembled in the mounting bores of the accessory case.

Accessories provided in the accessory drive section include the fuel control, with its governing device; the HP fuel oil pump or pumps; the oil sump; the oil pressure and scavenging pump or pumps; the auxiliary fuel pump; and a starter. Additional accessories, which may be included in the accessory drive section or which may be provided elsewhere, include a starting fuel pump, a hydraulic oil pump, a generator, an air-oil separator, and a tachometer. Most of these accessories are essential for the operation and control of any GTE. The particular combination and arrangement and location of engine-driven accessories depend on the use for which the GTE is designed.

The three common locations for the accessory drive section are on the side of the air inlet housing, under the compressor front frame, or under the compressor rear frame. One manufacturer of a generator engine used by the U.S. Navy had the reduction gear attached to the forward end of the compressor and the accessories mounted to the reduction gear.

LUBRICATION SYSTEM

The GTE lubrication system is designed to supply bearings and gears with clean lube oil at the desired pressures and temperatures. In some installations, the lubrication system also furnishes oil to various hydraulic systems. Heat absorbed by the lube oil is transferred to the cooling medium in a lube oil cooler.

The lubrication system shown in figure 1-35 is the dry-sump type, with a common oil supply from an externally mounted oil tank. The system includes the oil tank, the lube oil pressure pump, the scavenging pumps, the oil cooler, oil filters, the pressure-regulating valve, and filter and cooler bypass valves.

All bearings and gears in the engine and accessory drives are lubricated and cooled by the lubrication system. The lube oil supplied to each bearing in a GTE is specifically controlled by a calibrated orifice which provides the proper flow

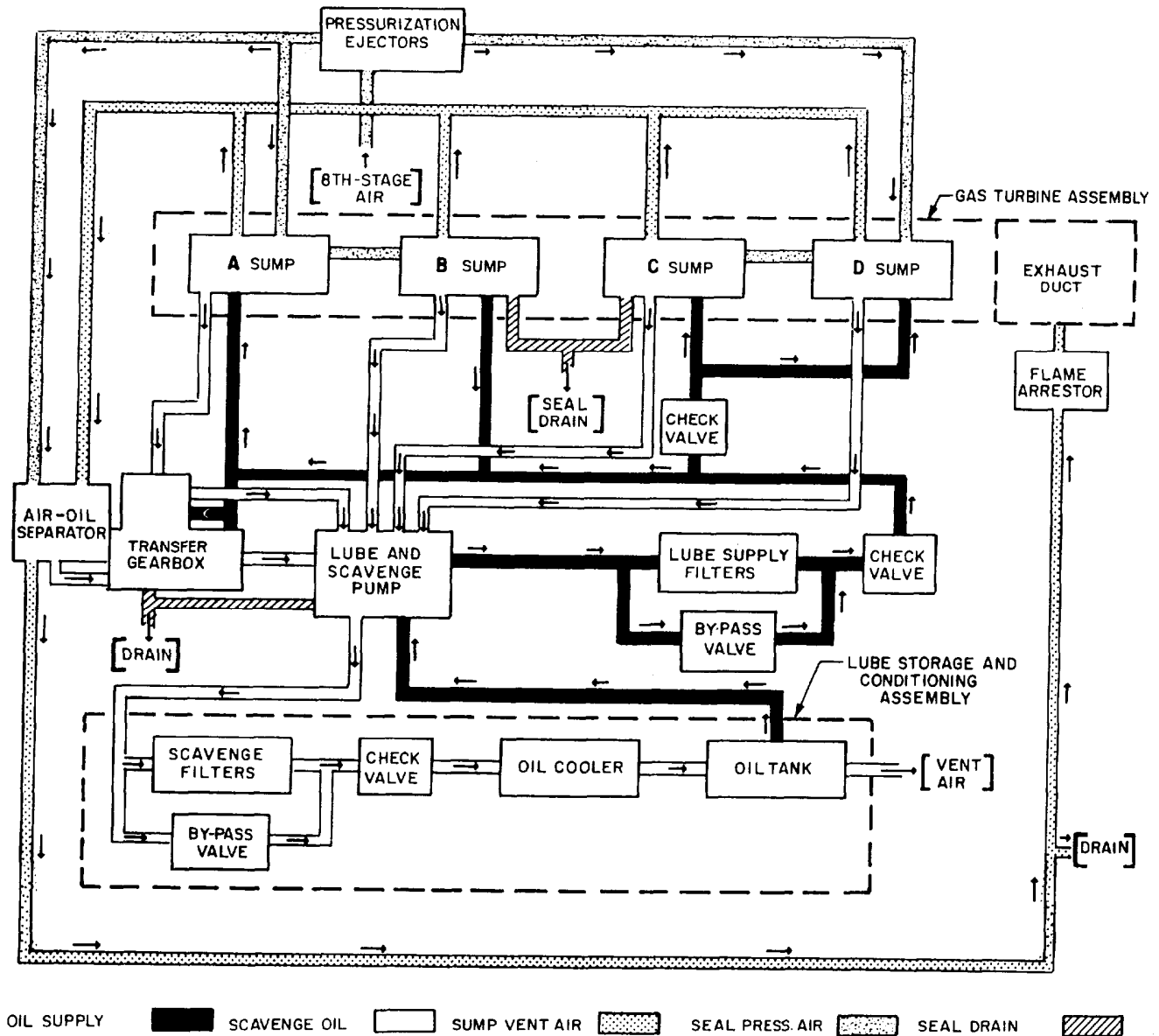


Figure 1-35.—Lubrication system schematic (typical).

of lube oil to the bearing at all engine speeds. This is sometimes known as a calibrated oil system. Since lube oil is supplied to the various parts of the system under pressure, provision is made to prevent the oil from leaking into unwanted areas, such as the compressors and turbines. This is usually accomplished by use of lip-type seals, labyrinth oil seals, or carbon ring pneumatic oil seals. We will discuss these seals in detail later in this section.

The lubrication system provides the GTE bearings, gears, and splines with adequate cool oil to prevent excessive friction and heat. Oil

nozzles direct the oil onto the bearings, the gears, and the splines. Separate scavenge elements in the lube and scavenge pump remove oil from the sumps and the transfer gearbox (accessory drive). The scavenged oil is returned to the lube storage and conditioning assembly where it is filtered, cooled, and stored. Scavenge oil is filtered by a duplex filter mounted on the lube storage tank.

Lubrication System Subsystems

The lubrication system is usually divided into three subsystems identified as lube supply, lube

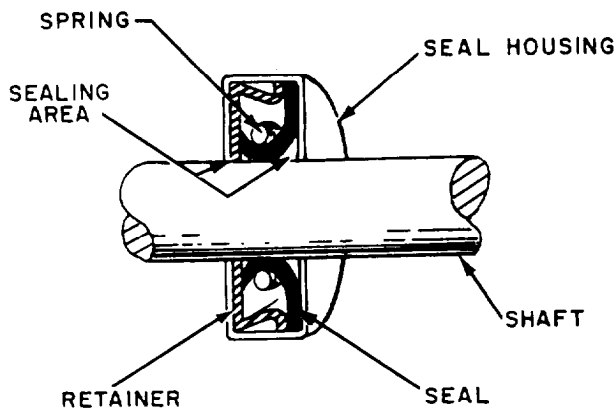


Figure 1-36.—Lip-type seal.

scavenge, and sump vent. We will discuss these subsystems and their components in chapter 2.

Oil Seals

Three types of oil seals are common to the GTEs, the lip-type seal, the labyrinth/windback, and the carbon ring.

LIP-TYPE SEAL.—The lip-type seal (fig. 1-36) is used to prevent leakage in one direction only. A metal frame is covered with a synthetic material, usually neoprene. The neoprene is somewhat smaller than the shaft. The elasticity of the neoprene will allow the shaft to slide through the seal. The seal is molded with a lip to retain a spring around the center. The spring keeps a snug fit around the center. The construction of the lip-type seal allows for some very slight misalignment and for axial movement of the

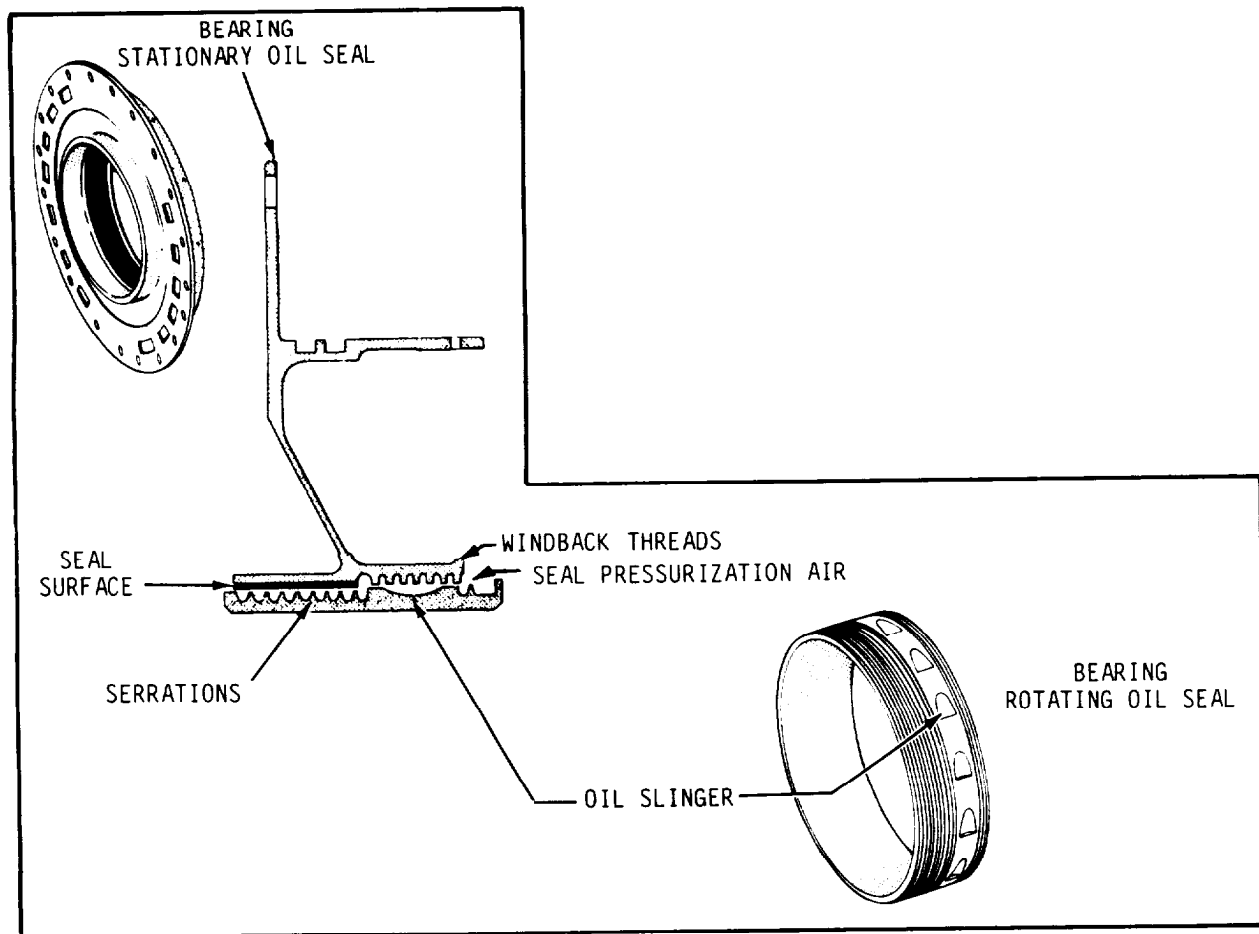


Figure 1-37.—Labyrinth/windback seal.

shaft. The lip seals are used where relatively low speeds and temperatures are encountered.

Two disadvantages of the lip-type seals are that (1) they will seal against only little or no fluid pressure, and (2) they are easily damaged. A burr on the shaft or dirt can tear the seal and cause leakage.

LABYRINTH/WINDBACK SEAL.—The labyrinth/windback seals (fig. 1-37) combine a rotating seal having oil slingers and a serrated surface with a stationary seal having windback threads and a smooth rub surface. The oil slingers throw oil into the windback threads, which direct the oil back to the sump area. The serrations cut grooves into the smooth surface of the stationary seal to maintain close tolerances throughout a large temperature range. This seal allows a small amount of seal pressurization air to leak into the sump, thereby preventing oil leakage.

CARBON RING SEAL.—The carbon seal (fig. 1-38) has a stationary, spring-loaded, carbon sealing ring and a rotating, highly polished steel mating ring. It prevents oil in the gearbox from leaking past the drive shafts of the starter, fuel pump, and auxiliary drive pad.

Another form of the carbon seal is also in use. The carbon rings are not spring-loaded. They move freely around the shaft and seal axially against the housing. When the engine is up to speed, the rings center themselves radially in the housing. Compressor bleed air is forced between

the carbon rings. The air pressure is forced out along the shaft in both directions. The pressure prevents oil from entering the compressor or turbine and combustion gases from reaching the bearings. The main disadvantage of this seal is minor oil leakage that occurs during start-up and run down as the oil pump moves oil before enough airflow prevents leakage. However, the leakage is so slight that the engine normally will reach its designated overhaul hours of operation before oil accumulation will have any effects.

STARTING SYSTEMS

The GTEs use a starter to turn the compressor at sufficient speed to initiate and sustain combustion. Both the compressor and the GG turbine must spin. In starting dual axial-flow compressor engines, the starter needs to rotate only the HP compressor. The starter's first requirement is to accelerate the compressor to provide enough airflow and pressure to support combustion in the burners.

Once fuel has been introduced and the engine has fired, the starter must continue to accelerate the compressor above the self-sustaining speed of the engine. The starter must provide enough torque to overcome rotor inertia and the friction and air loads of the engine.

Figure 1-39 shows a typical starting sequence for a GTE. When the starter has accelerated the compressor enough to establish airflow through

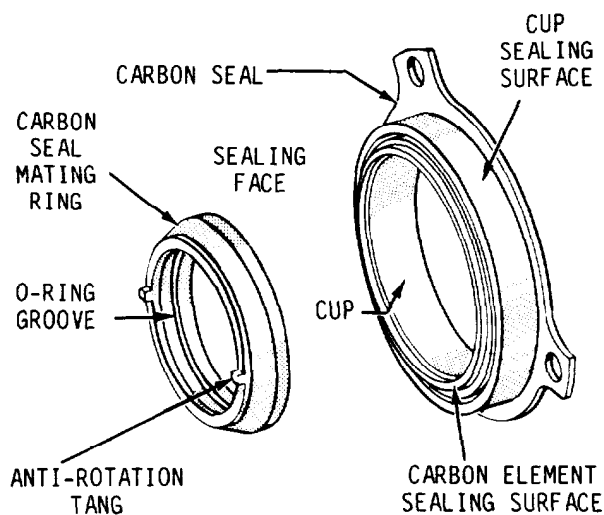


Figure 1-38.—Carbon ring seal.

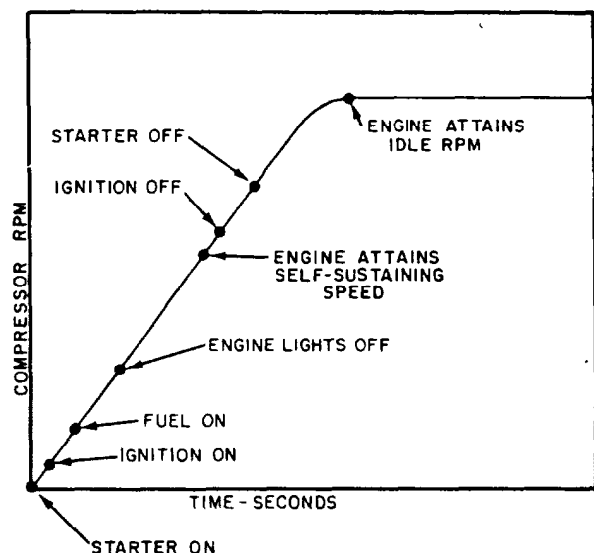


Figure 1-39.—Typical starting sequence for a GTE.

the engine, the ignition is turned on and the fuel valves are opened. The sequence of the starting procedure is important. At the time the fuel/air mixture is ignited, enough airflow must pass through the engine to support combustion.

After the engine has reached its self-sustaining or self-accelerating speed, the starter can be deactivated. If the starter is cut off below the self-sustaining speed, the engine may decelerate because it doesn't have enough energy to overcome its own friction and operating losses. It may also suffer a "hung start" in which it idles at a speed so low that it is unable to accelerate enough to obtain proper operating parameters. A hung-start engine will overheat because of a lack of cooling air. The starter must continue to boost engine speed well above self-sustaining speed to avoid hot or hung (false) starts, or a combination of both. In a hot start, the engine lights off, but because of a lack of adequate cooling and combustion air, the exhaust gas temperature exceeds the allowable limit for the engine.

At the proper points in the starting sequence, the starter and, usually, the ignition system will cut off. The higher the rpm before the starter cuts out, the shorter will be the total time required for the engine to attain idle rpm. This is because the engine and the starter are working together.

All GTE starters must be able to produce enough torque to start the engine properly. The GTEs must reach a certain minimum idle rate for a start to be satisfactory. This requires the torque characteristics of an acceptable starter to exceed by a good margin the amount of torque needed to overcome friction.

The GTEs use three basic types of starters and starter systems—electric, hydraulic, and pneumatic. Pneumatic (air-turbine) starters are the most commonly used on all except smaller engines, which generally use electric starters. Some marine GTE installations use hydraulic starters.

Another type of starter system is the air impingement system. Bleed air from another GTE is used directly in the HP turbine assembly to rotate the GG. Due to the volume of air required, the air impingement system is used primarily in starting aircraft engines and will not be covered in any further detail. We will describe the pneumatic starter system in chapter 2 of this TRAMAN.

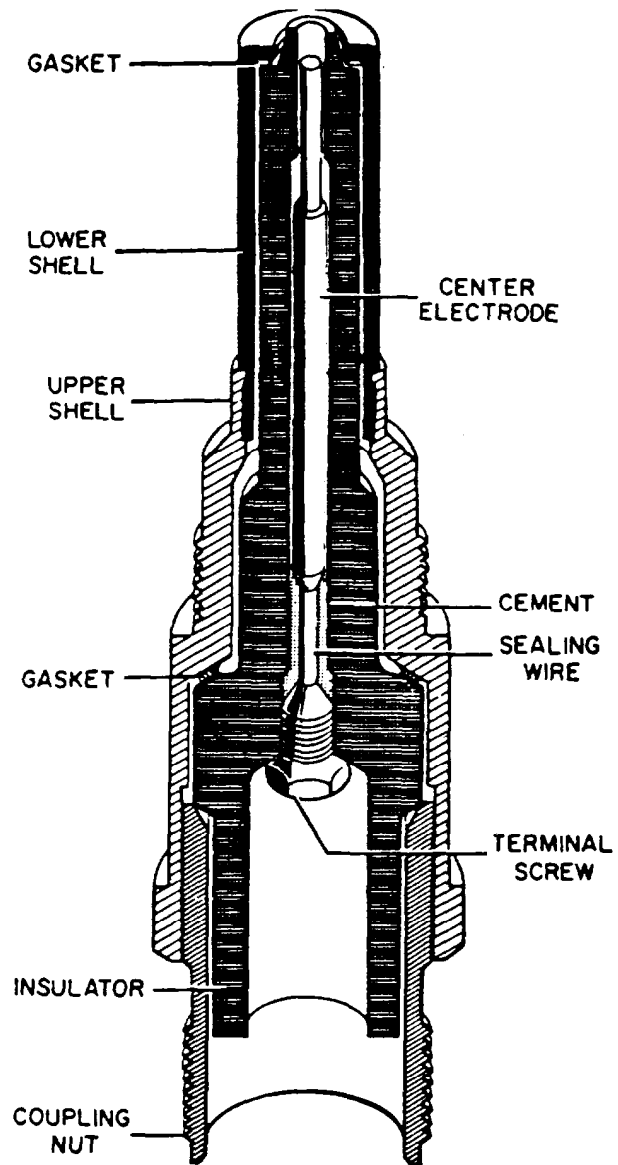


Figure 1-40.—Spark igniter.

SPARK IGNITER SYSTEM

Once adequate airflow has been established through the combustion area, fuel can be injected and the spark igniters start the burning process. The spark igniters are high-voltage electrical spark producers powered from the ignition exciter circuits.

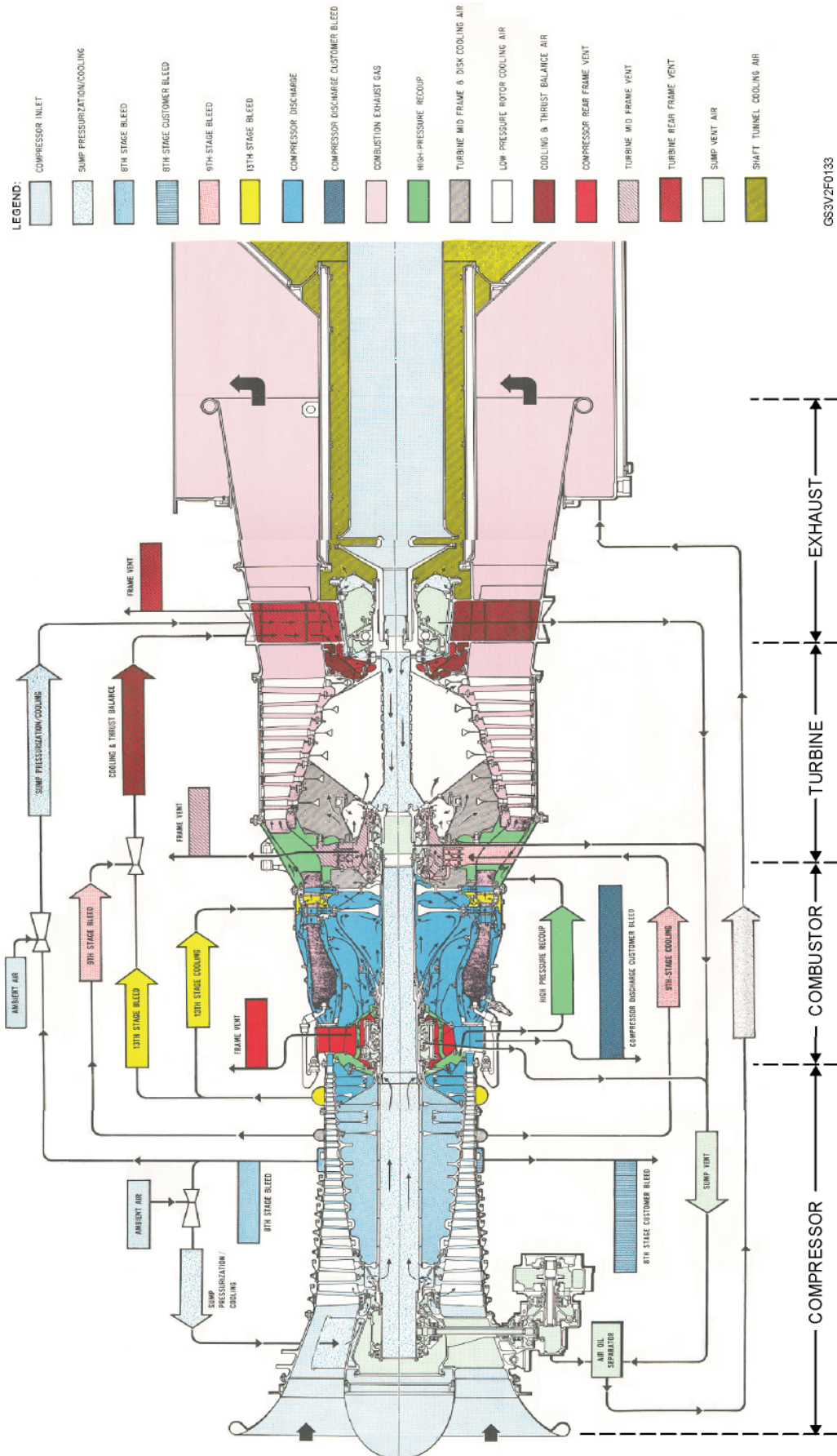
The ignition exciter derives its input power from the ship's service 60-Hz, 115-volt electrical system. Its function is to produce a high-energy spark at the spark igniter in the engine. This must be accomplished with a high degree of reliability

under widely varying conditions. These include internal pressure, humidity, temperature, vaporization, and carbon deposits on the spark igniter. To accomplish this, the capacitor discharges a spark of very high energy (about 100,000 watts). This concentration of maximum energy in minimum time achieves an optimum spark for ignition purposes. This spark is capable of blasting carbon deposits and vaporizing globules of fuel.

Spark igniters are of several types. Some resemble common automobile spark plugs. The more common annular gap types are shown in figure 1-40. Since they do not operate continually, they are usually durable and reliable, requiring only occasional cleaning to remove carbon from the tip and ceramic barrel.

SUMMARY

In this chapter you have learned about the principles and construction of GTEs. We have discussed the evolution of the GTE, the theory of operation, classifications of the different types of engines, and their subsystem components. Many other publications are available that discuss GTE construction in depth. This chapter was provided to give you the basis on which to expand your knowledge of marine GTEs. You may not feel you understand the temperature-pressure relationships in a simple GTE at this point. If so, you should review the sections of this chapter related to theory before continuing on to the material that follows.



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Figure 1-33.—LM2500 GTE airflow

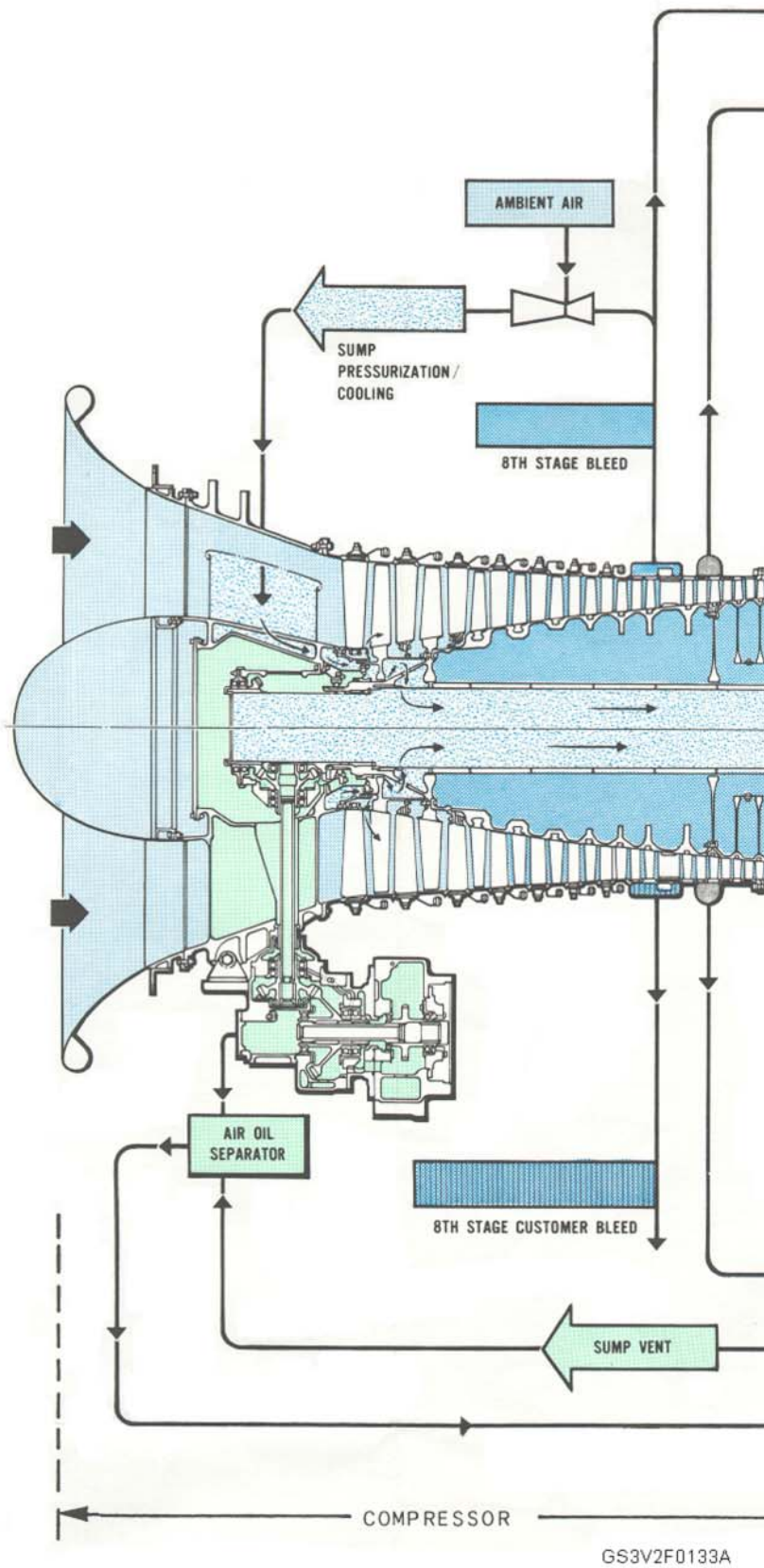


Figure 1-33A.—LM2500 GTE airflow.

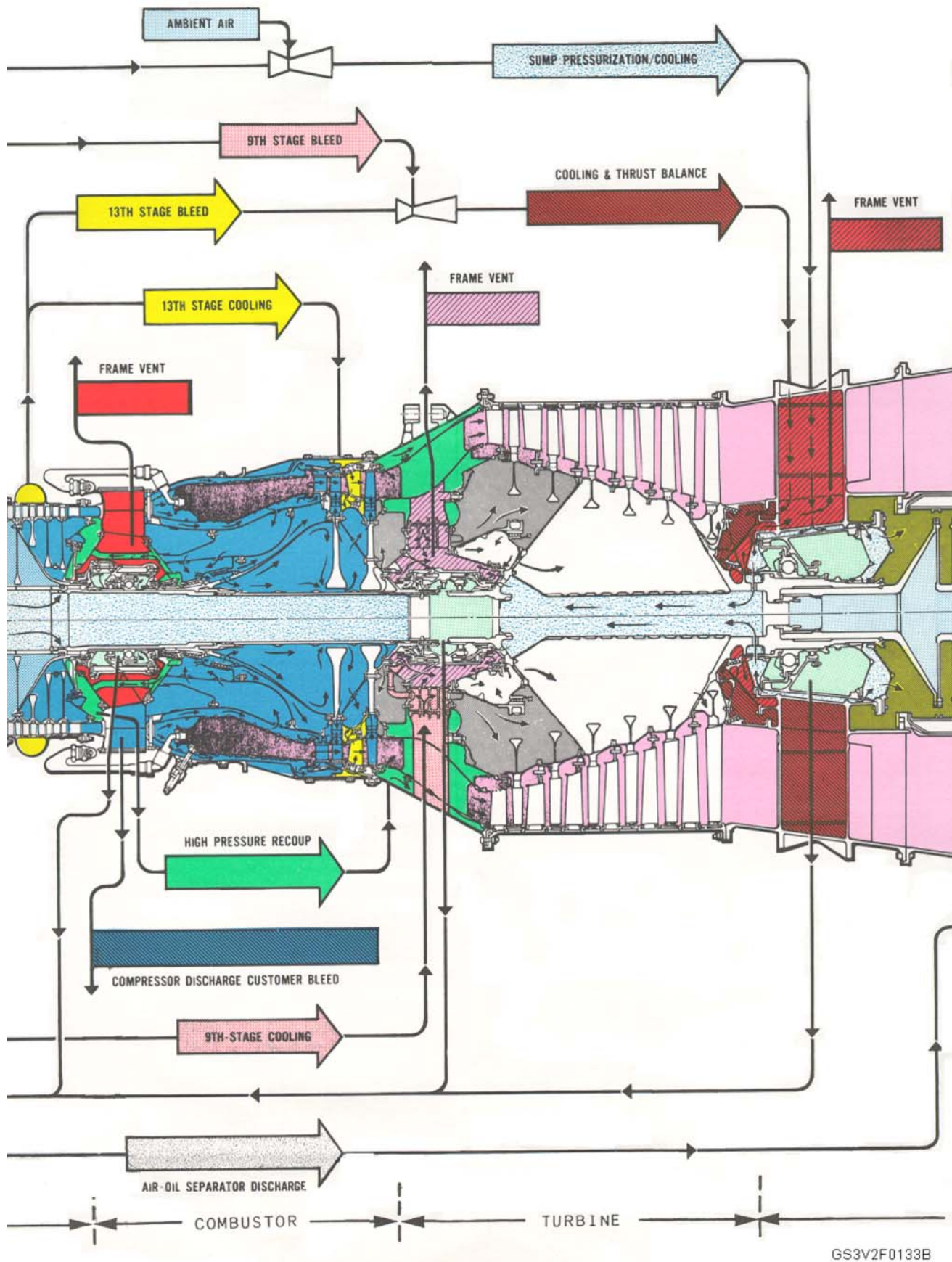


Figure 1-33B.—LM2500 GTE airflow—Continued..

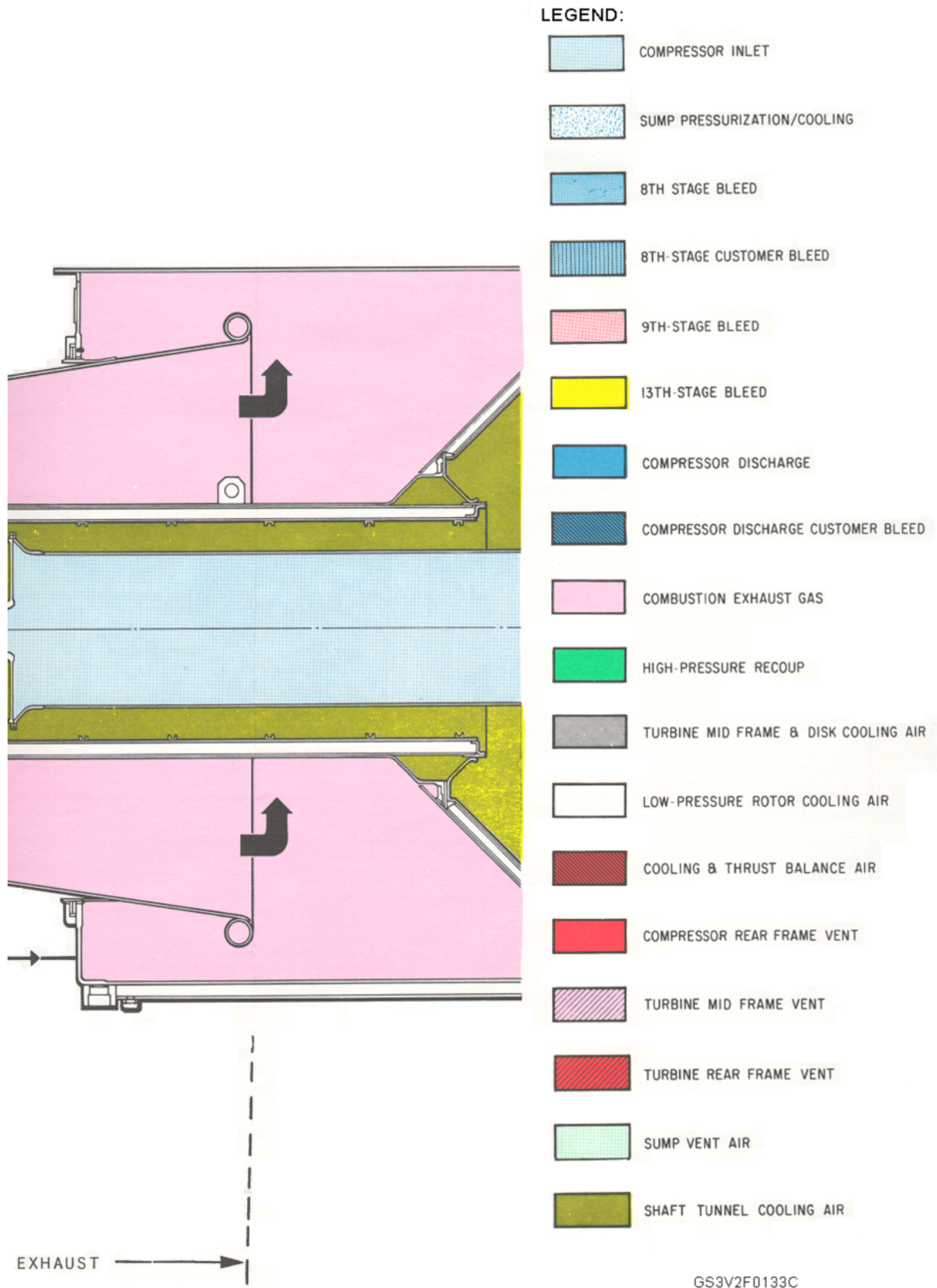


Figure 1-33C.—LM2500 GTE airflow—Continued.

APPENDIX I

GLOSSARY

ADIABATIC—To occur without loss or gain of heat by the substance concerned.

AERODYNAMICS—A branch of dynamics that deals with the motion of air and other gaseous fluids and the forces acting on bodies in motion relative to such fluids.

ALARM ACKNOWLEDGE—A push button that must be depressed to silence an alarm.

ALLOY—Any composition metal produced by the mixing of two or more metals or elements.

ALTERNATING CURRENT (ac)—An electrical current that constantly changes amplitude and polarity at regular intervals.

AMBIENT TEMPERATURE—The surrounding temperature, such as the air temperature that surrounds a conductor in a compartment or piece of equipment.

AMBIENT PRESSURE—The surrounding pressure, such as the air pressure that surrounds a conductor in a compartment or piece of equipment.

AMPERE (amp)—A unit of electrical current or rate of flow of electrons. One volt across 1 ohm of resistance causes a current flow of 1 ampere.

ANALOG SIGNAL—A measurable quantity that is continuously variable throughout a given range and that is representative of a physical quantity.

ANALOG-TO-DIGITAL CONVERSION (A/D or ADC)—A conversion that takes an analog in the form of electrical voltage or current and produces a digital output.

ANNULAR—In the form of or forming a ring.

ANTI-ICING—A system for preventing buildup of ice on the gas turbine intake systems.

ATMOSPHERE—A unit of measure equal to 14.696 psi or 29.92 inches of mercury (1 atmosphere = 14.696 psi).

ATMOSPHERIC PRESSURE—The pressure of air at sea level, about 14.7 psi.

AUTOMATIC PARALLELING DEVICE (APD)—The APD automatically parallels any two generators when an auto parallel command is initiated by the EPCC.

AUXILIARY CONTROL CONSOLE (ACC)—The console in CCS used to monitor the auxiliary systems on FFG-class ships.

AXIAL FLOW—Air flow parallel to the axis of the compressor rotor.

BABBITT—A white alloy of tin, lead, copper, and antimony that is used for lining bearings.

BAFFLE—A plate, wall, or screen used to deflect, check, or otherwise regulate the flow of a gas, liquid, sound waves, and so forth.

BATTERY—A device for converting chemical energy into electrical energy.

BLEED AIR—Air bled off the compressor stages of the GTEs. See BLEED AIR SYSTEM.

BLEED AIR SYSTEM—This system uses as its source compressed air extracted from the compressor stage of each GTE or GTG. It is used for anti-icing, prairie air, masker air, and LP gas turbine starting for both the GTEs and GTGs.

BLOW-IN DOORS—Doors located on the high hat assembly designed to open by solenoid-operated latch mechanisms if the inlet airflow becomes too restricted for normal engine operation.

BORESCOPE—A small periscope (instrument) used to visually inspect internal engine components.

BRIDGE CONTROL UNIT (BCU)—The console located on the bridge of the DDG-51 class ship that has equipment for operator control of ship's speed and direction.

BUS TIE BREAKER (BTB)—A device used to connect one main switchboard to another main switchboard.

BUS—An uninsulated power conductor (a bar or wire) usually found in a switchboard.

CALIBRATION—(1) The operation of making an adjustment or marking a scale so that the readings of an instrument conform to an accepted standard. (2) The checking of reading by comparison with an accepted standard

CANTILEVER—A horizontal structural member supported only by one end.

CASUALTY—An event or series of events in progress during which equipment damage and/or personnel injury has already occurred. The nature and speed of these events are such that proper and correct procedural steps will only serve to limit equipment damage and/or personnel injury.

CENTRAL CONTROL STATION (CCS)—The main operating station from which a majority of the engineering plant machinery can be controlled and monitored.

CENTRAL INFORMATION SYSTEM EQUIPMENT (CISE)—Located in CCS and is part of the PAMISE. It includes the general-purpose digital computer (ECU), S/CE No. 1, and supporting equipment.

CENTRIFUGAL FORCE—That force that tends to drive a thing or parts of a thing outward from a center of rotation.

CIRCUIT BREAKER (CB)—A device used to energize/de-energize an electrical circuit and for interrupting the circuit when the current becomes excessive.

CLASSIFICATION—A method of identifying and sorting various equipment and materials. For example: (1) check valve—swing check valve, stop check valve; (2) valve—solenoid valve, manual valve.

CLUTCH/BRAKE ASSEMBLY—a clutch/brake assembly for each GTE is mounted on the MRG housing to couple or decouple either or both engines to the drive train, to stop and hold the power turbine, and for shaft braking.

COALESCE—To grow together, unite, or fuse, as uniting small liquid particles into large droplets. This principle is used to remove water from fuel in the filter/seperator.

COHESION—The force that causes molecules that are brought close together to stick together.

COMBUSTION CYCLE—The process that includes compression of air, burning of compressed air/fuel mixture, expansion of gases, and removal of gases.

COMPRESSOR INLET TEMPERATURE (CIT or T_2)—The temperature of the air entering the gas turbine compressor (GTE) as measured at the front frame; one of the parameters used for calculating engine power output (torque) and scheduling combustion fuel flow and VSV angle.

COMPRESSOR DISCHARGE PRESSURE (CDP)—Compressor discharge pressure is sensed by a pressure tap on the compressor discharge static pressure sensing line to the MFC and piped to a base-mounted transducer on the GTE.

COMPRESSOR INLET TOTAL PRESSURE (P_{t2})—The pressure sensed by a total pressure probe mounted in the GTE compressor front frame.

COMPRESSOR—The component of a GTE that compresses the air.

CONCENTRIC—Having a common axis or formed about the same axis.

CONDUCTION—The transfer of heat through matter by communication of kinetic energy from particle to particle rather than by a flow of heated material.

CONTROLLABLE REVERSIBLE PITCH (CRP) PROPELLER—A propeller whose blade pitch can be varied to control the amount of thrust in both the ahead and astern directions. (Known as controllable pitch propeller (CPP) on FFG-class ships.)

CURRENT—The movement of electrons past a reference point. The passage of electrons through a conductor. It is measured in amperes.

DAMAGE CONTROL CONSOLE (DCC)—This console is located in CCS and provides monitoring for hazardous conditions (fire, high bilge levels, and so forth). It also monitors the ship's firemain and can control the fire pumps.

DATA MULTIPLEX SYSTEM (DMS)—A general-purpose information transfer system that provides data transfer for most of the major systems aboard the DDG-51 class ship.

DEAERATOR—A device that removes air from oil (for example, the lube oil storage and conditioning assembly (LOSCA) tank which separates air from the scavenge oil).

DEMAND DISPLAY INDICATOR (DDI)—A numerical display that is used to read values of parameters within the engineering plant.

DEMISTERS—A moisture removal device (GTE intake system) that separates water from air.

DENSITY—The quantity of matter contained in a body.

DIFFERENTIAL PRESSURE—The difference between two pressures measured with respect to a common basis.

DIFFUSER—A device for reducing the velocity and increasing the static pressure of a medium passing through a system.

DIGITAL-TO-ANALOG CONVERSION (D/A or DAC)—A conversion that produces an analog output in the form of voltage of current from a digital input.

DIRECT CURRENT—An essentially constant value electric current that flows in one direction.

DROOP MODE—This mode is normally used only for paralleling with shore power. This mode provides a varying frequency for any varying load. Droop mode inhibits the load sharing circuitry.

EDUCTOR—A mixing tube (jet pump) that is used as a liquid pump to dewater bilges and tanks. A GTE exhaust nozzle creates an eductor effect to remove air from the enclosure.

ELECTRIC PLANT CONTROL ELECTRONICS ENCLOSURE (EPCEE)—The EPCEE is part of the EPCE. It contains power supplies that provide the various operating voltage required by the EPCC on the CG- and DD-class ships.

ELECTRIC PLANT CONTROL CONSOLE (EPCC)—This console contains the controls and indicators used to remotely operate and monitor the generators and the electrical distribution system.

ELECTRIC PLANT CONTROL EQUIPMENT (EPCE)—The EPCE provides centralized remote control of the GTGS and electrical distribution equipment. The EPCE includes the EPCC and EPCEE and is located in CCS.

ELECTRONIC GOVERNOR (EC)—A system that uses an electronic control unit with an electrohydraulic governor actuator (EGA) to control and regulate engine speed.

EMERGENCY—An event or series of events in progress which will cause damage to equipment unless immediate, timely, and correct procedural steps are taken.

ENGINEERING CONTROL AND SURVEILLANCE SYSTEM (ECSS)—An automatic electronic control and monitoring system using analog and digital circuitry to control the propulsion and electric plant. The ECSS consists of the EPCE, PAMCE, PAMISE, PLOE, and SCE on the CG- and DD-class ships.

ENGINEERING OPERATIONAL SEQUENCING SYSTEM (EOSS)—A two-part system of operating instructions bound in books for each watch station. It provides detailed operating procedures (EOP) and casualty control procedures (EOCC) for the propulsion plant.

ENGINE ORDER TELEGRAPH (EOT)—A non-voice communication system provided between the command station (pilot house), CCS, and the main engine room.

EXECUTIVE CONTROL UNIT (ECU)—A computer (part of PAMISE) that is the nucleus of the information center of the ECSS. The ECU gathers data information from the ship's propulsion, auxiliary, and electric plant equipment.

EXPANSION—The increase in volume of the gases in a turbine after combustion by which the gases continue to turn the rotor while expending part of its internal energy and losing in pressure and temperature.

FEEDBACK—A value derived from a controlled function and returned to the controlling function.

FEEDWATER—Distilled water made in evaporators for use in boilers. Feedwater is more pure than drinking (potable) water.

FERROUS—Refers to metals having iron as the base metal.

FILTER—(1) A device that removes insoluble contaminants from the fluid power system. (2) A device through which gas or liquid is passed; dirt, dust, and other impurities are removed by the separating action.

FREE STANDING ELECTRONIC ENCLOSURE (FSEE)—The FSEE provides the supporting electronic and engine control interface between the GTE and the control consoles. One FSEE is located in each MER.

FREQUENCY—The number of cycles (as in an alternating electrical current) completed per second.

FRICTION—Resistance to the relative motion of one body sliding, rolling, or flowing over another with which it has contact.

FUEL SYSTEM CONTROL CONSOLE (FSCC)—Located in CCS and is the central station for monitoring and control of the fuel fill and transfer system.

FUEL OIL SYSTEM—This system provides a continuous supply of clean fuel to the GTEs.

FULL POWER—The condition in which both engines (GTEs) in one engine room are engaged and driving the reduction gear and propeller shaft.

GAS GENERATOR (GG)—The gas-producing section of any GTE. It usually has a compressor, a combustor, a high-pressure turbine, an accessory drive system, and controls and accessories.

GAS TURBINE ENGINE (GTE)—A GTE consists of a compressor, a combustor, a turbine, and an accessory drive system. Many variations of GTEs exist.

GAS GENERATOR SPEED ($N_{G \ G}$)—The speed sensed by a magnetic pickup on the transfer gearbox of the GTE.

GAS TURBINE GENERATOR SET (GTGS)—The GTGS has a GTE, a reduction gearbox, and a generator.

GENERATOR BREAKER (GB)—The GB is used to connect a generator to its main switchboard.

GOVERNOR CONTROL UNIT (GCU)—A static GCU is supplied for each GTGS consisting of a static exciter/voltage regulator assembly, field rectifier assembly, motor-driven rheostat, and mode select rotary switch. It controls the output voltage of the generator.

HEADER—A piping manifold that connects several sublines to a major pipeline.

HEAD TANK—A tank located higher than other system components to provide a positive pressure to a system by gravity.

HERTZ (Hz)—A unit of frequency equal to one cycle per second.

HIGH HAT ASSEMBLY—A removable housing over the main engine air intake ducts that contains the moisture separation system (demisters), inlet louvers, and blow-in doors.

HORSEPOWER (hp)—A standard unit of power that equals 550 foot pounds of work per second.

HUMIDITY—The weight of water vapor in grains per cubic foot of air.

HYDRAULIC—Conveyed, operated, or moved by water or other liquid in motion.

HYDRAULIC OIL POWER MODULE (HOPM)—A component located near the MRG to deliver control oil and high pressure (HP) oil to an oil distribution box for distribution to the propeller hub and activation of the pitch control rod within the shaft.

IMPELLER—A blade or series of blades of a rotor that imparts motion.

INERTIA—Any change in motion being measured by the acceleration of the center of mass.

INFORMATION CONTROL CONSOLE (ICC)—Part of the ECU. ICC No. 1 is used to program and run the computer. ICC No. 2 is the tape reader and is used to input the program into the ECU.

INLET GUIDE VANE (IGV)—The variable vanes ahead of the first stage of compressor blades of a GTE. Their function is to guide the inlet air into the GTE compressor at the optimum angle.

ISOCRONOUS MODE—This mode is normally used for generator operation. This mode provides a constant frequency for all load conditions. When two (or more) generators are operated in parallel, the isochronous mode also provides equal load sharing between units.

JOULES—Unit of energy. The work done when the point of application of 1 newton is displaced a distance of 1 meter in the direction of force.

JP-5—The primary type of fuel used for helicopters and small boats. The emergency source of fuel for the GTEs and GTGs.

KILOWATT—A unit of electrical power equal to 1000 watts. (A watt is a unit of power equal to the rate of work represented by a current of 1 ampere under a pressure of 1 volt.)

KINETIC ENERGY—Energy in motion.

LABYRINTH/HONEYCOMB SEAL—This seal combines a rotating element and a honeycomb stationary element to form an air seal. Used in GTEs to maintain close tolerances over a large temperature range.

LABYRINTH/WINDBACK SEAL—This seal combines a rotating element with a smooth surface stationary element to form an oil seal. The windback is a coarse thread on the rotating element of the oil seal which uses screw action (windback) to force any oil that might leak across the seal back into the sump.

LIQUID FUEL VALVE (LFV)—This valve meters the required amount of fuel for all engine operating conditions for the Allison 501-K17 GTE.

LOAD SHEDDING—Protects a generator from overloading by automatically dropping preselected loads when generator output reaches 100 percent.

LOCAL OPERATING PANEL (LOP)—The LOP is the local operating station for GTEs on the FFG-class ships. It is located in the MER and is used primarily for maintenance.

LUBE OIL STORAGE AND CONDITIONING ASSEMBLY (LOSCA)—The LOSCA is mounted remotely from the GTE and is a unit with a lube oil storage tank, a heat exchanger, a scavenge oil duplex filter, and a scavenge oil check valve (all mounted on a common base). Its function is to provide the GTE with an adequate supply of cool, clean lube oil.

MACHINERY CONTROL SYSTEM (MCS)—Provides centralized and remote monitoring and control of propulsion, electrical, auxiliary, and damage control systems of the DDG-51 class ship.

MAIN REDUCTION GEAR (MRG)—A locked train, double-reduction gear designed to reduce the rpm output of the GTE and drive the propeller shaft.

MAIN FUEL CONTROL (MFC)—A hydro-mechanical device on the propulsion GTE that controls N_{GG} , schedules acceleration fuel flow, deceleration fuel flow, and stator vane angle for stall-free, optimum performance over the operating range of the GTE.

MASKER AIR SYSTEM—This system disguises the sound signature of the ship and alters transmission of machinery noise to the water by emitting air from small holes in the emitter rings on the ship's hull.

MASS—The measure of the quantity of matter contained in a body.

METALLURGY—The science dealing with the structure and properties of metals and alloys, and the processes by which they are obtained from ore and adapted to the use of man.

MICRON—A unit of length equal to one millionth of a meter.

MIL—A unit of length equal to one thousandth of an inch.

NAVY STANDARD DAY—Parameters meeting the following requirements: sea level, barometric pressure of 29.92 inches of mercury, humidity of 0.00 inch of mercury, and a temperature of 59°F.

NOZZLE—A taper or restriction used to speed up or direct the flow of gas or liquid.

OIL DISTRIBUTION (OD) BOX—This box is located at the forward end of each MRG assembly. It directs HP oil from the HOPM to the propeller hub through the shaft bore. The OD box also establishes propeller pitch by using control oil from the HOPM to position the valve rod, which extends through the shaft to the hub.

ORIFICE—A circular opening in a flow passage that creates a flow restriction.

PARAMETER—A variable, such as temperature, pressure, flow rate, voltage, current, or frequency that may be indicated, monitored, checked, or sensed in any way during operation or testing.

PERMANENT MAGNET ALTERNATOR (PMA)—The PMA is mounted on the generator shaft extension of each GTGS and supplies speed sensing and power to the EG. The PMA also supplies initial generator excitation.

PHOTOELECTRIC—Electricity produced by the action of light.

PITCH—A term applied to the distance a propeller will advance during one revolution.

PLENUM CHAMBER—An enclosed space in which the pressure of the air is greater than the outside atmosphere.

POTENTIOMETER—A variable resistance unit having a rotating contact arm that can be set at any desired point along the resistance element.

POWER TURBINE INLET TOTAL PRESSURE ($P_{t5.4}$)—The pressure sensed by pressure probes located in the GTE turbine midframe and piped to a transducer on the bottom of the GTM.

POWER TURBINE INLET GAS TEMPERATURE ($T_{5.4}$)—The temperature sensed by thermocouples installed in the GTE midframe.

POWER TURBINE SPEED (N_{pt})—The speed sensed by magnetic pickups in the GTE turbine rear frame.

POWER LEVEL ANGLE (PLA)—A rotary actuator mounted on the side of the GTE fuel

pump and its output shaft lever. It is mechanically connected to the MFC power lever. The PLA actuator supplies the torque to position the MFC power lever at the commanded rate.

POWER TURBINE (PT)—The GTE turbine that converts the GG exhaust into energy and transmits the resulting rotational force via the attached output shaft.

POWER TAKEOFF (PTO)—The drive shaft between the GTGS GTE and the reduction gear. It transfers power from the GTE to the reduction gear to drive the generator.

PRAIRIE AIR SYSTEM—This system emits cooled bleed air from small holes along the leading edge of the propeller blades. The resulting air bubbles disturb the thrashing sound so identification of the type of ship through sonar detection becomes unreliable.

PRESSURE—Force per unit of area, usually expressed as psi.

PRIME MOVER—(1) The source of motion—as a GTE, (2) the source of mechanical power used to drive a pump, or compressor, (3) or rotor of a generator.

PROPELLER—A propulsive device consisting of a boss or hub carrying two or more radial blades. (Also called a screw.)

PROPULSION AUXILIARY CONTROL CONSOLE (PACC)—This console is located in CCS and is part of the PAMCE. It contains the electronic equipment capable of controlling and monitoring both propulsion plants and auxiliary equipment on a CG- or DD-class ship. (Also known as PACC on the DDG-51 class ship but not a part of PAMCE.)

PROPULSION AND AUXILIARY MACHINERY CONTROL EQUIPMENT (PAMCE)—This equipment is located in CCS, is part of the ECSS, and includes the PACC and PACEE. This equipment provides centralized control and monitoring of both main propulsion plants and auxiliary machinery on a CG- or DD-class ship.

PROPULSION AND AUXILIARY MACHINERY INFORMATION SYSTEM EQUIPMENT (PAMISE)—This equipment is located in CCS and is part of the ECSS. This equipment receives,

evaluates, and logs the engineering plant performance, status, and alarm state. The PAMISE contains the CISE and S/CE No. 1 on a CG- or DD-class ship.

PROPULSION CONTROL CONSOLE (PCC)—This is the main engine control console in CCS on an FFG-class ship. It is used for starting, stopping, and controlling the GTEs and propeller shaft.

PROPULSION LOCAL CONTROL CONSOLE (PLCC)—The PLCC is located in each engine room and is part of the PLOE. It has controls and indicators necessary for operator's control of one main propulsion plant and its supporting auxiliaries on a CG- or DD-class ship.

PROPULSION LOCAL OPERATING EQUIPMENT (PLOE)—The PLOE is located in each engine room and is part of the ECSS. It includes the PLCC and PLCEE. The PLOE provides for local control and monitoring of the main propulsion GTE and the associated auxiliary equipment on a CG- or DD-class ship.

PUMP—(1) A device that converts mechanical energy into fluid energy. (2) A device that raises, transfers, or compresses fluids or gases.

RADIALLY—Developing uniformly around a central axis.

REPAIR STATION CONSOLE (RSC)—Provides centralized control of the damage control equipment on DDG-51 class ships. The RSC serves as the primary control station when the DCC is not available.

RESISTANCE TEMPERATURE DETECTOR (RTD)—A temperature sensor that works on the principle that as temperature increases, the conductive material exposed to this temperature increases electrical resistance.

RESISTOR—A device possessing the property of electrical resistance.

RHEOSTAT—A variable resistor having one fixed and one moveable terminal.

ROTOR—A rotating wheel or group of wheels in a turbine.

SALIENT POLE GENERATOR—A generator whose field poles are bolted to the rotor, as opposed to a generator whose field poles are formed by imbedding field windings in the slots of a solid rotor.

SCAVENGE PUMP—A pump used to remove oil from a sump and return it to the oil supply tank.

SENSOR—The part of an instrument that first takes energy from the measured medium to produce a condition representing the value of the measured variable.

SHAFT CONTROL UNIT (SCU)—The SCU is located in each engine room. It has controls and indicators necessary for operator control of one main propulsion plant and its supporting auxiliaries on a DDG-51 class ship.

SHIP CONTROL CONSOLE (SCC)—This console is located on the bridge of CG- and DD-class ships. It has equipment for operator control of ship's speed and direction.

SHIP'S SERVICE DIESEL GENERATOR (SSDG)—The SSDG is the main source of electrical power for a ship. It uses a diesel engine as the prime mover for the generator.

SHIP'S SERVICE GAS TURBINE GENERATOR (SSGTG)—The SSGTG is the main source of electrical power for a ship. It uses a GTE as the prime mover for the generator.

SIGNAL CONDITIONING ENCLOSURE (S/CE)—Part of the PAMISE and provides the major input interface between the propulsion plant machinery and the ECSS control consoles. The S/CE accepts inputs from the plant machinery and outputs normalized signals to the ECSS control consoles. Also has alarm detection and alarm output circuitry. One S/CE is located in each engine room and one is a part of the CISE (located in CCS).

SOLENOID—A coil of wire in the form of a long cylinder that resembles a bar magnet. When current flows in the wire, a movable core is drawn into the coil.

SPLIT PLANT—The condition in which only one engine in an engine room is driving the reduction gear/propulsion shaft.

STALL—An inherent characteristic of all gas turbine compressors to varying degrees and under certain operating conditions. It occurs whenever the relationship between air pressure, velocity, and compressor rotational speed is altered so that the effective angle of attack of the compressor blades becomes excessive, causing the blades to stall.

STATOR—The body of stationary blades or nozzles of a turbine.

SUMMARY ALARM—An indicator at a console that indicates to an operator that one of several abnormal conditions has occurred on a certain piece of equipment.

SYNCHRO SELF-SHIFTING (SSS) CLUTCH—The SSS clutch is a fully automatic, free-wheel device that transmits power through gear-toothed elements.

TACHOMETER—An instrument used to measure the speed of rotation of a device.

TEMPERATURE—The quantitative measure of the relative hotness or coldness of an object.

THERMAL ENERGY—The potential and kinetic energy of particles of a body which can be evolved as heat.

THERMOCOUPLE—(1) a bimetallic device capable of producing an emf roughly proportional to temperature differences on its hot and cold junction ends. (2) A junction of two dissimilar metals that produces a voltage when the junction is heated.

THERMODYNAMICS—A branch of dynamics that deals with the applied forces caused by the application of heat.

THRUST BEARING—Bearing that limits the axial (longitudinal) movement of the shaft.

THRUST—The forward directed reaction force produced by a high-speed jet of air discharged rearward from a nozzle or orifice.

TOLERANCE—The allowable deviation from a specification or standard.

TORQUE—A force or combination of forces that produces or tends to produce a twisting or rotary motion.

TRANSDUCER—(1) A device that converts a mechanical input signal into an electrical output signal. (2) Generally, a device that converts energy from one form into another, always retaining the characteristic amplitude variations of the energy converted.

TRANSFORMER—A device composed of two or more coils, linked by magnetic lines of force, used to step up or step down an ac voltage.

TURBINE OVERTEMPERATURE PROTECTION SYSTEM (TOPS)—A system used on a CG- or DD-class ship to protect a surviving generator from overload if another generator fails.

TURBINE INLET TEMPERATURE (TIT)—The GTGS turbine inlet temperature on the Allison 501-K17. (Known as $T_{5.4}$ for an LM2500 GTE.)

ULTRAVIOLET (UV) SENSOR—A device that senses the presence of fire in the GTE and GTG enclosure and generates an electrical signal that is sent to the ECSS.

UNINTERRUPTIBLE POWER SUPPLY (UPS) SYSTEM—Critical ship control systems have a UPS as an emergency power source. The UPS is used to maintain operations during any interruption of the normal power source.

VACUUM—Pressure less than atmospheric pressure.

VARIABLE STATOR VANE (VSV)—A compressor stator vane that is mechanically varied to provide optimum, stall-free compressor performance over a wide operating range.

VELOCITY—The rate of motion in a particular direction. The velocity of fluid flow is usually measured in feet per second.

VENTURI—A device that depends for operation upon the fact that as the velocity of flow of air increases in the throat the pressure decreases.

VISCOSITY—The internal resistance of a fluid which tends to prevent it from flowing.

VOLT—A unit of electrical potential.

VOLTAGE—An electric potential difference, expressed in volts.

VOLUME—The amount of space that matter occupies.

VORTEX—That which resembles a whirlwind or whirlpool.

WASTE HEAT BOILER (WHB)—Each waste heat boiler is associated with a GTGS and uses the hot exhaust gases to convert feedwater to steam for various ship's services on CG-, DD- or CG- and DD- class ships.

WATT—A unit of electric power equal to the rate of work represented by a current of 1 ampere under a pressure of 1 volt.

APPENDIX II

ABBREVIATIONS AND ACRONYMS

This appendix is a listing of the abbreviations and acronyms used in this text. Although this is an extensive listing, it is not an all-inclusive list of abbreviations and acronyms used by the Gas Turbine Systems Technicians. The *GSE3/GSM3*, NAVEDTRA 10563, volume 1, also has an appendix II with abbreviations and acronyms used in the text. However, this list will help form a basis for your qualification under the PQS system and allow for rapid access to terms used by Gas Turbine Systems Technicians.

A

A/C—air conditioning
 ACC—auxiliary control console
 ADC—analog-to-digital converter
 AFFF—aqueous film forming foam
 AGB—accessory gearbox
 AM—area multiplexers
 AMR—auxiliary machinery room
 APD—automatic paralleling device
 ASROC—antisubmarine rocket
 ASW—antisubmarine warfare

B

BCU—bridge control unit
 BLISS—boundary layer infrared suppression system
 BTB—bus tie breaker

C

CB—circuit breaker
 CBR—chemical, biological, radiation

CCS—central control station
 CDP—compressor discharge pressure
 CHT—collecting, holding and transfer
 CISE—central information system equipment
 CIT—compressor inlet temperature
 CO₂—carbon dioxide
 CODAG—combined diesel and gas
 CODOG—combined diesel or gas
 COGOG—combined gas or gas
 COSAG—combined steam and gas
 CPU—central processing unit
 CRP—controllable reversible pitch
 CT—current transformer

D

DAC—digital-to-analog converter
 DCC—damage control console
 DDI—demand display indicator
 DFM—diesel fuel, marine
 DMS—data multiplex system
 DVM—digital voltmeter

E

ECSS—Engineering Control and Surveillance System

ECU—electronic control unit

EG—electrohydraulic (electric) governor

EHGA—electrohydraulic governor actuator

EMI—electromagnetic interference

EOOW—engineering officer of the watch

EOSS—Engineering Operational Sequencing System

EOT—engine order telegraph

EPCC—electric plant control console

EPCE—electric plant control equipment

EPCEE—electric plant control electronics enclosure

EPM—equivalent parts per million

F

FO—fuel oil

FOD—foreign object damage

FSCC—fuel system control console

FSEE—free standing electronic enclosure

ft³/min—cubic feet per minute

G

GB—generator circuit breaker

GCU—governor control unit

GG—gas generator

GMLS—guided missile launching system

GMT—greenwich mean time

gpm—gallons per minute

GSE—Gas Turbine Systems Technician (Electrical)

GSM—Gas Turbine Systems Technician (Mechanical)

GSs—Gas Turbine Systems Technicians

GT—gas turbine

GTE—gas turbine engine

GTG—gas turbine generator

GTGSs—gas turbine generator sets

GTM—gas turbine module

H

HF—high-frequency

HP—high-pressure

hp—horsepower

HSS—high-signal select

HVAC—heating, ventilation, and air conditioning

I

ICC—information center console

IGV—inlet guide vane

in.H₂O—inches of water

IOU—input-output units

IR—infrared

K

KOH—potassium hydroxide

L

lb/min—pounds per minute

lb/set—pounds per second

LCAC—landing craft, air cushion

LED—light-emitting diode

LFV—liquid fuel valve

LO—lube oil

LOCOP—local operating control panel

LOP—local operating panel

LOSCA—lube oil storage and conditioning assembly

LOSIP—local operating station instrument panel

LP—low-pressure

LSS—low-signal select

lube—lubricating

LVDT—linear variable-displacement transformer

M

MCS—machinery control system

MER—main engine room

MFC—main fuel control

MG—maintenance group

MPU—magnetic pickup unit

MRC—maintenance requirement card

MRG—main reduction gear

N

N_1 —speed voltage

N_{gg} —gas generator speed

NOAP—Navy Oil Analysis Program

$N_{p, t}$ —power turbine speed

NRTC—nonresident training course

O

OD box—oil distribution box

OOD—officer of the deck

P

PACC—propulsion and auxiliary control console

PAMCE—propulsion and auxiliary machinery control equipment

PAMISE—propulsion and auxiliary machinery information system equipment

PCB—printed circuit board

PCC—propulsion control console

PCS—propulsion control system

PG—patrol combatant

PKP—potable potassium bicarbonate

PLA—power lever angle

PLCC—propulsion local control console

PLOE—propulsion local operating equipment

PMA—permanent-magnet alternator

PMS—Planned Maintenance System

PQS—Personnel Qualification Standard

$P_{s, 3}$ —compressor discharge static pressure

PSEA—power supply enclosure assembly

psia—pounds per square inch absolute

psid—pounds per square inch differential

psig—pounds per square inch gauge

PT—power turbine

P_{t2} —compressor inlet total pressure

$P_{t5.4}$ —power turbine inlet total pressure

PTO—power take-off

PWB—printed wiring board

R

RC—resistive capacitive

RFI—radio-frequency interference

RM—remote multiplexers

rpm—rotations per minute

RSC—repair station console

RTD—resistance temperature detector

RTE—resistance temperature element

S

SKE—signal conditioning enclosure

SAC—starting air compressor

SCCP—self-cleaning centrifugal purifier

scfm—standard cubic feet per minute

SCS—supervisory control status

SEM—standard electronic module

SHP—shaft horsepower

SPM—speed phase matching

srpm—shaft rpm

SS—ship's service

SSAS—ship's service air system

SSDG—ship's service diesel generator

SSGTGS—ship's service gas turbine generator set

SWBD—switchboard

T

T_2 —compressor inlet temperature

$T_{5.4}$ —power turbine inlet gas temperature

TC—traffic controllers

TGB—transfer gearbox

TIT—turbine inlet temperature

TOPS—turbine overtemperature (overload) protection system

TRAMAN—training manual

U

UPS—uninterruptible power supply

UV—ultraviolet

V

VERTREP—vertical replenishment

VSV—variable stator vane

W

WDCM—washdown countermeasure

WHB—waste heat boiler

X

xdcr—transducer

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