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GAS TURBINE ENGINE : A BRIEF OVERVIEW

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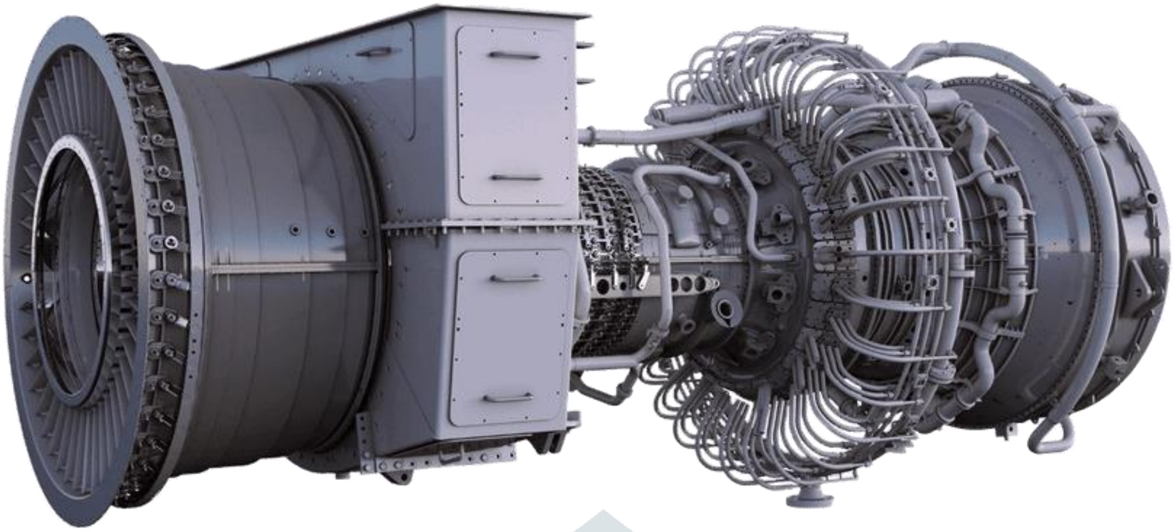
ABSTRACT

Gas turbine engines are known for their efficiency, power-to-weight ratio, and adaptability to a wide range of applications, making them an exemplary technological success in propulsion. This overview reviews the basic concepts and mechanisms of operation of gas turbine engines, focusing on the thermodynamic processes that control their operation. Important parts, including the exhaust system, turbine, combustion chamber and compressor, are presented in detail to show how they contribute to the process of transforming fuel energy into useful mechanical work. From the first aviation engines to the most recent turbomachines used in industry and power generation, gas turbine technology has evolved over time. Challenges such as improving efficiency, reducing emissions and preserving material durability are being addressed through ongoing research and development initiatives. After all, the gas turbine engine will always influence the future. This paper gives the brief overview of gas-turbine engine.

KEYWORDS : PROPULSION, THERMODYNAMICS, BRAYTON CYCLE, COMPRESSORS, COMBUSTION CHAMBERS, INLETS, NOZZLE, TURBINE, COMBUSTION, EXHAUST, EFFICIENCY

INTRODUCTION

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in between. The compressor, which draws air into the engine, pressurizes it, and feeds it to the combustion chamber at speeds of hundreds of miles per hour. The combustion chamber, typically made up of a ring of fuel injectors that inject a steady stream of fuel into combustion chambers where it mixes with the air. The mixture is burned at temperatures of more than 2000 degrees F. The combustion produces a high temperature, high pressure gas stream that enters and expands through the turbine section. The turbine is an intricate array of alternate stationary and rotating aerofoil-section blades. As hot combustion gas expands through the turbine, it spins the rotating blades. The rotating blades perform a dual function: they drive the compressor to draw more pressurized air into the combustion section, and they spin a generator to produce electricity.



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Hero LM 6000 Gas Turbine

OPERATING PRINCIPLE OF GAS TURBINE ENGINE

The basic gas turbine engine is described by the idealized Brayton air cycle. Air enters the air compressor (also called "gas producer") at point 1 under normal atmospheric pressure and temperature, P1 and T1. It is then compressed isentropically to point 2, where the pressure and temperature are now P2 and T2. From point 2, air flows into the combustion chamber where fuel is injected and burned at constant pressure, causing the temperature to increase to T3 and the volume to expand to V3. From the combustion chamber, the heated gases enter the power turbine, where they perform work by rotating the output power shaft. These gases expand to a pressure close to atmospheric pressure and are expelled at point 4 at a temperature above atmospheric pressure. Ideally, it would be possible to continuously flow the same fluid through this circuit and the transition from point 4 to point 1 would be a cooling process. Basically, this step is accomplished by exhaling into the atmosphere and taking in a new charge of air. In this cycle, about 30% of the fuel used is available as power. In addition, about 30% are used to control air compressors, 30% are included in hot exhaust gases and 10% are lost due to radiation and lubrication system. The simple turbines for industrial guests of the cycle burn more fuel than comparable moving machines. However, there are various methods available to reduce direct fuel consumption or to use the exhaust heat available to reduce the total fuel requirements for the structures. Three methods available are the regeneration, the extraction of the heat of waste and the processing of the combined cycle. Regeneration or recuperation uses a heat exchanger in which the exhaust heat is recovered to preheat the compressed intake air before the combustion chamber. The increased combustion air temperature reduces the fuel required to maintain the inlet temperatures of the power turbine. This heat recovery can increase the turbine's thermal efficiency to approximately 35 to 40%. The available horsepower output of the unit will drop slightly because of increased pressure losses due to the regenerator. Initial costs and additional maintenance expense of a regenerative cycle usually outweigh its advantages for most producing installations. However, where fuel prices are high and there are no waste heat users, the use of the regenerative cycle should be considered. The energy in the turbine exhaust stream can also be used to generate steam. This is called a combined cycle because mechanical energy is available from both the power turbine output and the steam turbine output. The energy used to drive the steam turbine contributes to the overall thermal efficiency because the steam is generated without additional fuel consumption. A combined cycle system can increase the overall thermal efficiency up to 40%.

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Working of a Gas-Turbine Engine

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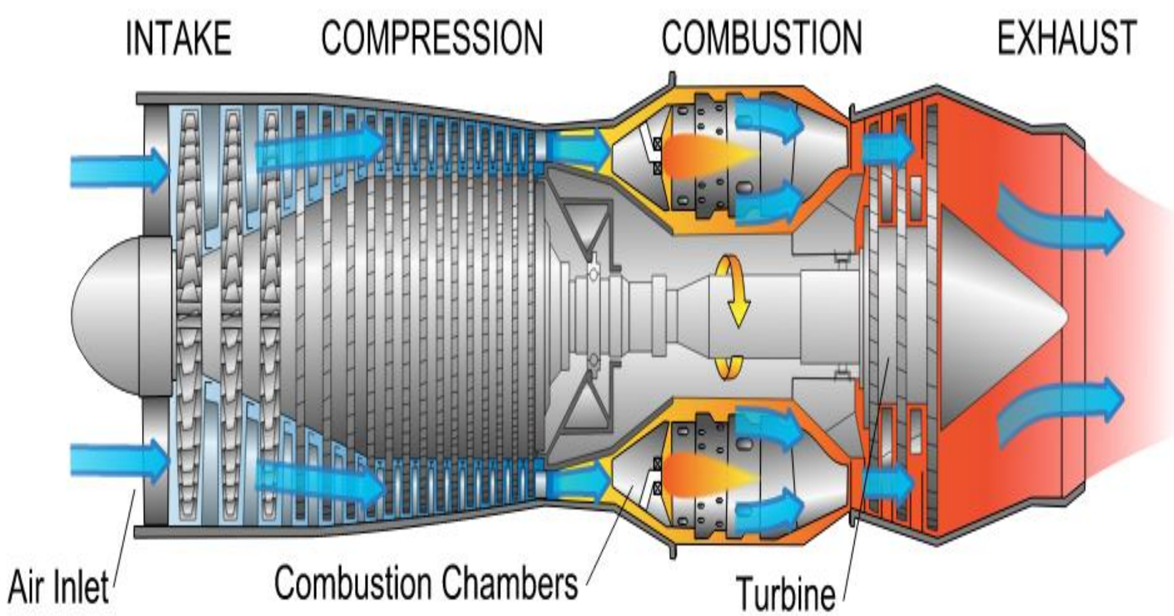
Process diagrams for the Brayton cycle.

TYPES OF GAS-TURBINE ENGINE

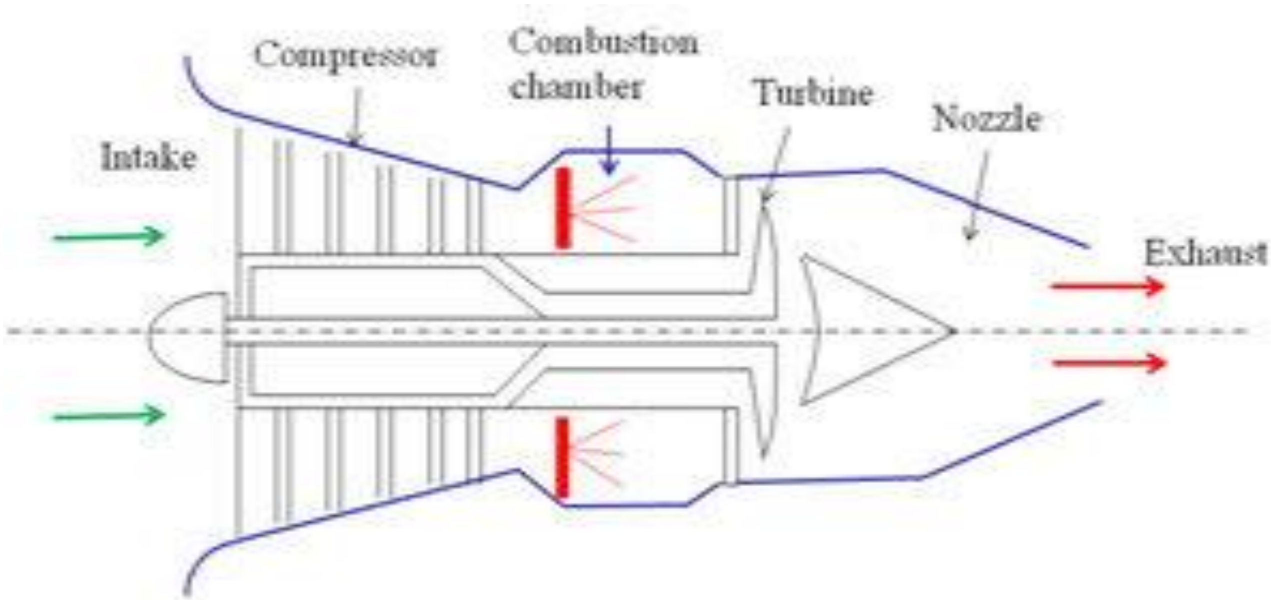
Here are basic types of gas-turbine engine which consists of many components.

1. Turbojet Engine
2. Turbofan Engine
3. Turboprop Engine
4. Turboshaft Engine
5. Ram-jet Engine



TURBOJET ENGINE

By adding the nozzle and the inlet to the gas generator basically a turbojet engine is constructed. Von Ohain (first flight, August 27, 1939) and Whittle (first flight, May 15, 1941) were the first to deploy the turbojet as an aircraft propulsion system.



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Schematic of simple turbojet engine

WORKING OF TURBOJET ENGINE

Air is compressed in the compressor and inlet of a turbojet, fuel is mixed with the air and burned in the combustor, and the gas stream is expanded through the turbine and nozzle to generate thrust. The compressor is turned by the expansion of gas through the turbine. The engine's ability to convert internal energy to kinetic energy results in net thrust. The work being done on the air causes an increase in temperature and pressure in the compressor portion. Temperature of the gas is further increased by burning fuel into the compressor portion. The turbine segment converts energy from the gas stream to shaft power, which turns the compressor. Expansion removes energy, resulting in lower temperatures and pressure. The nozzle expands the gas stream, resulting in significant exit kinetic energy. The engine's parts must perform efficiently to create maximum thrust with little weight.

COMPONENTS OF TURBO-JET ENGINE

Compressor: Draws in and compresses air to prepare it for combustion.

Combustion System: Combines fuel and compressed air and ignites them, producing hot gasses.

Gas Producer Turbine: Extracts energy from hot gases and converts it into mechanical energy.

Power Turbine : The power turbine converts the remaining energy from the hot gases into mechanical energy, which drives the output shaft.

Rotor: Converts the turbine's mechanical energy into rotational energy.

Housing: Houses the compressor, combustion system, and turbine and provides structural support and seals. Accessory Drive Assembly: Driven by the compressor, this assembly powers components such as engine lubricating oil and fuel pumps.

Propellant nozzle: converts the remaining energy of the turbine exhaust into a high-speed jet, producing thrust (in turbojet engines). Cooling system: As it provides air or bleeding to blades with turbines, blades, and disk cooling, you can increase the temperature of turbine input.

Secondary Air System: The air cooling of the turbine, the flow of the rolling cavity, and the hollow are emphasized to ensure the lifespan of rotors and bearings.

COMPRESSORS

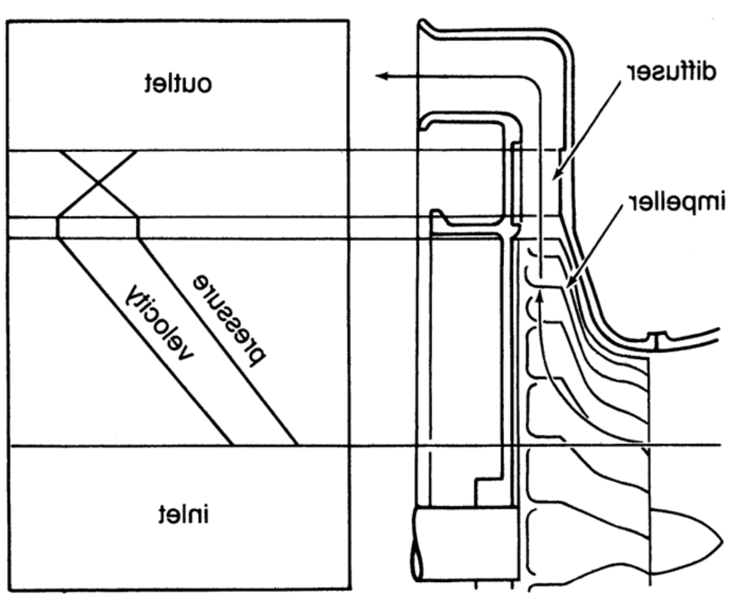
1.CENTRIFUGAL COMPRESSORS

Centrifugal compressors are used in small gas turbines and the driven units in most gas compressor trains. These are an integral part of petrochemical industry
large tolerance of process fluctuations. Centrifugal compressors range in pressure ratios of 1:3 per stage to as high as 12:1 on experimental models. Centrifugal compressors in general are used for high-pressure ratios and lower flow rates compared to lower-stage pressure ratios and higher-flow rates in axial compressors.

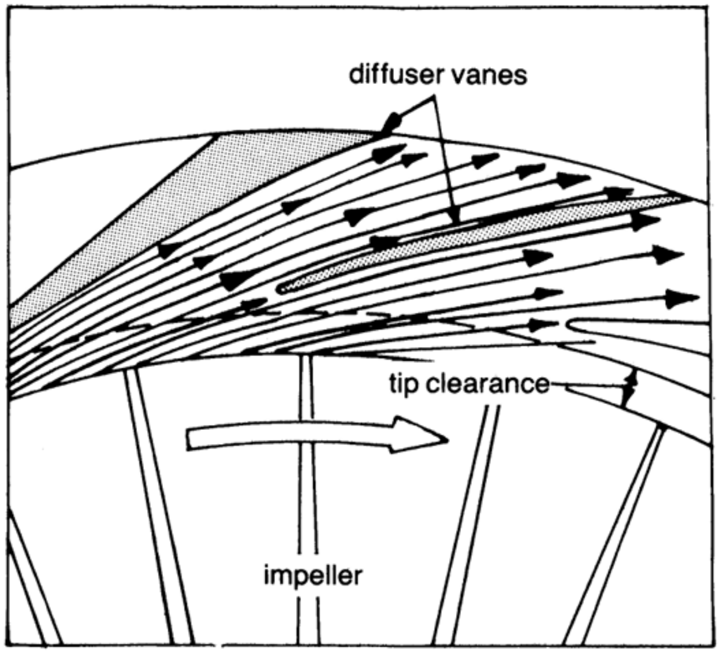
WORKING OF CENTRIFUGAL COMPRESSORS

Centrifugal compressors the fluid is forced through the impeller by rotating impeller blades. The velocity of the fluid is converted to pressure partially in the impeller and partially in the stationary diffusers. Most of the velocity leaving the impeller is converted to pressure energy in the diffuser , the diffuser consists essentially of vanes which are tangentially to the impeller , these vane passages to convert the velocity head into pressure energy. The inner edges of the vanes are in line with direction of the resultant flow.

Pressure and velocity through a centrifugal compessor



Flow entering a vaned diffuser



2. AXIAL COMPRESSORS

An axial compressor is a type of gas compressor that constantly pressurizes gases using a revolving, airfoil-based construction. In this structure, the gas flows parallel to the axis of rotation, distinguishing it from other types of compressors, such as centrifugal ones. The action is divided into phases, each consisting of a rotor (spinning blades) that accelerates the gas and a stator (stationary blades) that diffuses the flow, converting kinetic energy into higher pressure.

Axial compressors are well-known for their great efficiency and ability to manage high mass flow rates, making them ideal for use in gas turbines, jet engines, and a variety of industrial operations.

WORKING OF AXIAL COMPRESSORS

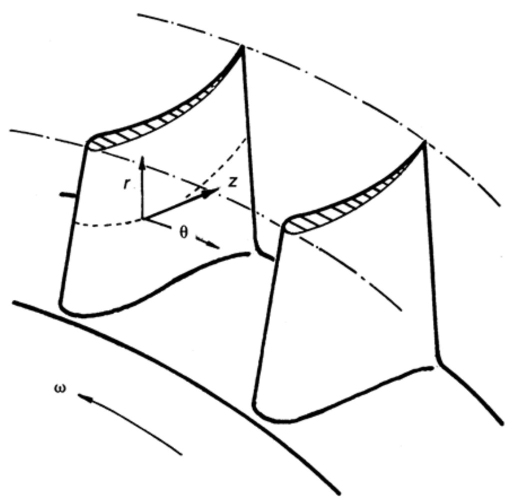
1. Basic Structure: An axial compressor consists of multiple stages, each comprising a rotor (a series of rotating blades) and a stator (stationary blades). The rotor accelerates the incoming air, while the stator diffuses the airflow to convert kinetic energy into increased pressure.

2. **Flow Dynamics**: Air enters the compressor in an axial direction, and as it passes through each stage, its pressure increases incrementally. The typical pressure increase per stage ranges from 1.1:1 to 1.4:1. This allows for substantial overall pressure increases, achieving ratios of up to 40:1 in aerospace applications and around 30:1 in industrial settings.

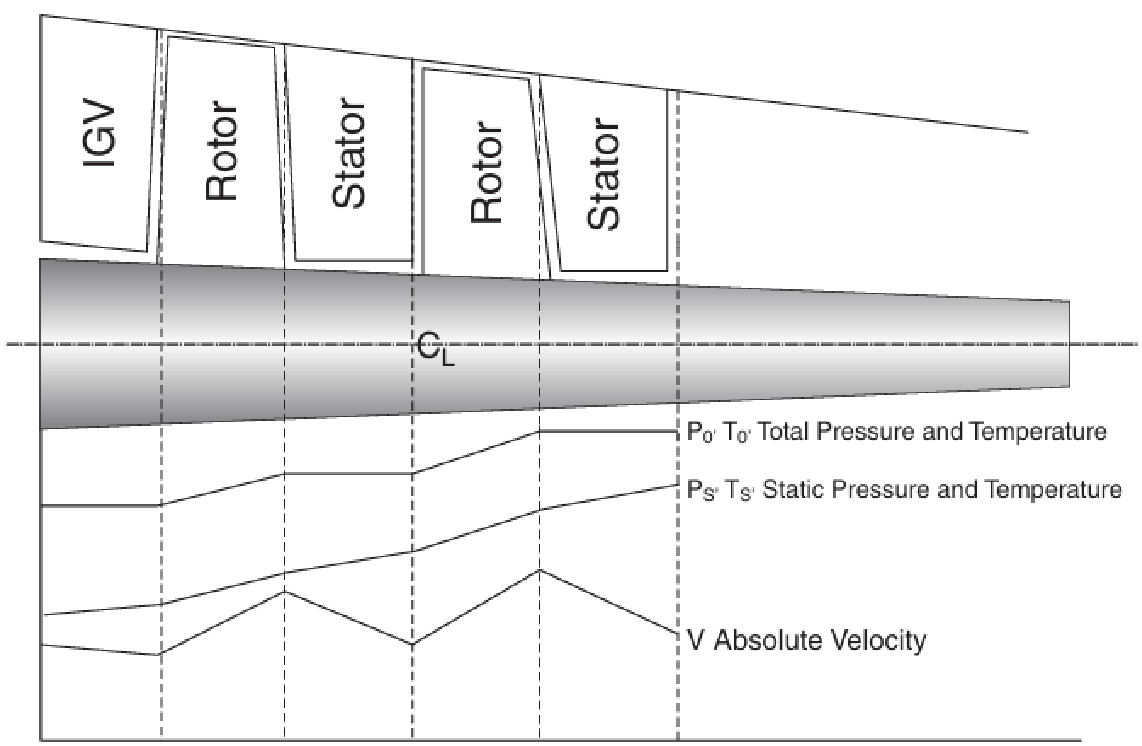
3. Inlet and Exit Guide Vanes: To optimize airflow and ensure the correct angle of entry into the rotor, axial compressors often incorporate Inlet Guide Vanes (IGVs) at the entrance. Similarly, Exit Guide Vanes (EGVs) are used at the compressor's exit to further control the flow before it enters the combustion chamber.

4. Performance Characteristics: The efficiency of axial compressors can be very high, often exceeding 90% in optimal conditions. The performance is influenced by factors such as the number of stages, blade design, and operating conditions.

5. Advancements: Recent developments in axial compressor technology focus on increasing pressure ratios, improving materials, and enhancing cooling techniques. These advancements are crucial for improving the overall efficiency of gas turbines, which are increasingly required to meet stringent environmental regulations.



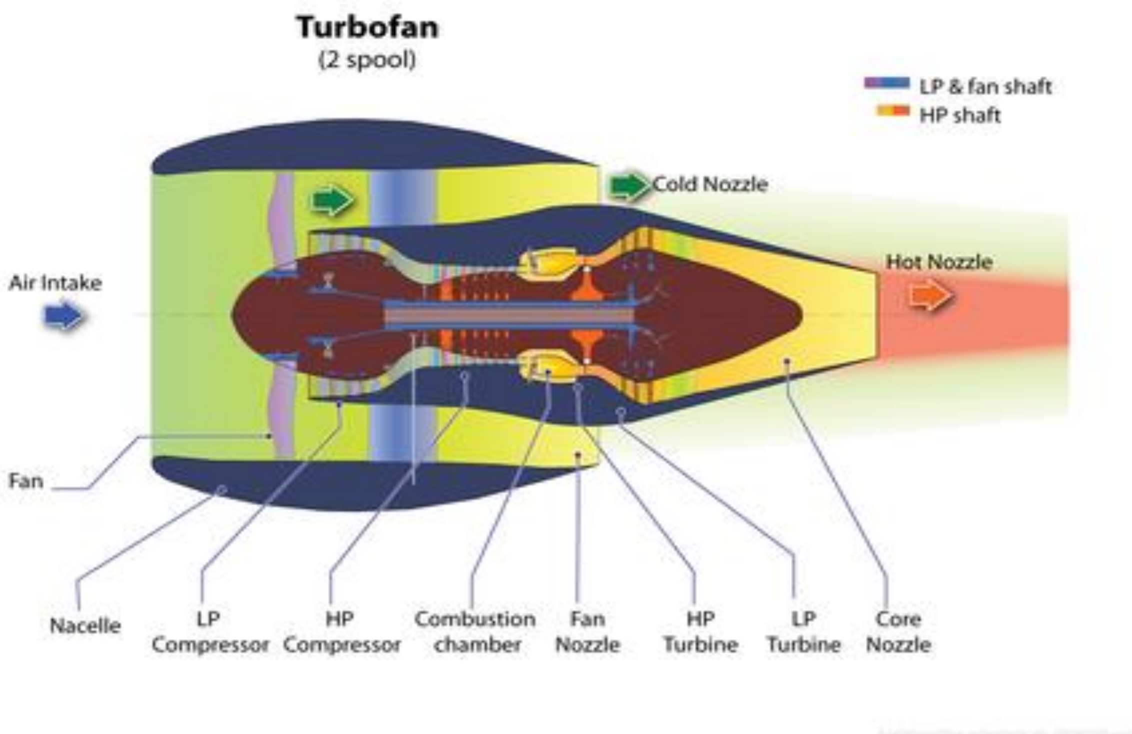
Co-ordinate system of axial flow compressor



Variation of enthalpy, velocity and pressure through an axial flow compressor

TURBO-FAN ENGINE

The turbofan engine consists of an inlet, a fan, a gas generator and a nozzle.A section is shown in the turbofanof the turbine's work is used to power the fan. Generally the turbofanThe engine is more economical and efficient than the turbojet engine to a limited extent kingdom of flight. Thrust-specific fuel consumption is lower for turbofans and indicates greater fuel economy operation. The turbofan also accelerates a larger air mass to a lower speed compared to a turbojet for greater propulsion efficiency. The frontal surface of a turbofan is quite large compared to that of a turbojet, and for this reason it results in more resistance and more weight. The impeller diameter is also aerodynamically limited when compressibility effects occur.



Schematic diagram illustrating a modern 2-spool turbofan engine installation in a nacelle

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WORKING OF TURBO-FAN ENGINE

Air Intake: Air enters the engine through the fan, which accelerates a significant portion of it (bypass air).

Compression: The remaining air (core air) is compressed by the compressor stages.

Combustion: Fuel is added to the compressed air and ignited in the combustion chamber, producing hot gases.

Expansion: The hot gases expand through the turbines, extracting energy and driving the compressor and fan.

Thrust Production: The bypass air, now accelerated by the fan, and the hot exhaust gases from the nozzle combine to produce thrust.

COMPONENTS OF TURBO-FAN ENGINE

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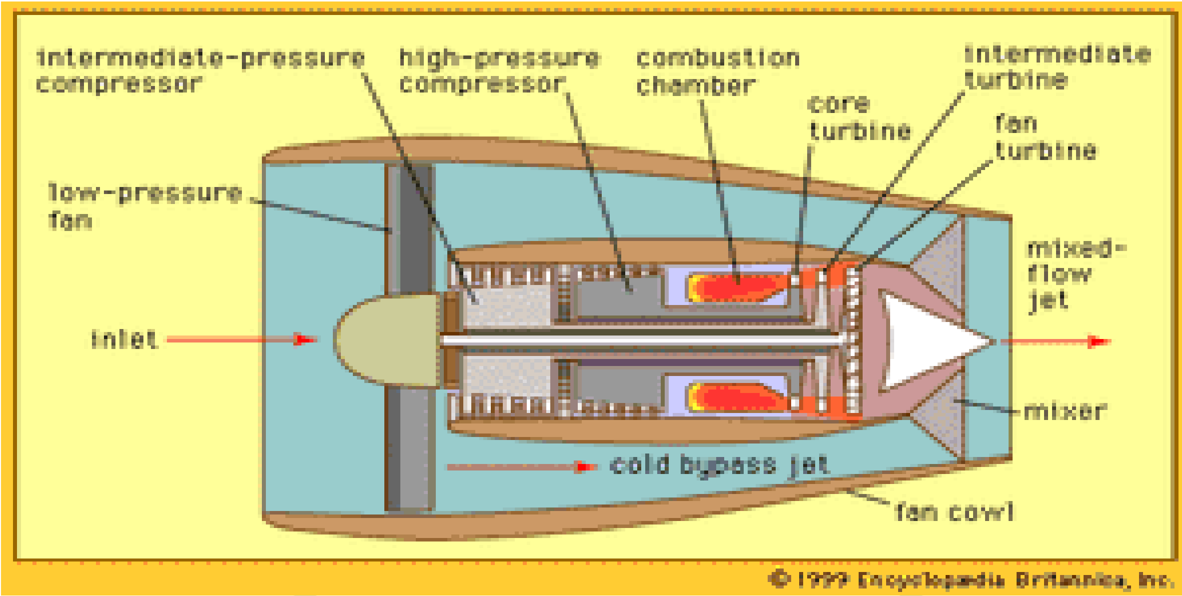

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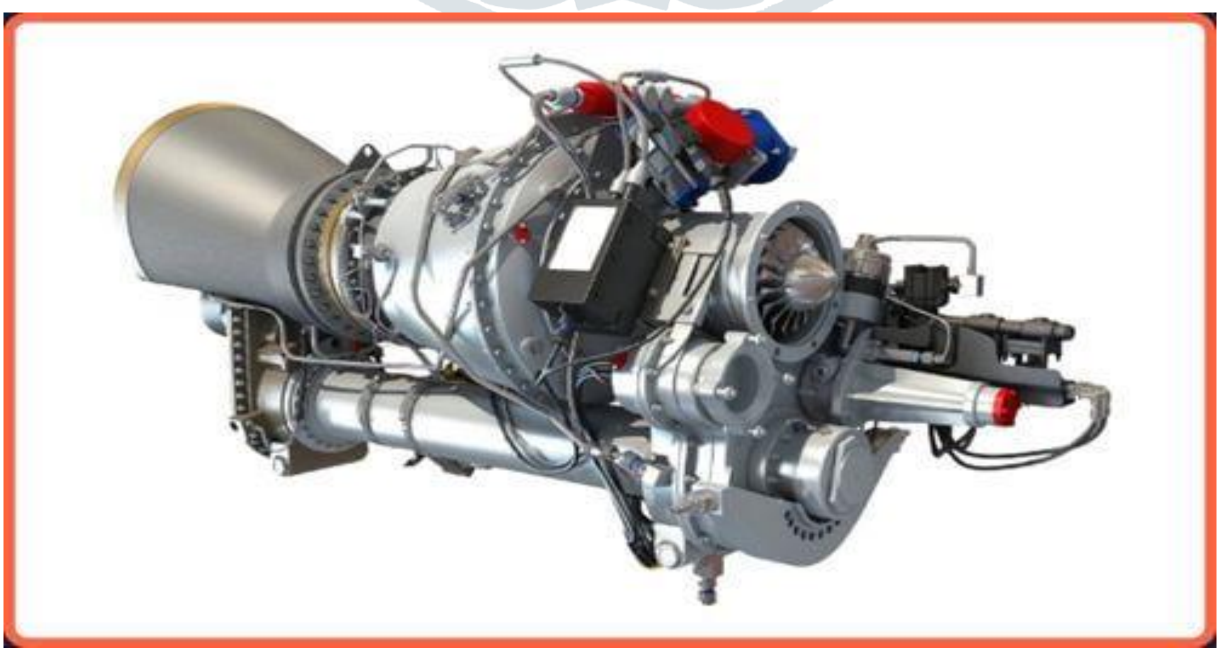
Working of Turbo-fan Engine

TURBOSHAFT ENGINE

The turboshaft engine generates power from the shaft to run the machine rather than creating thrust to fly the aircraft. Turboshaft engines are commonly used in tiny applications, such as helicopters and other power units.The turboshaft uses the same idea as the turbojet used to propel the aircraft to generate energy for the engine, and a compressor will be installed.The main distinction between a turbojet engine and a turboshaft engine is that the former has a power av section. It also has an output shaft and a turbine, which have been integrated into the design.



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WORKING OF TURBO-SHAFT ENGINE

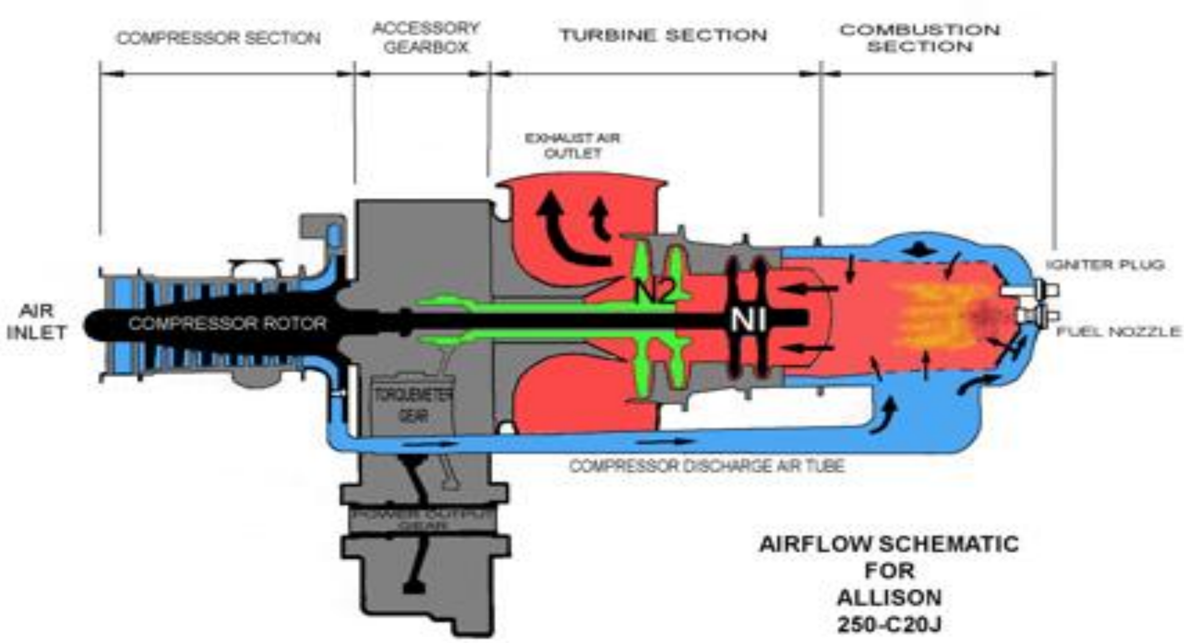
Induction: Air is drawn into the compressor

Compression: Air is compressed and mixed with fuel

Combustion: Fuel-air mixture ignites, producing hot gases

Expansion: Hot gases expand through the turbine, generating power

Exhaust: Exhaust gases are directed to a turbine or nozzle, converting remaining energy into heat



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COMPONENTS OF TURBO-SHAFT ENGINE

Compressor: Increases air pressure

Combustion Chamber: Adds energy through combustion

Turbine: Extracts power from hot gases

Gearbox: Transfers power to the output shaft

RAMJET ENGINE

Ramjet is an air-breathing jet engine with no major moving parts. It uses the craft's forward momentum to suck in air and a specially formed intake tube to compress it for burning. After gasoline is sprayed into the engine and ignited, combustion is self-sustaining. As with other jet engines, forward thrust is generated by the rearward surge of hot exhaust gases.

Ramjets perform best at Mach 2 (twice the speed of sound) and above. Ramjets generate no static thrust, hence some means of propelling them at high speeds are required.

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leduc 010 ramjet prototype

COMPONENTS OF RAMJET ENGINE

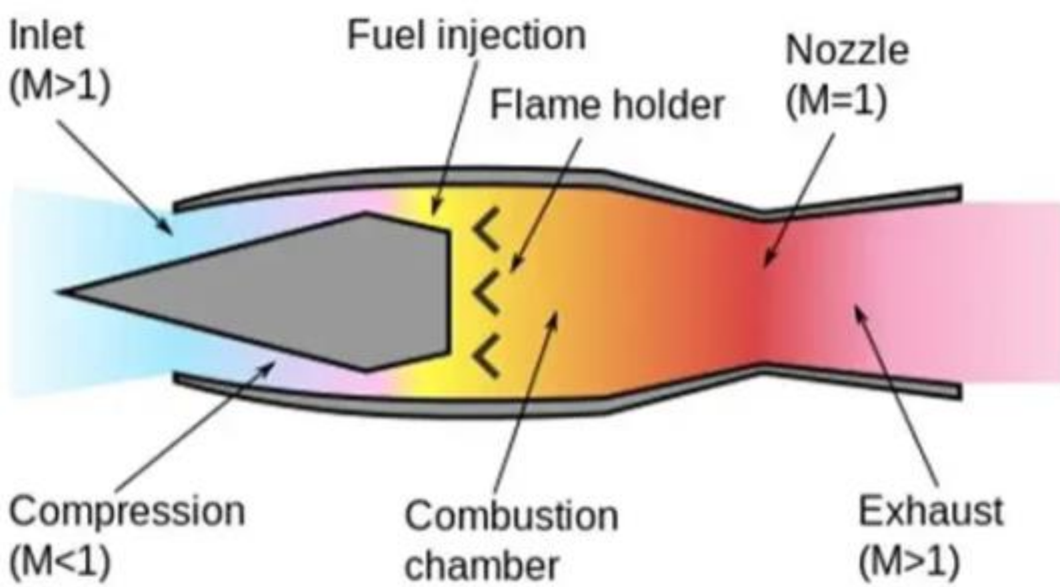
Inlet: Captures and compresses incoming air using shockwaves created by the intake configuration.

Combustion Chamber (or Combustor): Mixes compressed air with fuel and ignites it, sustaining combustion.

Exhaust Nozzle: Expels combustion products to produce thrust.

WORKING OF RAMJET ENGINE

The ramjet engine consists of an inlet, a combustion zone, and a nozzle. The ramjet does not have the compressor and turbine as the turbojet does. Air enters the inlet where it is compressed and then enters the combustion zone where it is mixed with the fuel and burned. The hot gases are then expelled through the nozzle, developing thrust. The operation of the ramjet depends upon the inlet to decelerate the incoming air to raise the pressure in the combustion zone. The increased pressure allows the ramjet to operate. The higher the speed of the incoming air, the more the pressure increases. For this reason, the ramjet operates best at high supersonic speeds. At subsonic speeds, the ramjet is inefficient and to start the ramjet, air must enter the inlet at a relatively higher speed.



Ramjet Engine

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CONCLUSION

The results suggest that while gas turbine engines are advantageous for high-performance applications, their cost and complexity require careful consideration in design and operational planning. Future technological developments could potentially mitigate some of these challenges, paving the way for wider adoption across industries.

TURBOPROP ENGINE

A turboprop is a gas turbine engine that primarily powers a propeller as the thrust generator. It varies from a jet engine in that the engine generates very little thrust compared to the propeller's contribution. The turboprop engine produces significantly more power per unit weight than a piston engine. A turboprop is a gas turbine engine that uses the power generated by the combustion of fuel to rotate a propeller. The momentum generated by the propellers serves as the aircraft's only thrust source. Turboprop engines power a wide range of aircraft, from single-engine land planes to multi-engine oversea aircraft.

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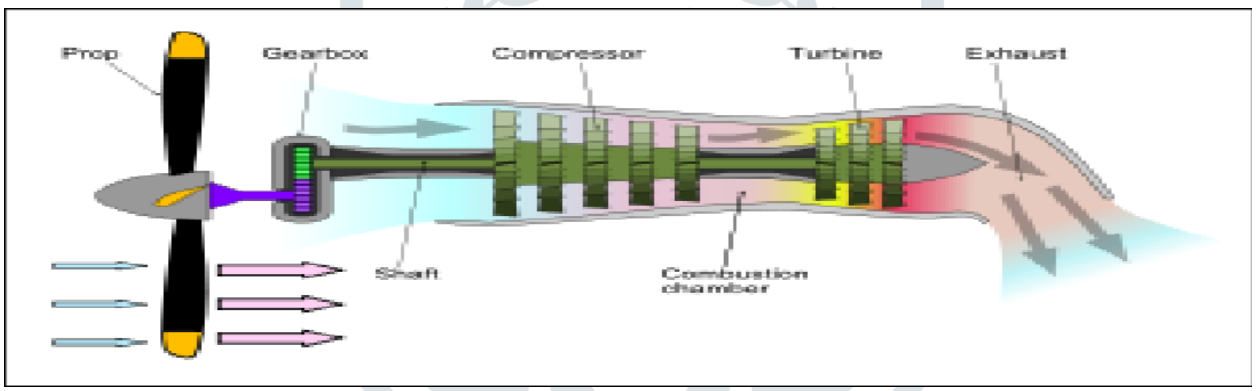
TURBO-PROP ENGINE



https://www.researchgate.net/profile/Anees-Naji/publication/319451328/figure/fig2/AS:667845331542039@1536238143900/Schematic-diagram-showing-the-operation-of-a-turboprop-engine-28.png

DIAGRAM OF TURBO-PROP ENGINE

COMPONENTS OF TURBO-PROP ENGINE

Propeller: The propeller generates thrust, driven by the turbine's output shaft.

Gear Reduction Unit: A gearbox that reduces the high-speed output of the turbine to match the propeller's rotational speed.

Compressor: Compresses air, which is then mixed with fuel in the combustor.

Combustor: A chamber where fuel is added to the compressed air and ignited, producing hot gas.

Gas Turbine: A turbine that extracts energy from the hot gas produced in the combustor, converting it into mechanical energy.

Nozzles: Also known as propelling nozzles, these are responsible for accelerating the exhaust gases, generating additional thrust.

WORKING OF TURBO-PROP ENGINE

Air is sucked into the compressor via a diffuser, and its kinetic energy is transformed to static pressure.The compressed air next enters the combustor, where fuel is injected and ignited to create a high-temperature, high-pressure gas.The heated gas expands through the turbine, moving the blades and producing shaft power.The turbine shaft is coupled to the gear reduction unit, which slows the high-speed spinning to a speed sufficient for the propeller.The propeller transforms shaft power into thrust, which propels the airplane forward.Exhaust gases exit the engine through nozzles, accounting for a minor part of total thrust.

REFERENCES

1. Jet and Gas Turbine Engines Kenneth W. Bushell, in Encyclopedia of Physical Science and Technology (Third Edition), 2003

2. Prime Movers* Ken Arnold, Maurice Stewart, in Surface Production Operations: Design of Gas-Handling Systems and Facilities (Second Edition), 1999

3. Development and progress in aeroacoustic noise reduction on turbofan aeroengines Xiran Liu, ... Xiaofeng Sun, in Progress in Aerospace Sciences, 2022

4. Elements of Gas Turbine Propulsion Jack D. Mattingly (Department of Mechanical and Manufacturing Engineering) Seattle University With a Foreword By Hans van O Hain

5. Elements of Propulsion : Gas Turbine & Rockets Jack D. Mattingly (Professor Emeritus) Department of Mechanical Engineering Seattle University, Seattle, Washington With a Foreword By Hans van O Hain (German Inventor of Jet Engine)

6. Gas Turbine Engineering Handbook (2nd Edition) Meherwan P. Boyce Managing Partner, The Boyce Consultancy Fellow, American Society of Mechanical Engineers Fellow, Institute of Diesel and Gas Turbine Engineers, U.K

7. Thermal Analysis of a gas-turbine cycle for a turbojet engine Rana Adil Abdul-Nabe (Teacher, Ministry of Higher Education, Institute of the Musaib Technical Institute, Republic of Iraq) Dr. Mohammad Tariq (Assistant Professor, Department of Mechanical Engineering, SSET, SHIATS-DU, Allahabad, India, 211007)
https://www.researchgate.net/publication/341188588_THERMAL_ANALYSIS_OF_A_GAS_TURBINE_CYCLE_FOR_A_TURBOJET_ENGINE_INTERNATIONAL_JOURNAL_OF_ADVANCED_RESEARCH_IN_ENGINEERING_AND_TECHNOLOGY_IJARET_IJARET_C_I_A_E_M_E

8. Selecting the Power Plant (Snorri Gudmundsson BSc(AE), MSc(AE), FAA DER(ret.), in General Aviation Aircraft Design, 2014)
https://doi.org/10.1016/B978-0-12-397308-5.00007-6

9. Parametric Analysis of a Turbofan Engine with Intercooling and Heat Recuperation(Anees Naji University of Al-Qadisiyah)
https://www.researchgate.net/publication/319451328_Parametric_Analysis_of_a_Turbofan_Engine_with_Intercooling_and_Heat_Recuperation