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T-120

EDQP STUDY PAPER

GAS TURBINE PROPULSION AND POWER GENERATION

REV. B
2/85

CATEGORY:

TECHNICAL -T

SHIPS AND SHIP SYSTEMS -1

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ENGINEERING DUTY OFFICER QUALIFICATION PROGRAM (EDQP)

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Lesson Topic: Gas Turbine Propulsion and Power Generation, T-120 Rev.B.

Time : 2 Hours.

Instructional Materials: See References below.

Terminal Objective : Complete the Engineering Duty Basic Qualification Program.

Enabling Objective : Obtain an understanding of Marine Gas Turbine Propulsion and Power Generation Systems.

Study Method : See attached study paper.

Practical Factors : See paragraph 7, page 27.

Questions : See paragraph 8, page 28.

Supplementary References : See Bibliography attached.

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GAS TURBINE PROPULSION AND POWER GENERATION

1. INTRODUCTION

The gas turbine engine is a significant advancement in the state-of-the-art marine propulsion system. Gas turbines are used as the propulsion plant on guided missile cruisers, guided missile destroyers, destroyers, guided missile frigates, patrol boats (hydrofoil and conventional), and landing craft. As of 1985, over 125 surface combatants were powered by gas turbines or a combination of gas turbines and/or diesels. The majority of gas turbines being used in the Navy are General Electric LM 2500 engines; however, others are also used. Although present marine gas turbines are modified aircraft engines, increasing military and commercial use in the marine environment may cause specific designs for ships to become available.

There are several advantages to using gas turbines in ships. They have a very high power to weight ratio: approximately 2 hp/lb as compared to 0.3 hp/lb for the same power from a diesel. They operate with very little vibration, which makes them difficult for submarines to detect with sonar. Probably the biggest advantages for naval applications are that gas turbines can be brought from a cold start to full power in less than a minute and they can change loads very rapidly due to the small inertia of the moving parts.

There are some disadvantages and other factors to be considered in the use of gas turbines. Maintenance can be difficult: "A pencil mark on a compressor turbine blade or a fingerprint in the wrong place can cause failure of the part." However, because of the modularity and lightness of the engine, it can often be easily replaced completely at any facility having a crane. Since the engine requires a large supply of air intake, the wet and salty environment in which the engine must operate dictates effective control of the moisture and corrosives of the air. Complete internal water washdowns are frequently used to fight the effects of the sea air. Control systems are complex because of the quick response time needed to control a gas turbine and the large number of operating parameters and conditions that must be observed. Because the gas turbine produces a large amount of exhaust heat, it is an easy target for heat-seeking missiles.

The objective of this paper is to provide the basic principles of operation of the marine gas turbine, an excellent engine that can be used for both propulsion and power generation on many types of vessels.

2. PRINCIPLES OF THE MARINE GAS TURBINE ENGINE

The marine gas turbine engine provides continuous power, as opposed to the gasoline engine, which provides power pulses. All gas turbines operate on the same principles, although there are variations in the design. The basic turbine engine consists of a compressor section, a combustion section, and a turbine section. When combined, compressor and combustion sections are frequently referred to as the "gas generator." The turbine section is connected to whatever system the engine is driving. Air enters the compressor section, where the pressure is increased. The temperature of the compressed air is increased by burning fuel in the combustion chamber. The high-temperature, high-pressure air is then expanded through a series of turbine blades. The expanding air turns the turbine blades, producing useful work, and is expelled through the exhaust. Part of the power provided by the turbine section is used to operate the compressor and any engine auxiliaries, such as pumps, fans, and starters. The remainder of the power is then available to drive the propulsion system, electrical generator, or both.

Thermodynamically, the gas turbine follows the Brayton cycle. In an ideal Brayton cycle, the working fluid (air) enters the engine at atmospheric pressure; undergoes isentropic, adiabatic compression; and is subjected to a constant pressure combustion/heating process. The air is then isentropically (constant entropy) and adiabatically (without gain or loss of heat) expanded through the turbine blades and exhaust nozzle until it reaches atmospheric pressure again. This differs from a gasoline engine (Otto cycle) because, in the ideal Otto cycle, the combustion and exhaust steps take place in a constant volume instead of at a constant pressure. Figures 2-1 and 2-2 illustrate a comparison of the sequence of events of the ideal Brayton cycle and the ideal Otto cycle. It is important to note that the cycles represented in Figures 2-1 and 2-2 are "ideal" cycles and that the performance of actual engines is much less efficient. The efficiency of a gas turbine depends upon the compressor pressure ratio, turbine inlet temperature, and any internal losses. These items will be discussed further in later sections.

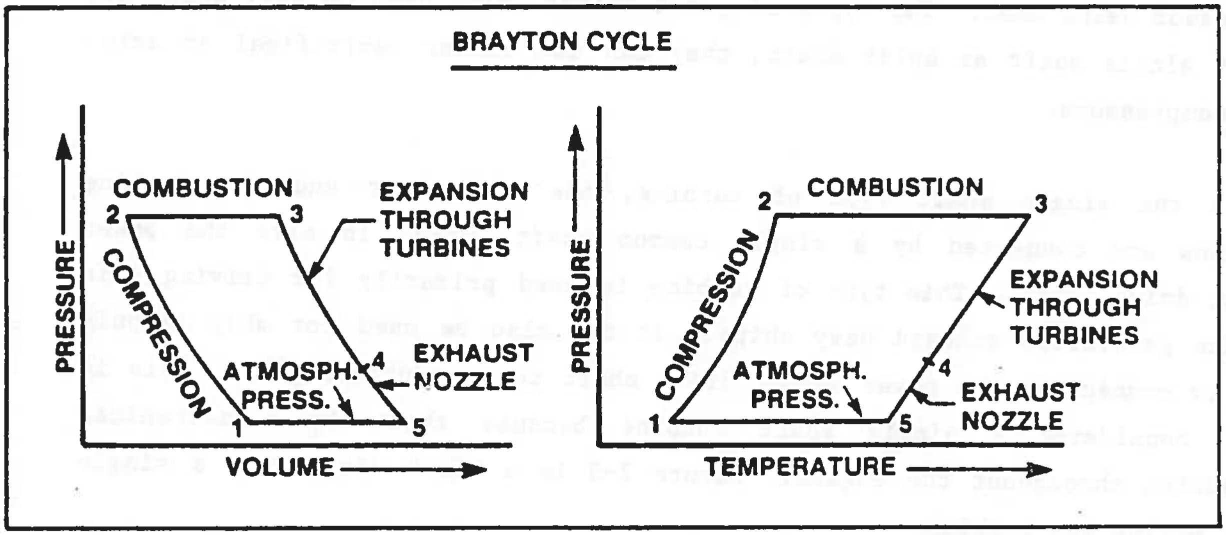

Figure 2-1. Cycle Events of the Gas Turbine Engine

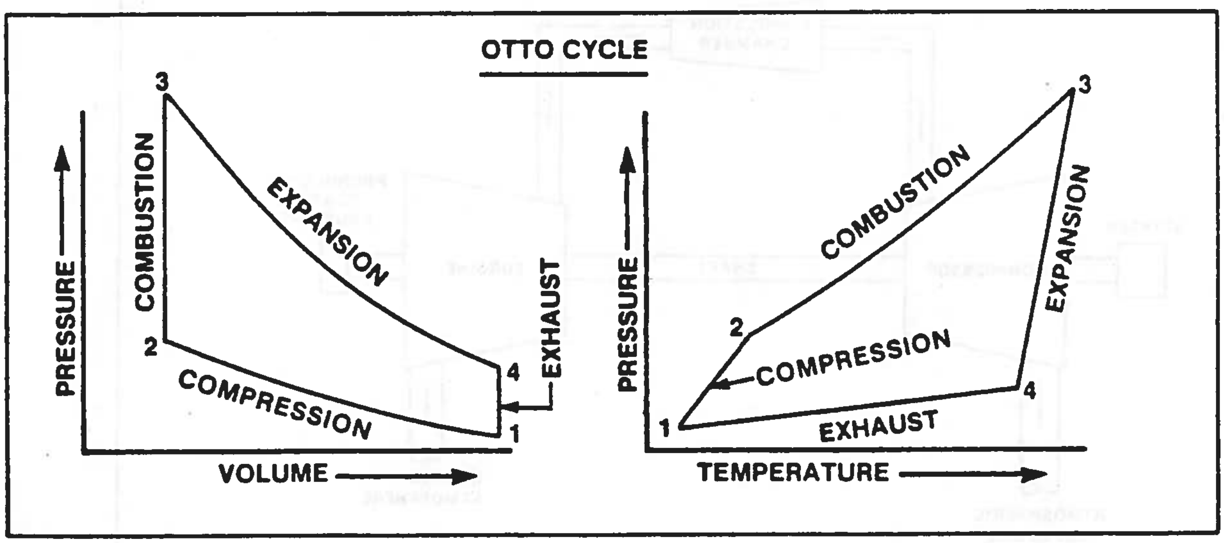

Figure 2-2. Cycle Events of Four-Cycle Piston Engine

The several different types of marine gas turbines are usually identified by the mechanical arrangement of the component sections and the type of compressor being used. The types of gas turbines being used on Navy ships are either single shaft or split shaft; they can use either centrifigal or axial flow compressors.

In the single shaft type of turbine, the compressor and the turbine sections are connected by a single common shaft, which is also the power output drive shaft. This type of turbine is used primarily for driving ship service generators onboard Navy ships. It can also be used for ship propulsion by connecting the power output drive shaft to a reduction gear. This is still considered a single shaft turbine because there is a mechanical connection throughout the engine. Figure 2-3 is a block diagram of a single shaft marine gas turbine.

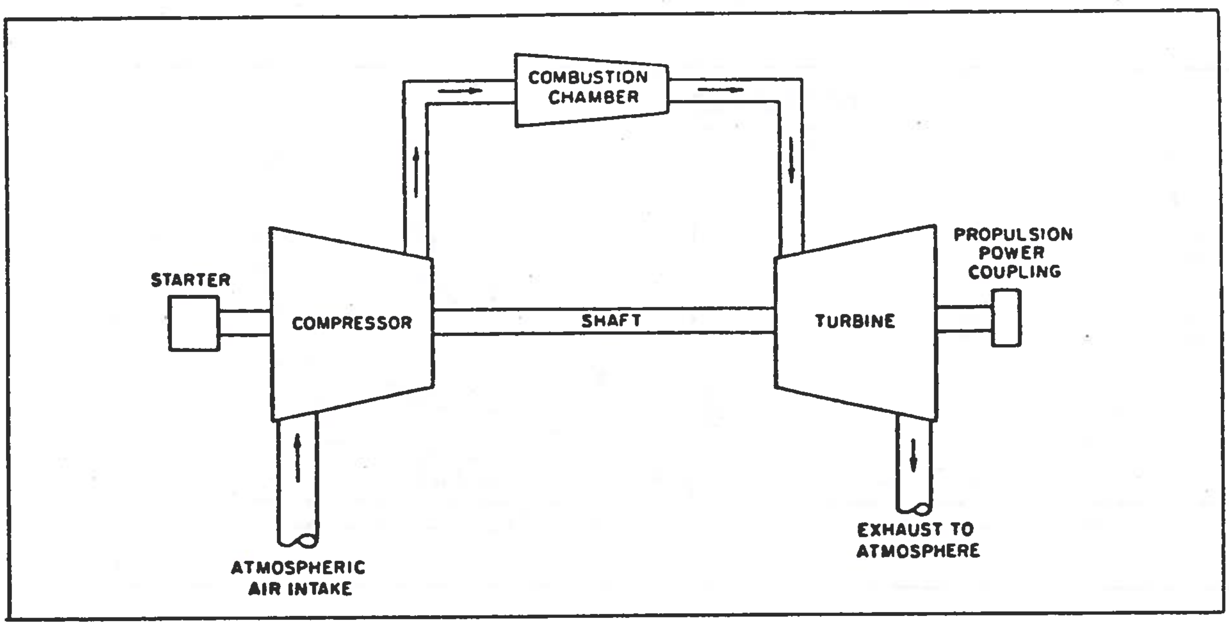

Figure 2-3 Single Shaft Engine

A split shaft gas turbine has two turbines, one in the gas generator section and one serving as a power generating turbine. The gas generator section of the engine is not mechanically connected by a rotating shaft to the power generating turbine section. Instead, the working fluid (air) leaving the gas generator turbine passes through the power turbine. The only shaft in the gas generator section connects the compressor and the gas generator turbine. Thus, the gas generator turbine is supplying only the driving power for the compressor; a separate shaft connects the power turbine to the drive system. This type of marine turbine allows for easier control of shaft rotation direction and speed; it also requires less starting torque, since the starter does not have to turn the output shaft or drive system. Split shaft marine gas turbines are the type commonly used in the propulsion systems onboard the DD 963 and FFG 7 class ships. Figure 2-4 is a block diagram of a split shaft engine.

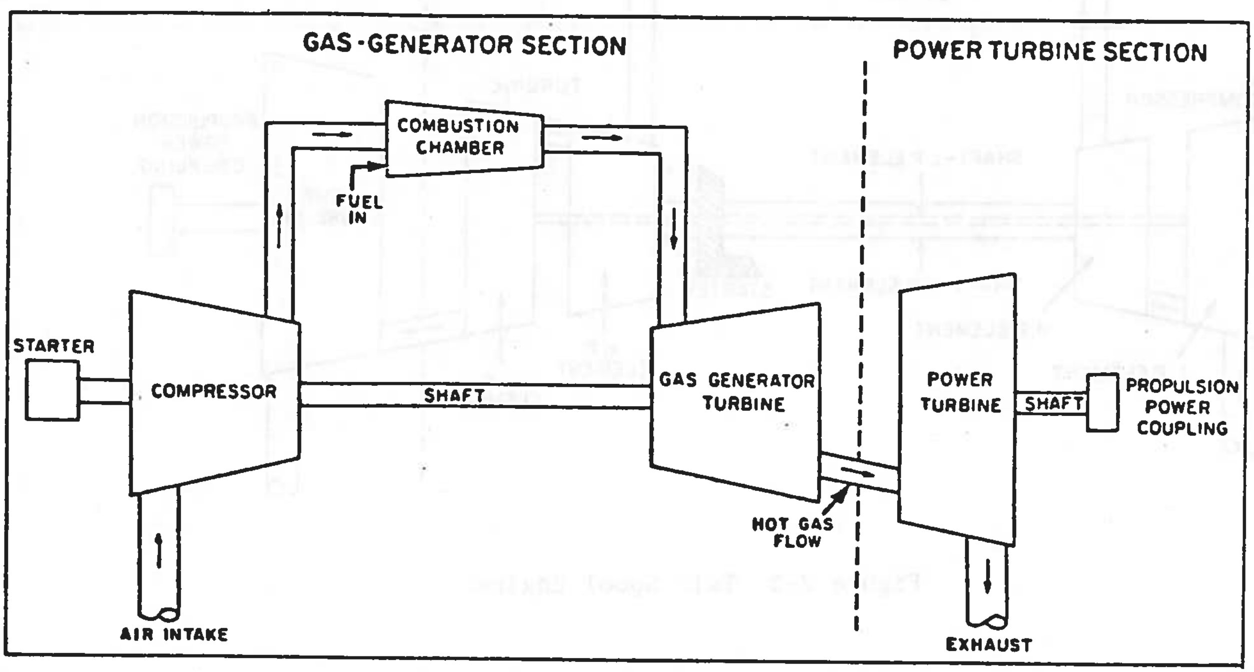

Figure 2-4. Split Shaft Engine

The Hamilton class high endurance cutters of the Coast Guard use another type of marine gas turbine in their propulsion system known as a twin spool or multistage gas turbine. Twin spool gas turbines are very similar to a split shaft gas turbine, the only difference between the two types being in the gas generator section. In the twin spool gas turbine, the gas generator section contains a high pressure compressor, a low pressure compressor, a high pressure turbine, and a low pressure turbine. The high pressure turbine is connected to the high pressure compressor by a hollow shaft, and the low pressure compressor is connected to the low pressure turbine by a shaft inside the high pressure system shaft. The two shafts turn independently. Figure 2-5 is a block diagram of a twin spool engine.

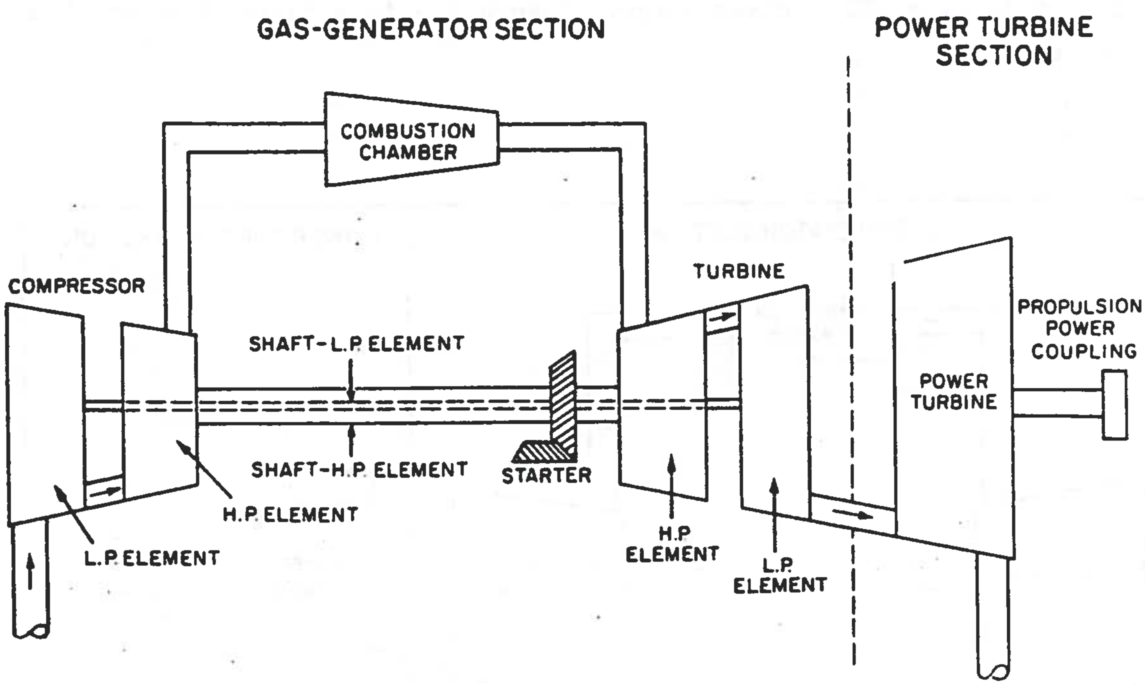

Figure 2-5 Twin Spool Engine

3. COMPONENTS AND OPERATION OF THE MARINE GAS TURBINE ENGINE

3.1 Compressors.

The compressor is used to raise the pressure and reduce the volume of air flowing through the engine. As mentioned earlier, there are two types of compressors used in marine gas turbine engines, centrifugal flow and axial flow. Figure 3-1 illustrates a centrifugal flow compressor and Figure 3-2 illustrates an axial flow compressor. Centrifugal flow compressors, with either single or double-entry impeller, were widely used in the early engine designs. Some engines have been designed with multistage centrifugal compressors, consisting of two or more single-entry compressors mounted in tandem on a common shaft.

Centrifugal compressor airflow starts out as an axial flow near the compressor hub. The high rotational velocity of the compressor rotor accelerates the air radially, imparting high velocity or kinetic energy to the air. The air flows into a diffuser section where the air velocity is reduced, converting the kinetic energy into pressure energy. From here the airflow may go to the combustor or to the inlet of another compressor stage.

While centrifugal flow compressors were once generally limited to a pressure ratio of approximately 5 to 1, there has been considerable development in recent years. Recent developmental centrifugal flow compressors have demonstrated a pressure ratio of 10:1. The centrifugal compressor is of greatest interest to small size engines where its low cost, ease of manufacture, and ruggedness offer attractive advantages. However, its large frontal area and lower efficiency make it unattractive for large engines.

The general evolution has been toward axial flow compressors since the trend has been toward increasing pressure ratios. Some advanced technology engines now have overall pressure ratios of 25 to 1 or higher.

In an axial flow compressor, the airflow remains basically parallel to the rotational axis of the compressor. The compressor is built up of stages, each stage consisting of a row of rotating blades attached to disks mounted on a central shaft, called the rotor, and a row of fixed blades, called stators, attached to the compressor case. Each blade acts as a small wing increasing and decreasing the air velocity, which results in a pressure rise. The only difference between a compressor blade and an aircraft wing is the relationship between airflow and velocity of the airflow. The airflow over a wing increases or decreases as the airplane velocity increases or decreases. In a

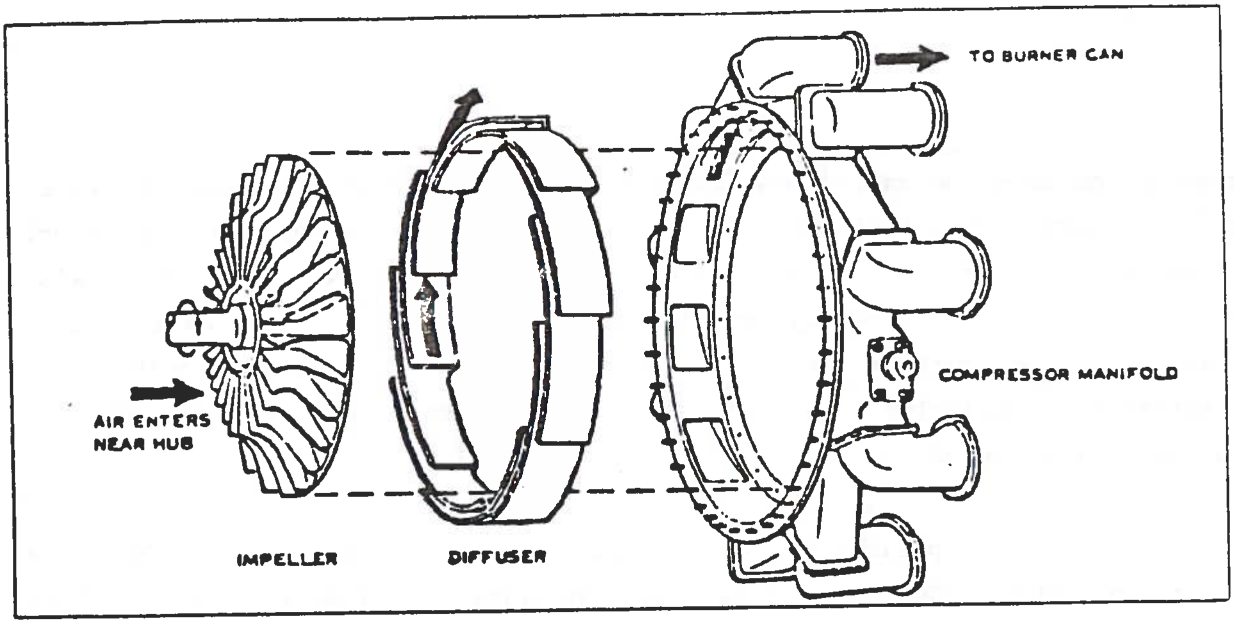

Figure 3-1. Typical Centrifugal Flow Compressor

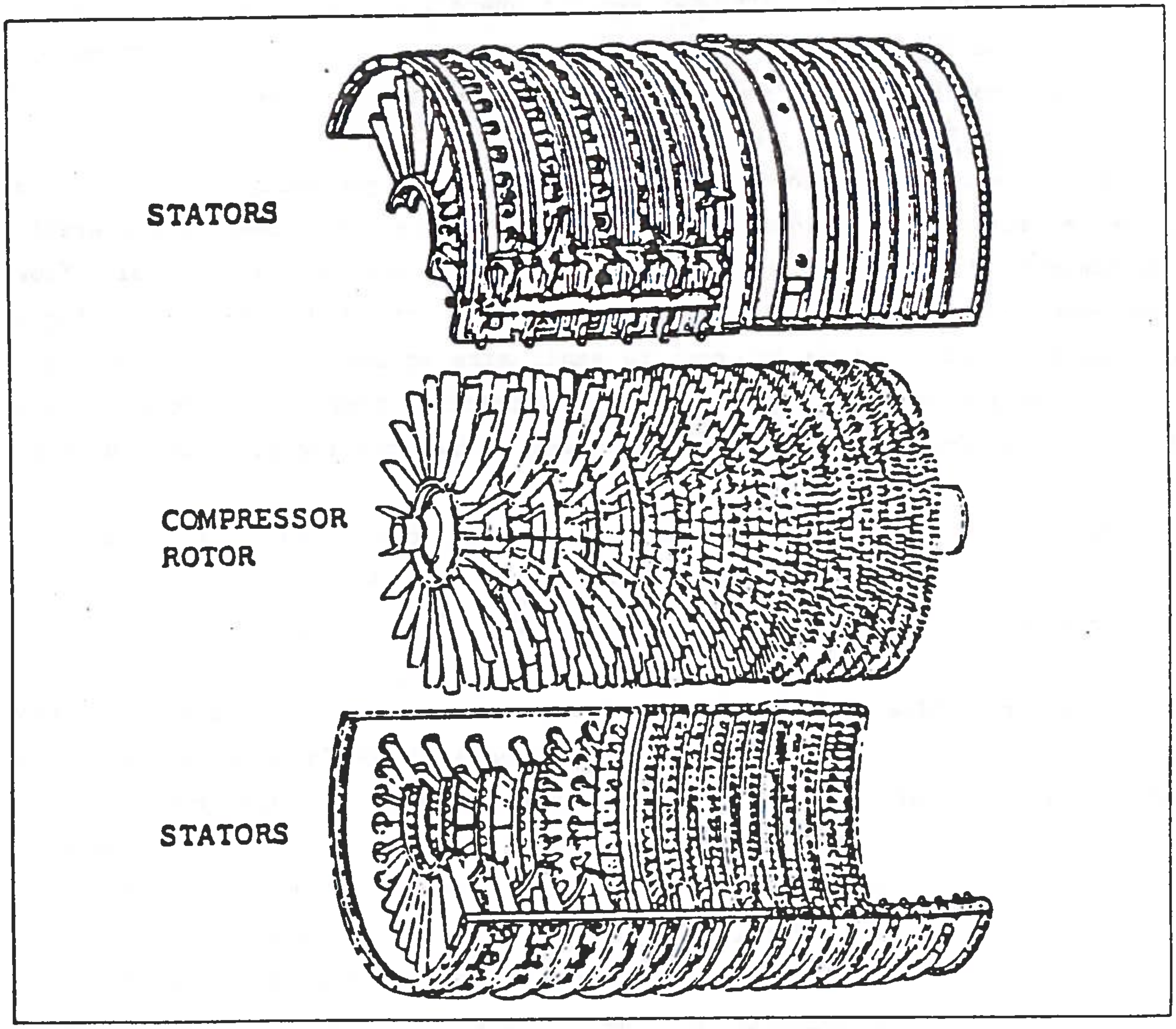

Figure 3-2. Typical Axial Flow Compressor

compressor, the airflow velocity is the resultant vector of airflow through the compressor and the rotor speed, either of which can vary. The pressure ratio is not added from stage to stage, but is increased by multiples at each succeeding stage. As the pressure increases through each stage, the air becomes more dense and requires less volume. Because of this and to prevent a large reduction of airflow velocity through the compressor the cross-sectional area of each stage is gradually decreased from the low pressure end to the high pressure end. The rotor and stator blades become shorter toward the rear stages.

Although compressors have been designed that have the same discharge velocity as the inlet velocity, it is usual to have the discharge velocity lower than the inlet velocity so that excessive diffusion is not required to reduce the velocity to the low level essential for efficient combustion in the burner.

A compressor is rated according to its pressure ratio and mass airflow. The compressor being a volume flow device, the ratings are achieved only at a specified RPM under standard inlet air conditions.

As with any airfoil device, effectiveness gradually increases to an optimum point, followed by a rapid decay known as a stall or surge. An airfoil stalls when its maximum angle of attack or the angle between the airfoil and the airflow velocity vector is exceeded. This can happen in a marine gas turbine compressor if the compressor RPM is constant and the airflow is decreased by a blockage of the intake or if the airflow is constant and the compressor RPM is rapidly increased, such as occurs when increasing ship speed. In various degrees, stall is a characteristic shared by all types of gas turbine compressors. It is most noticeable in axial flow compressors with a high pressure ratio. Airflow over stalling compressor blades tends to become very turbulent. During engine operation, stalls may occur, ranging from mild to severe cases. Mild stalls may be indicated by abnormal engine noises such as rumbling, chugging, or choo-chooing. More severe stalls can cause very loud bangs and may be accompanied by flame or smoke at the engine exhaust or inlet. Compressor stalls may cause temperature increases or fluctuations of exhaust gas, RPM fluctuation, pressure ratio decrease or vibration of the engine, and poor engine response to throttle movements. These conditions, particularly temperature increases, can cause significant damage to the compressor. All stalls should be noted in the engine log; reoccurring stalls are a malfunction and require maintenance actions.

Since the marine gas turbine must be able to operate at variable speeds and compressor stalls depend on the compressor RPM and mass airflow, some means must be used to control the airflow through the compressor so that speed may be changed without stalling the compressor. This can be accomplished using various methods, two of the most common methods being compressor bleed (pop-off) valves and variable inlet guide vanes and stators. Bleed (pop-off) valves are usually located between stages of the compressor and are automatically opened or closed to allow various amounts of air to escape from the compressor. These valves usually depend on the speed of the engine, the compression ratio, and the inlet temperature.. They will open at low compression ratios and close at high compression ratios. Bleeding the compressor decreases the airflow across the rear stages and increases the flow across the forward stages.

Variable inlet guide vanes (vanes and stators are synonymous) physically change the angle or attack of the stators. They are also automatically and hydraulically controlled based on the fuel pressure, engine speed, and inlet temperature. At low engine speeds they are at their minimum angle of attack. As the engine is accelerated, they rotate until they are open to their maximum angle of attack.

3.2 Combustors.

The function of the combustion chamber or combustor is to heat the working fluid (air), which is necessary to allow the turbine to produce more work than was put into the compressor. The combustor takes part of the compressed air from the compressor, mixes it with fuel (usually JP-5, a light distillate aircraft fuel oil), and ignites it. The combustion increases the temperature of the air, increases its velocity, and slightly decreases the pressure. Of the total airflow from the compressor, only approximately 25 percent enters the combustion process; the mixing rate is an air to fuel ratio of approximately 15 to 1. The remaining 75 percent of the airflow bypasses the fuel nozzles and is introduced into the combustor through cooling slots. There are several types of combustor designs used in marine gas turbines, such as cellular, cannular, and annular (these types refer to the physical shape of the combustion chamber). No matter what the shape, they all work on the same principle of combustion. Figure 3-3 is a diagram of the cross section of a typical combustor.

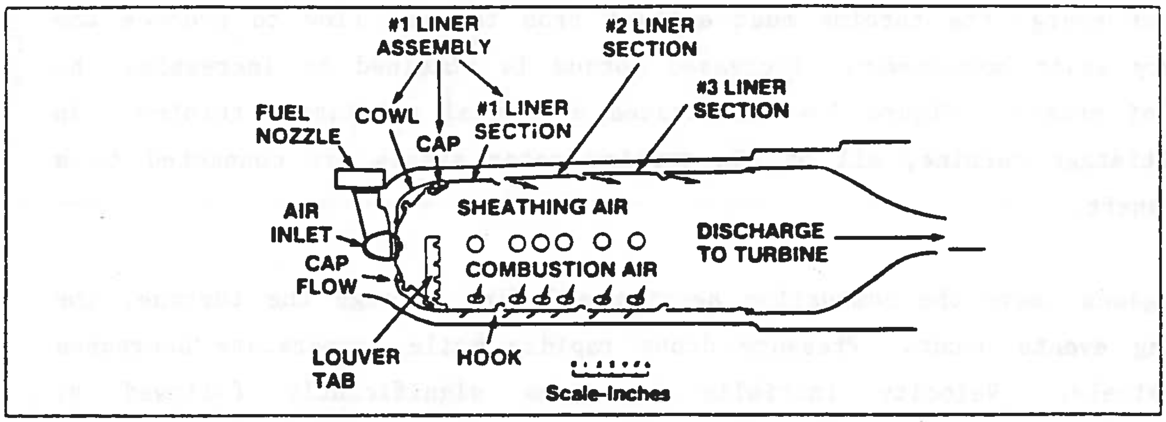

Figure 3-3 Cross Section of Metal-Cooled Combustor

3.3 Turbines.

The turbine provides the shaft horsepower necessary to drive the compressor and the engine accessories, by extracting kinetic energy from the expanding gases released from the combustor. The energy thus extracted reduces the pressure and temperature of the gases.

To produce the necessary driving torque, a turbine may consist of one or more stages. Each stage is composed of a row of stationary nozzle guide vanes, which direct the high velocity gases onto a row of moving blades attached to the turbine rotor disk. The general shape of the nozzle guide vanes and blades is that of an airfoil shape similar to the rotors and stators on the compressor. The number of turbine stages required is determined by the amount of energy the turbine must extract from the gas flow to produce the necessary shaft horsepower. Increased torque is obtained by increasing the number of stages. Figure 3-4 illustrates a typical multistage turbine. In the multistage turbine, all of the turbine rotor stages are connected to a common shaft.

As gases leave the combustion section and flow through the turbine, the following events occur. Pressure drops rapidly while temperature decreases progressively. Velocity initially increases significantly followed by progressive decreases and increases across each turbine stage. The decreases in velocity, temperature, and pressure occur in the turbine as the cross-sectional area increases. The reduction in temperature, pressure, and velocity reflects the energy extraction from the hot gases by each turbine stage.

In the actual operation of a turbine, energy extraction is accomplished by impulse and/or reaction of the expanding air against the moving blades on the rotor disk. Turbines are classified by their primary method of operation. There are two commonly used types, impulse and reaction.

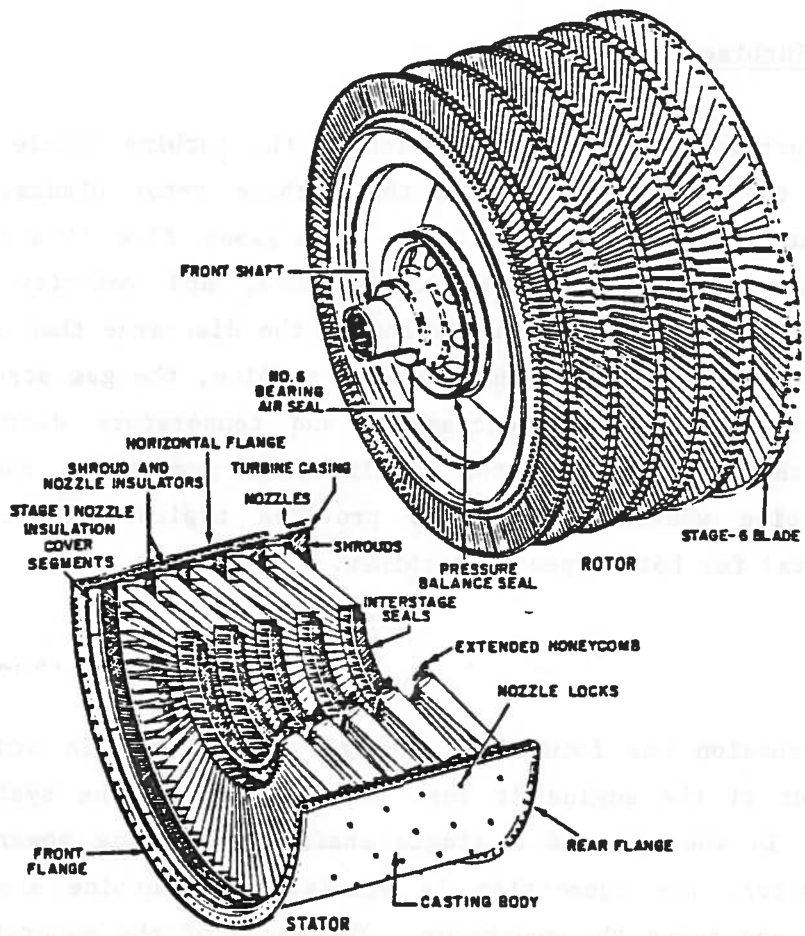

Figure 3-4. Multistage Turbine

3.3.1 Impulse Type Turbine.

In the impulse turbine, the nozzle is convergent, the inlet area being larger than the discharge area. As the gases leave the nozzle, they are expanded and accelerated resulting in a decrease in pressure and temperature. The accelerated gases are directed against the rotor blades (buckets). The cross-sectional flow area of the rotor is constant, consequently there is no significant change in gas temperature, pressure, or velocity across the rotor. The turning force is the result of the impulse of the accelerated gases against the rotor blades.

3.3.2 Reaction Type Turbine.

In the reaction turbine, the primary function of the turbine nozzle is to direct the gases at the proper angle onto the turbine rotor blades. The nozzle has a constant cross-section flow area, and gases flow through the nozzle with relatively constant pressure, temperature, and velocity. The cross-sectional flow area of the rotor is smaller at the discharge than at the rotor inlet. As the gas flows through the reaction turbine, the gas stream is turned, velocity increased, pressure decreased, and temperature decreased. The acceleration of the gases through the turbine rotor creates a reaction that drives the turbine wheel. Figure 3-5 provides typical examples of turbine blades (buckets) for both types of turbines.

3.4 Drive System.

Thus far the discussion has focused on the gas generator. In order to obtain useful work out of the engine it must be connected to the system or unit to be powered. In the case of a single shaft gas turbine powering a ship's service generator, the connection is simple: the turbine shaft is directly connected to and turns the generator. The speed of the generator is controlled by the speed of the turbine.

For propulsion systems using a split shaft gas turbine, the drive system is slightly more complex. As previously stated, in a split shaft gas turbine the power of the engine is derived from a power generating turbine which is not mechanically connected by a shaft to the gas generator. The shaft from the power generating turbine would be turning at much too high a speed (anywhere from 3600 RPM to 100,000 RPM for typical marine gas turbines) to efficiently turn a propeller directly. Therefore, it is connected to a reduction gear, which reduces the shaft RPM to a usable number. In multiple shaft ships, the power turbine must be oriented to ensure the appropriate shaft rotation direction. For example, on a twin shaft vessel, the rotation of the shafts must be in opposite directions in order to propel the ship in a straight line. The easiest way to do this is to reverse the direction of one turbine. Figures 3-6 and 3-7 illustrate typical arrangements for the FFG 7 class frigate and the DD 963 class destroyers.

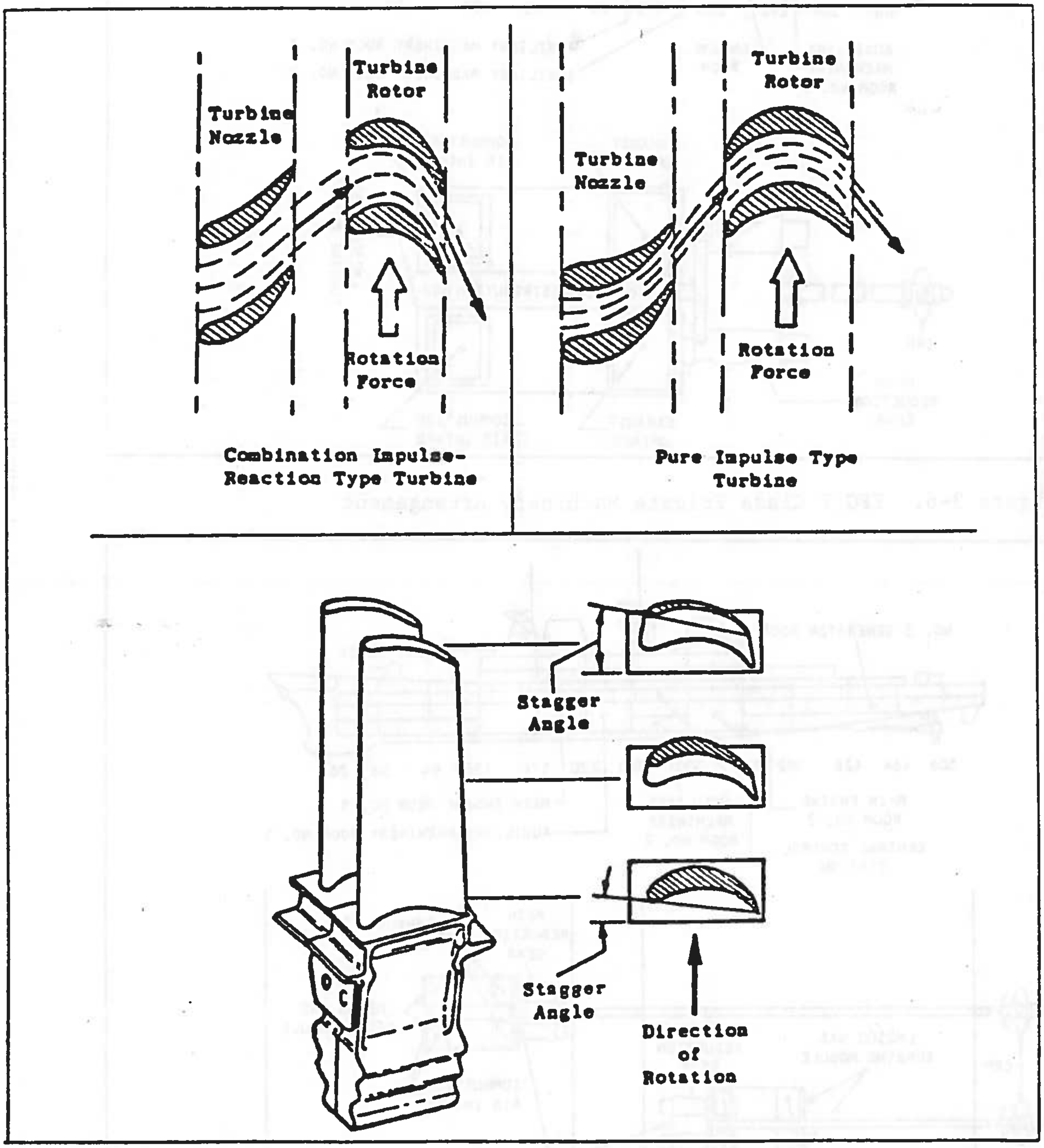

Figure 3-5. Typical Turbine Blades (Buckets)

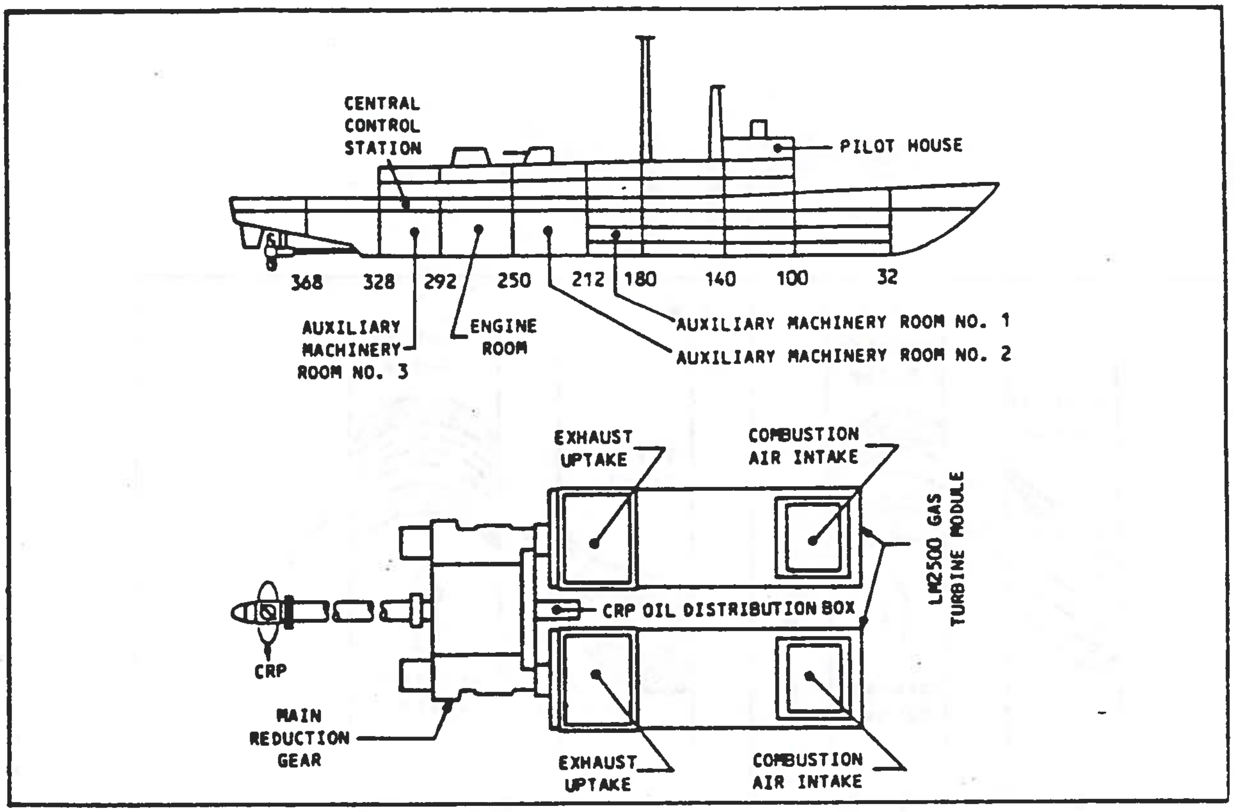

Figure 3-6. FFG 7 Class Frigate Machinery Arrangement

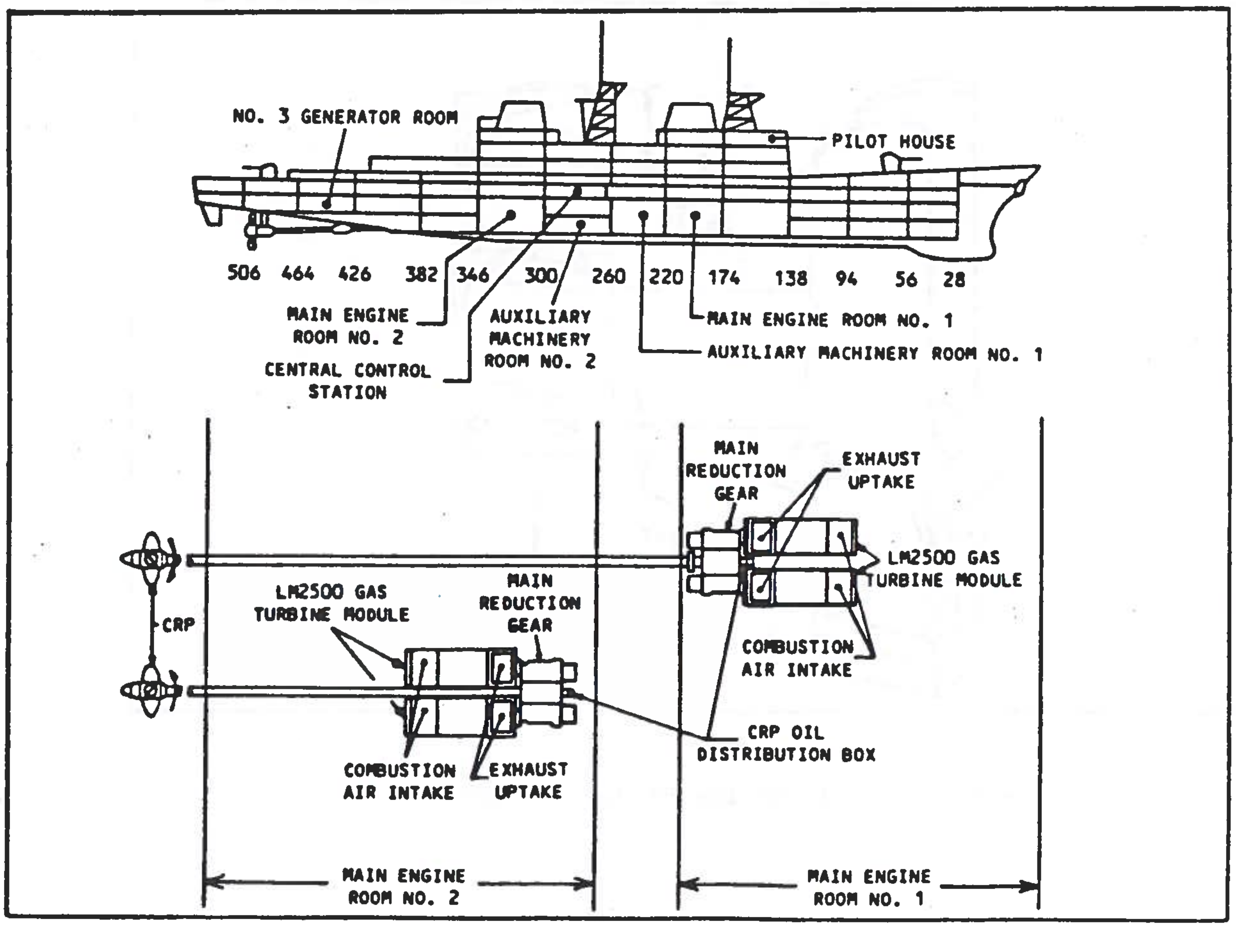

Figure 3-7. CG 47 and DD 963 Class Destroyer Machinery Arrangement

Another factor in the drive system of the gas turbine is the need for flexibility in the mounting system. Gas turbines would be damaged by distortions in the hull if the turbines are mounted rigidly to the deck; they must therefore be mounted using shock or spring mounts. Figures 3-8 and 3-9 illustrate typical installation of the LM 2500 engine.

4. CONTROLLABLE-REVERSABLE PITCH PROPELLERS

Because the gas turbine is not directly reversible, a means must be provided in the system for propulsion astern. Most non-turbine powered ships encounter this problem and use a reversing gear to solve it. A reversing gear for a gas turbine would be very large and very expensive. Reversing gears also require the shaft rotation to be stopped before the gears can be engaged. This does not allow full use of the ability of the gas turbine to quickly change speeds. An alternative, which is becoming more popular with designers, is the use of controllable-reversable pitch propellers (CRPs). CRPs are used on most Navy gas turbine powered vessels.

On a CRP the angle of attack or pitch of each blade is controllable. It can be adjusted from a full ahead position (large positive pitch) to a no thrust position (zero pitch) to a full astern position (large negative pitch) without changing the direction of rotation of the shaft. The use of a CRP allows the speed of the ship to be changed substantially without drastically changing the engine speed. Thus, the pitch control of the propeller blades can be linked to the most optimal shaft RPM, allowing the engine to operate at its most efficient engine speed at a variety of ship speeds.

The use of a CRP provides for generation of greater astern thrust because no change is needed in the shaft rotation. Because this astern thrust can be provided more quickly than through the use of a reversing gear, ships using CRPs have shorter stopping distances and are more maneuverable.

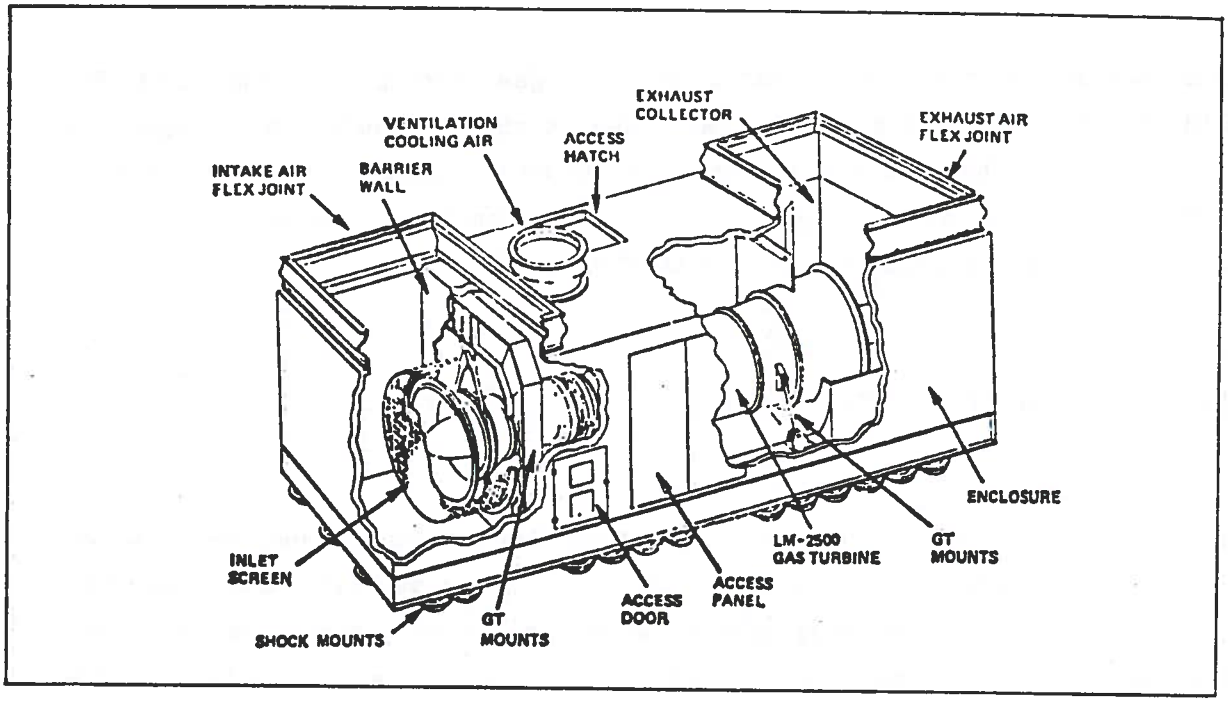

Figure 3-8. LM 2500 Engine Showing Mounting and Enclosures (Rains and d'Arcy, 1972)

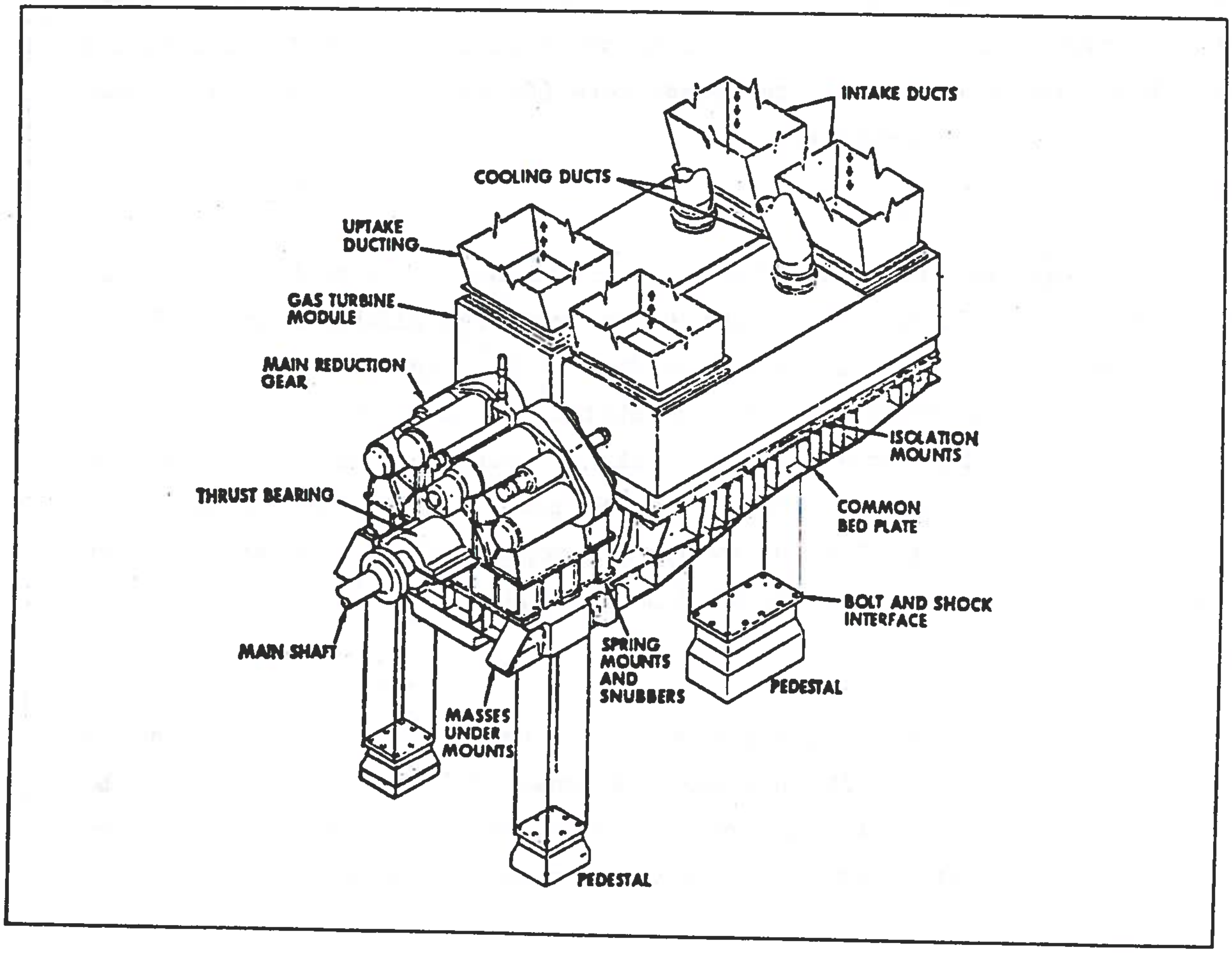

Figure 3-9 LM 2500 Engine, Twin Arrangement in DD 963 Destroyers
(Rains and d'Arcy, 1972)

In the operation of a CRP, normally one control device affects both the shaft RPM and the propeller pitch, which ensures that optimum conditions exist at all vessel speeds. However, there are usually bypass systems that allow each to be controlled separately to some extent. In most CRP applications, control is set up to first change the blade pitch until full pitch is achieved, at which time shaft RPMs are increased until the desired condition is reached. To reduce speed, this process occurs in reverse. You should be aware, however, that during pitch changes, minor changes in shaft RPM are also taking place in order to ensure an optimal match between propeller pitch and shaft RPM. The typical relationship between shaft speed and pitch is illustrated in Figure 4-1.

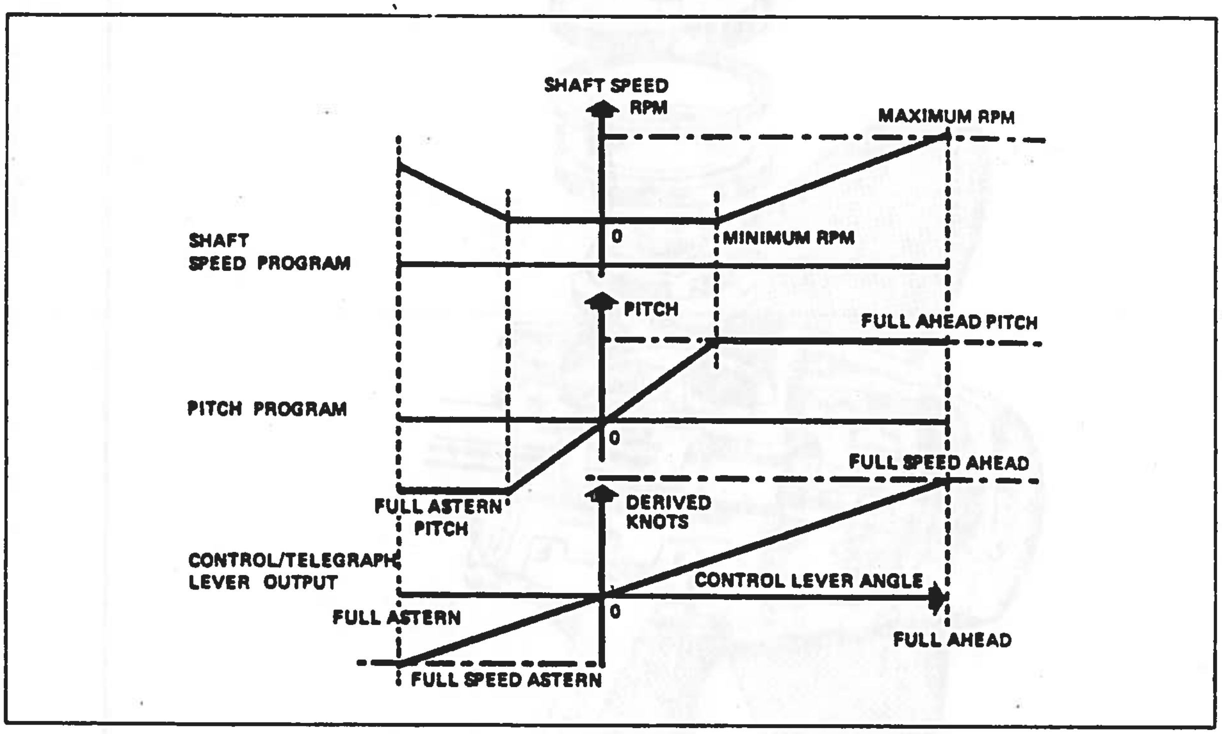

Figure 4-1. DDH 280 Pitch-Rev/Min Program (Sunley and Patterson, 1969; Sachs, 1969)

CRPs normally operate using a hydraulic system. The pitch control drives hydraulic pistons through the use of a servomechanism. These hydraulic pistons send impulses through hydraulic lines in the propeller shaft. The hydraulic lines coming from the shaft are connected to either a geared drive or a series of pistons in the propeller hub. The gear drives or pistons move the propeller blades. The blades are interconnected so they move evenly together to prevent propeller unbalance. Figure 4-2 illustrates a cutaway view of a typical CRP propeller.

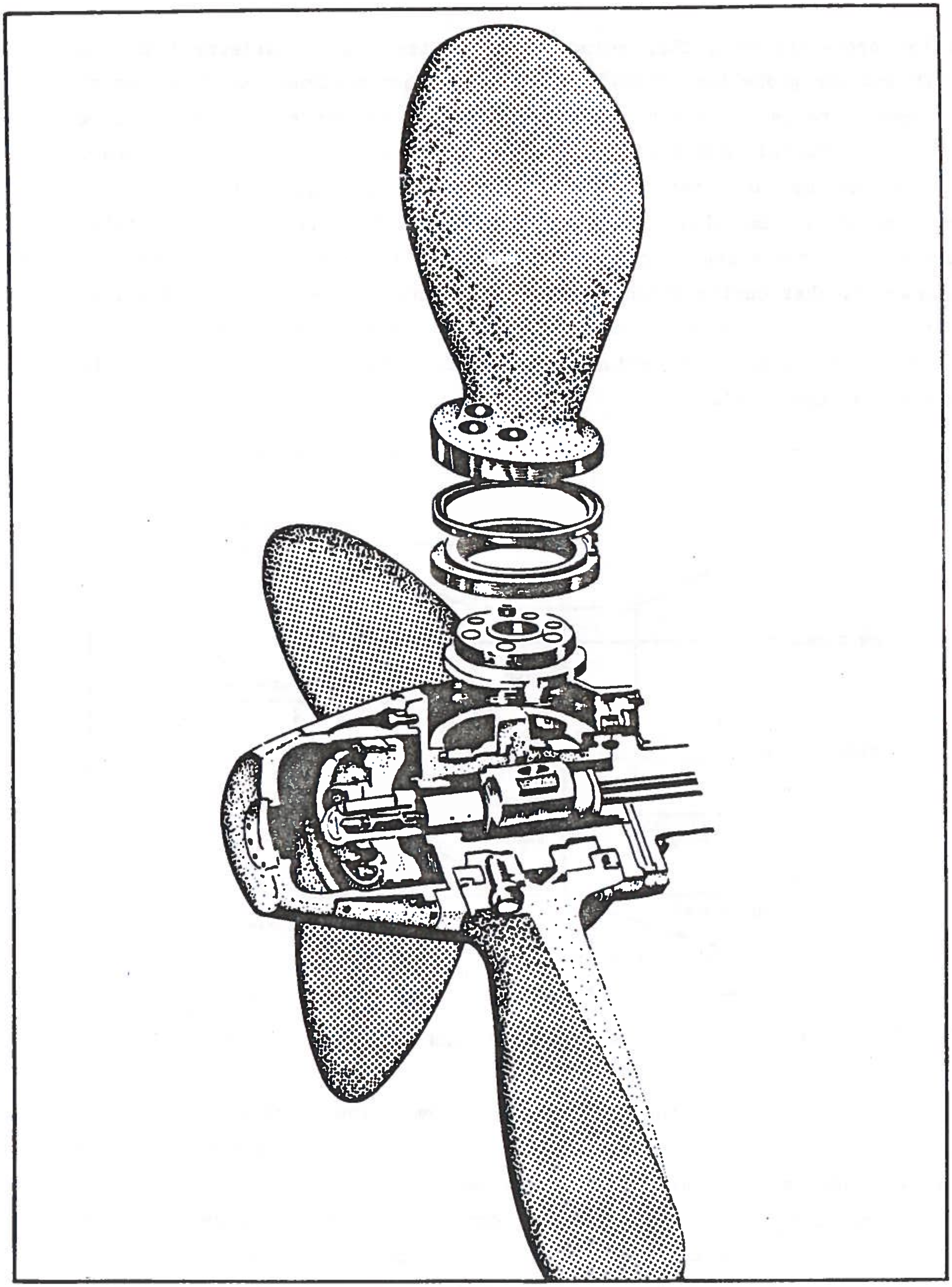

Figure 4-2. Cutaway View of KaMeWa Controllable-Pitch Propeller

5. CONTROL SYSTEMS

To take advantage of the very fast response times of gas turbine engines, the control systems must be automated since the number and speed of the required control actions exceed the capabilities of human operators. Automation includes both human control of the system from remote locations and "closed loop" or nonhuman control of various parts of the system.

Automation of gas turbines is a necessity demanded by their low inertia, fast response, and exacting control requirements involving prevention of compressor surge, overtemperature, or overspeed. When engines are locally controlled, the control is still through the electrical/electronic control system. There is no capability for fully manual control (mechanically step sequencing without automatic check of the prerequisites) of gas turbines. Starting and stopping of the gas turbines is either manual or fully automatic, using programmed starting/shutdown sequences (step sequencing using automatic means of checking the prerequisites). Manual starting is nonetheless dependent on various interlocks and safety permissives.

Due to the low rotor inertia of gas turbines and their high power capability, another potential hazard is overspeed, with the associated possibility of engine destruction. The LM 2500 gas turbines could reach destructive speeds in less than one second under a sudden drop-load condition if the maximum fuel rate were maintained; hence reliable, failsafe topping governors and overspeed trip systems are essential. Even with redundant controls and safeguards, disaster provisions such as a fuel cutoff valve or overspeed trips must be available in case of catastrophic machinery failure.

Application of CRP propellers, the rapid response of gas turbines, and the ability of gas turbines to furnish very large torques present other ship control problems not previously encountered in warship design. During full power maneuvers (e.g., acceleration, crashback, crashahead, or high speed turns), extremely large propeller and turbine shafting torques, propeller thrusts, and individual blade spindle torques are developed. These peak loads, unless controlled, could cause transmission and propeller failure. Therefore, considerable attention is given to the design of integrated throttle and gas turbine control systems to provide controls for torque limiting and many other safeguards.

A propulsion plant computer is used in both the DD 963 and FFG 7. Use of a computer as a central signal processor in both these ships provides an enormous capability for data processing and display. Detailed analysis of plant conditions is immediately available for numerous main machinery and auxiliary systems, providing condition monitoring, status display, alarming, and trend analysis at several locations. The FFG 7 uses the plant computer for centralized throttle control and other control functions as well as for monitoring. The DD 963 plant computer provides detailed analysis of plant conditions at many locations throughout the plant.

The DD 963 and FFG utilize, for the first time on large U.S. naval ships, the feature of a single centralized propulsion and machinery control center remote from the engine rooms. In the DD 963 all engines on both shafts are normally controlled from this single location. This concept has been in use on British ships for many years and more recently on the Canadian DDH-280 class destroyers. Fall-back control of machinery in either manual or semi-automatic modes is available from the local operating centers in the immediate vicinity of the engines. This redundant local machinery control feature is mandatory for combatant ships, where battle damage could wipe out the primary control centers.

The propulsion control systems of these ships incorporate direct throttle control from the bridge, a capability heretofore available only in smaller craft and in a few noncombatant Navy ships in recent years. Direct throttle control enhances the mobility and effectiveness of ships, eliminating engine order delays and errors, while exploiting the faster response capability of gas turbine engines. Back up throttle control is also available in the central control station and in the engine room because of battle damage considerations.

Automated machinery control systems, in addition to providing increased response times and machinery/personnel safety, have allowed the means to obtain the following objectives:

a. Increased ship availability (through system reliability).

b. Increased thermal efficiency.

c. Reduced maintenance.

d. Reduced human error.

e. Reduced manning requirements.

f. Reduced life-cycle cost (through reduced manpower requirements).

To explain how these automated control systems work, the focus will be on the control of propulsion systems, with the understanding that the engine control for other applications of the gas turbine (e.g., ship service generators) is very similar. The operator of a gas turbine begins the control process simply by pressing the "start" button, which initiates an automatic sequence that must be followed in order to bring the system on-line. Gas turbines are started by electrically, hydraulically, or pneumatically turning the compressor until it reaches a speed high enough to be self-sustaining. The ignition is turned on, fuel is injected, and the engine lights off. After this happens, the ignition is turned off and the starter is secured. In this way, hang starts (idle speed too low) or hot starts (lack of adequate cooling air) can usually be avoided. The computer's built-in logic follows the sequence exactly and, therefore, protects the engine against potential hazards.

Information concerning the operation of the engine must be provided to all the automatic control systems. This information is provided by various sensors and measurements such as temperature at the inlet and exhaust; pressure at various locations; RPM of the shaft, compressor, and turbine; and fuel flow. Using these parameters, two methods can be used to control the engine: power control or speed control. Usually these methods are combined. Power control involves sensing the turbine speed, which depends on the load imposed, and controlling the fuel flow into the combustor through the use of an automatic throttling valve. This method of control is good for a gas turbine because, at a particular load, engine speed is normally close to being constant. Speed control also uses regulation of the fuel supply to control the engine; however, it senses changes in shaft RPM. Speed control is not effective at cruising speed because small changes in shaft RPM may not significantly change the load imposed and, therefore, no changes will occur in the gas generator. Speed control is normally used during maneuvering situations.

In the control system, governors and trips are used to control the engine. Governors and trips can be based on either RPM of the components or temperatures. If either of these parameters becomes too high, the governors or trips automatically reduce the fuel supply. These features are designed to protect the engine from excessive temperatures or speeds.

During acceleration or deceleration, the rates at which the fuel flow or airflow can be increased or decreased must be controlled. A sudden increase in fuel or air flow can cause overspeeds and high temperatures before they can be prevented by the trips and governors. A sudden decrease in fuel can cause the air/fuel ratio in the combustor to be so high that combustion cannot be supported (flameouts), which could allow fuel to be dumped onto the hot parts of the engine. Therefore, the computer control logic will only allow increases and decreases to be made at certain rates.

As previously mentioned, all of these controls are automated. When the control handle at any control location is moved, a signal is sent to the central processor. The central processor translates this command into an engine or shaft RPM and propeller pitch signals. The engine or shaft RPM signal is derived from the control handle position through a preprogrammed table of RPMs for various handle positions. The propeller pitch signal is derived in a similar manner. The tables are programmed into the processor to ensure the combinations of RPM and pitch produce the desired output of ship speed based on its design performance characteristics. These signals are adjusted to compensate for ambient temperature, pressure, and sea state determined by various sensors. Corrected signals are then sent to the pitch control unit and fuel control devices such as the bleed (pop-off) valves or variable inlet guide vanes on the compressor (see paragraph 3.1). Should any of the signals exceed the operating parameters of the engine, the governing devices will be activated to prevent overspeeds or excessive temperatures. Figure 5-1 is a propulsion control functional block diagram for a DD 963 gas turbine.

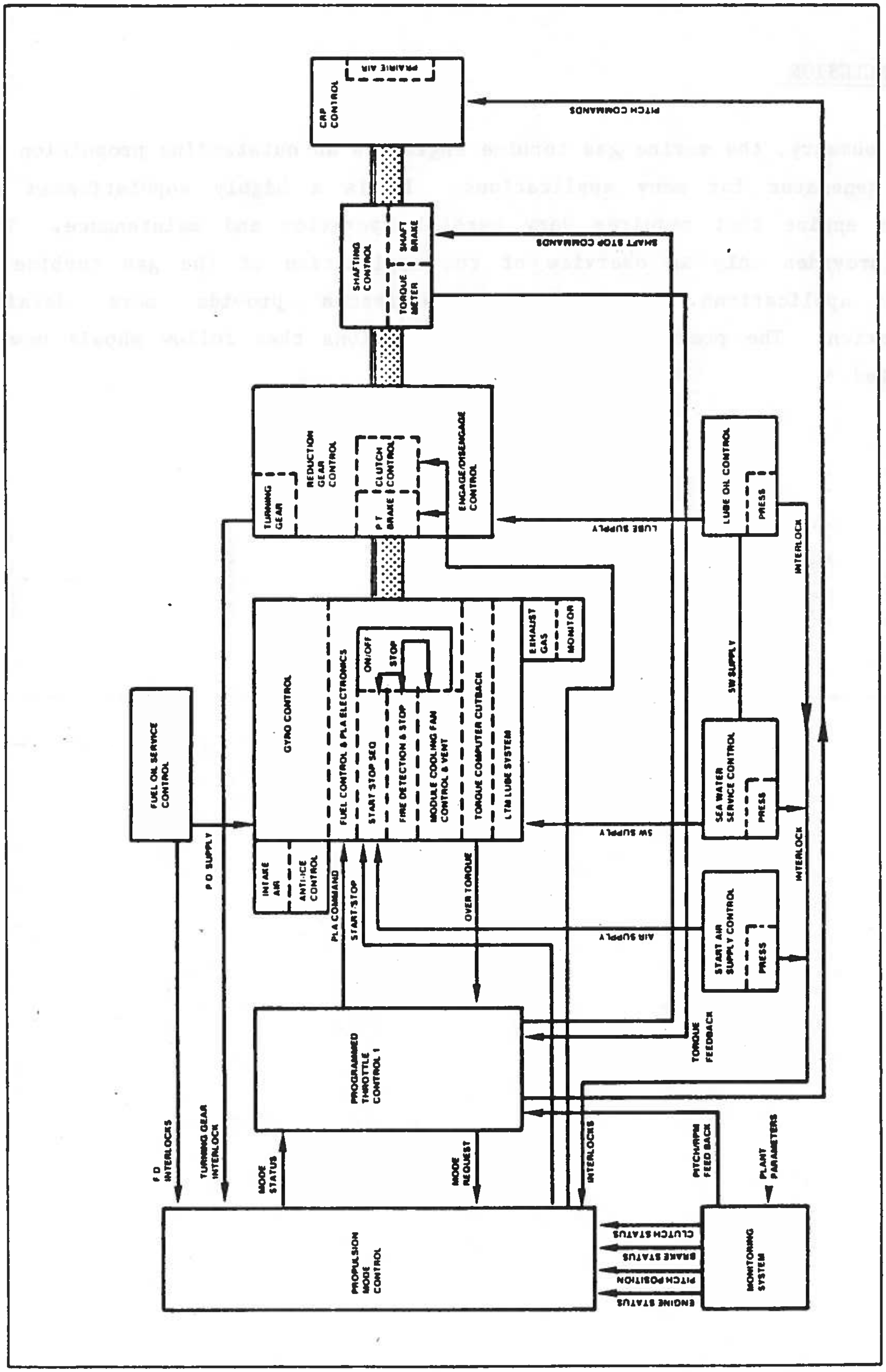

Figure 5-1 Propulsion Control Functional Block Diagram

6. CONCLUSION

In summary, the marine gas turbine engine is an outstanding propulsion and power generator for many applications. It is a highly sophisticated and complex engine that requires very careful operation and maintenance. This paper provides only an overview of the application of the gas turbine to marine applications. The listed references provide more detailed information. The practical factors and questions that follow should now be completed.

7. PRACTICAL FACTORS:

Practical Factor	Date Completed
a. View the physical layout of the machinery control system (bridge, central control station, and main engine room) and of the LM 2500 and 501K-17 engines onboard a DD 963, FFG 7, or CG 47 class ship.	
b. Observe the mechanical rigging of the variable stators and fuel control on the LM 2500. (Note: The angular settings of vanes determine the stall margin of the compressor.)	
c. View the central control station readout gauges for compressor inlet temperature (CIT), compressor discharge pressure (CDP), and exhaust gas temperature (EGT) (T5.4 on LM 2500).	
d. Borescoping is used to inspect the interior of a gas turbine engine to determine compressor damage, fuel nozzle clogging, and high pressure turbine deterioration. If possible, participate in a borescope inspection of the compressor and high pressure turbine sections.	
e. If possible, observe the changeout of an LM 2500 or 501K-17 engine.	
f. If possible, observe the operation of an FFG 7, CG 47, or DD 963 propulsion plant maneuvering underway.	

8. QUESTIONS:

a. Name the different types of marine gas turbines and explain the differences.

b. Name the basic components of a gas turbine engine.

c. Draw and briefly explain the Brayton Cycle PV and PT diagrams for a gas turbine engine.

d. Name two types of compressors and explain the difference between them.

e. Why do the rotor and stator blades become shorter with each compressor stage?

f. What parameter change in the air flow through the compressor can cause compressor stalls?

g. Name methods used in compressor design to prevent stalls in "off-design" speeds.

h. Explain how the velocity, temperature, and pressure change as the hot gases leave the combustor section to do useful work.

i. Explain the geometric differences between a reaction type and an impulse type turbine nozzle.

j. What are the advantages of using a CRP?

k. Describe the normal relationship between propeller pitch and shaft RPM using a CRP.

l. Why must gas turbine control systems be automated?

m. Name six objectives achieved through the use of an automated gas turbine control system.

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(Consult Latest Revisions Prior to the On-the-Job Usage)

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