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MARINE GAS TURBINE ENGINES

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ABSTRACT

This article deals with marine gas turbine engines. In this article we have attempted to study the various components in certain detail. Also we have made an attempt to compare various marine gas turbine engines with their respective counterparts based on grounds such as technical data , general information and applications. As we have a lot of data to retain in this article , things have been stated and explained as and when encountered.

HISTORY

The first devices to have extracted rotary mechanical energy from a flowing gas stream were windmills. What followed was the smokejack, first started or initialized by Leonardo da Vinci and then later discussed in detail by Wilkins John, done in 1648. This device had a good number of horizontal sails which were mounted on vertical shafts and were subsequently driven by the humid and hot air which rose from a chimneys. With the help of further simple systems for gearing, the smokejack had been used to turn a roasting spit.

Numerous reaction air-turbine drives had been pioneered during the 19 century. These made use of air, which was hence compressed by reciprocating compressors, so as to drive rotary drills, saws, and other devices. Many such units and devices are still in use, but have very less in common with the modern gas-turbine engines, which does have compressors, combustion chamber, and turbines so as to make up self-contained prime movers.

INTRODUCTION

MARINE GAS TURBINE ENGINES

A marine gas turbine engine is an internal combustion engine which uses gas as the working fluid to turn a certain turbine. The term gas turbine engine may also be used to describe a complete internal combustion engine consisting of at least a turbine, a combustion chamber or a compressor.

GENERAL CHARACTERISTICS OF A GAS TURBINE ENGINE

Propulsive thrust or useful work is obtained from a gas turbine engine. This obtained useful work or propulsive thrust may drive a pump, propeller or develop thrust by accelerating turbine exhaust flow through a nozzle in case of pure jet aircraft engine. Large amounts of output can be received for the same amount of input as in case of a reciprocating internal combustion engine.

It is much smaller and compact compared to the reciprocating internal combustion engine. A gas turbine delivers rotary shaft power directly. It is conceptually a simple device but for an efficient unit the components must be properly chosen and manufactured. High temperatures and stresses are encountered during operation. In large units they become cost effective and hence are deployed where large units are present.

GAS TURBINE ENGINE CYCLES

IDEALIZED SIMPLE OPEN CYCLE GAS TURBINE CYCLES:

Gas turbines operate on a cycle in which air taken from the atmosphere is compressed in devices known as axial or centrifugal flow compressors. This above mentioned cycle is referred to as an open cycle. The air is then fed into a combustion chamber. Fuel (kerosene) is also mixed with the air which just entered at a pressure which remains constant. Additional air has to be used to ensure that the combustion chamber exit temperature is kept low enough to allow the turbine to operate properly. This air is bypassed around the burning section and mixed with very hot combustion gases. To produce shaft power, the combustion products are expanded to the atmospheric pressure in the turbine. More than 50 percent of the output of the turbine is required to operate the compressor and the remainder is used to drive pump, propeller or other device.

An idealized gas-turbine engine, in essence a cycle in which the losses are negligible is considered to work as per the idealized Brayton cycle. Say that air enters the compressor at 15 degrees centigrade and at the atmospheric pressure and is compressed to one mega pa, it then absorbs heat from the fuel until the temperature reaches 1100 degrees centigrade prior to expansion back to the turbine. This idealized unit (system) would require the turbine to be something around 1.68KW for each kilowatt of useful work with 0.68 KW required to drive the compressor. Hence the thermal efficiency for the above mentioned example would be around 48 percent.

ACTUAL SIMPLE OPEN CYCLE PERFORMANCE

The importance of highly efficient turbines and compressors is illustrated as follows: For every kilowatt of net power produced, the turbine must produce 2.71 kilowatt while the compressor work becomes 1.71 kilowatt and hence the thermal efficiency drops to 25,9 percent. Hence modern units are designed that the compressor as well the turbine efficiencies are somewhat in the range of 85 to 90 percent.

Efficiency and power output can be altered by raising the turbine inlet temperature. Turbine blades require special blade cooling as they travel at high speeds and are subject to several centrifugal stresses, the turbine inlet temperatures reach or even exceed 1100 degrees centigrade. For every maximum turbine inlet temperature, there has to be an optimum pressure ratio as well. Modern marine as well as aircraft gas turbines operate at turbine inlet above 1370 degrees centigrade as well as pressure ratios of above 30:1.

INTERCOOLING, REHEATING AND REGENERATION

In gas turbine engines attention must be paid to weight and diameter size. Hence we cannot add more equipment to improve the performance of the gas turbine engine. However, in case of stationery gas turbine engines, components can be added to improve efficiency. These components or rather improvements may include, 1) Decrease in compression work by immediate cooling 2) Decrease in consumption of fuel by regeneration 3) After partial expansion, increasing the turbine output by reheating. . For the first improvement we are required to compress air at nearly constant temperature. This for all practical purposes is approximated by intercooling. Cooling as we all know will decrease the volume of air of air to be handled and thus will also decrease the compression work required. . For the second improvement we are required to reheat the air in a second set of combustion chambers and eventually feeding this mixture into a low pressure turbine for final expansion. This process is similar to reheating used in a steam turbine. . For the third improvement the hoe exhaust gases from the turbine are passed through a heat exchanger to increase the temperature of the leaving air. This air is the air which leaves the compressor prior to combustion. Hence the amount of fuel needed to reach the desired turbine inlet temperature is also reduced. The increase in efficiency is however economical only for units that are run almost continuously as there are a lot of initial costs associated with almost each step.

MAJOR COMPONENTS OF GAS TURBINE ENGINES:

MAJOR COMPONENTS OF GAS TURBINE ENGINES

1).COMPRESSOR

Early gas turbines used centrifugal compressors which were relatively simple and inexpensive. They were however not as good as modern axial flow compressors in terms of efficiencies and also they used limited pressure ratios. Centrifugal compressors are used primarily in industrial units.

An axial flow compressor is entirely reverse of a reaction turbine. The blade passages look like twisted highly curved aerofoils. These aerofoil like blades must exert a tangential force on the fluid with the pressures on one side being higher than the other. The flow velocity between the blade passages reduces and hence the flow is diffused. This seems to happen in the case of a subsonic flow. Pressure won't rise along the blades but we will notice that there is a subtle variation . Further, one can perform tests of stationery blade assemblies known as cascades in special wind tunnels. Actual blade arrangements in rotating assembly require special test setups or rigs.

Blades must satisfy both the criteria in order to have the system working efficiently: 1). Have the correct aerodynamic shape.
2). Become light and not prone to critical vibrations.

The fundamental difference between the centrifugal flow compressors and the axial flow compressors can be stated as follows. 1).The blades are shaped completely differently. Typically a centrifugal compressor seems to look more like a turbocharger in general whereas the axial compressor is a flat disk that looks like a fan. In this fan individually manufactured plates are inserted

Difference is also in how they are operated and in also how they are maintained. Flow through a centrifugal compressor is turned perpendicular to its rotation axis, whereas air in an axial compressor flows parallel to the axis of rotation.

Axial blades are aerofoils which compress air by the process of forcing it aft/stern into a converging space via downwash the same just as a wing would generate lift by the process of downwash. Efficient, but is sensitive to angle of attack and aerodynamic stall, just like a regular wing is, so therefore is sensitive to flow disruptions as well.

A centrifugal compressor is essentially a spinning duct which forces air into a converging space or volume just purely by centrifugal force imparted to air within it as it would spin. Less efficient, and kind of very less sensitive to flow disruptions and a lot more easier to make.

2). **COMBUSTION CHAMBER** The air which leaves the compressor has to be slowed down and then split into two streams. These streams are referred to as the large stream and the small stream. The smaller stream is fed into a region where fuel which is atomized is injected and burned. The flame used to do so is held firmly in its position by a large turbulence generating obstruction. The larger stream which is cooler is then fed into the chamber through holes along a combustion liner. This has an effect of reducing the overall temperature to a level suitable for the turbine inlet. Combustion can be carried out in a series of nearly cylindrical elements referred to as cans or if feasible in a singular annular passage. Also to tackle the problem of not being able to achieve nearly uniform exit temperature distributions we can resort to methods such as the partial internal reversed flow.

3).**TURBINES**

The turbines work on the principle of reaction with hot gases and thereby expanding up to eight stages. Terms such as one and two spooled turbines are something we tackle a lot when it comes to dealing with marine gas turbine engines. If the turbine drives an external load the scenario becomes something as follows: Part of expansion frequently takes place in a high pressure turbine. This turbine also drives the compressor. Remaining expansion takes place in a free turbine connected to the load. There exists really high temperatures at the turbine inlet which call for deploying special metallic alloys for turbine blades. These blades which are subjected to really high temperatures must also be cooled by colder air drawn directly from the compressor and are hence fed by the use of internal passages. The processes in use to accomplish the same are as follows:

1). Jet impingement to be done on the hollow blades in the inside part

2). Bleeding of air to form a cooling blanket over the outside of the blades.

A recent large aircraft engine design which operates with an overall pressure ratio of 30:51 will use two high pressure turbine stages in order to drive 11 high pressure stages on the outer spool, the speed of rotation being somewhere close to 9860 rev per minute while we have 4 low pressure turbine stages driving the fan for bypass air as well as 4 additional low pressure compressor stages turning at 3600 rev per min. For stationery units, a total of 3 to 5 turbine stages is more generally deployed.

APPLICATIONS

As we would discuss superficially gas turbine engines are used in aircraft and marine propulsion purposes. They may also be used for industrial purposes, electric power generation , automative propulsion and so on

ELECTRIC POWER GENERATION

In the field of electric power generation, gas turbine engines are faced with competition against steam turbines which are used in larger central power stations while diesel engines are being used in smaller plants. The efficiency of a gas turbine engine is low although it may have cost a little lesser. Yet, as compared with its contemporaries it hardly takes any time to set up a marine gas turbine engine. Hence we find gas turbines being used in many electrical applications where the prime focus is only on the initial charges although considerations such as the fuel charges may initially seem relevant too. Operating at reduced turbine inlet temperatures earlier commercial stationery plants used aircraft units. The high rotational speed of aircraft turbines required special gearing to drive electric generators. More recently, units have been made for direct use at 3,600 revolutions per minute. Units up to 200,000 KW were made, although the majority are quite less than 100,000 KW. These turbines operate up to 6,000 hours per year on liquid fuels and natural gas. Typical turbine-inlet temperatures for larger units are from about 980 to 1,260 centigrade.

Efficiency is improved by adding regenerators to make use of the higher turbine exhaust temperatures (which are about 480 to 590 Celcius). A modern development requires feeding the gas turbine exhaust into a steam generator where more fuel is burnt, which produces steam of moderate pressure in steam turbine. An overall thermal efficiency of nearly 50 percent is attained for the combination, making them one of the most fuel-efficient power plants currently available.

INDUSTRIAL USES

With sizes in the range of 1000 to 5000 HP, industrial gas-turbine engines are used for certain applications. These are driving compressors for pumping natural gas from pipelines, where a part of the gas serves as the fuel. Such units are automated so that hardly any supervision is required. A gas turbine is used in an oil refining process called the Houdry process, in which pressurized air passes to burn collected carbon. The hot gases then drive a turbine. This is done directly without a combustion chamber. The turbine, then drives a compressor to pressurize the air for the process. Portable gas turbines having radial compressors are used to operate pumps.

MARINE PROPULSION

Lightweight and compactness are the factors giving gas turbine engine engines an edge over the steam and diesel counterparts in this area of application

LOCOMOTIVE PROPULSION

A large number of locomotives are based on gas turbine engines that use heavy oil. Because of the high cost of heavy fuel oils the gas turbine based version of locomotives is becoming less competent day by day and also the fact that they have only had moderate success makes their usage quite restricted. Moreover, the low efficiency of a open-cycle gas turbine worsens at part-load or during idling when considerable amount of fuel is needed for the compressor to be driven while producing no useful power.

AUTOMATIVE PROPULSION

Gas turbine engines have low emissions compared to their gasoline counterparts and hence were contemplated for the use in automobiles like 40 years ago. But they have over time become impractical, uneconomical and obsolete because of their disadvantages such as sky rocketing manufacturing costs as well as the associated low inherent efficiency.

END OF PART 1 . THE REST INVOLVES SPECIFIC GAS TURBINE ENGINES

GENERAL ELECTRIC AVIATION

The gas turbine engines produced by the GE Aviation are sometimes abbreviated as LMs. The General electric has always been a key player these gas turbine engines and as a result they have 1300 LMs operating in the respective navies of a swashbuckling 34 navies and in 500 different ship types. In this section we discuss certain famous models of the LM family in an attempt to scrutinize them based on the general features, technical attributes and some marine applications.

1) LM 2500

The LM2500 marine gas turbine is a simple cycle, 2 shaft, really higher performance engine. Inspired from CF6-6 aircraft engines of the GE, the LM2500 has a gas generator, a power turbine, pinned fuel and lube oil pumps, a fuel control system along with a speed governing one, associated inlet sections and hence exhaust sections, lube systems and scavenge systems as well as controls/devices for initializing and monitoring engine operation. The LM2500 is GE's widely-utilized gas turbine, used by 34 navies worldwide. Possible applications for the LM2500 are patrol boats, corvettes, frigates, destroyers and auxiliary ships and carriers for aircrafts. The LM2500 is available/obtained as a military generator set.

TECHNICAL DATA

- ∗ 1.1) Output : 25,060 kW
- ∗ 1.2) SFC : 227 g/kW hour
- ∗ 1.3) Heat rate : 9705 kJ/kW hour
- ∗ 1.4) Exhaust gas flow : 70.5 kg/sec
- ∗ 1.5) Exhaust gas temperature : 566 degree centigrade
- ∗ 1.6) Power turbine speed : 3600 rpm

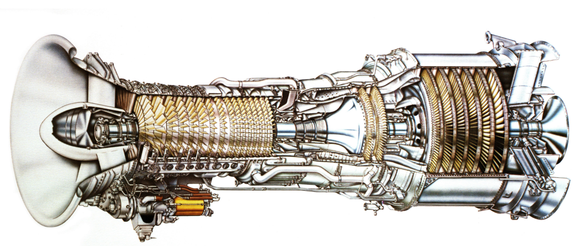

FIGURE 1. LM 2500

2) LM 2500 +

At a simple cycle thermal efficiency of around 40 percent, the LM2500+ version of the LM family delivers or is 20 percent more useful / efficient compared to its basic LM2500 counterpart. The higher efficiency implies lower SFC. Moreover the availability and the reliability are almost identical as in the case of the LM2500. Maintenance is simple and easy owing to the simple modular design, which does feature split compressor casings, in place blade and vane replacements, in place hot section maintenance and external fuel nozzles. The LM2500+ have found their use in military combatant ships and also in the case of amphibious ships. They have certain uniqueness about their generator set being used.

TECHNICAL DATA

- ∗ 1.1) Output : 30,200 kW
- ∗ 1.2) Heat rate : 9227 kJ/kW hour
- ∗ 1.3) Exhaust gas flow : 85.9 kg/sec
- ∗ 1.4) Exhaust gas temperature : 518 degree centigrade
- ∗ 1.5) Power turbine speed : 3600 rpm
- ∗ 1.6) SFC : 215g/kW hour

3) LM 2500 + G4

LM2500+G4 is the fourth generation of the LM2500 leading industry. Main features include greater power (17 percent) as compared to the above discussed generation three LM2500+, and almost the same high reliability, availability and the same

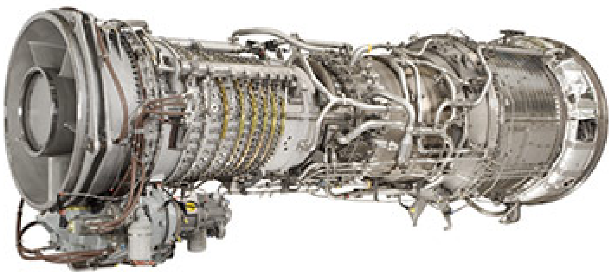

FIGURE 2. LM 2500 +

high efficiency (lower SFC). The LM2500+G4 system's modular design enables for its easy and time to time repair and rejuvenation, with splitcompressor casings, in-place blade and vane replacements, in-place section maintenance and its external fuel nozzles. The LM2500+G4 is best suited for the French, Italian and Moroccan FREMM frigates and some military ships, and is found out as a generator set.

TECHNICAL DATA

* 1.1) Output : 35,320 kW
* 1.2) Heat rate : 9,150 kJ/kW hour
* 1.3) Exhaust gas temperature : 549 degree centigrade
* 1.4) SFC : 214g/kW hour
* 1.5) Power turbine speed : 3600 rpm
* 1.6) Exhaust gas flow : 93 kg/sec

4) LM 6000

Utilized for high power requirements,the LM6000 is a unique cycle, 2 shaft, really great performance gas turbine engine that is inspired from CF6-80C2 high bypass turbofan engine for aircrafts. There are two models of the LM6000: the LM6000PC is a 46 MW engine, and the LM6000PG has an output power of 52 MW. Making full use of the CF6-80C2 fairly low pressure system's normal working rotary speed of 3600 rpm, the LM6000PC does couple loads straight to the low pressure turbine shafts. This feature allows the common grounds of the CF6-80C2 and the LM6000 to be kept.

TECHNICAL DATA : LM 6000 (PC vs PG)

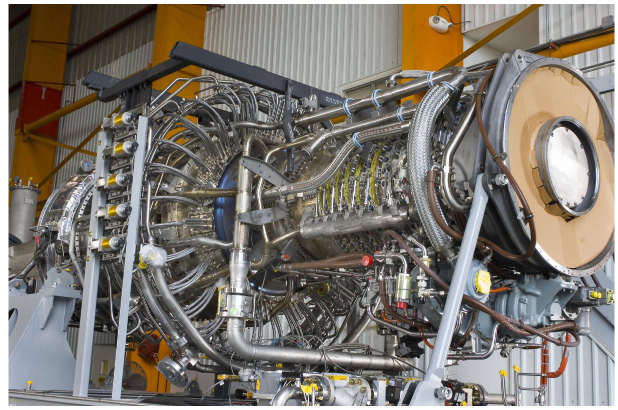

FIGURE 3. LM 2500 + G4

* 1.1) Output : 46, 123 kW versus 52, 689 kW
* 1.2) SFC : 202.7 g/kW hour versus 203.6 g/kW hour
* 1.3) Heat rate : 8675 kJ/kW hour versus 8773 kJ/kW
* 1.4) Exhaust gas flow : 130 kg/sec versus 139 kg/sec
* 1.5) Exhaust gas temperature : 456 degree centigrade versus 494 degree centigrade
* 1.6) Power turbine speed : 3600 rpm versus 3850 rpm

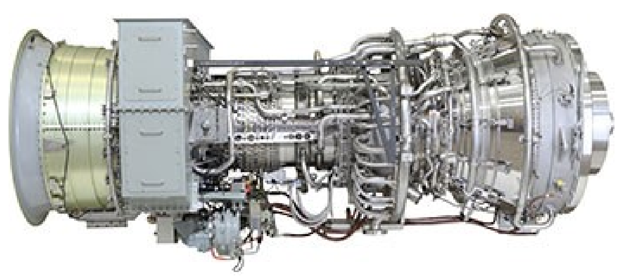

FIGURE 4. LM 6000 PC

5) LM 500

Utilized for low power requirements ,the very unique cycle, 2-shaft LM500 provides aero coupled power turbine, and is similar in designing to GEs proven LM2500 gas turbine. The LM500 is basically/essentially a CF34 engine without having its very own unique fan and is very similar in materials being used.

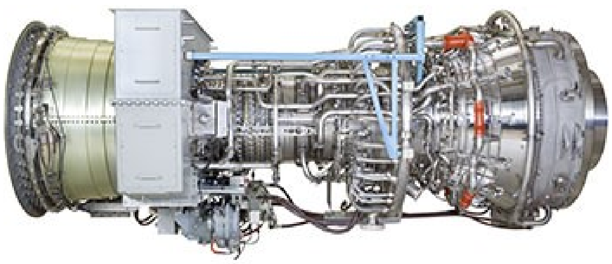

FIGURE 5. LM 6000 PG

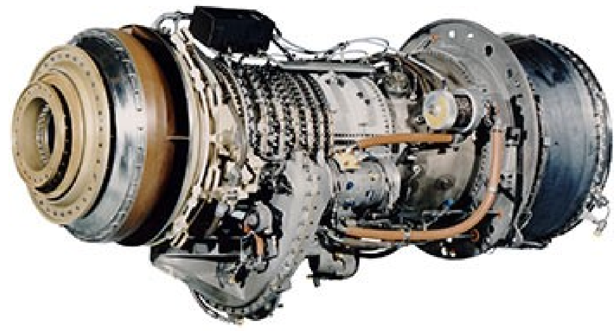

FIGURE 6. LM 500

The LM500 utilizes a changeable stator compressor which is driven by aircooled, 2 stage turbine. The LM500 has the latest in proven designing technological advancement /enhancement and corrosion-resistant material so as to provide mature designs with greater reliability and life of the components. This gas turbine is ideal for marine applications which require less weight and fuel economies. The LM500 is best suited for patrol boats and hydrofoils, as well as available and used as a military generator set.

TECHNICAL DATA

∗ 1.1) Output : 4750 kW
∗ 1.2) SFC : 269.5 g/kW hour
∗ 1.3) Heat rate : 11,520 kJ/kW hour
∗ 1.4) Exhaust gas flow : 16.4 kg/sec
∗ 1.5) Exhaust gas temperature : 565 degree centigrade
∗ 1.6) Angular speed : 7000 rpm

NOW CONSIDERING ROLLS ROYCE ENGINES IN THE MARINE ENGINEERING DOMAIN

As compared to the GE Aviation, Rolls Royce has lesser gas turbine engines to cater to the marine engineering domain. However, it has produced some certain gas turbine engines such as the MT7 and MT30 gas turbine engine which are pretty much worthy of being discussed.

MT7 and MT30

MT7 and MT30 ON GROUNDS OF TECHNICAL DATA

(1) MT7

∗ 1.1) Power output : 4 to 5 MW
∗ 1.2) Rotation and rpm : Anticlockwise and 15000 rpm
∗ 1.3) Length : 1500 mm
∗ 1.4) Fuel : Marine diesel , kerosene and F76 Military diesel

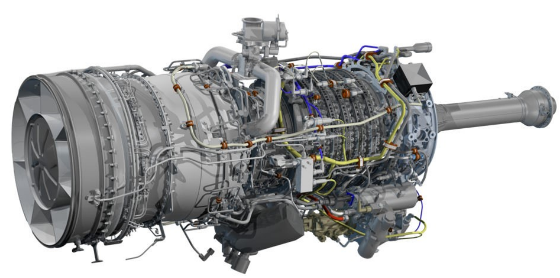

FIGURE 7. MT 7

(2) MT 30

∗ 1.1) Power : 30 to 40 MW
∗ 1.2) Dimensions : 8.7 X 2.66 X 3.6 all in m
∗ 1.3) Weight : 6500 kg unpackaged and 30000 kg packaged
∗ 1.4) Output shaft rpm : 2800 to 3600 in mechanical drive

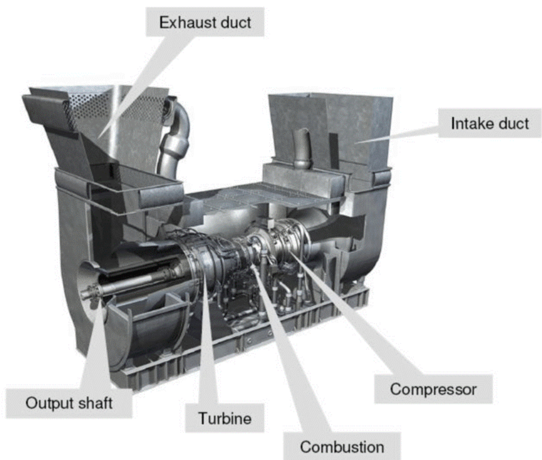

FIGURE 8. MT 30

CONCLUSION AND INFERENCES

A gas turbine engine is a type of internal combustion engine which utilizes the mixture of air and fuel to produce energy. It basically has an upstream rotating compressor coupled with a downstream turbine with the combustion chamber/unit in between. As shown, a gas turbine engine is a one of its kind engine which has mainly 3 parts: the compressor, the combustion chamber and the turbine. Here we only attempt to summarize the functions of the various parts without much technicality being involved.

1) The compressor:
The compressor is where the air intake occurs in the turbine. The air is then compressed and hence its pressure increases. This increase in the pressure of air helps in creating a better air fuel mixture in the combustion chamber.

2) The combustion chamber:
The combustion chamber is where the fuel is mixed with the air that comes through the compressor . This fuel air mixture which now forms is then burnt in the combustion chamber. The combustion chamber and the process of combustion provides energy to these molecules which would prove to be helpful in creation of energy in the turbine section.

3) The turbine:
In the turbine the mixture which passes the stage 1 and stage 2 of the marine gas turbine engine enter together. In the turbine there are a series of blades which are connected to a common shaft. These blades are arranged at such an angle that the ignited air causes them to move, thereby rotating the shaft.

These marine gas turbine engines have indeed been instrumental in a number of applications. Also the content to a certain extent helps us to understand the core of marine engineering as a distinguished branch of engineering altogether.

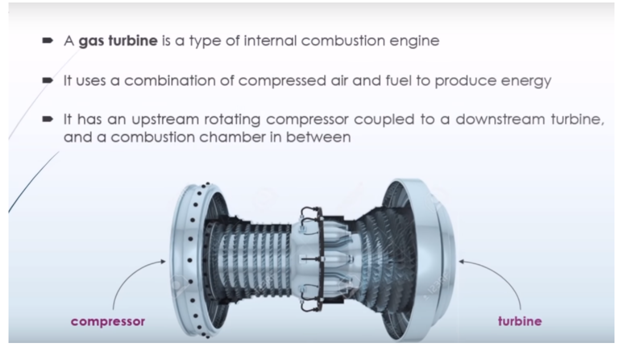

FIGURE 9. IN GENERAL GAS TURBINE ENGINE

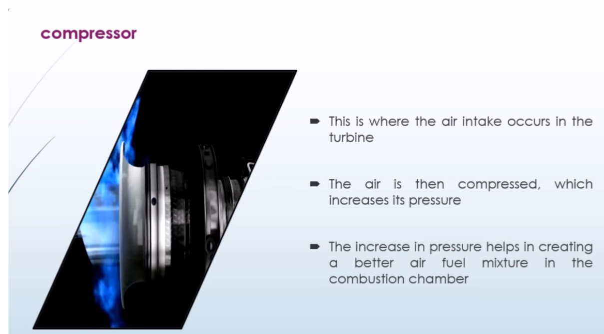

FIGURE 10. COMPRESSOR

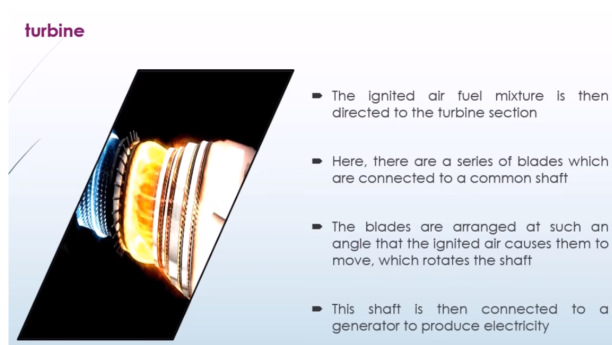

FIGURE 11. TURBINE

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