International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 12 Issue 7, July-2023, Impact Factor: 7.957

Advancements in Gas Turbine Engine Technology: A Conceptual Aspect

Shreya Mane

Department of Research and Development, Astroex Research Association, Deoria-274001, India

ABSTRACT

One of the most crucial internal combustion engines for modern transportation is the gas turbine. Any potential enhancements to the gas turbine engines' efficiency would reduce the global annual consumption of fossil fuels and, consequently, the emissions of harmful greenhouse gases. In order to enhance the performance of gas turbines, modelling and simulation have received a lot of attention in the aviation industry. Gas turbines are crucial for the generation of electricity and power. Due to their effectiveness, dependability, and versatility, gas turbine engines are essential in many different industries, including aviation, power generation, and marine propulsion. An extensive study and analysis of developments in gas turbine engine technology are presented in this presentation.

Keywords: Basic operation of gas turbine, working, advantages, disadvantages, applications.

INTRODUCTION

The most adaptable piece of turbo gear available today is the gas turbine. It can be employed in a variety of ways in crucial sectors like aviation, oil and gas, process facilities, power generation, and smaller allied industries. In essence, a gas turbine combines fuel that is burned with air that is compressed in the compressor module. A turbine is used to expand the resulting gases. The compressor, which is on the same shaft as the turbine, is driven by the turbine's shaft, which continues to rotate. Up until the turbine's rotation is up to design speed and can keep the entire unit operating, the first rotor motion is provided by a separate starter unit.An internal combustion engine that uses air as its operating fluid is called a gas turbine. The engine transfers chemical energy from fuel to mechanical energy by driving the engine and propeller with gaseous energy from the working fluid (air), which then propels the aircraft.In both aviation and the production of power, gas turbines are utilised in a wide range of applications. Because these engines can power large aircrafts and are economical to operate, they are particularly crucial for aviation. Today, a lot of focus has been placed on improving these engines' fuel efficiency and usability while lowering their noise levels. This accomplishes the goal of reducing emissions' negative effects on the environment and resource consumption. Gas turbine design and performance enhancement rely heavily on thermal and materials engineering.

Because they combine harsh circumstances in terms of rotational speed with high gas temperatures (up to 2100 K for military engines), gas turbines are among the most advanced technologies. Given that such a system's miniaturisation results in extraordinarily high rotational speeds (like 106 rpm), it creates serious technical challenges. Additionally, reducing the system's size adversely affects the flow and combustion process. Such devices require three-dimensional micro fabrication techniques and the exploration of novel materials.

A gas turbine engine, also known as a combustion turbine engine, is a type of internal combustion engine that converts the chemical energy of a fuel, typically a hydrocarbon-based fuel, into mechanical energy through the combustion process. Gas turbine engines are widely used in various applications, including aviation, power generation, marine propulsion, and industrial processes. A gas turbine is an engine made to transform the energy of a fuel into usable power, like mechanical power or a jet's high-speed thrust.

Essentially, a gas turbine is made up of a power conversion part and a gas generator section. Combustion turbine is another name for a gas turbine. An example of an internal combustion engine is that. It operates on the Brady Cycle principle. There are three primary divisions in it:

Compressor

Fluid is suctioned using compressors, which then transport the compressed fluid to the combustion chamber.

Combustor
A combustion chamber is a space where fuel and fluid combine and burn. The combustion by-products are then directed over the turbine.

Turbine
We obtain our work output with the aid of the turbine. When dealing with big, stable plants, the work output is often to achieve the output shaft work. The output of an aeroplane is to supply thrust.

Heat Exchangers
In order to disperse heat into the environment, heat exchanges are used in closed gas turbines. The cooled hot gas is forced to pass once again over the compressors.

BASIC OPERATIONS OF GAS TURBINES

An internal combustion engine is a gas turbine. The majority of today's passenger, freight, and military aircraft are propelled by gas turbine engines of various sizes and configurations. Intake, compressor, combustion chamber, turbine, and propelling nozzle are the main five parts of a turbine. Simple steps can be used to explain the operating concept. The compressor receives the air through the inlet and performs one or more compression stages before delivering the high-pressure air flow to the turbine inlet.

Fuel is then sprayed into the air and ignited in the combustion chamber to add energy. A high temperature flow made up of a combination of combustion gas and air is produced during combustion. In the turbine, the high-temperature, high-pressure gas expands to reach the exhaust pressure. One portion of the energy is transformed into rotational or kinetic energy, which results in the output of shaft work.

The compressor is driven in this way. The propelling nozzle's thrust is created by another component. The reaction of accelerating a mass of gas results in the mechanical force known as thrust [1,2]. Figure 1 displays a schematic representation of the engine configuration as well as typical temperature-entropy and pressure-volume diagrams for a gas turbine engine.

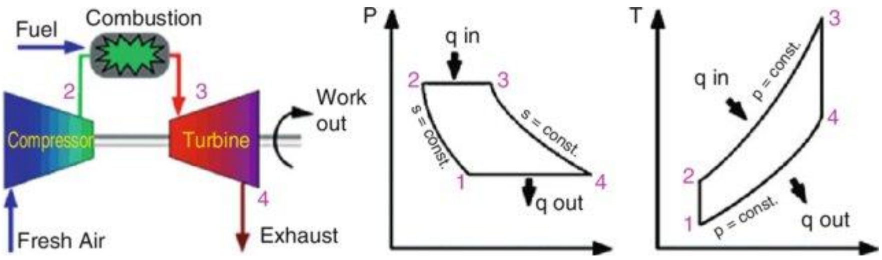

Fig 1. (a): Idealized Brayton cycle for gas turbines, (b): T-s Diagram, (c): P-V Diagram [3]

The air is forced into the turbines' compressors where it is combined with the fuel and burned under constant pressure. These make use of one or more compressors. The fuel that is injected is either liquid or gaseous in form. The hot gas that results from this is permitted to expand through the turbines to do the work. In general, the turbine's job is to extract energy from the gas leaving the combustion chamber at high pressure and high velocity. 60% of this work in efficient gas turbines goes towards air compression. The remaining effort can be used to generate electricity and mechanical power.

Working of Gas Turbine Engine
Gas turbines operate according to the Brayton Cycle, which compresses the air isentropically before burning it under continuous pressure, expanding it isentropically, and finally returning to the initial state.

a) **Isentropic Process**: In this method, pressurised air is drawn into the compressor.
b) **Isobaric Process**: Since the combustion chamber is open to flow in and out, the compressed air arrives there and is heated at a constant pressure while the fuel burns.
c) **Isentropic Process**: The heated, pressurised air then releases its energy by expanding via a turbine in the isentropic process (step c). The compressor is driven in part by the work that the turbine extracts.
d) **Exhaust:** Isobaric Process.

Turbojet
Frank Whittle of the Royal Air Force created the first centrifugal-flow turbojet in 1930, and Hans von Ohain of Germany also created a comparable engine that was patented in 1935 [4]. Due to their high exhaust speed, short

frontal area, and relative simplicity, turbojet engines have since become very ubiquitous and are still used in many medium-range cruise missiles.

A turbojet turbine is built to provide thrust to propel the aircraft and power to drive the compressor. To create a very powerful thrust jet, the entire gas flow is directed through the combustion chamber and the expansion of the exhaust gases in the propelling nozzle to atmospheric pressure. The exhaust jet of a turbojet gas turbine has a high exit velocity, which reduces its efficiency at low speeds. The specific fuel consumption is significant, especially at subsonic speeds (i.e., low speeds) [5].

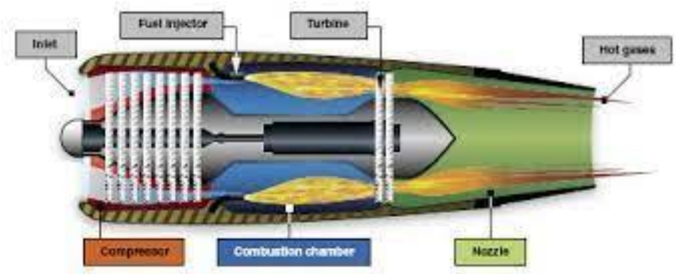

Fig. 2. Arrangement of a turbojet gas turbine [6]

The fouling of axial flow compressors is a critical operational issue, and gas turbine operators must take every precaution to prevent it, particularly in the deregulated and fiercely competitive power market. Additionally, it matters in the mechanical drive sector where a drop in gas turbine production has a direct impact on plant throughput. Foulants in the ppm range can deposit on the blading, severely degrading performance. Reduced airflow and compressor isentropic efficiency as a result of compressor fouling reduce the "rematching" of the gas turbine and compressor, which lowers power production and thermal efficiency.

Operating Conditions for Turbine Blades

The high-pressure turbine blade has drawn the most interest from academics because of the problem it presents in the gas turbine sector. For example, today's high pressure turbine blades receive compressed air bled from the compressor and it is injected to the turbine blades through small holes drilled on them, with the purpose of establishing a protection layer on the edge of the blades and ensuring that the blades are not damaged. This allows high pressure turbine blades to operate at increasingly high gas temperatures. [7].

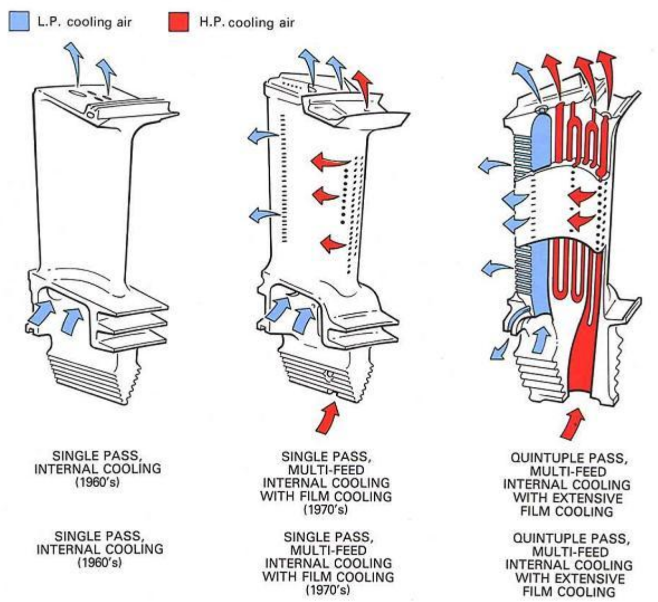

Fig. 3. High pressure turbine blades with internal cooling

Materials Used in Turbine Blades

The most cutting-edge and complex technology is used in every area of modern gas turbines, and because of their harsh operating conditions, construction materials are no exception. As previously stated, the point at the turbine inlet is the most challenging and difficult because of the numerous challenges present there, including the high pressure, high rotational speed, vibration, and extreme temperatures (1400°C to 1500°C). The blades in table 1 experience the effects of the aforementioned rush characteristics. [8].

Table 1. Severity of the different surface-related problems for gas turbine applications

	Oxidation	Hot Corrosion	Interdiffusion	Thermal Fatigue
Aircraft	Severe	Moderate	Severe	Severe
Land-based Power Generator	Moderate	Severe	Moderate	Light
Marine Engines	Moderate	Severe	Light	Moderate

Gas turbine blades are made using cutting-edge materials and contemporary alloys (superalloys) that contain up to ten significant alloying elements, but their microstructure is very simple; they are made of rectangular blocks of stone that are stacked in a regular pattern and held together by thin bands of cement. Tantalum has replaced the intermetallic form of titanium that was once utilised in this material (cement), which has changed throughout time. [9].Improvements in oxidation resistance and high temperature strength resulted from this adjustment. However, the nickel, which contains significant amounts of tungsten and rhenium, has undergone the most significant shift. These components work wonders to strengthen solutions.

Continuing Development

In the last few decades, turbine engines have been able to run at higher temperatures and, under the rules of thermodynamics, with higher efficiency thanks to thermally deposited ceramic coatings on metallic turbine blades. [10]. Turbine engines used for propulsion and power generation now operate better because to ceramic thermal barrier coating. The engine can operate at higher temperatures while minimising harmful effects on the metal turbine blades by covering them with a refractory insulating ceramic [11].

Advantages of Gas Turbines

1. It has very high power-to-weight ratio, compared to reciprocating engines.
2. It is smaller than most reciprocating engines of the same power rating.
3. It moves in one direction only, with far less vibration than a reciprocating engine.
4. Fewer moving parts than reciprocating engines.
5. Low operating pressures.
6. High operation speeds.
7. Low lubricating oil cost and consumption
8. Low lubricating oil cost and consumption

Disadvantages

1. Cost is much greater than for a similar-sized reciprocating engine since the materials must be stronger and more heat resistant. Machining operations are also more complex.
2. Usually less efficient than reciprocating engines, especially at idle.
3. Delayed response to changes in power settings.

Applications of Gas Turbine

Aviation

Gas turbine engines, specifically turbofan engines, are widely used in commercial and military aircraft for propulsion. Their high power-to-weight ratio, efficiency, and reliability make them ideal for powering aircraft of all sizes, ranging from small regional jets to large commercial airliners and military fighter jets.

Power Generation

Gas turbine engines play a significant role in electricity generation. They are employed in both standalone power plants and combined cycle power plants. In standalone power plants, gas turbines drive electrical generators directly, while in combined cycle plants, waste heat from the gas turbine is used to generate steam, which drives a steam turbine for additional electricity generation. Gas turbine-based power plants are efficient, flexible, and well-suited for peaking power generation and grid stability support.

Oil and Gas Industry

Gas turbine engines are extensively used in the oil and gas industry for various applications. The power compressors for natural gas pipeline transmission, drive pumps for oil and gas extraction, and provide energy for offshore platforms and floating production storage and offloading (FPSO) vessels. Gas turbines offer reliable and efficient energy solutions in demanding oil and gas operations.

Marine Propulsion
Gas turbine engines are employed in marine vessels, including naval ships, cruise liners, and high-speed ferries, for propulsion. Their compact design, high power output, and rapid response time make them suitable for applications where quick acceleration and high manoeuvrability are required.

Industrial Processes
Gas turbine engines are used in various industrial processes that require mechanical drive and power generation. They provide energy for compressors, pumps, and generators in industries such as chemical plants, refineries, manufacturing, and mining. Gas turbines are favoured for their efficiency, reliability, and ability to burn a variety of fuels.

District Heating and Cooling
Gas turbine engines can be utilized in combined heat and power (CHP) systems to provide district heating and cooling. In CHP applications, waste heat from the gas turbine is captured and used for space heating, water heating, and absorption chilling, improving overall energy efficiency and reducing environmental impact.

Emergency Power Systems
Gas turbine engines serve as backup power systems in critical facilities such as hospitals, data centers, and airports. These engines can quickly start and supply electricity during power outages or grid failures, ensuring uninterrupted operation of essential services.

Microturbines and Distributed Generation
Gas turbine-based microturbines are used for distributed generation in applications such as remote communities, residential complexes, and small-scale industrial operations. Microturbines provide localized power generation, reducing transmission losses and increasing energy efficiency.

CONCLUSION

Gas turbine engines continue to play a vital role in our modern society, driving progress in transportation, power generation, and industrial processes. The integration of advanced technologies, such as digital monitoring, predictive maintenance, and hybrid power systems, holds promise for even greater advancements in the future.Gas turbines are a versatile and effective power generation solution used in both industrial and aviation applications. This technology calls for better, more durable materials, particularly for the first row of turbines and combustion chambers, where temperatures can reach extraordinarily high levels.Gas turbine engines continue to play a vital role in our modern society, driving progress in transportation, power generation, and industrial processes. The integration of advanced technologies, such as digital monitoring, predictive maintenance, and hybrid power systems, holds promise for even greater advancements in the future.

REFERENCES

[1]. H. Rick, “Gasturbinen und Flugantriebe “, Springer Vieweg Verlag Berlin, 2013.
[2]. P. W. Philip and F. Paul, “Gas Turbine Performance”, 2nd ed., Blackwell Science Ltd Oxford, 2004.
[3]. National Aeronautics and Space Administration (2014) Gas Turbine Propulsion. Available from: http://www.grc.nasa.gov/WWW/k-12/airplane/turbine.html [Electronically accessed 11th January 2015].
[4]. T. James, “back to propellers”, Engineering & Technology, 4 (10), pp. 63-65, 2009.
[5]. P. W. Philip and F. Paul, “Gas Turbine Performance”, 2nd ed., Blackwell Science Ltd Oxford, 2004.
[6]. Flight Learnings (2011) Types of Turbine Engines. Available from http://www.flightlearnings.com/2010/03/06/types-of-turbine-engines/ [Electronically accessed 25th January 2015].
[7]. Kurt H. Stern Metallurgical and Ceramic Protective Coatings ISBN 0412544407 Chapman & Hall.
[8]. Miller, R.A “Thermal Barrier Coatings of Aircraft Engines: History and directions” Journal of Thermal Spray Technology 1997, pp 35 – 42.
[9]. Narendra B – Dahotre, T. S – Sudarshan Intermetallic and Ceramic Coatings ISBN 0824799135 CRC Press.
[10]. De William W. Bathie Fundamentals of Gas Turbines ISBN 0471311227 Wiley.
[11]. De Matthew J. Donachie, Stephen James Donachie Superalloys: A Technical Guide – Pag 319 ISBN 0871707497 Technology – 2002.