CHAPTER 6

GAS TURBINES

This chapter will provide you with a basic understanding of the history and development of gas turbine engines. This chapter will also discuss basic gas turbine engine theory, types, construction features, and operating principles.

HISTORY AND BACKGROUND

Until recent years, it has not been possible to separate gas turbine and jet engine technology. The same people worked in both fields, and the same sciences were applied to both types of engines. Recently, the jet engine has been used more exclusively as a part of aviation. The gas turbine has been used for the generation of electricity, ship propulsion, and experimental automobile propulsion. Many operational turbine power plants use aircraft jet engines as a gas generator (GG), adding a power turbine (PT) and transmission to complete the plant.

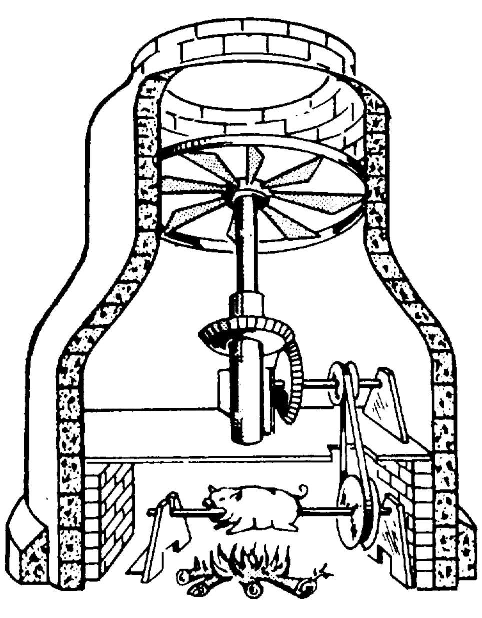


Figure 6-1.—DaVinci's chimney jack.

In the last chapter we discussed Hero, a scientist from Alexandria, Egypt. Many sources credit him as the inventor of the *aeolipile* (see chapter 5, fig. 5-1). The aeolipile is considered by many sources to be the first turbine engine.

Throughout the course of history, there are examples of other devices that used the principle of expanding gases to perform work. Among these were inventions of Leonardo DaVinci (fig. 6-1) and Giovanni Branca (fig. 6-2).

In the 1680s, Sir Isaac Newton described the laws of motion. All devices that use the theory of jet propulsion are based on these laws. Newton's steam wagon is an example of his reaction principle (fig. 6-3).

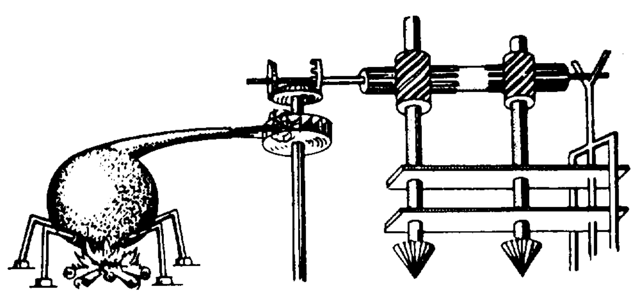


Figure 6-2.—Branca's jet turbine.

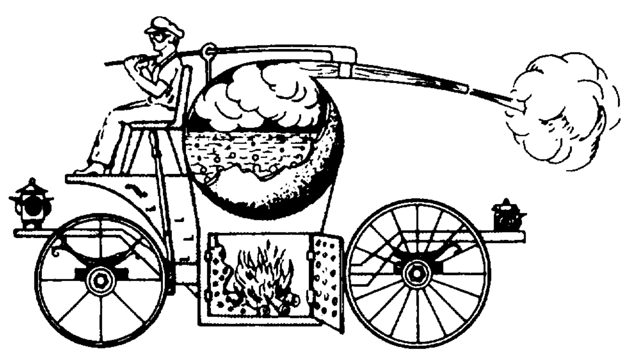


Figure 6-3.—Newton's steam wagon.

TWENTIETH-CENTURY DEVELOPMENT

The patent application for the gas turbine, as we know it today, was submitted in 1930 by an Englishman, Sir Frank Whittle. His patent was for a jet aircraft engine. Using his ideas, along with the contributions of such scientists as Coley and Moss, Whittle developed a working gas turbine engine (GTE).

AMERICAN DEVELOPMENT

The United States entered the gas turbine field in late 1941 when General Electric was awarded a contract to build an American version of a foreign-designed aircraft (gas turbine) 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 from scratch the first all-American gas turbine engine. Their engineers designed the first axial-flow compressor and annular combustion chamber. Both of these ideas, with minor changes, are the basis for the majority of gas turbine engines in use today.

MARINE GAS TURBINES

The concept of using a gas turbine to propel a ship goes back to 1937 when a Pescara free-piston gas engine was used experimentally with a gas turbine. The free-piston engine, or "gasifier" (fig. 6-4), is a form of diesel engine that uses air cushions instead of a crankshaft to return the pistons. It was an effective producer of pressurized gases, and 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/gas turbine combination. In 1957, the United States put into service the liberty ship *William Patterson*, having six free-piston engines driving two turbines.

The gasifier, or 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 horsepower (hp) gas turbine to drive the center of three shafts. In 1951, in an experimental application, the tanker *Auris* replaced one of four diesel engines with a 1200 hp gas turbine. In 1956, the *John Sergeant* had a remarkably efficient installation that used a regenerator to recover heat from the exhaust gases.

By the late 1950s, gas turbine marine engines were becoming widely used in combination with conventional propulsion equipment mostly by European navies. Gas turbines were used for high-speed operation, and conventional plants were used for cruising. The most common arrangements were the combined diesel or gas turbine (CODOG) or the combined diesel and gas turbine (CODAG) systems. Diesel engines give good

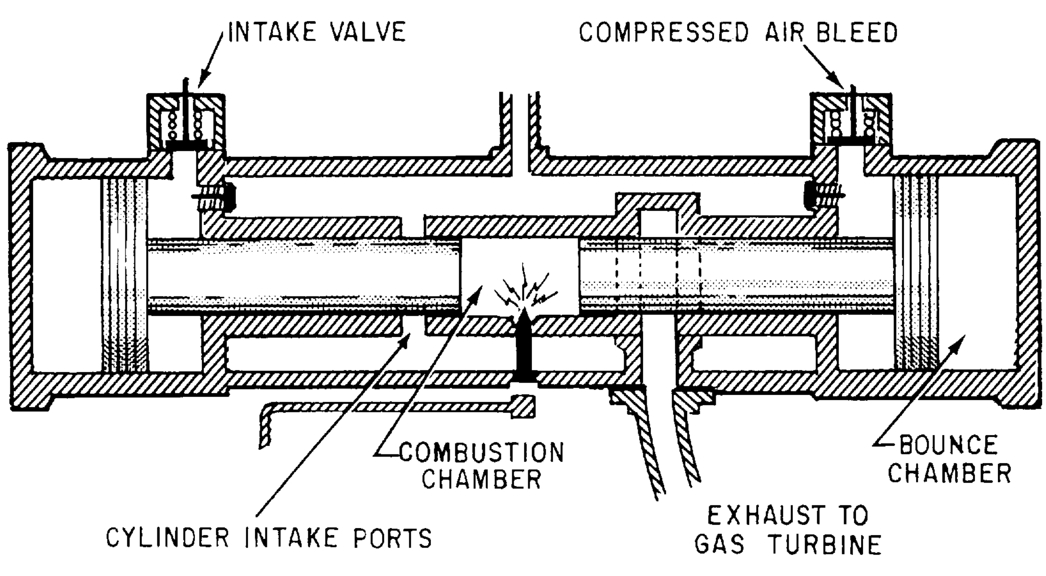


Figure 6-4.—Free-piston engine.

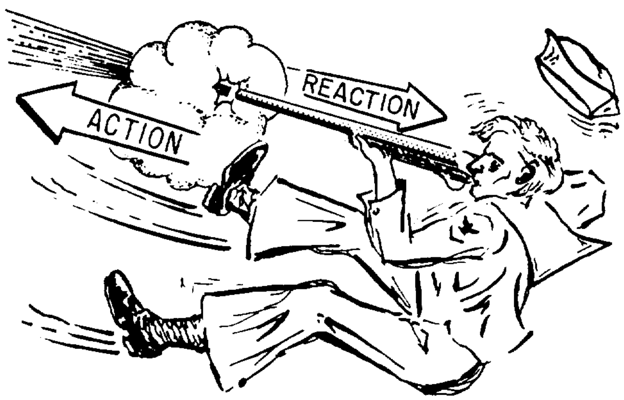


Figure 6-5.—Newton's third law of motion.

cruising range and reliability, but they have a disadvantage when used in antisubmarine warfare. Their low-frequency sounds travel great distances through water, making them easily detected by passive sonar. Steam turbines have been combined with gas turbines in the steam and gas turbine propulsion (COSAG) configuration to reduce low-frequency sound. This configuration requires more personnel to operate and does not have the range of the diesel combinations. Another configuration, the combined gas turbine or gas turbine (COGOG) has also been successful. The British County class destroyers use the 4,500 hp Tyne gas turbine engine for cruising and the 28,000 hp Rolls Royce Olympus engine for high speed.

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 LM 1500 gas turbine for operating at high speed. As a result of the increasing reliability and efficiency of new gas turbine deigns, the Navy has now designed and is building cruisers, destroyers, and frigates that are entirely propelled by marine gas turbine engines.

BASIC ENGINE THEORY

Newton's third law of motion states that for every action there is an equal and opposite reaction. If you have ever fired a shotgun and felt the recoil, you have experienced an example of action-reaction (fig. 6-5). This law of motion is demonstrated in a gas turbine by hot and expanding gases striking the turbine wheel (action) and causing the wheel to rotate (reaction).

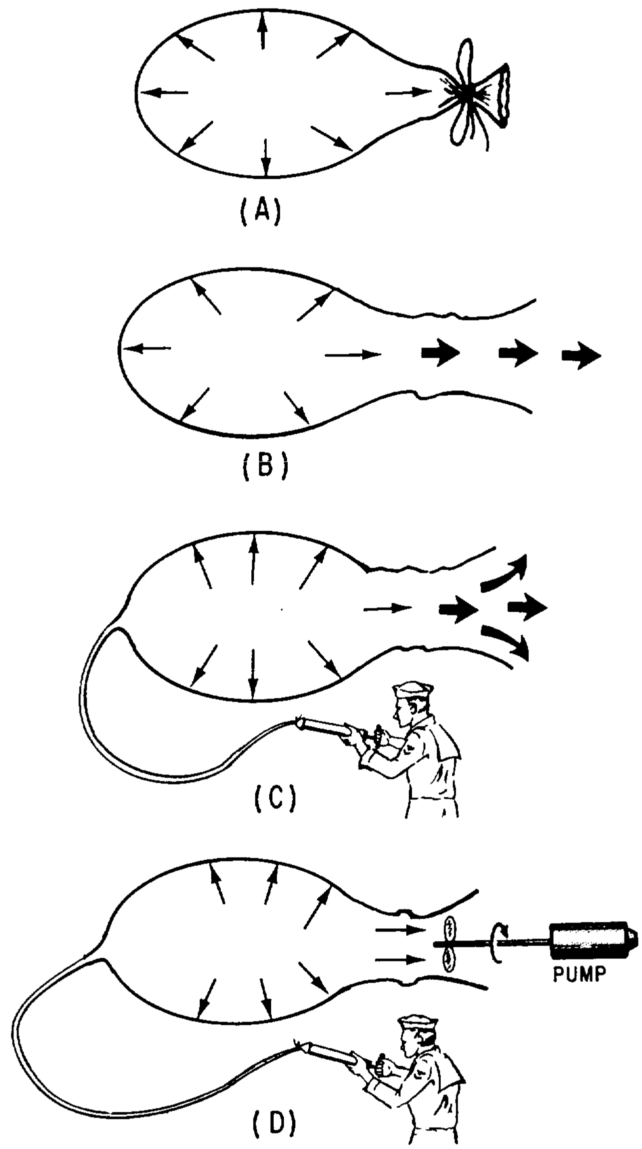


Figure 6-6.—Turbine operating theory.

OPERATING PRINCIPLES

Figure 6-6 demonstrates the basic principles of gas turbine operation.

A blown-up balloon (fig. 6-6, view A) does nothing until the trapped air is released. The air escaping rearward (fig. 6-6, view B) causes the balloon to move forward (Newton's third law). If we could keep the balloon full of air (fig. 6-6, view C), the balloon would continue to move forward.

If a fan or pinwheel is placed in the air stream (fig. 6-6, view D), the pressure energy and velocity energy will rotate the fan and it can then be used to do work.

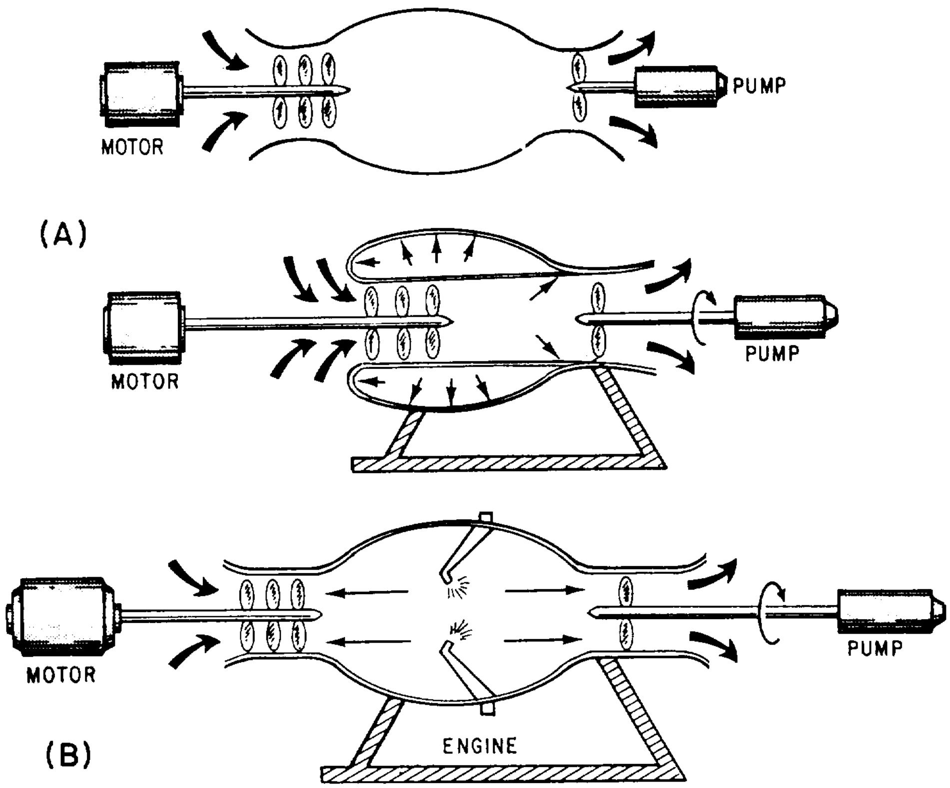


Figure 6-7.—Turbine operating theory.

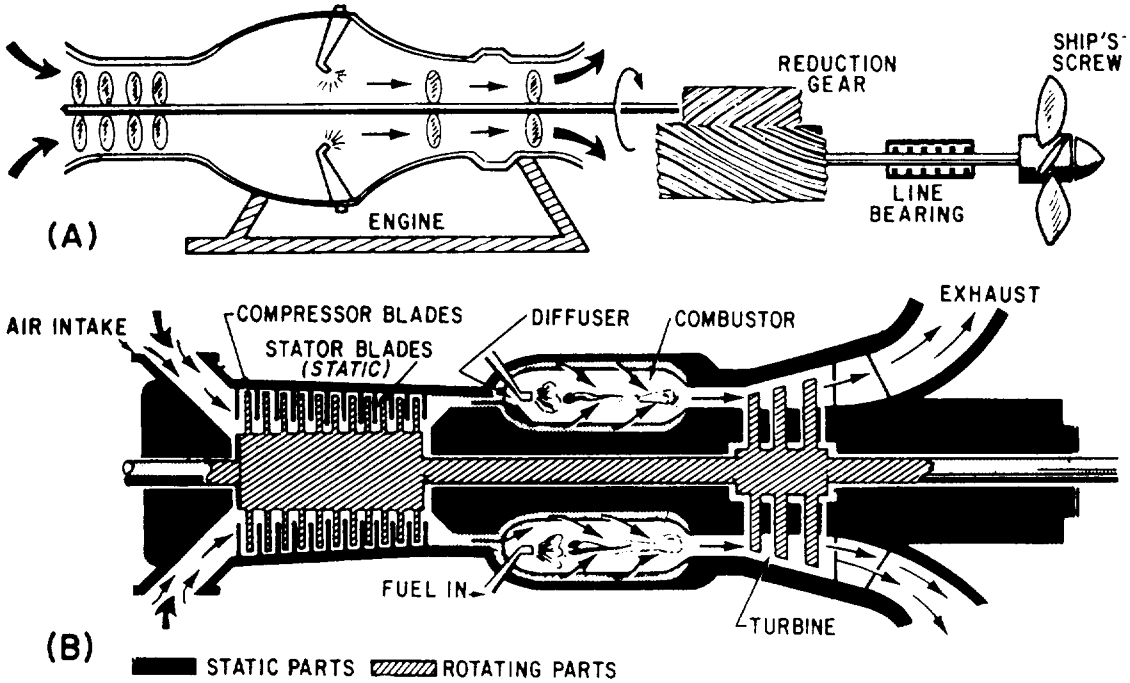


Figure 6-8.—Practical demonstration of turbine operating theory.

By replacing the balloon with a stationary tube or container and filling the tube with air from a fan or series of fans, we can use the discharge air to do work by turning a fan at the rear of the tube (fig. 6-7, view A).

If fuel is added and combustion occurs, we greatly increase both the volume of air and the velocity that propels it over the fan. This increases the horsepower the fan will produce (fig. 6-7, view B). The continuous pressure created by the inlet fan, or compressor, prevents the hot gases from going forward.

Next, if we attach a shaft to the compressor and extend it back to a turbine wheel, we have a simple gas turbine. It can supply power to run its own compressor and still provide enough power to do useful work, such as to drive a generator or propel a ship (fig. 6-8, view A).

By comparing view A with view B in figure 6-8, you can see that a gas turbine is very similar to our balloon turbine.

THEORETICAL CYCLES

A cycle is a process that begins with certain conditions, progresses through a series of events, and returns to the original conditions.

As an introduction to gas turbine operation, consider first the reciprocating engine, which operates on the Otto cycle. (fig, 6-9, view A). The Otto cycle consists of four basic events that occur at different times but in the same place,

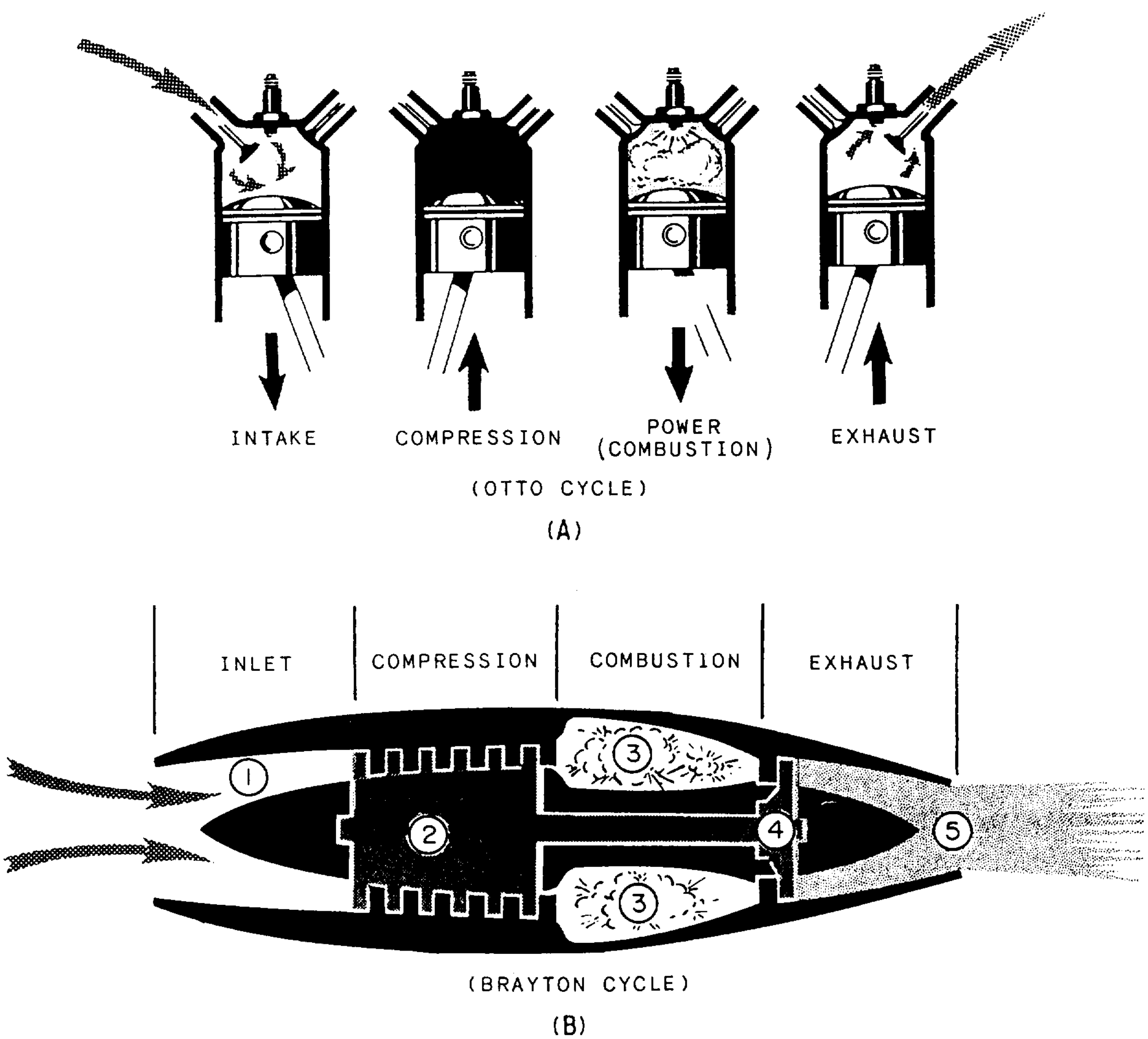


Figure 6-9.—A comparison of reciprocating and gas turbine engine cycles.

inside a cylinder of the engine. The events are (1) intake, where a mixture of air and fuel is drawn into the cylinder; (2) compression, where the mixture is squeezed into a much smaller volume; (3) power (or combustion), where the mixture is burned; and (4) exhaust, where the burned fuel/air mixture is forced from the cylinder. Now consider the gas turbine engine.

The gas turbine engine operates on the Brayton cycle (fig. 6-9, view B). The Brayton cycle consists of the same four events as the Otto cycle. However, all four events occur at the same time, but in different locations within the gas turbine engine.

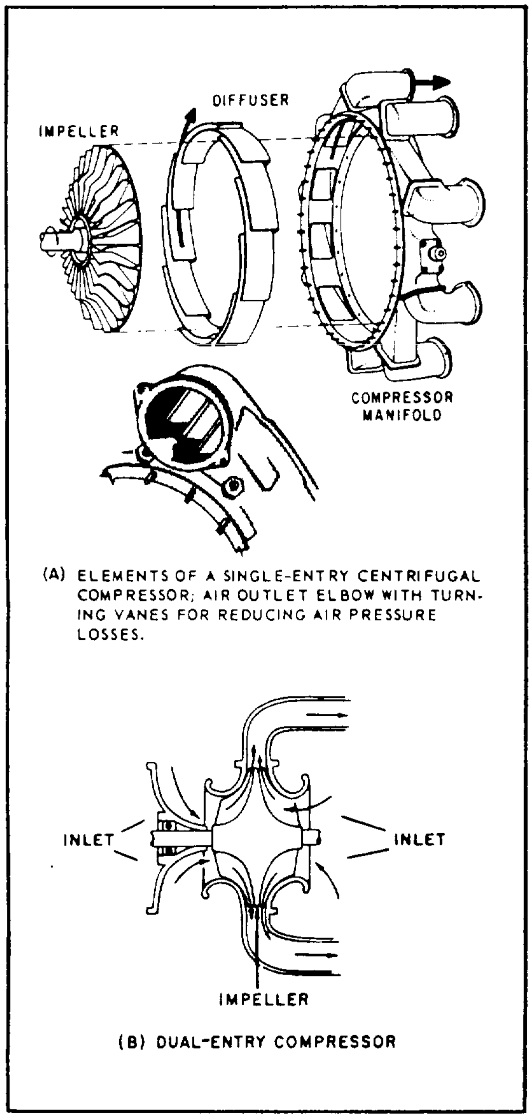


Figure 6-10.—Centrifugal compressor.

During the Brayton cycle, air enters the inlet (1) at atmospheric pressure and constant volume. As the air passes through the compressor (2), it increases in pressure and decreases in volume. In the combustor (3), the air mixes with fuel and burns. During combustion, pressure remains constant, but the increased temperature causes a sharp increase in volume. The gases at constant pressure and increased volume enter the turbine (4) and expand through it. As the gases pass through the turbine rotor, the rotor turns kinetic and thermal energy into mechanical energy to do work. The gases are released through the exhaust (5), with a large drop in volume and at constant pressure. The cycle is now completed.

GAS TURBINE ENGINE TYPES AND CONSTRUCTION

There are two primary means of classifying gas turbine engines: (1) by the type of compressor used and (2) by how the power is used.

CENTRIFUGAL COMPRESSOR

The centrifugal compressor draws in air at the center or eye of the impeller and accelerates it around and outward. It consists of an impeller, a diffuser, and a compressor manifold. The diffuser is bolted to the manifold, and often the entire assembly is referred to as the diffuser. For ease of understanding, we will treat each unit separately.

The impeller may be either single entry or dual entry (fig. 6-10). The principal differences between the single entry and dual entry are the size of the impeller and the ducting arrangement. The single-entry impeller (fig. 6-10, view A) permits ducting directly to the inducer vanes, as opposed to the more complicated ducting needed to reach the rear side of the dual-entry type. Although slightly more efficient in receiving air, single-entry impellers must be of greater diameter to provide sufficient air.

Dual-entry impellers (fig. 6-10, view B) are smaller in diameter and rotate at higher speeds to ensure sufficient airflow. Most gas turbines of modern design use the dual-entry compressor to reduce engine diameter. A plenum (an enclosure in which air is at a pressure greater than that outside the enclosure) chamber is also required for dual-entry compressors, since the air must enter the engine at almost right angles to the engine axis. The air must surround the compressor at positive pressure to give positive flow.

The compressor draws in air at the hub of the impeller and accelerates it radially outward by centrifugal force through the impeller. It leaves the impeller at high speed and low pressure and flows through the diffuser (fig. 6-10, view A). The diffuser converts the high-speed, low-pressure air to low-speed, high-pressure air. The compressor manifold diverts the low-speed, high-pressure air from the diffuser into the combustion chambers. In this design, the manifold has one outlet port for each combustion chamber.

The outlet ports are bolted to an outlet elbow on the manifold. The outlet ports ensure that the same amount of air is delivered to each combustion chamber.

The outlet elbows (known by a variety of names) change the airflow from radial to axial flow. The diffusion process is completed after the turn. Each elbow contains from two to four turning vanes that perform the turning process and reduce air pressure losses by providing a smooth turning surface.

AXIAL-FLOW COMPRESSOR

In the axial-flow engine, the air is compressed while continuing its original direction of flow parallel to the axis of the compressor rotor. The compressor is located at the very front of the engine. The purpose of the axial compressor is to take in ambient air, increase the speed and pressure, and discharge the air through the diffuser into the combustion chamber.

The two main elements of an axial-flow compressor are the rotor and stator (fig. 6-11). The rotor is the rotating element of the compressor. The stator is the fixed element of the compressor. The rotor and stator are enclosed in the compressor case.

The rotor has fixed blades that force the air rearward much like an aircraft propeller. In front of the first rotor stage are the inlet guide vanes (IGVs). These vanes direct the intake air toward the first set of rotor blades. Directly behind each rotor stage is a stator. The stat or directs the air rearward to the next rotor stage (fig. 6-12). Each consecutive pair of rotor and stator blades constitutes a pressure stage.

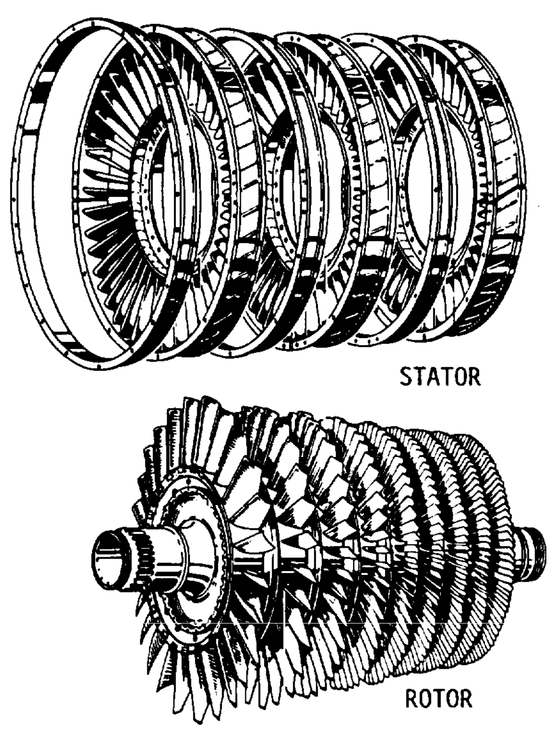


Figure 6-11.—Stator and rotor components of an axial-flow compressor.

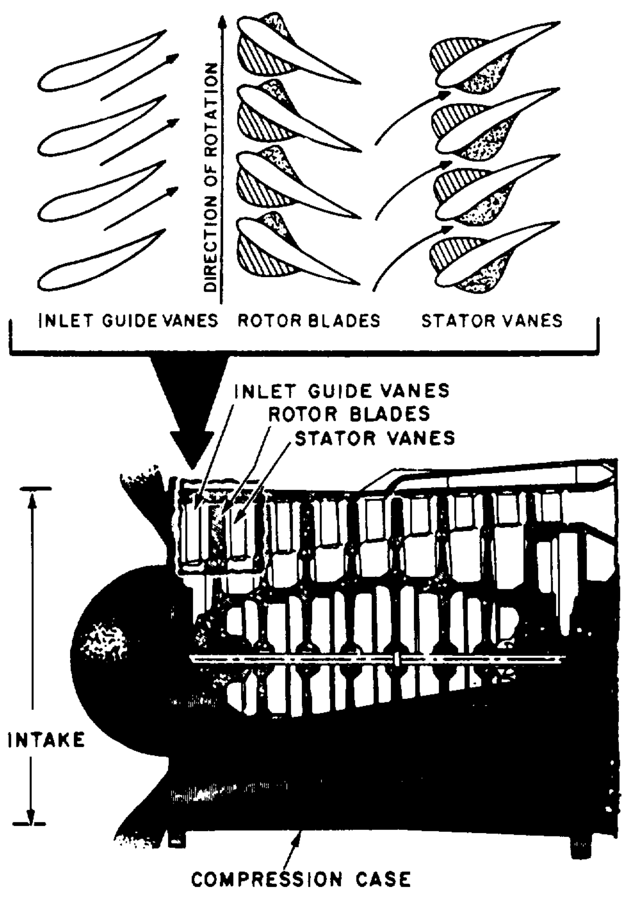


Figure 6-12.—Operating principle of an axial-flow compressor.

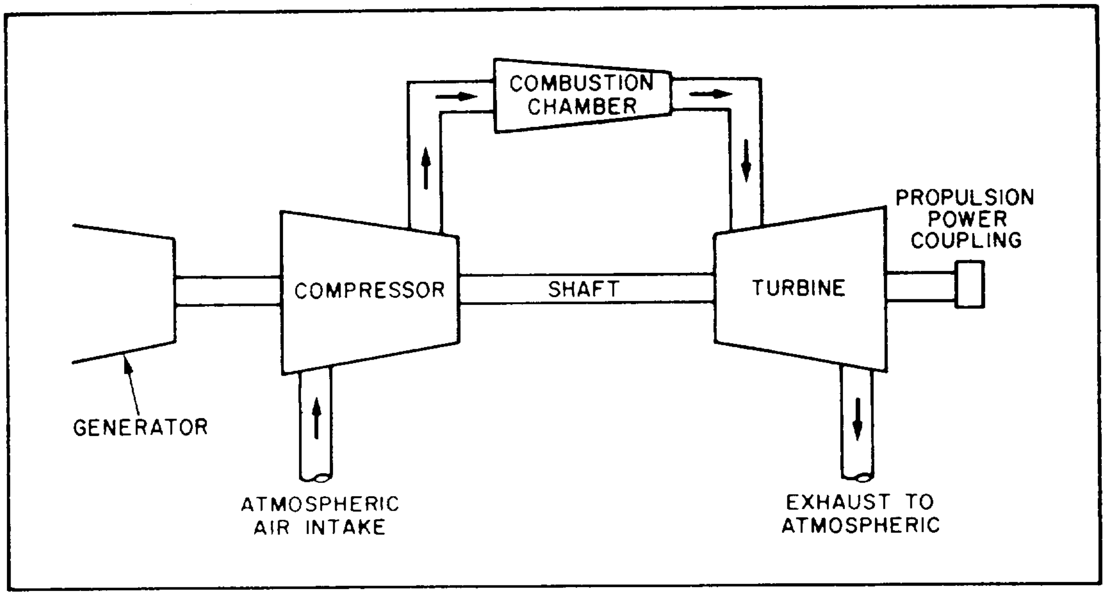


Figure 6-13.—Single-shaft gas turbine.

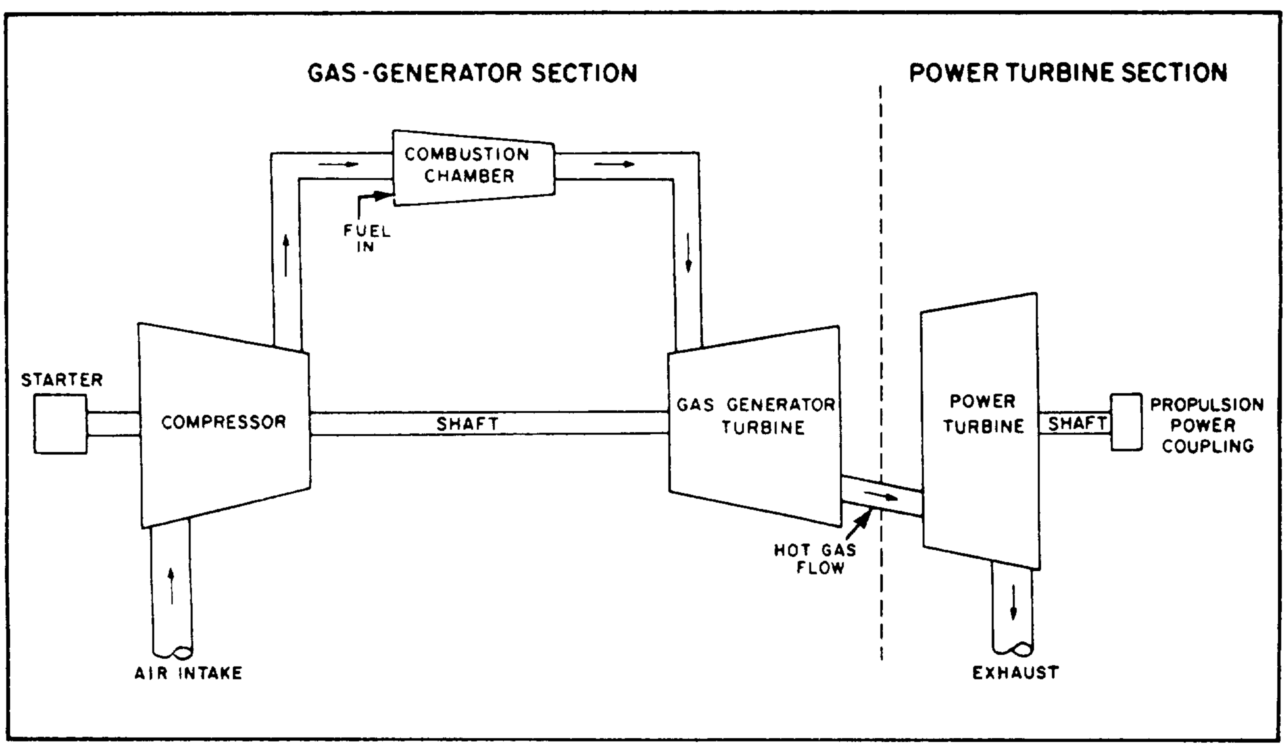


Figure 6-14.—Split-shaft gas turbine.

The action of the rotor increases air compression at each stage and accelerates the air rearward. By virtue of this increased velocity, energy is transferred from the compressor to the air in the form of velocity energy.

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

CLASSIFICATION BY POWER USAGE

There are basically three types of gas turbines in use. They are the single shaft, split shaft, and twin spool. Of these, the single shaft and split shaft are the most common in naval vessels. We mention the twin-spool type because the U.S. Coast Guard Hamilton class cutters use the twin-spool gas turbine.

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.

Figure 6-13 is a block diagram of a single-shaft gas turbine. The power output shaft is connected directly to the same turbine rotor that drives the compressor. In most cases, there is a speed decreaser or reduction gear between the rotor and the power output shaft. However, there is still a mechanical connection throughout the entire engine. The arrangement shown is typical for the gas turbine generator sets aboard DD-963 and CG-47 class ships.

In the split-shaft gas turbine (fig. 6-14), there is no mechanical connection between the gas-generator turbine and the power turbine. The power turbine is the component that does the usable work. The gas-generator turbine provides the power to drive the compressor and accessories. With this type of engine, the output speed can be varied by varying the gas generator speed. Also, under certain conditions, the gas generator can run at a reduced rpm and still provide maximum power turbine rpm. This greatly improves fuel economy and also extends the life of the gas-generator turbine. The arrangement shown in figure 6-15 is typical for propulsion gas turbines aboard the DD-963, FFG-7, CG-47, and PHM-1 class ships.

ENGINE CONSTRUCTION

Recall that a gas turbine engine is composed of four major sections (fig. 6-15): (1) compressor, (2) combustor, (3) turbine, and (4) accessory. We will briefly discuss the construction and function of each of these sections. We will use the LM2500 gas turbine as an example. The LM2500 is a split-shaft gas turbine.

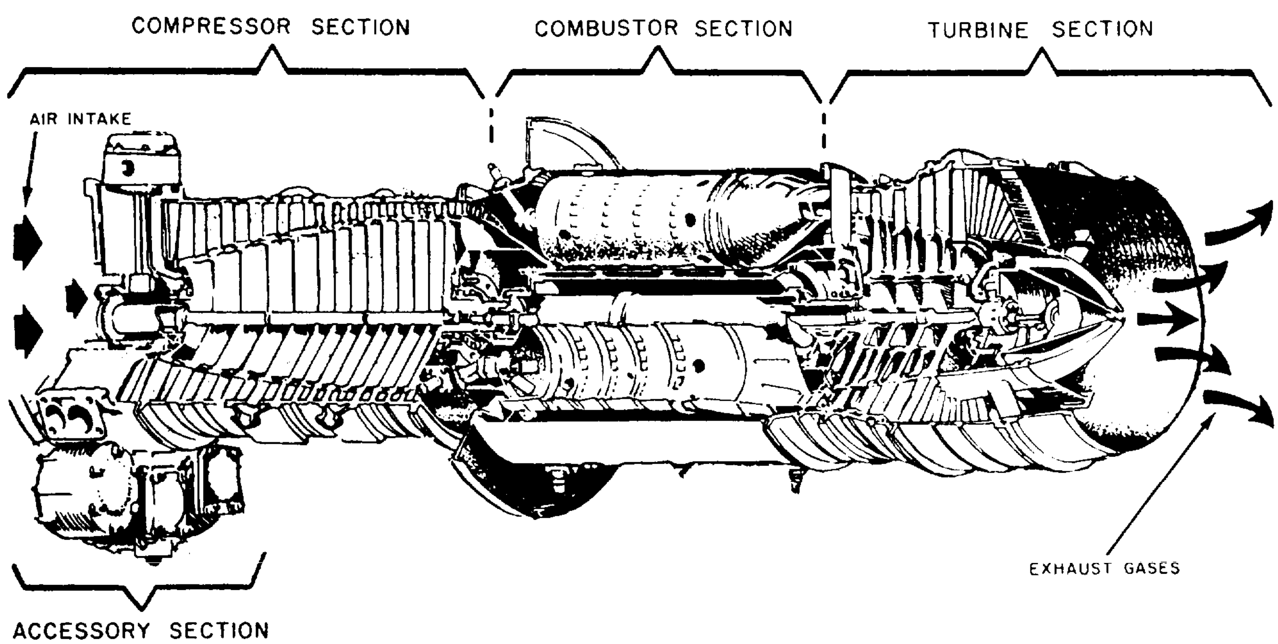
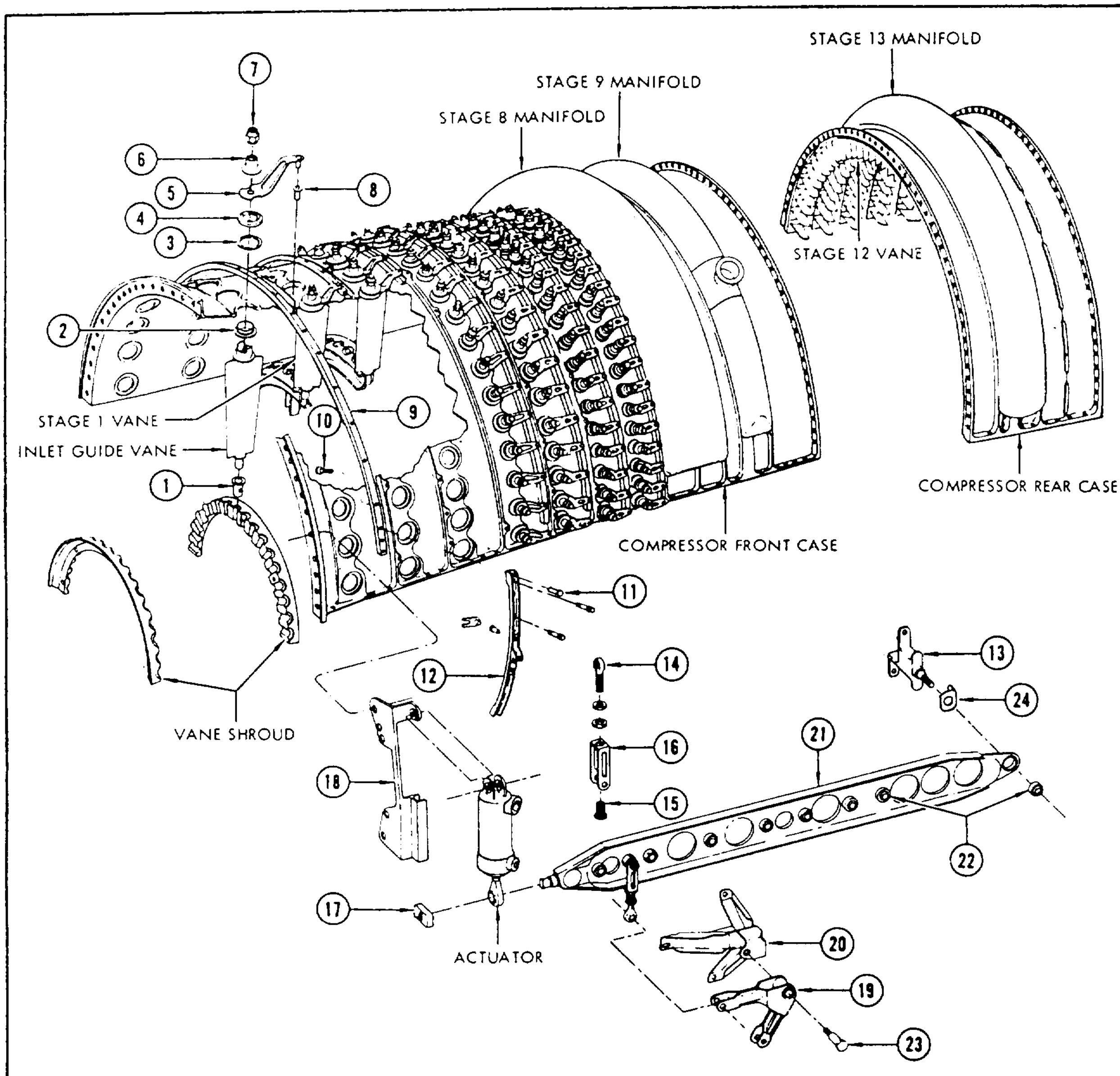


Figure 6-15.—Typical gas turbine.



LEGEND:

1. VANE SHROUD BUSHING (IGV, 1 & 2)
2. FLANGED BUSHING
3. WASHER
4. SPACER (COLOR CODED)
5. LEVER ARM
6. SLEEVE
7. LOCKNUT
8. SLEEVE
9. ACTUATION RING SEGMENT
10. ACTUATION RING SPACER
11. LINE-UP PIN
12. CONNECTING LINK
13. ACTUATION LEVER MOUNT
14. ROD END AND BEARING
15. PUSH ROD
16. ACTUATION LEVER CLEVIS
17. ACTUATION LEVER GUIDE
18. ACTUATOR AND GUIDE BRACKET
19. FEEDBACK BELLCRANK
20. FEEDBACK BELLCRANK BRACKET
21. VANE ACTUATION LEVER
22. SELF ALIGNING BEARINGS
23. SHOULDER BOLT
24. SPACER

Figure 6-16.—Compressor case, LM2500 engine.

Compressor

The rotor and stators are enclosed in the compressor case (fig, 6-16). Modern engines use a case that is horizontally divided into upper and lower halves. The halves are normally bolted together with either dowel pins or fitted bolts. These parts ensure proper alignment to each other and in relation to other engine assemblies that bolt to either end of the compressor case.

On some older engines, the case is a one-piece cylinder open on both ends. The one-piece compressor case is simpler to manufacture; however, any repair or detailed inspection of the compressor rotor is impossible. The engine must be removed and taken to a shop where it can be disassembled for repair or inspection of the rotor or stators. On many split-case engines, either the upper or lower case can be removed for maintenance and inspection with the engine in place.

The compressor case is usually made of aluminum or steel. The material used will depend on the engine manufacturer 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 to bleed air during starting and acceleration or at low-speed operation.

Preceding the stators and the first stage of the compressor rotor is a row of IGVs. The function of the IGVs varies somewhat, depending on the size of the engine and 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 can be moved to direct the airflow at the proper angle to reduce drag on the first-stage rotor.

Small and medium engines have stationary stators. On large engines, the pitch of the vanes on several stators can be changed. For example, in the LM2500 engine (fig. 6-16) the first six stators of the 16-stage rotor are variable,

Rotor blades (fig. 6-17) are usually made of stainless or iron-based, super-strength alloys. Methods of attaching the blades in the rotor disk rims vary in different designs, but they are commonly fitted into disks by either bulb (fig. 6-17, view A) or fir-tree (fig. 6-17, view B) type roots. The blades are then locked with grub screws, peening, lockwires, pins, or keys.

The stator vanes project radially toward the rotor axis and fit closely on either side of each stage of the rotor. The stators have two functions. They receive air from the air inlet duct or from each preceding stage of the rotor and then deliver the air to the next stage or to combustors at a workable velocity and pressure. They also control the direction of air to each rotor stage to obtain the maximum compressor-blade efficiency. The stator vanes are usually made of steel with corrosion- and erosion-resistant qualities. Frequently, the vanes are shrouded by a band of suitable material to simplify the fastening problem. The vanes are welded into the shrouds, and the outer shrouds are secured to the inner wall of the compressor case by retaining screws.

Combustion Chambers

There are three types of combustion chambers: (1) can type, (2) annular type, and (3) can-annular type. The can-type chamber is used primarily on

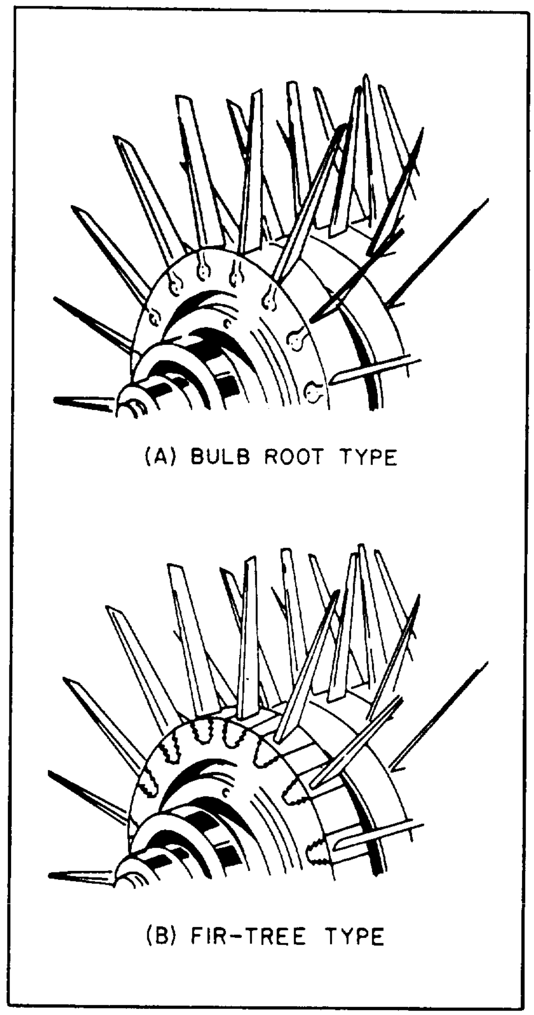


Figure 6-17.—Rotor blades.

engines that have a centrifugal compressor. The annular and can-annular types are used on axial-flow compressors.

The combustion chambers have presented one of the biggest problems in gas turbines. The extreme stresses and temperatures encountered are not experienced in other types of internal-combustion engines. The liners are subjected to temperatures as high as 4000°F in a matter of seconds.

The combustion chamber must operate over a wide range of conditions. It must withstand high rates of burning, have a minimum pressure drop, be light in weight, and have minimum bulk.

The inner and outer liners or shrouds are perforated with many holes and slots throughout their length. Air is admitted through these holes to protect the liner and to cool the gases at the chamber outlet.

The through-flow passages are used in practically all modern engine combustion chambers. In the through-flow path, the gases pass through the combustion section without a change in direction.

The annular combustor liner (fig. 6-18) is usually found on axial-flow engines. It is probably one of the most popular combustion systems in use. The construction consists of a housing and 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 and to impart a swirling motion for better atomization of fuel. There are also 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, and the inner liner prevents flame from contacting the turbine shaft housing.

Large holes and slots are located along the liners to (1) admit some cooling air into the

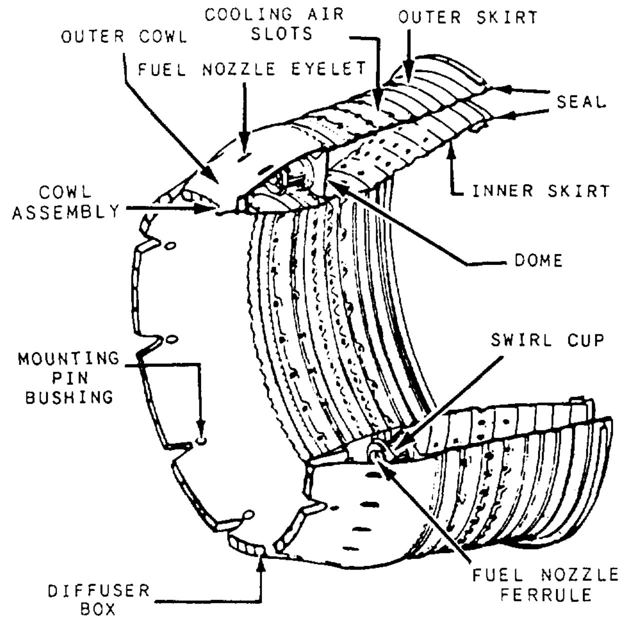


Figure 6-18.—Combustor liner.

combustion space towards the rear of the space to help cool the hot gases to a safe level, (2) center the flame, and (3) admit air for combustion. The gases are cooled enough to prevent warpage of the liners.

The space between the liners and the case and shaft housing forms the path for secondary air. The secondary air provides film cooling of the liners and the combustor case and shaft housing. At the end of the combustion space and just before the first-stage turbine nozzle, the secondary air is mixed with the combustion gases to cool them enough to prevent warping and melting of the turbine section.

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, however. On some engines, the liners are one-piece and cannot be removed without engine disassembly.

Turbines

In theory, design, and operating characteristics, the turbines used in gas turbine engines are quite similar to the turbines used in a steam plant. The gas turbine 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 terms *gas-generator turbine* and *power turbine* are used to differentiate between the turbines. The gas-generator turbine powers the gas generator and accessories. The power turbine powers the ship's propeller through the reduction gear and shafting.

The turbine that drives the gas generator is located directly behind the combustion chamber outlet. This turbine consists of two basic elements: the stator or nozzle and the rotor. Part of a stator element is shown in figure 6-19. A rotor element is shown in figure 6-20.

The rotor element of the turbine consists of a shaft and bladed wheel(s). The wheel(s) are attached to the main power transmitting shaft of the gas turbine engine. The jets of combustion gas leaving the vanes of the stator element act upon the turbine blades and cause the turbine wheel to rotate in a speed range of 3,600 to 42,000 rpm, depending upon the type of engine. The high rotational speed imposes severe centrifugal loads on the turbine wheel. At the same time, the high temperature (1050° to 2300 °F) results in a lowering of the strength of the material. Consequently, the engine speed and temperature must be controlled to keep turbine operation within safe limits. The operating life of the turbine blading usually determines the life of the gas turbine engine.

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. The high-velocity exhaust gases leaving the turbine nozzle vanes act on the blades of the turbine wheel. This causes the assembly to rotate at a high rate of speed. This turbine rotation, in turn, causes the compressor to rotate.

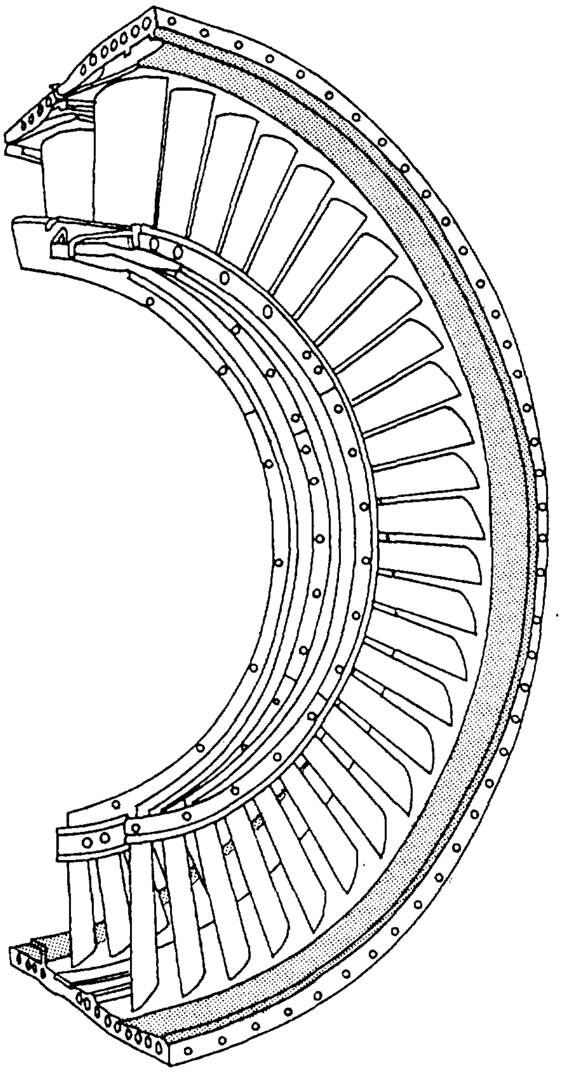


Figure 6-19.—Stator element of turbine assembly.

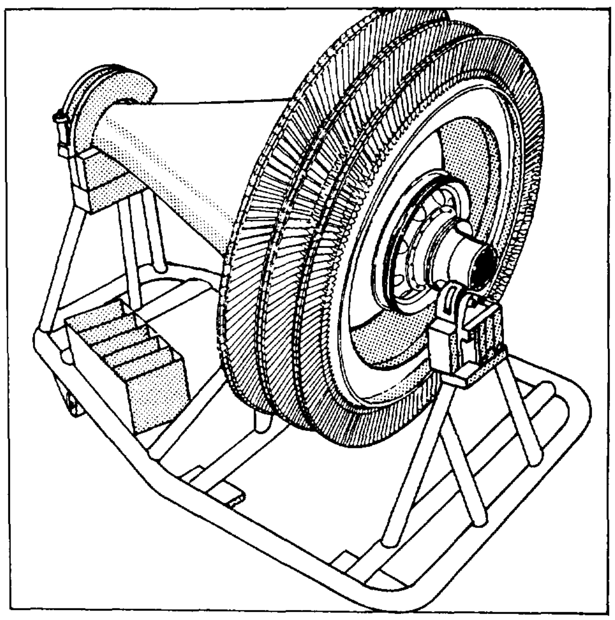


Figure 6-20.—Rotor element of turbine assembly.

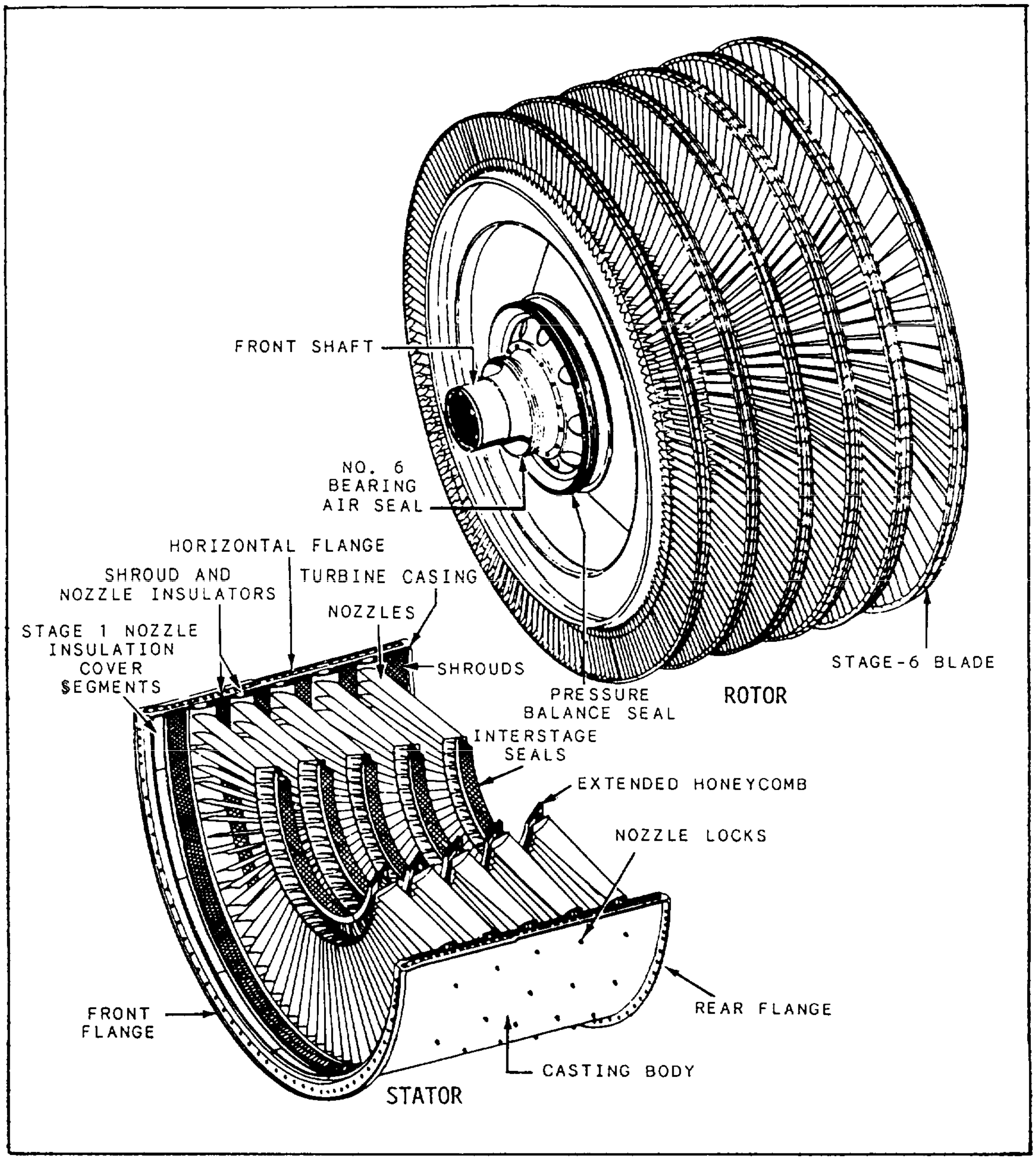


Figure 6-21.—Power turbine.

The power turbine (fig. 6-21) is a multistage unit located behind the gas-generator turbine. There is no mechanical connection between the two turbines. The power turbine is connected to a reduction gear through a clutch mechanism. A controllable reversible-pitch (CRP) propeller is used to change direction of the vessel.

Accessories

Because the turbine and the compressor are on the same rotating shaft, a popular misconception is that the gas turbine engine has only one moving part. This is not so. A gas turbine engine requires a starting device, some kind of control mechanism, and power takeoffs for lube oil and fuel pumps. The accessory drive section (fig. 6-15) of the gas turbine engine takes care of these various accessory functions. The primary purpose 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 is driven by the engine rotor through an accessory drive shaft gear coupling. The reduction gearing within the case provides suitable drive speeds for each engine accessory or component. The accessory drives are supported by ball bearings assembled in the mounting bores of the accessory case.

Accessories usually provided in the accessory drive section include the fuel control (with its governing device), the high-pressure 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, and a tachometer. Most of these accessories are essential for the operation and control of any gas turbine engine. However, the particular combination and arrangement and location of engine-driven accessories depend on the use for which the gas turbine engine is designed.

The three common locations for the accessory section are on the side of the air inlet housing, under the compressor front frame, or under the compressor rear frame.

GAS TURBINE OPERATION

Naval engineers are constantly striving to design a more reliable engineering plant that provides quick response and requires fewer personnel to operate it. With advances in engineering technology, the use of solid-state devices and the addition of logic and computer systems, some of these design goals were achieved in the automated central operating system (ACOS).

As shown in figure 6-22, ACOS centralizes the engineering plant with all controls and indicators located at the central control station (CCS). The use of logic and computer systems reduces

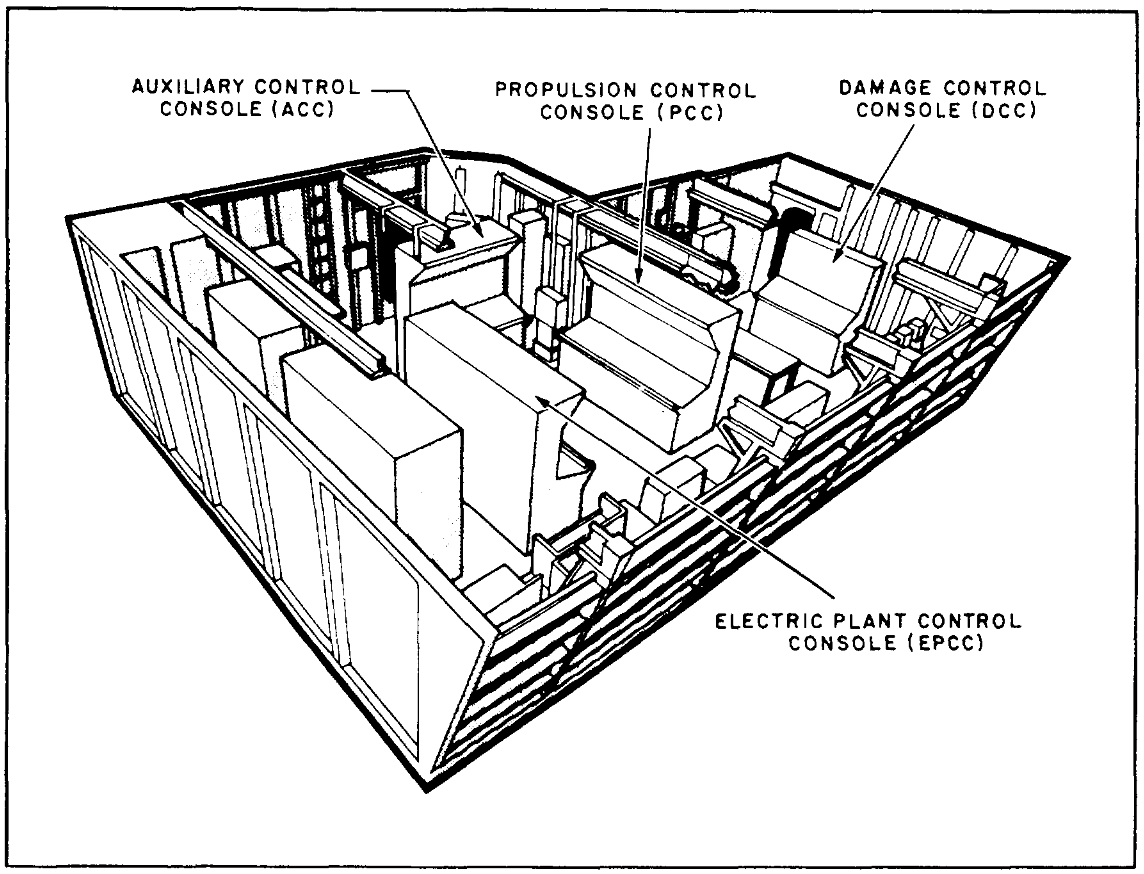


Figure 6-22.—Typical central control station (CCS) for FFG-7 class ships.

the chance of operator error in performing engineering functions. Automatic bell and data loggers reduce the task of hourly readings previously taken by watch standers. Probably the single most important function is the automatic and continuous monitoring of the engineering plant conditions (parameters) and the subsequent automatic alarm if a condition exceeds a set limit.

This section will describe the ACOS that deals with the gas turbine reduction gear and the CRP propeller propulsion system that is currently being installed in new construction ships.

The ACOS provides the means for operating the ship's propulsion plant safely and efficiently. It furnishes the operators with the controls and displays required to start and stop the gas turbine engines. It also furnishes the operators with the controls necessary to change the ship's speed and direction by changing the gas turbine speed and the pitch of the propeller. These operations are performed at panels or consoles containing the necessary controls and indications for safe operation.

GENERAL DESCRIPTION

The propulsion plant may be operated from the following three stations:

1. The local control console
2. The central control console
3. The ship control console

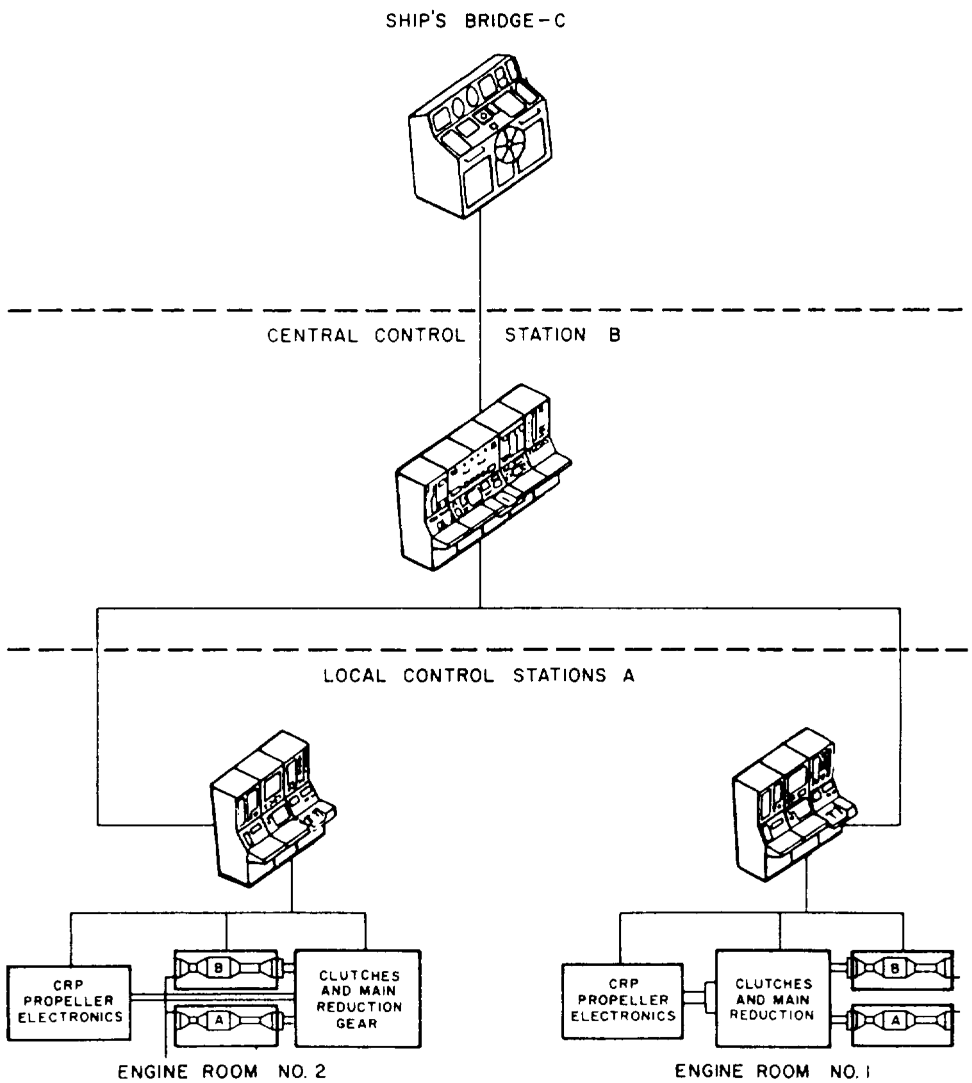


Figure 6-23.—Propulsion control system.

Figure 6-23 is a simplified diagram of the entire propulsion control system.

LOCAL CONTROL CONSOLE

The local control console is a secondary operating station. It is located in the engine room near the propulsion equipment. It controls and contains the necessary controls and indicators to permit direct local (manual) control of the propulsion equipment. The direct local mode of control, although still electronic, permits operation of the equipment in a manual mode. The local control console provides facilities for local control of plant starting, normal operation, monitoring, and stopping. Figure 6-24 shows propulsion control stations including the local operating console. The two main controls on this console are the remote throttle control and the pitch control. The remote throttle provides control of the power produced by the gas turbine engine. This control is graduated in percent of gas

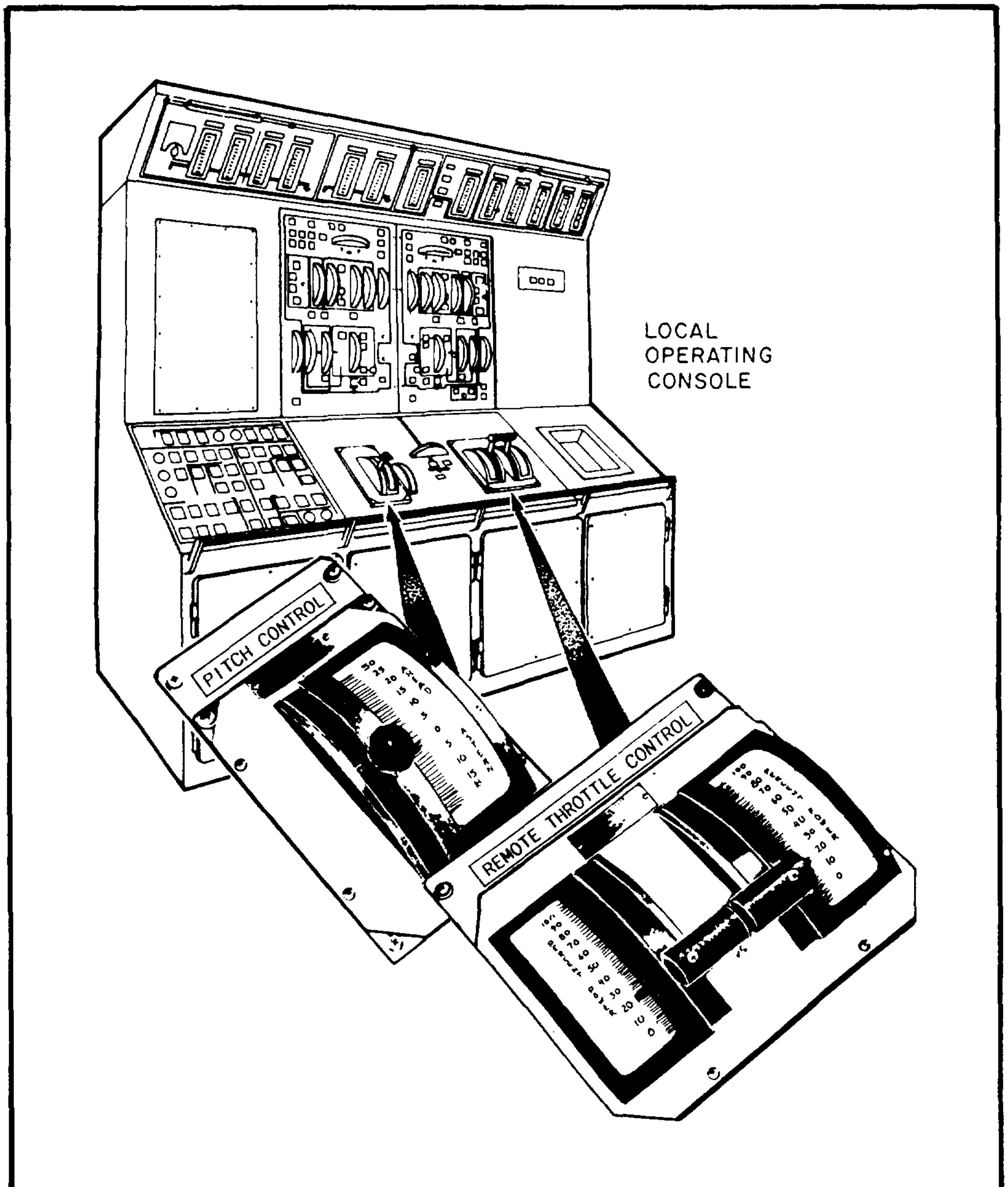


Figure 6-24.—Propulsion control console (local).

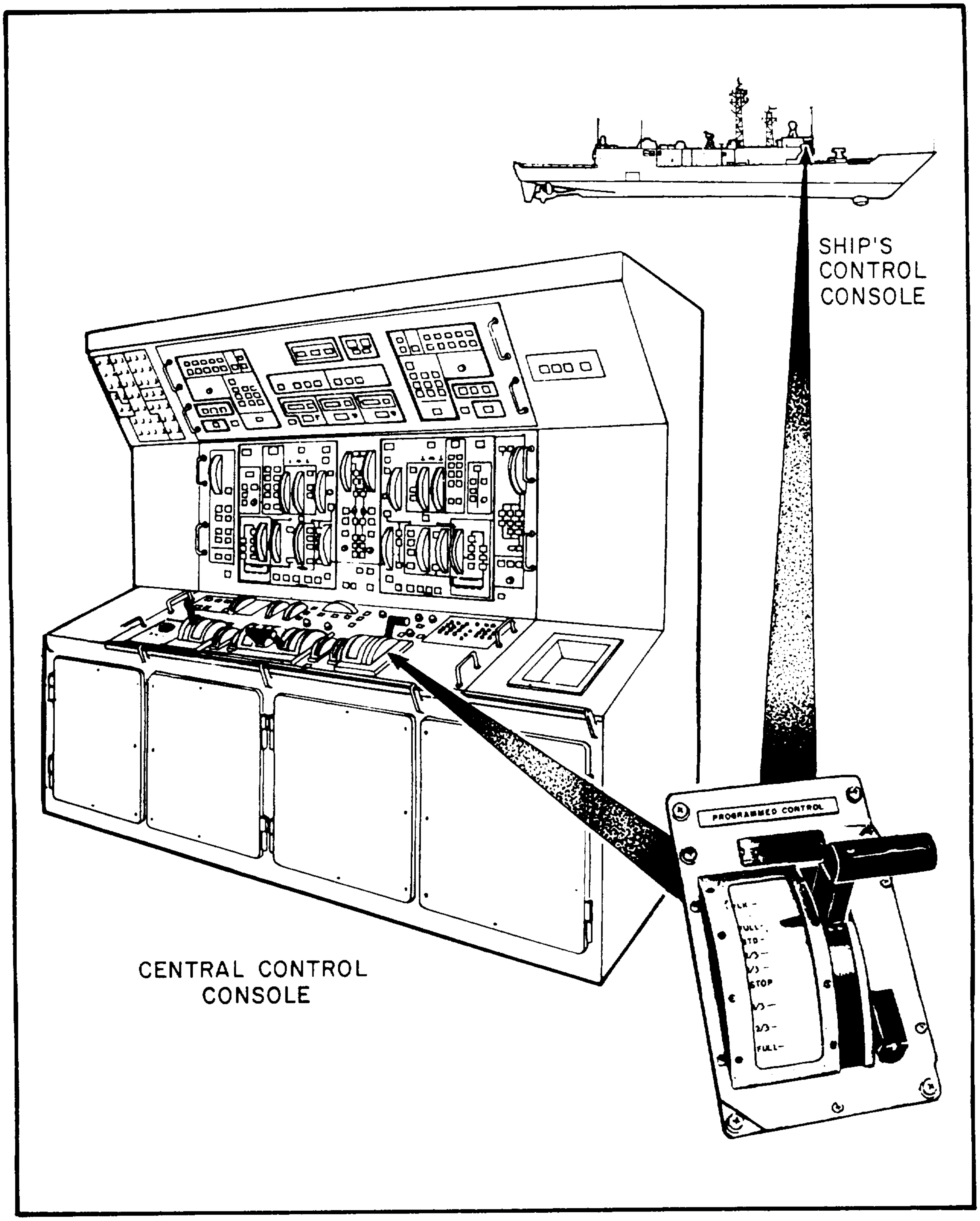


Figure 6-25.—Propulsion control console (central).

turbine engine speed and has control levers similar to an airplane throttle. The pitch lever provides control of the propeller pitch angle. By varying the pitch angle, the ship's speed may be changed. The pitch lever is graduated in feet of pitch either ahead or astern.

CENTRAL CONTROL CONSOLE

The central control console is the primary operating station for the propulsion plant and is located in the CCS. The CCS is the main engineering watch station. This console provides the operator with the necessary controls and displays for starting and stopping the gas turbine engines. Controls on the central control console allow the operator to vary the ship's ahead or astern speed within established design limitations by changing the pitch of the propeller and the speed of the propeller shaft.

The central control console (fig. 6-25) provides two distinctly different methods of controlling the ship's progress through the water. The first method requires the operator to individually adjust three levers on the console. One lever changes the direction and amount of pitch applied at the ship's variable-pitch propeller. Each of the remaining two levers controls the speed of one of the gas turbine engines. This is a duplicate set of controls that are the same as the controls on the local control console.

The second and primary method of operating the ship's propulsion plant involves the use of a single control lever and a special-purpose digital computer contained in the control system. This technique for controlling the engines and the propeller pitch with one control and the digital computer is referred to as single-lever programmed control.

Single-lever programmed control of the ship's propulsion plant can also be maintained from the ship control console (SCC) located on the bridge. However, the lever on the bridge's SCC panel can be operated only after the operator in the CCS relinquishes control.

SHIP CONTROL CONSOLE

This station is located on the ship's bridge. This console has a throttle control, a propulsion plant alarm, and shaft speed and propeller pitch indicators.

CONSOLE OPERATING OVERVIEW

Using modern electronics, computers, and precisely placed sensing equipment, the operator at the central control console can "see" and manipulate the entire propulsion plant. The operator is assisted by sensor-scanning equipment that can check out the plant more thoroughly in a fraction of a second than an engine-room messenger could in 30 minutes. The scanning circuits are wired with information about the operating parameters of all the critical points monitored and will sound off immediately if these are exceeded. The operator's control is extended not only by remote operation of all engine controls but also by wired-in expertise from electronic components that "know" all the right steps and procedures for all normal plant operations as well as most emergency procedures.

There are two directions of information flow in a gas turbine propulsion system. The first is from the sensing and measuring devices on the plant equipment. The second is from the operator and the console to the engine control devices. The first or input flow begins as an electrical signal from a sensor. These signals are "conditioned" so that they can be handled by the digital computer. Some of the signals are displayed on indicators at the operating stations. Most of these indicators are for vital equipment functions.

The control of high-performance engines and other machinery is a complex operation. Automatic central-type operating systems permit a single operator to perform this operation by extending individual ability to sense and to control. As these systems prove their effectiveness and reliability, their use will increase.

ADVANTAGES AND DISADVANTAGES OF THE GAS TURBINE PROPULSION SYSTEM

The gas turbine, 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, which has the next best power-to-weight characteristics, the gas turbine operates on cheaper and safer fuel. The smoothness of the gas turbine, compared with reciprocating engines, has made it even more desirable in aircraft because less vibration reduces strains on the airframe. In a warship, the lack of low-frequency vibration in gas turbines 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 gas turbines economical in terms of horsepower-per-dollar on initial installation, and their increasing reliability makes them a cost-effective alternative to steam turbine or diesel engine installation. In terms of fuel economy, modern marine gas turbines can compete with diesel engines and may be superior to boiler/steam turbine plants when these are operating on distillate fuel.

However, there are some disadvantages to gas turbines. Since they are high-performance engines, many parts are under high stress. Improper maintenance and lack of attention to details of procedure will impair engine performance and may ultimately lead to engine failure. A pencil mark on a compressor turbine blade or a fingerprint in the wrong place can cause failure of the part. The turbine takes in large quantities of air that may contain substances or objects that can harm the engine. Most gas turbine propulsion control systems are complex because several factors have to be controlled, and numerous operating conditions and parameters must be monitored. The control systems must react quickly to turbine operating conditions to avoid casualties to the equipment. Gas turbines produce loud, high-pitched noises that can damage the human ear. In shipboard installations, special soundproofing is necessary. This adds to the complexity of the installation and makes access for maintenance more difficult.

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

The second tactical disadvantage is the requirement for depot maintenance and repair of major casualties. The turbines cannot be repaired in place on the ship and must be removed and replaced by rebuilt engines if anything goes wrong. Here too, design has reduced the problem; an engine change can be accomplished wherever crane service or a Navy tender is available, and the replacement engine can be obtained.

SUMMARY

This chapter has given you some basic information on gas turbine engines and gas turbine control systems. For a more in-depth look at gas turbines, refer to *Gas Turbine Systems Technician (Mechanical) 3 & 2,* NAVEDTRA 10548-2.