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By: REZOUG Mohammed El Hadi

**Comparative Study and CFD Simulation for a Gas Turbine Combustion Chamber
Using Hydrogen as an Alternative Fuel**

Sonatrach Compression Station SC3 – GPDF Gas Pipeline



Publicly defended on/...../....., in front of the jury composed of:

Mr. ROSTANE Brahim	Tlemcen University Center	President
Mr. BENMANSOUR Karim	Tlemcen University Center	Supervisor
Mr. LORABI Khaled	GPDF-SonatrachCo-Supervisor	
Mr. GUELLIL Hocine	Tlemcen University Center	Examine

Academic year: 2024 - 2025

DEDICATION

I dedicate this work to

-To my parents, who always encourage me to be the best I can be and make the right career choices. I'm where I am today thanks to them.

-To for my little sister.

-To my esteemed colleagues at the university.

Special thanks are extended to

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Mr. LAMRI Mohammed (*Operations Technician in Sonatrach company*)

Mr. CHAOUCH Hadj Ahmed (*instrumentation technician in Sonatrach company*)

Mr. KHOUANI TAHAR (*HSE Technician in Sonatrach company*)

Mr. SERIANE Boubeker (*Operations Technician in Sonatrach company*)

Mr. RAHATI Nour Eddine (*Operations Engineer in Sonatrach company*)

Mr. BAHOUSSI Abess (*Operations Technician in Sonatrach company*)

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Nomenclatures

GPDF: Gas Pedro Duren Farel

SC3: Station de Compression 3

PGT: Power Generation Turbine

LM 2500: Land Marine 2500

GG: Gas Generator

VGC: Gas Control Valve

FGS: Fuel Gas Security

VSR: Shut-off / Regulating Valve

Ui: three elements that make up the speed

e: internal energy

Yi: Mass fraction of species

ρ : Fluid density

U: Velocity Vector

Di: Diffusion Coefficient

Ri: Reaction Rate

Si: Additional Source Term

k: turbulent kinetic energy

Abstract

A gas turbine is an internal combustion engine that converts the thermal energy of hot gases into mechanical energy in the form of rotary motion. These turbines are used in various industrial sectors, including power generation, aviation, and hydrocarbon processing and transportation.

The PGT25 gas turbine, developed by GE Oil & Gas. Installed at the GPDF SC3 compressor station, this turbine compresses natural gas destined for Spain.

In this study, a comparative simulation was carried out for a combustion chamber of a PGT 25 gas turbine, the first one used natural gas as a fuel, and the second one used hydrogen as an alternative fuel, in order to see the behavior of the hydrogen flame and the possibility of applying this fuel in the PGT25 gas turbine.

Keywords: Gas Turbine, Combustion Chamber, Hydrogen, Natural Gas , Non-Premixed Combustion.

Résumé

Une turbine à gaz est un moteur à combustion interne qui convertit l'énergie thermique des gaz chauds en énergie mécanique sous forme de mouvement rotatif. Ces turbines sont utilisées dans divers secteurs industriels, notamment la production d'électricité, l'aviation, le traitement et le transport des hydrocarbures.

La turbine à gaz PGT25, développée par GE Oil & Gas, est installée à la station de compression SC3 de GPDF et comprime le gaz naturel destiné à l'Espagne.

Dans cette étude, une simulation comparative a été réalisée pour une chambre de combustion d'une turbine à gaz PGT 25. La première utilisait du gaz naturel comme combustible, la seconde de l'hydrogène comme combustible alternatif. Cette simulation visait à étudier le comportement de la flamme d'hydrogène et les possibilités d'application de ce combustible dans la turbine à gaz PGT25.

Mot Clé : Turbine a Gaz , Chambre de Combustion , Hydrogène, Gaz Naturelle , combustion Non Pré mélangé .

المخلص

التوربين الغازي هو محرك احتراق داخلي يُحوّل الطاقة الحرارية للغازات الساخنة إلى طاقة ميكانيكية في حركة دورانية. تُستخدم هذه ، الذي PGT25 التوربينات في قطاعات صناعية مُختلفة، بما في ذلك توليد الطاقة، والطيران، ومعالجة ونقل الهيدروكربونات. توربين الغاز يضغط الغاز الطبيعي المُخصّص لإسبانيا. GPDF SC3، مُركّب في محطة ضغط GE Oil&Gas طورته شركة

حيث استخدم الأول الغاز الطبيعي كوقود، بينما استخدم الثاني PGT 25 في هذه الدراسة، أُجريت محاكاة مقارنة لغرفة احتراق توربين غاز PGT25 الهيدروجين كوقود بديل، وذلك لدراسة سلوك لهب الهيدروجين وإمكانية استخدام هذا الوقود في توربين الغاز.

الكلمات المفتاحية: توربين غازي، غرفة الاحتراق، الهيدروجين، الغاز الطبيعي، الاحتراق غير المختلط مسبقاً

General Introduction

Generale Introduction

In an era where environmental concerns and the pursuit of sustainable energy solutions is at the forefront of global agendas, integrating hydrogen (H₂) as alternative fuels in gas turbines emerges as a promising avenue of carbon dioxide (CO₂) emission reduction.

Harnessing hydrogen for combustion will include challenges. There are risks inherent in the development of new technology, new infrastructure, and hydrogen in particular. Flame sensors play a vital role in mitigating those risks.

Gas turbines powered by fossil fuels have been widely used for power generation and mechanical drive for many years, owing to their compact mechanical structure, high power-to-weight ratio, and quick start-up. However, due to its high calorific value and low emissions, many Original Equipment Manufacturers (OEMs) expect hydrogen to gradually replace fossil fuels, assuming the necessary infrastructure is in place.

Leading energy companies, utilities, turbine manufacturers, and technology providers are making significant commitments and investments in hydrogen-related projects, pilot demonstrations, and research initiatives. Many OEMs have introduced gas turbines or upgrade programs that permit burning hydrogen as an alternative fuel. The combustion properties of hydrogen are quite different than those of natural gas. Hydrogen has a high energy content per unit mass, making it an attractive option for fueling gas turbine. However, on a volume basis, hydrogen is one-third less energy-dense than methane (CH₄) so it takes three times the volume flow of hydrogen to provide the same energy input as natural gas.

Chapter I

Sonatrach Oil and Gas Company

I.1. Introduction

In this chapter a general description of 'SONATRACH Oil and Gas Company' as well as the different activities carried out by it is included, the prospects for the production and use of hydrogen, and the main role of the compression station SC3.

I.2. Sonatrach

A national oil and gas company among the most efficient in the world, Sonatrach is the leading hydrocarbons group in Africa. For 60 years Sonatrach has fully played its role as the driving force of the national economy. Its mission is to develop Algeria's significant hydrocarbons reserves. The group has 154 subsidiaries and holdings, including around fifteen wholly owned companies, working daily to enhance the country's oil and gas value chain. These include the national geophysical company 'ENGAO', the national drilling company 'ENAFOR', the major national oil works company 'ENGTP', and the national petroleum marketing and distribution company 'NAFTAL'. (Malik, 2018)

I.2.1. Sonatrach Activities

I.2.1.1. Exploration and Production

Since the creation of Sonatrach the hydrocarbons exploration and production activity has grown in strength thanks to the technological expertise and know-how of the teams in the search for and discovery of new deposits on the national territory and throughout the world. (Malik, 2018)

I.2.1.2. Pipeline Transport

Pipeline transportation ensures the transport of liquid and gaseous hydrocarbons produced by exploration and production activity. Sonatrach pipeline network in Algeria extends over nearly 20,000 kilometers. (Malik, 2018)

I.2.1.3. Liquefaction and Separation

The liquefaction and separation activities are responsible for transforming hydrocarbons through the liquefaction of natural gas and separation of LPG. A pioneer in the LNG industry Sonatrach has become one of the world's leading players in production and marketing of liquefied natural gas and by-product such as propane, ethane, butane and gasoline. The world's first liquefaction complex [GL4Z] was established in 1964 in Arzew. (Malik, 2018)

I.2.1.4. Refining and Petrochemical

With the aim of developing its resources Sonatrach through its investment program in the refining and the petrochemical sectors, aims to become a key player in Algeria's industrialization. Currently Sonatrach operates six refineries domestically including one specifically for condensate, as well as one refinery abroad. It also has two operational petrochemical complexes. Sonatrach's development project aims to upgrade and strengthen current refining capacities and establish an efficient petrochemical industry by developing and transforming available resources across all segments of the hydrocarbon chain. (Malik, 2018)

I.2.1.5 Commercialization

As a part of its go-to-market strategy Sonatrach has defined two major goals:

- ensure the supply of oil and gas products to the domestic market.
- Improve the value of its exports and strengthen its market share globally. (Malik, 2018)

I.3. Sonatrach Renewable Energy Perspectives

Sonatrach is embarking on a green energy journey by launching an ambitious renewable energy development and energy efficiency project. The Algerian government plans to harness inexhaustible resources such as solar power, building on a strategy aimed at diversifying energy sources and preparing Algeria for the future by combining intelligence and initiative. Algeria is embarking on a new era of energy sustainability. The revised renewable energy plan calls for the installation of nearly 22,000 MW of renewable energy capacity by 2030 for the domestic market, while maintaining export as a strategic objective, provided market conditions are favorable. The revised energy efficiency plan targets energy savings of nearly 63 million TOE by 2030 in all sectors (buildings, public lighting, transportation, and industry). To achieve this, it includes the use of efficient lighting, improved thermal insulation, and the installation of solar water heaters. Similarly, the adoption of clean fuels (LPG and CNG) and efficient industrial equipment is envisaged. The energy efficiency program will contribute to reducing CO₂ emissions by 193 million metric tons. (Algeria, Energy Ministry of, 2019)

I.3.1. Solar Potential

Due to its geographical location, Algeria boasts one of the largest solar reserves in the world. Across almost the entire country, solar exposure exceeds 2000 hours per year and can reach up to 3900 hours per year in highlands and Sahara. Each year a horizontal area of one square meter receives approximately 3 kWh/m² in the north and more than 5.6 kWh/m² in the far south. (Algeria, Energy Ministry of, 2019)

Locality	Installed Capacity [MW]	Commissioning
Tindouf	09	2015
Ilizi	03	2015
Adrar	20	2015
Adrar	03	2015
Tamanrasset	13	2015
Naama	20	2016
Adrar	06	2016
Adrar	05	2016
Laghouat	20	2016
Ouargla	30	2017

Table I.14 343 MW Photovoltaic power plant project (Algeria, Energy Ministry of, 2019)

I.3.2. Wind Potential

Wind energy in Algeria varies greatly depending on the location. This is mainly due to its extremely varied topography and climate. Indeed, our vast nation is divided into two distinct geographic regions. The northern Mediterranean, distinguished by a 1200-kilometer coastline and a mountainous landscape, is typified by the two massifs of the Tell Atlas and the Saharan Atlas. Between these two zones are plains and highlands with a continental climate. The south, for its part, is characterized by a Saharan climate. The graph below shows that the south has higher speeds than the north, mainly in the southeast region where speeds exceed 7 m/s and even reach over 8 m/s around Tamanrasset. Regarding the north, a rather low average speed is generally observed. However, microclimates are observed in the coastal area of Oran, Béjaïa and Annaba as well as in the highlands of Tereza, Biskara, Msila and elBayadh (6 to 7 m/s) and in the far south (≥ 8 m/s). (Algeria, Energy Ministry of, 2019).

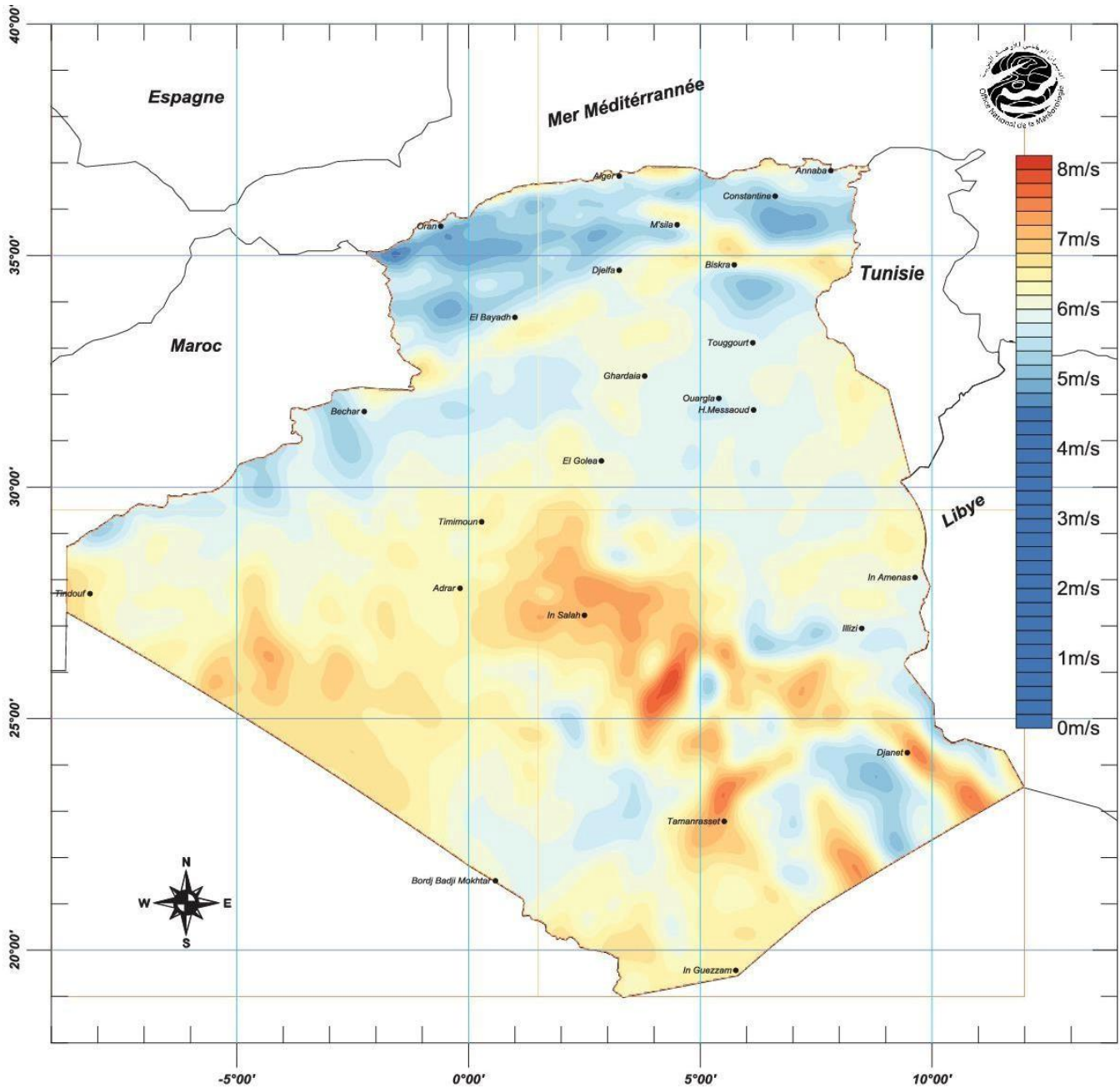


Figure I.1. Map of the Average Annual Wind (Period 2001-2015) (Algeria, Energy Ministry of, 2019)

I.3.3. Potential of Geothermal Energy

The assemblage of geological, geochemical and geophysical information led to the detection of more than two hundred thermal springs that have been identified in the Northern parts of the country. about a third of them (33%) have temperature exceeding 45°C. in Biskra springs can reach temperatures as high as 118°C.

Chapter I: Sonatrach Oil and Gas Company

three areas where the thermal gradient exceeds 5°C/100m have been identified through research on this phenomenon. Relizane, and Maskara and Guelma. (Algeria, Energy Ministry of, 2019).

I.3.4. Hydraulic Potential

The total volume of rain falling on Algerian soil is considerable, estimated 65 billion cubic meters. However, it provides little benefit to the country as there are very few rainy days; it is concentrated in small areas, there is intense evaporation and rapid drainage towards the sea. Generally speaking, surface resources decrease from the north to the south. It is currently estimated that useful and renewable resources amount to approximately 25 billion cubic meters, approximately two-thirds of which are surface resources. 103 dam sites have been identified. More than 50 dams are currently in operation. (Algeria, Energy Ministry of, 2019)

I.4. Green Hydrogen the New Challenge in Algeria

Energy supply and energy pollution reduction are major challenges for the development of a modern country like Algeria. The term challenge here explicitly raises the question of the challenges modern societies face in meeting the basic energy needs of population and responding to their increase directly induced by population growth, with a view to sustainable development. The major challenges are therefore to promote the rational management of fossil fuels and to develop the use of renewable energy while preserving the environment. Hydrogen today appears to be an essential energy solution to ensure the sustainability of energy resources, reduce the carbon footprint, and protect the environment. The introduction of hydrogen into the current energy system is possible through the use of a hydrogen-enriched fuel mixture. (Fethia, 2023)

I.4.1 Production of Hydrogen

Global hydrogen production amounts to approximately 55 million tons per year, and is generally obtained from various fossil fuel sources, such as natural gas (49%) or oil, 29% comes from natural gas, 18% from coal, and only 4% of hydrogen production comes from the decomposition of water by electrolysis.

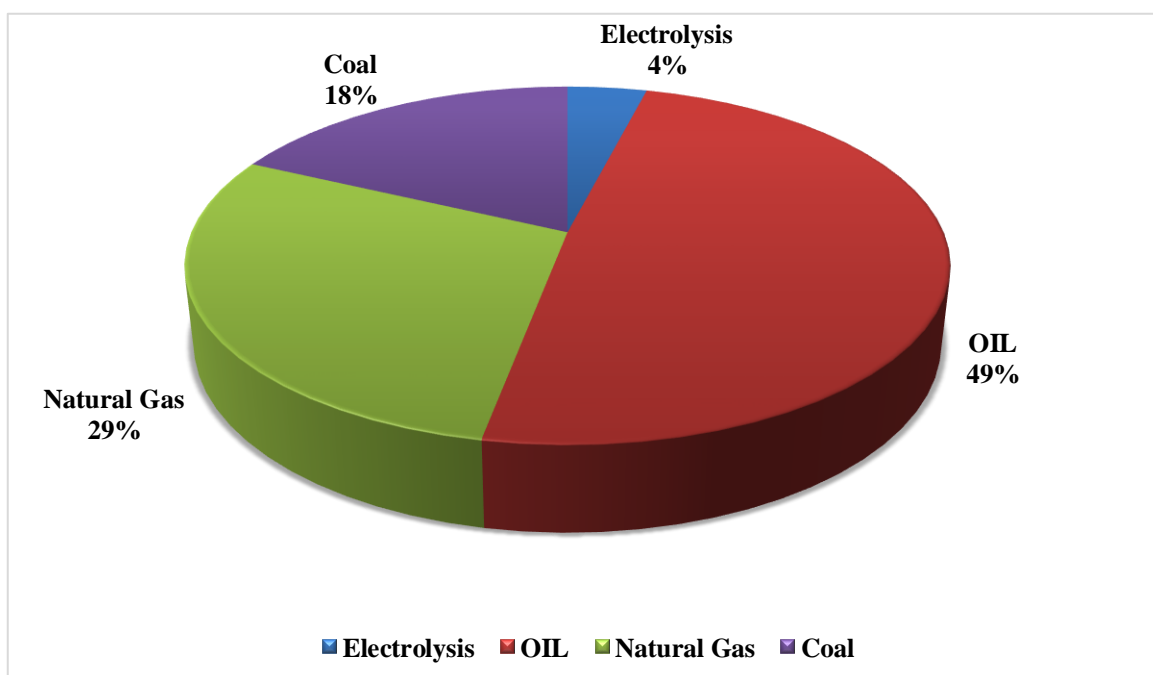


Figure I.2 Distribution of Hydrogen production methods (Fares, 2023)

The hydrogen we currently produce comes primarily from the decomposition of hydrocarbons, particularly through the reforming of natural gas vapors and the partial oxidation of hydrocarbons. The transformation of coal into gas. However, these methods will not help reduce our dependence on fossil fuels, but also encourage the emission of greenhouse gases (GHG) into the atmosphere. Regarding fossil fuel methods, only water decomposition could be considered. It also provides significant quantities of hydrogen while reducing greenhouse gas (GHG) emissions. This method, which is in line with the goals defined by the Hydrogen - Renewable Energy Division of the Sonatrach, should be increasingly used in the context of sustainable development. (Fares, 2023)

I.4.2. Green Hydrogen Production by Water Electrolysis

The first demonstration of water electrolysis dates back to the 1800s, thanks to Nicholson and Carlisle (2). This method requires electricity to separate the water molecule into hydrogen and dioxygen, equation: $\text{H}_2\text{O} + \text{electricity} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2 + \text{heat}$ (1), It is available in several versions, at different temperatures, namely:

- Low-temperature alkaline water electrolysis ($< 200^\circ\text{C}$) is performed using an aqueous solution of sulfuric acid (H_2SO_4) or potassium hydroxide (KOH).
- High-temperature water electrolysis ($> 400^\circ\text{C}$) uses a ceramic membrane that conducts oxide or protonic ions, which must be integrated into a concentrated solar power system or a reactor. High-temperature nuclear power to benefit from an economical steam source.

Pollution-free hydrogen production is optimally achieved through water electrolysis. However, when fossil fuels are used as the primary electricity source, the issue of the problem of environmental pollution remains unresolved. Therefore, electricity from renewable energy sources is essential for carbon-free hydrogen production. Nevertheless, high-temperature electrolysis offers several advantages over low-temperature electrolysis. In terms of energy, the total energy requirement is reduced thanks to the high temperature, which increases the efficiency of the reaction, compared to that required for traditional electrolysis. (Fares, 2023)

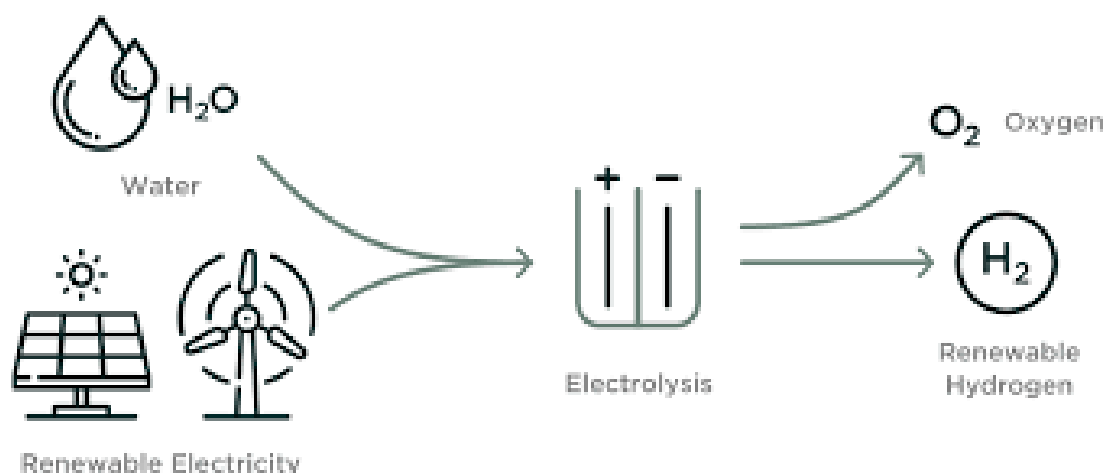


Figure I.3 Water Electrolyze Process (Fares, 2023)

I.4.3. Powering the Gas Turbine with Hydrogen

Modern gas turbines are capable of operating on a wide range of hydrogen concentrations. This can be blue hydrogen, green hydrogen, or hydrogen produced from an alternative low- or zero-carbon production process. Blending hydrogen and natural gas aims to reduce CO₂ emissions over time. In this case, the amount of CO₂ reduction will be a function of the percentage of H₂ in the fuel. The amount or percentage of H₂ in the fuel can be measured based on volume, mass, or heat input. There is a significant difference in hydrogen fluxes based on these methods due to the difference between hydrogen energy density on a mass and volume basis, as shown in Table.

Proprieties	Methane	Hydrogen
Formula	CH₄	H₂
Molecular Weight [g/mol]	16	2
Hight Calorific Value per Volume [MJ/Nm³]	35.8	10.8
Hight Calorific Value per Mass [MJ/Kg]	50	120

Table I.2 Comparison of the proprieties of the hydrogen and methane (Fethia, 2023)

The key to assessing the emissions of a fuel blend is the relative thermal contribution of the fuel components, especially since methane and hydrogen have very different energy densities. This is a crucial distinction because incorporating small proportions of hydrogen into the fuel, on an energy basis, will have a significant effect on reducing CO₂ emissions, there is a linear relationship between CO₂ reduction and the hydrogen content of the fuel. To achieve a 50% reduction in CO₂ emissions, a blend consisting of 50% hydrogen and 50% methane (as a percentage based on energy value) is required. (Fethia, 2023)

I.4.4. Challenges of hydrogen in Gas Turbines

Although the use of hydrogen can help reduce the carbon footprint, some hurdles remain to be overcome due to the differences between hydrogen and many conventional hydrocarbons. Key points to consider regarding combustion issues are:

Heat energy: As shown in Table, hydrogen has twice the energy density of methane when considered by mass. However, in terms of volume, hydrogen is one-third less energy-dense than methane. Thus, three times the volume flow rate of hydrogen is required to provide the same amount of heat (energy) as methane. Therefore, to operate a gas turbine powered exclusively by hydrogen, a fuel accessory system must be configured to meet the required flow rates.

Flame speed: In a reaction, flame speed is the rate at which unburned gases diffuse within the reaction. The flame speed produced by hydrogen is faster than that of many hydrocarbons. Table shows flame speeds for a variety of hydrocarbon fuels. Rapid flame propagation is a key characteristic in determining the size of a gas turbine combustion chamber.

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Carburant	Laminar flame speed (cm/s) under stoichiometric conditions
Hydrogen	170
Methan	38.3
Ethane	40.6
Propane	42.3

Table I.3 Laminar Flame Speed (Fethia, 2023)

Typically, systems are configured to operate on a set of fuels that have a defined range of flame speeds. Due to the significant difference between the flame speeds of methane and hydrogen, combustion systems configured to operate on methane (natural gas) may not be suitable for operation with a high-hydrogen fuel. In many cases, operation with a high-hydrogen fuel requires a combustor specifically configured for the various combustion conditions. (Fethia, 2023)

I.4.5. Comparison of the cost of hydrogen delivered to Germany (production + transport) from different countries, by 2040

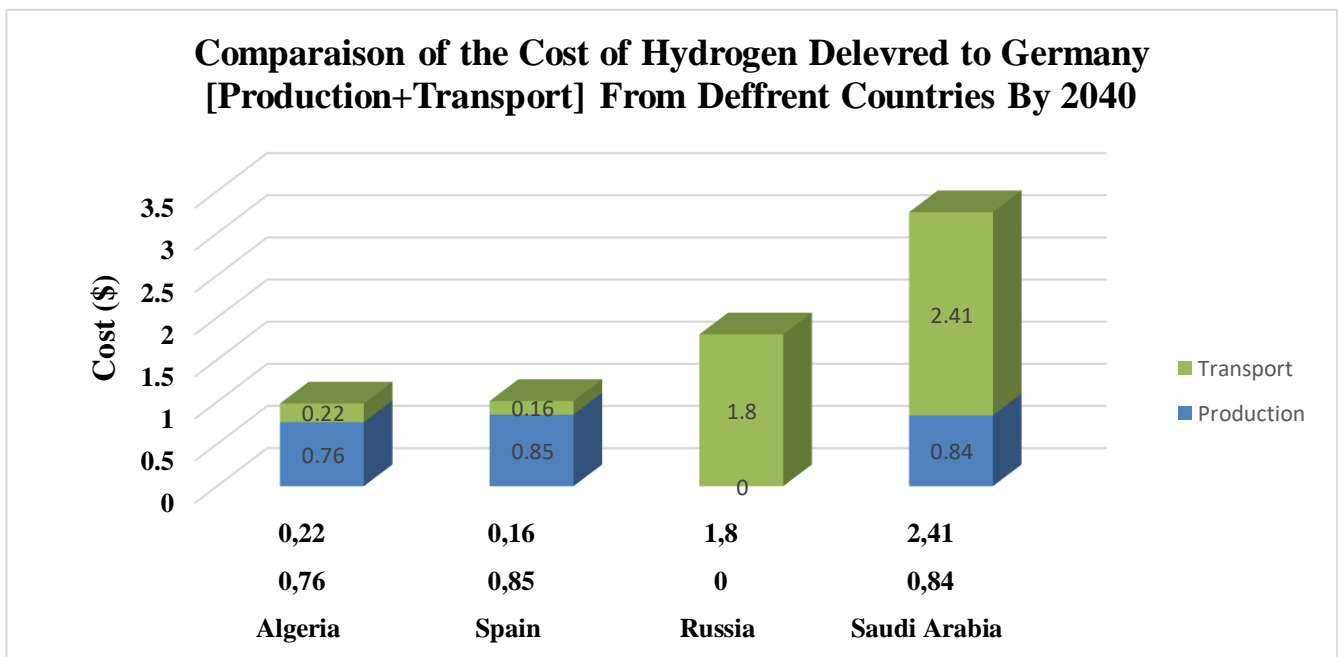


Figure I.4 Comparison of the Cost of Hydrogen Delivered to Germany (Algeria, Energy Ministry of, 2019)

The Graph represents the cost of production and transport of hydrogen to Germany for different countries [Algeria, Russia, Saudi Arabia, Spain], we can notice that the histogram increases from the minimal cost to the maximum cost. Algeria takes first place with the best cost of [0.76\$ production + 0.22\$ transport] with a total of 0.98\$ for 1KG of Hydrogen, then we have Spain in second position the total between production and transport is 1.01\$ for 1KG, Russia has low solar potential, so production is almost zero in this country. Saudi Arabia takes fourth place with a total cost of 3.25\$ [0.84 production+ 2.41 transport].

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So, we can say that Algeria has a gigantic energy potential, which gives it the opportunity to always be competitive in the international hydrogen energy market.

I.5. GPDF Pipeline General Description

The Maghreb-Europe gas pipeline, now known as Pedro Duran Farell, now connects the largest field of HASSI-R'MEL in Algeria to SEVILLE in SPAIN via MOROCCO, currently offline, the Strait of Gibraltar, and the new line via pipeline E-GPDF with MEDGAZ, which directly operates to SPAIN. It was constructed jointly by the Algerians and the Spaniards.

The Algerian section of the GPDF consists of a pipeline of 48 inches in diameter, connecting the departure terminal from HASSI-R'MEL to the arriving terminal from MACHRAA-ENNOUAR at the **Algeria-Moroccan** border.

The optimal future exploitation of the pipeline allows the transport of 19.6 billion cubic meters of natural gas per year with the installation of four new compression stations. (Sonatrach, 2004)



I.5.1. Description of the GPDF Compression Station 3

A compression station SC3 is set up at Cut Station N°3 in the center of the GPDF (Gas pipeline Pedro Duran Farell) to provide the gas needs of Spanish and Portuguese consumers. The purpose of the SC3 station is to transmit the requested gas flow to the ARICHA's arrival terminal.

- One of the two turbo-compressor units that make up the SC3 station is currently operating. The valves and pipes needed to install a third turbo-compressor unit were supplied by the manufacturer, ABB LGM. The turbine has 23.17 MW of electricity. Every turbo-compressor is situated in a separate structure that has ventilation, gas detection, and fire control systems.

-The electricity required to meet the living base's needs can be produced by the SC3 compression station. Two turbo-alternators make up the station; one is operational and the other is standby. The SOLAR CENTAURUS 40 DE 2.5 MW power turbo alternators are the brand.

-The station is strengthened by a 30 kV SONELGAZ line. A 320KVA power group saves the station in the event that the turbo alternator units and the SONELGAZ line malfunction. (Sonatrach, 2004)

I.5.2. GPDF Compression Station Services

I.5.2.1. Fire Water, Service Water, Drinking Water

All water available on site is transported to the Compressor Station via a pipeline from a well located in the area. The water is stored in the Raw Water Storage Tank and used for various services:

ChapterI: Sonatrach Oil and Gas Company

Water Services	Minimum Network Pressure (Bar)
Fire water for the life base	8
Fire water for the life base	8
Services Water	4
Drinking Water	6

TableI.4WaterServices(Sonatrach, 2004)

I.5.2.2. Air Instruments, Air Service

The Air Compression and Drying Package produces all of the compressed air that is available in the plant:

-Minimum network pressure 8bar.

-maximum temperature 50°C.

-Dew point -20°C (10bar).

I.5.2.3. Gas turbocharger and turbo alternator

All the pressurized gas available in the facility arrives from the main process line of the Gas Pipeline by means of the “tie in” at the entrance to the Compression Station. The stationEquipped with a gas treatment skid gas for the needs of:

Gas Services	Minimum Network Pressure (Bar)
Turbo compressor Fuel Gas	32
Turbo compressor Starting Gas	50
Turbo alternator Fuel Gas	18
Turbo alternator Starting Gas	25
Gaz for motorized valves	45
Gaz Instrument	10

TableI.5Gas Services(Sonatrach, 2004)

I.5.2.4. Electric Service

Availablevoltage: 380V/ 3ph / 50Hz, 220V / 1ph / 50Hz.

Maximum power available: 2500Kw. (Sonatrach, 2004)

Conclusion

In the first chapter, we saw the different activities of the Sonatrach company in the energy sector and the company's aspirations to produce green hydrogen locally and achieve the ecological energy transition and the possibilities to use it like energy vectors in gas turbine.

Chapter II

Turbo Compressor Bloc and PGT25 Gaz Turbine Overview

II.1. Introduction

In this chapter we will see the fundamental component of the turbo compressor bloc and the overview of the PGT25 gas turbine.

II.2. Gaz Turbine General Description

A gas turbine is a mechanical device that harnesses the energy of pressurized gas, typically air, to generate power. It operates by compressing incoming air, mixing it with fuel, igniting the mixture, and then allowing the high-speed exhaust gases to drive a turbine. This technology finds extensive use in aircraft engines, power plants, and various industrial applications, providing efficient and reliable power generation and propulsion.

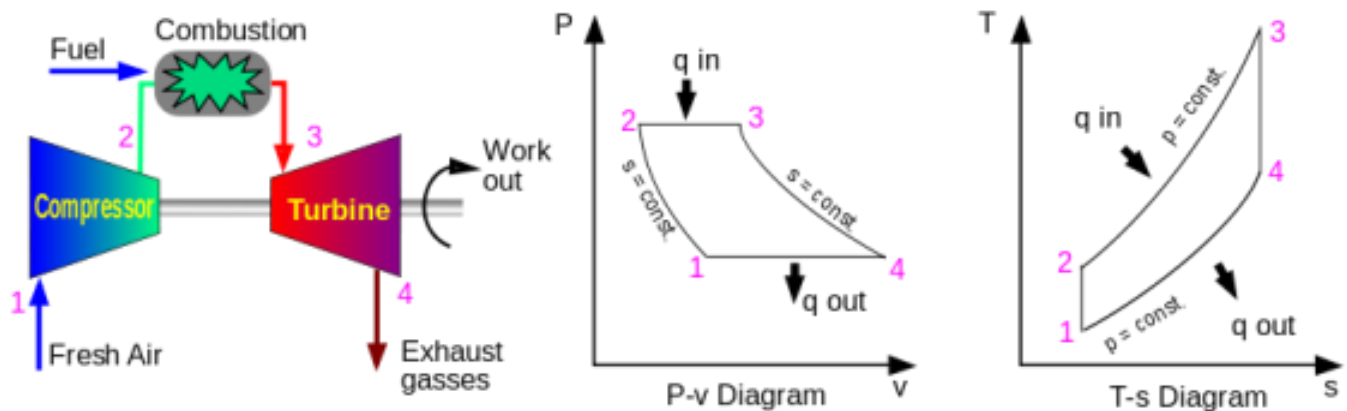


Figure II.1 Gas Turbine

The gas turbine stands as a rotary internal combustion engine, serving as a streamlined alternative to traditional reciprocating piston engines. It represents a straightforward method for generating power, characterized by its distinctive ability to compress ambient air and introduce heat via the combustion of fuel within a designated combustion chamber, commonly referred to as a combustor. (Testbook, 2023)

The 4 stages of the Brayton cycle:

- compression (1 → 2): Air is compressed in a compressor (pressure and temperature increase).
- Heat addition at constant pressure (2 → 3): Fuel is burned in the combustion chamber, increasing the temperature at constant pressure.
- Adiabatic Expansion (3 → 4): Hot gases expand in a turbine, producing mechanical work.
- Heat rejection at constant pressure (4 → 1): The exhaust gases are cooled before being released into the atmosphere.

II.2.1. Gaz Turbine Components

A compressor, combustion chamber, turbine, and occasionally a power turbine are the main parts of a gas turbine. Incoming air is compressed by the compressor before combining with fuel in the combustion chamber and igniting. The main turbine is powered by high-velocity exhaust gases, which generate mechanical energy for a variety of uses, such as power generation or airplane propulsion. (Testbook, 2023)

II.2.1.1. Air Compressor

The air compressor and the turbine are both installed on a single shaft and are positioned between the combustion chamber and the turbine. Due to their inability to start themselves, gas turbines need a starting motor. The purpose of the air compressor is to take in air, compress it, and raise its pressure. Large and sophisticated gas turbines are better suited for axial design compressors with several stage. (Testbook, 2023).

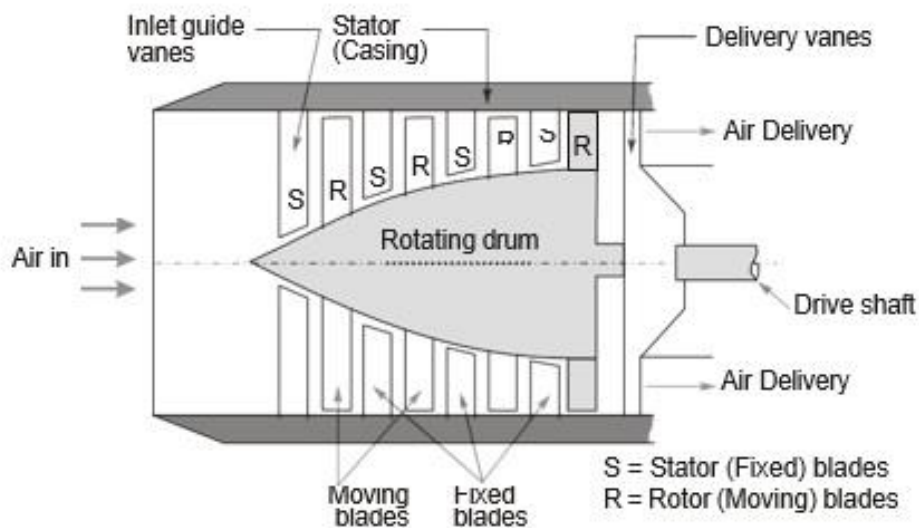


Fig.

Figure II.2 Axial Compressors Component (Made Easy, 2024)

II.2.1.2. Combustion Chamber

This part combines fuel and compressed air to create a fuel-air mixture that burns and sends the combustion products into the gas turbine. Effective burning of the fuel mixture is ensured by the high air pressure. Natural gas, gaseous fuel, or liquid fuel are frequently used in gas turbines. Annular combustor chambers, can (multi-can) combustor chambers, and can-annular combustor chambers are the three types of combustion chambers that are commonly used. Fuel nozzles can be simplex or dual fuel kinds, and fuel is injected at the upstream end as a finely atomized spray. Certain gas turbines are "bi-fuel," meaning they can burn both liquid and gas fuel. (Gubbala Sessa S, Overview of a Gas Turbine and the different methods to improve its Thermal Efficiency, 2013).

Chapter II: Turbo Compressor Bloc and PGT25 Gaz Turbine Overview

II.2.1.2.1 Can Type Combustion Chamber

Can combustor is a self-contained cylindrical combustion chamber. Each can has its own fuel injector, igniter, liner, and casing. The primary air from the compressor is guided into each individual can, where it is decelerated, mixed with fuel, and then ignited. The secondary air also comes from the compressor, where it is fed outside of the liner (inside of which is where the combustion is taking place). The secondary air is then fed, usually through slits in the liner, into the combustion zone to cool the liner via thin film cooling. In most applications, multiple cans are arranged around the central axis of the engine and share their exhaust to the turbine. Can type combustors were most widely used in early gas turbine engines owing to their ease of design and testing (one can can be tested individually, rather than having to test the whole system). Can type combustors are easy to maintain, as only a single can needs to be removed, rather than the whole combustion section. Most modern gas turbine engines (particularly for aircraft applications) do not use can combustors, as they often weigh more than alternatives, additionally the pressure drop across the can is generally higher than other combustors, on the order of 7%. (Aerospace Notes, 2025).

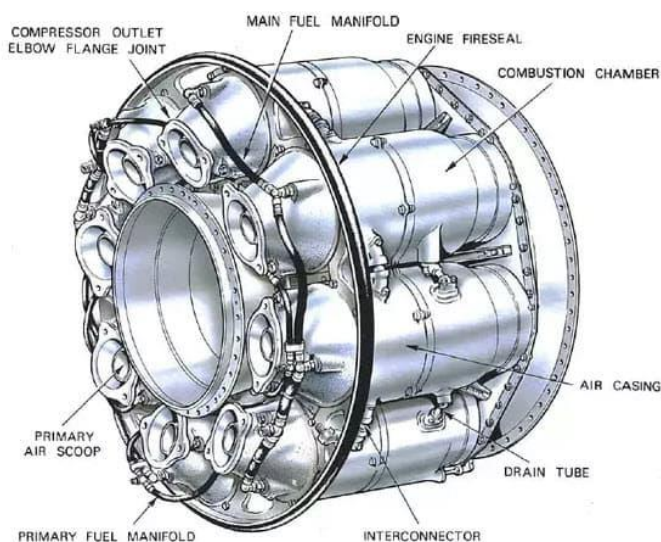


Figure II.3 Can Type Combustion Chamber (Aerospace Notes, 2025)

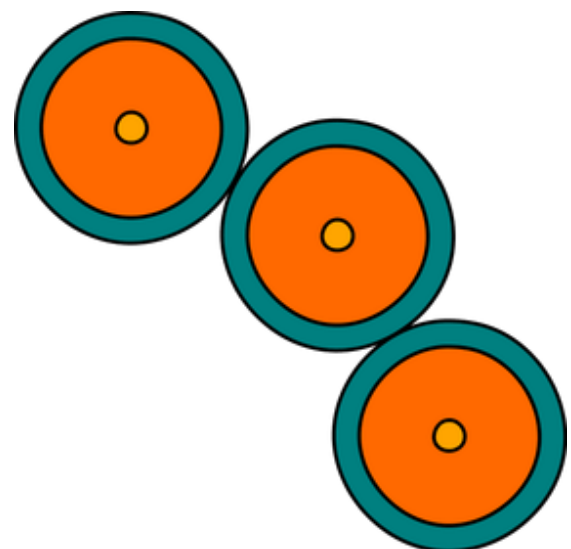


Figure II.4 Cross Section for Can Combustion Chamber (Aerospace Notes, 2025)

II.2.1.2.2. Cannular Type Combustion Chamber

Like the can type combustors, cannular combustors have discrete combustion zones contained in separate liners with their own fuel injectors. Unlike the can combustor, all the combustion zones share a common ring (annulus) casing. Each combustion zone no longer has to serve as a pressure vessel. The combustion zones can also 'communicate' with each other via liner holes or connecting tubes that allow some air to flow circumferentially. The exit flow from the cannular combustor are generally a more uniform temperature profile, which is better for the turbine section. It also eliminates the need for each chamber to have its own igniter. Once the fire is lit in one or two cans, it can easily spread to and ignite the others. This type of combustor is also lighter than the can type and has a lower pressure drop on the order of 6%. However, a cannular combustor can be more difficult to maintain than a can combustor. An example for a gas turbine

engine utilizing a cannular combustor is the General Electric J79 and the Rolls Royce Tay turbofans use this type of combustor as well.(Aerospace Notes, 2025).

ChapterII: Turbo Compressor Bloc and PGT25 Gaz Turbine Overview

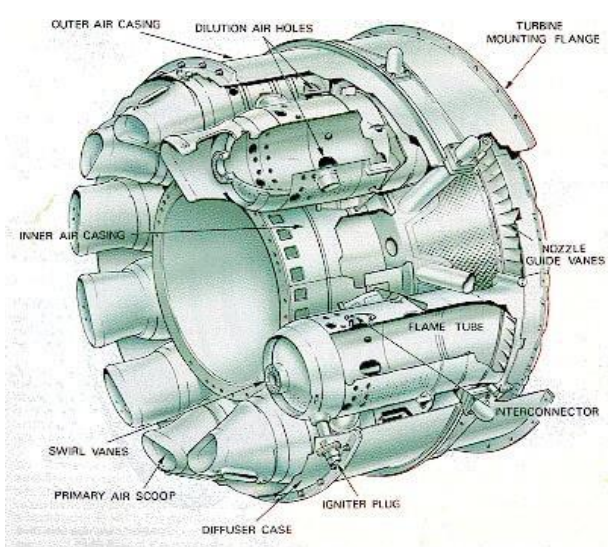


Figure II.5Canular Type Combustion Chamber(Aerospace Notes, 2025)

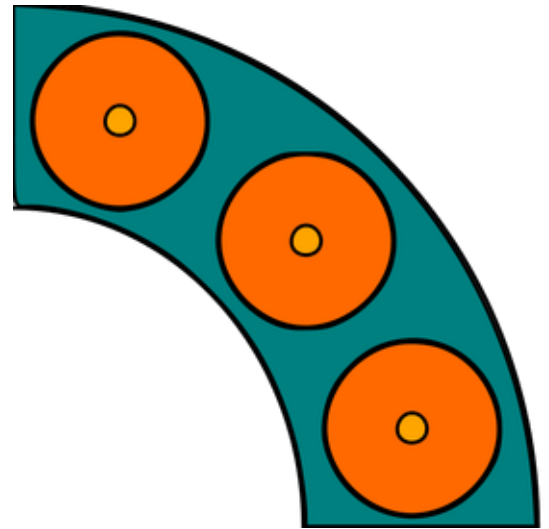


Figure II.6Cross Section for Cannular Type Combustion Chamber(Aerospace Notes, 2025)

II.2.1.2.3. Annular Type Combustion Chamber

The final and the most commonly used type of combustor is the fully annular combustor. annular combustors do away with the separate combustion zones and simply have a continuous liner and casing in a ring (the annulus). there are many advantages to annular combustors, including more uniform combustion, shorter size (therefore lighter), and less surface area, additionally, annular combustors tend to have very uniform exit temperature. they also have the lowest pressure drop of the three designs on the order of 5%. The annular designs are also simpler, although testing generally requires a full-size test rig. an engine that uses an annular combustor is the CFM international CFM56. most modern engines use annular combustors, likewise most combustors research and development focus on improving this type.(Aerospace Notes, 2025)

Chapter II: Turbo Compressor Bloc and PGT25 Gaz Turbine Overview

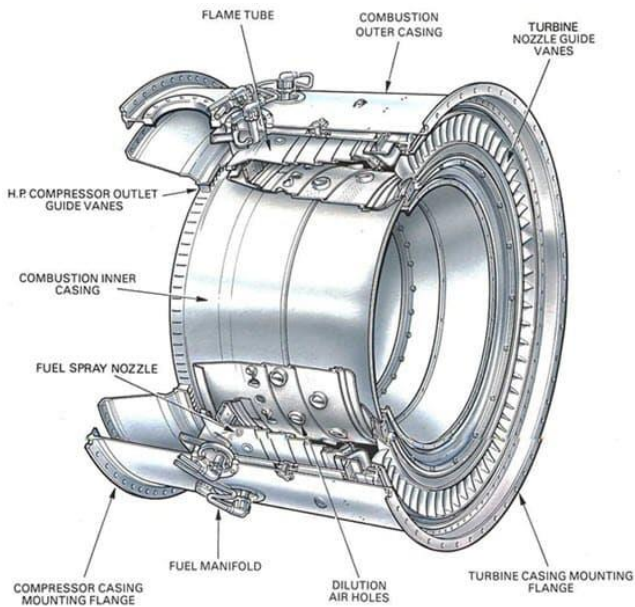


Figure II.7 Annular Type Combustion Chamber

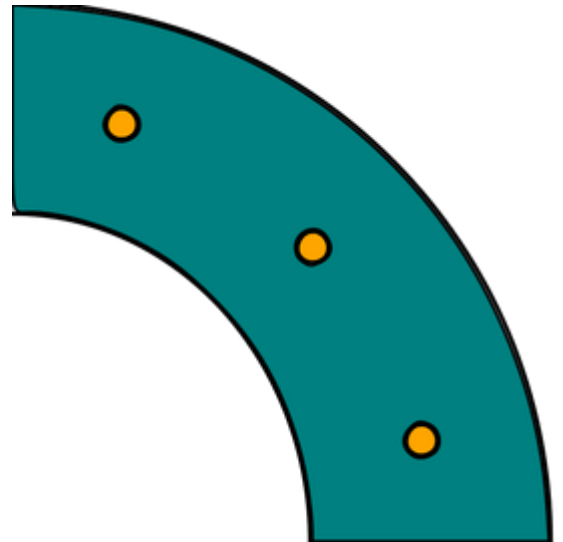


Figure II.8 Cross Section of Annular Type Combustion Chamber of Annular Type Combustion Chamber

II.2.1.3. Turbine

Hot gases travel through the multistage gas turbine, where their kinetic energy is transformed into shaft horsepower. A gas turbine has both stationary and moving blades, just like a steam turbine. The purpose of stationary blades is to guide the gas flow to the rotor blades and modify their speed. A generator is attached to the shaft of the turbine. (Khaljani, 2015)



Figure II.9 Turbine

II.2.2. Gaz Turbine Application

II.2.2.1. Industrial Application

With sizes typically ranging from 1,000 to 50,000 horsepower, industrial gas-turbine engines can be used for many applications. These include driving compressors for pumping natural gas through pipelines, where a small part of the pumped gas serves as the fuel. Such units can be automated so that only occasional on-site supervision is required. A gas turbine can also be incorporated in an oil refining process called the Hourly process, in which pressurized air is passed over a catalyst to burn off accumulated carbon. The hot gases then drive a turbine directly without a combustion chamber. The turbine, in turn, drives a compressor to pressurize the air for the process. Small portable gas turbines with centrifugal compressors also have been used to operate pumps. (Landis, 2025)

II.2.2.2. Electric Power Generation

Gas turbines must contend with diesel engines in smaller plants and steam turbines in larger central power plants when it comes to the production of electric power. For modestly large units, a gas turbine's starting cost is lower than that of either option, but it also has a lower intrinsic efficiency. However, compared to a steam unit that takes many hours to start up, a gas-turbine unit takes up less space and can be put online in a matter of minutes. Gas-turbine engines are therefore frequently employed as medium-sized "peak load" plants to operate sporadically during brief periods of elevated power demand on an electric system. In this instance, initial expenses take precedence over gasoline charges. Aircraft units running at lower turbine-inlet temperatures were used in the first commercial stationary plants. To power electric generators, aircraft turbines needed specialized gearing due to their high spinning speed. Special units have more recently been created that can operate directly at 3,600 rotations per minute (in the US). While most installations are smaller than 100,000 kilowatts, units as large as 200,000 kilowatts have been constructed. These turbines have run on natural gas or liquid fuels for up to 6,000 hours annually. Large units typically have turbine-inlet temperatures between 980° and 1,260° C, with turbine blade cooling being employed at the higher temperatures. Adding a regenerator to take advantage of the high turbine exhaust temperatures (usually between 480° and 590° C) might increase efficiency. As an alternative, the hot exhaust gases can be used to prepare the combustion air entering a steam boiler via a heat exchanger if the gas turbine is a peak-load unit for a constantly operating steam power plant. In a more recent development, the gas turbine exhaust is fed straight into a steam generator, which burns more fuel to produce moderately pressurized steam for a steam turbine. These combined units are said to have an overall thermal efficiency of around 50%, making them the most fuel-efficient power plants on the market right now. (Landis, 2025)

II.2.2.3. Marine propulsion

In this area of application, the gas-turbine engine has two advantages over steam- and diesel-driven plants: it is lightweight and compact. During the early 1970s a ship powered by a gas turbine capable of 20,000 horsepower was successfully tested at sea by the U.S. Navy over a period of more than 5,000 hours. Gas turbines were subsequently selected to power various new U.S. naval vessels. (Landis, 2025)

II.2.2.4. Automotives Propulsion

Beginning in the early 1960s, gas-turbine engines were suggested for use in automobiles. Despite their small size and weight for a given power output and their low exhaust emissions when compared to gasoline engines, gas-turbine cars have been shown to be unfeasible and uneconomical due to their high manufacturing costs, low thermal efficiency, and poor part-load and idling performance. (Landis, 2025)

II.2.3. Classification of Gas Turbines

Based on their uses and design characteristics, gas turbines are divided into several categories. These categories include marine turbines for ship propulsion, industrial turbines for mechanical drive and power generation, and aviation turbines for aircraft propulsion. Different kinds of gas turbines meet a variety of needs and applications:

II.2.2.5.1. Open Cycle Gas Turbine

The combustion chamber, turbine, and compressor are the three main parts of an open-cycle gas turbine. By pulling in outside air, the compressor boosts air pressure, while the combustion of fuel in the combustion chamber raises air temperature. In the turbine, heated gases from the combustion chamber expand and exert mechanical force. (Testbook, 2023)

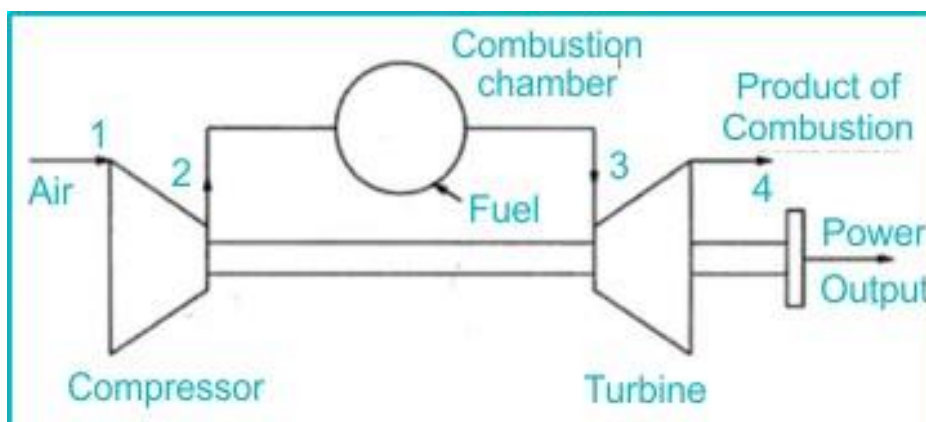


Figure II.10 Open Cycle Gas turbine (Testbook, 2023)

II.2.2.5.2. Closed Cycle Gas Turbine

The working fluid, usually air or another appropriate medium, leaves the compressor of a closed-cycle gas turbine and is heated by an external heat source at a comparatively constant pressure. After that, the turbine receives the high-temperature, high-pressure air. After the turbine, an external cooling agent cools the fluid to its starting temperature before it is recycled back to the compressor. With little phase change, this closed-loop technique allows for consistent fluid consumption. A closed-cycle gas turbine's schematic is shown in the above figure. (Gubbala Sesha S, 2013)

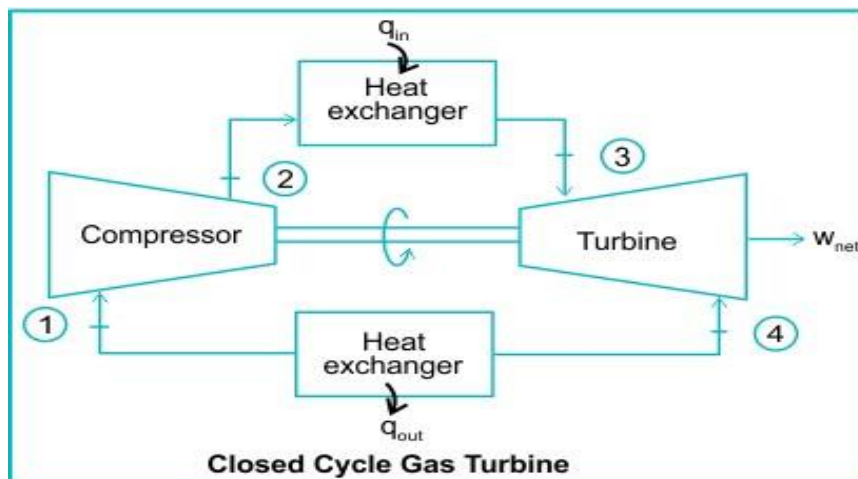


Figure II.11 Close Cycle Gas Turbine (Gubbala Sesha S, 2013)

II.2.2.5.3. Aero-Derivative Gas Turbine

Aero-derivative gas turbines find use in electrical power generation due to their rapid load response and shutdown capabilities. They are also employed in the marine industry to reduce weight. (Gubbala Sesha S, 2013)



Figure II.12 Aero-Derivative Gas Turbine (Gubbala Sesha S, 2013)

II.2.2.5.4. Scale Jet Engines

Also known as miniature gas turbines, scale jet engines can produce up to 22 Newtons of thrust and are easily constructible by many mechanical engineers using basic tools like a metal lathe. (Testbook, 2023)



Figure II.13 Scale Jet Engines (Gubbala Sessa S, 2013)

II.2.3. Gas Turbine Auxiliary

Aircraft use smaller auxiliary gas turbines for a variety of purposes, including ventilation, air conditioning, and powering jet engines using compressed air. Additionally, they provide mechanical power to drive shafted accessories or start larger jet engines. (Testbook, 2023)

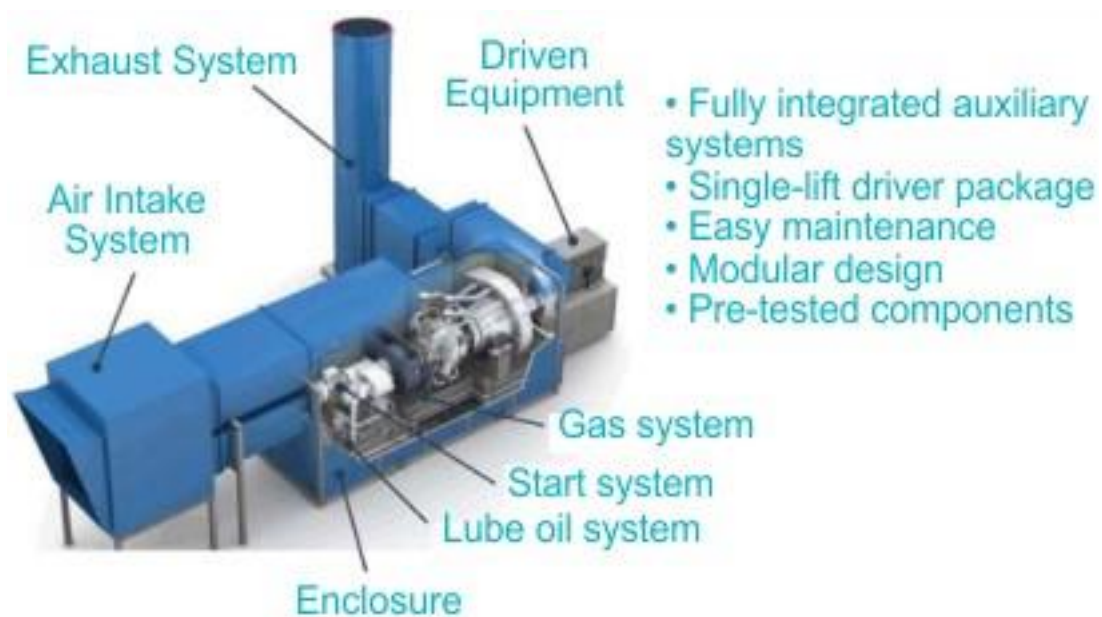


Figure II.14 Gas Turbine Auxiliary (Testbook, 2023)

II.3. Turbo Compressor Bloc in the compression station SC3

The compressor block is a building that contains the most important mechanical equipment in the compression station [the PGT 25 gas turbine, the compressor 801, and the synthetic and mineral oil lubrication system]. (Sonatrach, 2004)

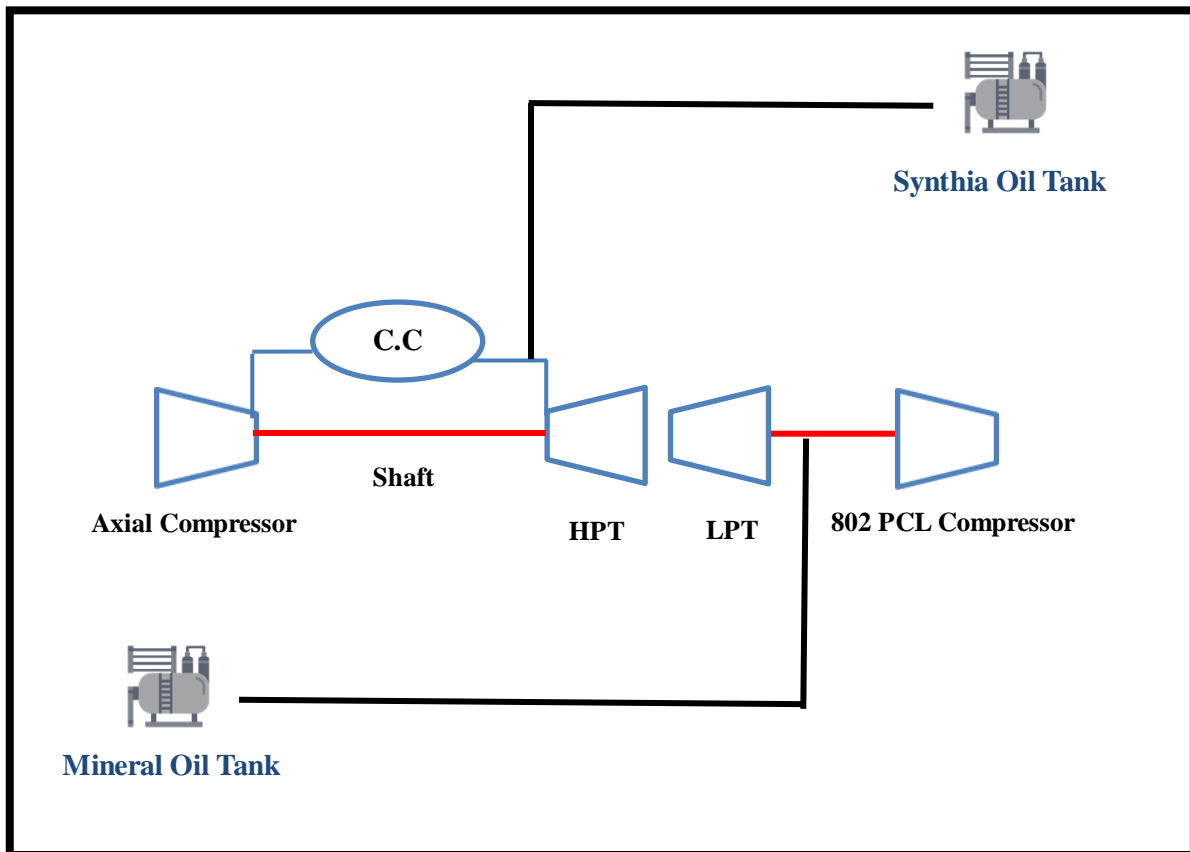


Figure II.15 Turbo Compressor Bloc Schematization

II.3.1. PGT25 Gas Turbine Overview

II.3.1.1. General Electric Oil and Gas and Nuovo Pignone Collaboration

The PGT25 gas turbine is a product of GE Oil & Gas, which is now part of Baker Hughes, a GE company. The original design and development of the PGT25 were significantly influenced by Nuovo Pignone, an Italian company that GE acquired. Nuovo Pignone has been a key player in the development of gas turbine technology and has a long history of engineering and manufacturing industrial equipment, including gas turbines, compressors, and pumps. Nuovo Pignone's expertise in gas turbine technology contributed to the development of the PGT25, making it a reliable and efficient solution for various applications, including power generation and mechanical drive. The PGT25 is known for its high performance, operational flexibility, and ability to handle a wide range of fuel gases, making it suitable for a variety of industrial and energy sector applications. After the acquisition by GE, Nuovo Pignone became an integral part of GE Oil & Gas, leveraging its extensive experience in gas turbine technology and its well-established manufacturing capabilities. The collaboration

Chapter II: Turbo Compressor Bloc and PGT25 Gas Turbine Overview

between GE and Nuovo Pignone has enabled the continuous improvement and development of gas turbines like the PGT25, ensuring they meet the evolving needs of the industry. The PGT25 and its variants, including the PGT25+ and PGT25+G4, reflect the combined engineering prowess of GE and Nuovo Pignone, offering enhanced performance, reliability, and efficiency for customers worldwide. (Company, 2025)

II.3.1.2. PGT25 Gas Turbine Description

The PGT 25. gas turbine comprises a gas generator LM 2500 (G.E.) and a power turbine designed and manufactured by Nuovo Pignone. Its power output is 23261 kW and the rotational speed is 6500 RPM under ISO conditions. The turbine consists of two mechanically independent rotors (first shaft nominal speed 10000 RPM, second shaft nominal speed 6500 RPM). The first rotor includes the axial compressor (with 16 stages of compression) and the two stages of the high-pressure turbine (H.P.). The axial compressor compresses the air that is to be delivered to the combustion chamber, and the H.P. turbine is only provided to drive the axial compressor. On the second rotor (L.P. - low pressure - or control shaft), there is the control shaft which drives the centrifugal compressor through a mechanical coupling. The axial compressor is connected to the air suction duct through a soundproofed duct. The turbine is equipped with an SAC annular combustion chamber and combustible gas burners. The gases burned at high temperatures and under pressure flow through the nozzles of the first stage, the H.P. nozzles, and finally the power turbine. (Company, 2025)

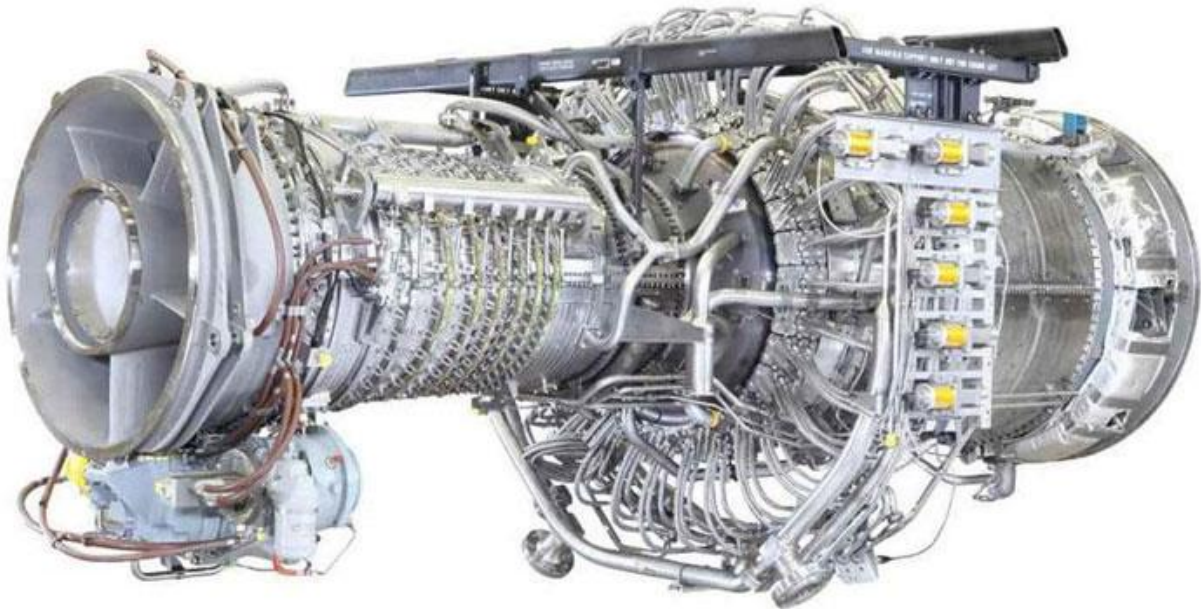


Figure II.16 PGT25 Gas Turbine (Company, 2025)

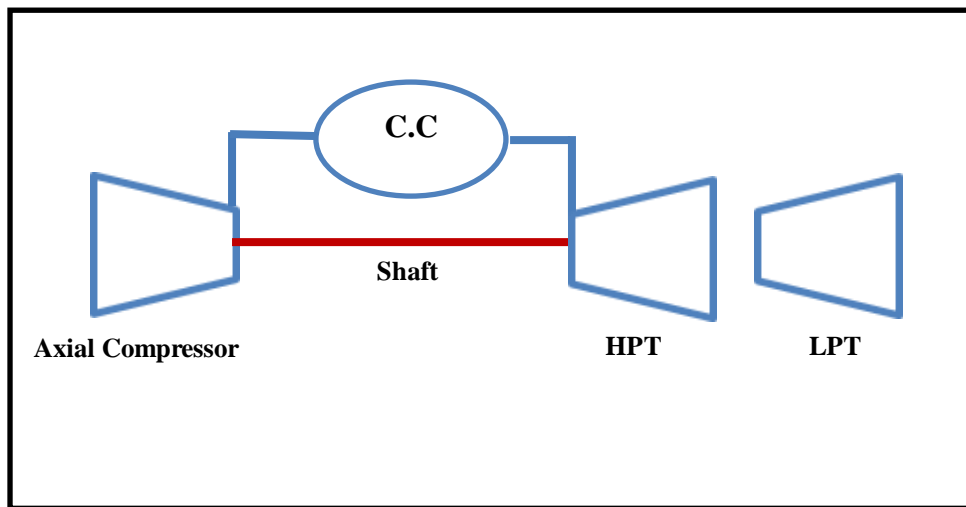


Figure II.17 Descriptive Diagram for PGT25 Gas Turbine

Gas Generator + Power Turbine

The PGT25 is equipped with:

- gas fuel metering skid, with three manifolds supplying all burners.
- NOx and carbon monoxide emission control system (dry low emission).
- turbine start-up and launch system up to 2000 RPM.
- gear box where lubrication pumps, synthetic oil extraction, and a hydraulic control pump are engaged. A raised box of 640 liters of synthetic oil for lubrication.
- Two alternating current fans and one direct current fan for cooling the turbine enclosure and to maintain positive pressure in the package. A 96-cartridge conical and cylindrical air filtration package.
- fireproof skid with 22 CO2 bottles for rapid and slow discharge.

II.3.1.3. Intake Section

The intake section, which is constituted by an inlet nozzle and an inlet cone of the gas generator in such a way as to send a regular and turbulence-free air flow into the compressor section of the gas turbine. The standard inlet nozzle contains a spray sleeve for use in injecting compressor immersion cleaning solutions when starting the gas generator with the choke. (Company, 2025)

II.3.1.3.1. Pulse Jet Air System

Is a part made to maximize airflow into the combustion chamber, improving the turbine's overall performance and combustion efficiency. In order to improve fuel and air mixing, this system uses pulsations or modulations in the airflow, which results in more stable combustion and lower emissions. The PGT25's Pulse Jet Air system may have the following important features:

Chapter II: Turbo Compressor Bloc and PGT25 Gaz Turbine Overview

Pulsating Airflow: To make combustion more dynamic and effective, the system produces pulses or modulations in the airflow entering the combustion chamber.

Enhanced Mixing: The process encourages greater fuel and air mixing by creating pulsations in the airflow, which increases combustion efficiency and lowers emissions.

Combustion Stability: The gas turbine operates dependably thanks to the Pulse Jet Air system's assistance in maintaining stable combustion under a range of operating circumstances.

Efficiency Optimization: By improving airflow dynamics, the technology helps the gas turbine operate more efficiently overall, which boosts power production and fuel economy. (Company, 2025)

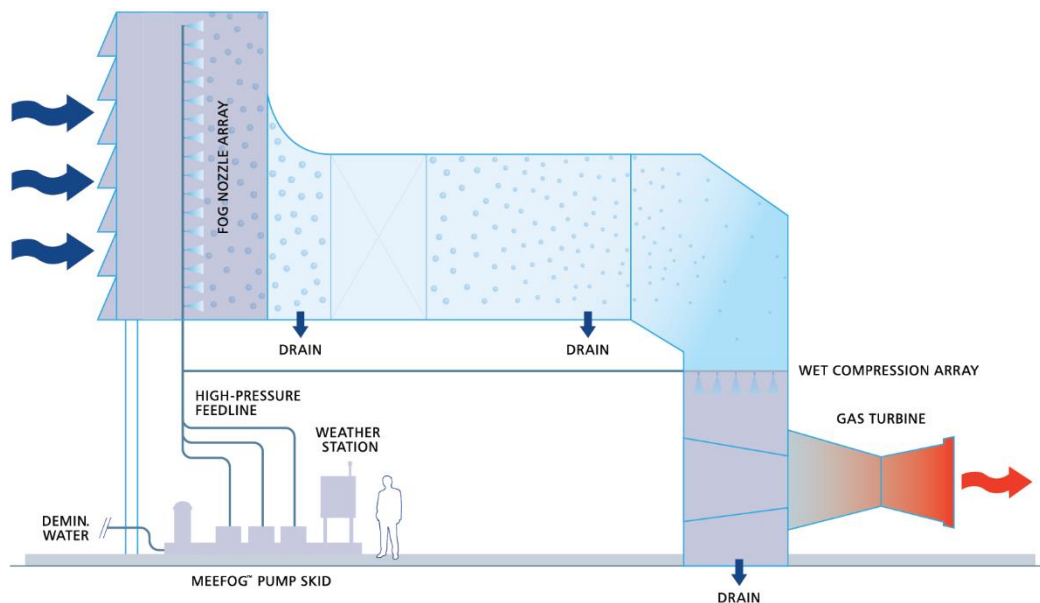


Figure II.18 PGT25 Gas Turbine Air Intakes Section

II.3.1.4. Axial Compressor Section

The 16-stage compressor has axial flow and a high-pressure ratio of 18.1 under ISO conditions, although the real ratio is 17.6. The compressor's front frame, rotor, stator, and rear frame are its primary parts. Although compressing air for combustion is the compressor section's main function, some air is also taken for gas turbine cooling. The first seven stages of the stator vanes and the intake guide vanes (IGV) are changeable; their angular positions vary according to the compressor's speed and input temperature (CIT). Furthermore, the rectified speed limiter guarantees that the compressor runs continuously throughout the operation cycle. (Company, 2025)

II.3.1.4.1. Compressor Front Frame CFF

Inlet Guide Vanes is what IGV stands for. Inlet Guide Vanes (IGVs) are parts that are placed near the compressor section's inlet in the context of compressors, especially in gas turbine engines. Controlling and directing the airflow into the compressor is their main duty. IGVs are movable vanes or blades that can alter their position or angle to control the direction and speed of airflow prior to it entering the compressor blades.

Engineers can optimize the airflow for various operating situations, such as fluctuating load demands or ambient conditions, by modifying the angle of the IGVs. Effective compressor functioning is ensured by the appropriate placement of IGVs via:

- Managing the incoming air's angle of attack to enhance compressor efficiency.
- Controlling airflow to avoid stall or surge situations, which might harm the compressor.
- Improving the compressor's capacity to manage fluctuating working circumstances, like shifts in the surrounding temperature or elevation.
- To sum up, in gas turbine engines and other compressor systems, IGVs are essential for maximizing compressor performance and guaranteeing dependable operation. (Company, 2025)

II.3.1.4.2. Compressor Rotor

The drum/disc construction of the compressor rotor has circular dovetail grooves. Several blade stages can be positioned on a single rotor structural component by using drums. Three major joints and seven major structural components are fastened together using bolts. At stage 2, a straightforward bolted joint connects the first stage disc, the second stage disc (with the integrated front false shaft), and the drum for stages 3–9. Stages 3–9 drums are fastened together with a stage 10 disc, while stages 11–13 drums are joined at stage 10. The rear shaft comes after the drum for stages 11–13, and the drum spans stages 14–16 with a straightforward bolted junction at stage 13. All flanged joints have retaining grooves to support the rotor and guarantee proper part placement. (Company, 2025)

II.3.1.4.3. Compressor Stator

The compressor stator has 16 stator blade stages plus an inlet guide vane (IGV) stage. Stages one through six and the IGVs are vary. Each of the four bolted components that make up the stator casing has an endoscopic examination port implanted. The stator enclosure has three bleed air lines welded to it. The bearing drain housing is pressurized and cooled using the purge air that is drawn from inside the annular sector at the end of the eighth-stage blades. In order to pressurize the compressor rotor rear bearing drain housing seals, air from stage 9 is sent to the back through the center of the rotor via an air duct that is supported by the compressor's front and rear shafts. The intermediate turbine frame and the power turbine wheels are cooled by the purge air that is drawn out between the ninth and tenth stages' blades. The second stage of the high-pressure turbine's nozzle is cooled by the purge air that is drawn from between the thirteenth and fourteenth stages' blades. The first and second stages' inlet guiding vanes are strengthened. Bolts hold together these reinforcements, which are aluminum extrusions divided into front and back sections. The rotor's sealing teeth are matched with the first and second-stage blade reinforcements. (Company, 2025)

II.3.1.4.4. Compressor Rear Frame CRF

The outer casing, hub, braces, and bearing drain housing for the rear bearing of the compressor rotor make up the compressor rear frame. The combustion chamber, fuel manifold, 30 fuel nozzles, two spark igniters, and the turbine's first stage nozzle support are all supported by its exterior casing. The hub absorbs the bearing's axial and radial loads as well as a part of the first-stage nozzle load, which are then transferred to the casing via ten radial braces. The combustion chamber, fuel nozzles, and first-stage turbine nozzle can all be inspected via the six endoscopic examination openings located in the front portion of the intermediate

flange casing. The high-pressure turbine's nozzles and blades can be inspected through two openings in the back of the casing. (Company, 2025)

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II.3.1.4.5. Variable Stator Vanes

Together, these parts modify the compressor's internal and external airflow, increasing its dependability, adaptability, and efficiency.

Function: To alter the angle at which air flows from one row of rotor blades to the next, VSVs are positioned at different points throughout the compressor. Maintaining the ideal aerodynamic loading of the blades throughout the compressor depends on this modification.

Efficiency Optimization: By modifying the stator vane angles to correspond with the compressor's operating circumstances, the VSV system improves efficiency over a broad range of loads and speeds. Reducing emissions and fuel consumption requires this optimization.

Surge Prevention: The VSV system assists in preventing compressor surge, a condition that can result in operational instability and possible damage, by modifying the airflow angles and preserving steady airflow conditions within the compressor.

-The first two phases of VSVs and IGV are tip-shrouded.

-The compressor inlet temperature (T2) and gas generator speed (NGG) affect the angular positions of the IGVs and stages 1 through 6 vanes, which are changeable.

-The vane air foil's ideal angle of attack for effective operation without compressor stall is provided by this variable. (GE Oil & Gas, 2021)



Figure II.19 PGT25 Gas Turbine Air Compressor (Company, 2025)

II.3.1.5. Combustion Chamber Section

Four major components—the hood (diffuser), the dome, the inner skirt, and the outer skirt—are riveted together to form the combustion chamber, which is a single annular compressor system. The pressurized air is diffused and distributed by the hood and the back compressor frame. It guarantees even temperature distribution to the turbine, uniform combustion, and consistent airflow to the combustion chamber across a broad operating range. In the front (low temperature) section of the hood, the combustion chamber is positioned on support pins spaced equally apart in the rear compressor frame. These pins guarantee that the hood is centered in the diffuser tube and positioned positively axially and radially. In order to maintain airflow, the supporting structure is integrated into the rear compressor frame braces. Fuel-air mixing and flame stabilization are guaranteed by thirty axial turbulence cups that create swirl in the dome, one at each fuel nozzle. A cooling air film shields the dome's interior surface from high combustion temperatures. Venturi-shaped guides on the revolving cup avoid carbon accumulation on the fuel nozzles. A sequence of overlapping rings joined by brazed and resistance-welded connections make up the combustion chamber covers. They are shielded from excessive combustion, and air flows in via. (Mohammed, 2024)

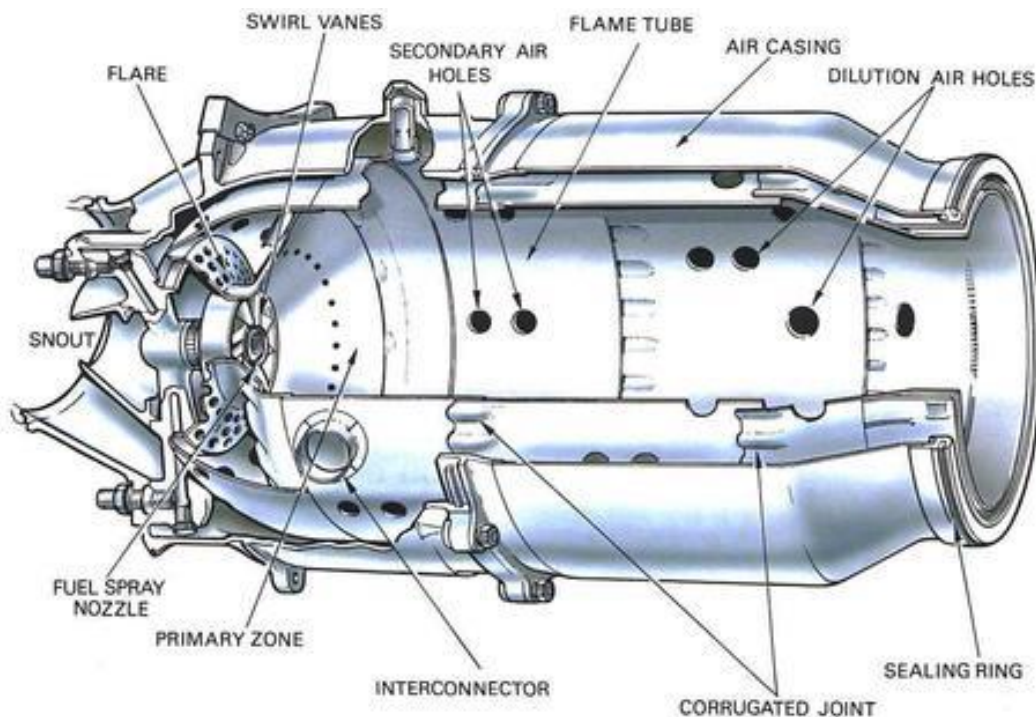


Figure II.20 PGT25 Gas Turbine Combustion Chamber

II.3.1.5.1. DLE Combustion System

With its Dry Low Emission (DLE) combustion system, the PGT25 gas turbine is a major development in gas turbine technology, particularly when it comes to minimizing environmental effect without sacrificing efficiency. One of the best examples of how contemporary turbines are made to satisfy strict emissions and efficiency standards is GE's PGT25 gas turbine, which frequently uses this technology. This is a thorough rundown of the DLE system, particularly as it relates to the PGT25 gas turbine. (Mohammed, 2024)

Pre-Mixing Technology: The PGT25 turbine's DLE system makes use of cutting-edge pre-mixing technology. Before burning, fuel and air are well combined, which promotes more thorough combustion and much lower temperatures. The production of carbon monoxide (CO) and nitrogen oxides (NO_x), which are frequent byproducts of high-temperature combustion, is decreased by this procedure. **Staged Fuel Injection:** To better regulate the combustion process, the PGT25's DLE system uses staged fuel injection. The technology can sustain ideal combustion conditions under a variety of operating circumstances by infusing fuel into the combustion chamber at various times. This phased strategy ensures stable combustion and operational flexibility while reducing emissions.

Low Emissions: The PGT25 turbine's DLE system's main benefit is its low NO_x and CO emissions, which allow it to comply with the strictest environmental requirements in the world, particularly those in areas with severe air quality standards.

Operational Efficiency: Despite its focus on reducing emissions, the PGT25 with DLE technology does not sacrifice operational efficiency. The turbine maintains high thermal efficiency, ensuring that fuel consumption and operating costs remain competitive.

Fuel Flexibility: Natural gas, diesel, and low-BTU gases are among the fuels that the PGT25's DLE system can handle. This adaptability is essential for consumers looking to switch to cleaner fuels and for operations in various geographic regions. (Mohammed, 2024)

II.3.1.5.2. Singal Annular Combustion SAC

Fuel and air are combined and burned in a single annular combustion chamber in the SAC system. Multiple combustion chambers or the more intricate layouts found in DLE systems stand in contrast to this architecture. While the SAC may not attain the same low levels of NO_x and CO emissions as a DLE system, its simpler design can have benefits in terms of manufacturing and maintenance.

Design and Operation: The PGT25's SAC is made to maximize fuel and air mixing in order to produce a steady and effective combustion process. It injects gasoline into the airflow using a number of fuel nozzles placed around the annulus. The air is provided by the compressor section of the turbine, and the mixture is ignited in the combustion chamber, driving the turbine blades in the turbine section.

Emissions Controls: Although SACs typically emit more emissions than DLE systems, improvements in nozzle design and combustion control have made it possible for PGT25 turbines with SACs to comply with regulations in a number of jurisdictions. In order to reduce NO_x output, the design prioritizes reaching complete combustion and lowering peak combustion temperatures.

Efficiency and Performances: The PGT25's SAC design seeks to preserve high combustion efficiency, guaranteeing that fuel is used efficiently to generate energy. The turbine's overall performance, including its power production and fuel consumption rates, is influenced by its efficiency. (Mohammed, 2024)

II.3.1.6. High Pressure Gas Turbine

The first and second stage turbine nozzles, the intermediate turbine frame, and the high-pressure turbine rotor make up the high-pressure turbine section. The hot gas from the combustion chamber is directed into the rotor blades at the ideal angle and speed by the turbine nozzles. Bearing N°4 supports the turbine rotor's front side at the compressor rotor's rear shaft. Bearing N°5 of the intermediate turbine frame supports the rear of the rotor. The compressor rear frame houses and supports the turbine nozzles.

- Number of Turbine: 02
- Joint Plane: Horizontal flange
- First Stage Guide: Fixed
- Second Stage Guide: Variable (Mohammed, 2024)

II.3.1.6.1 High pressure Turbine Rotor

A conical front shaft, two disks with blades and locking mechanisms, a conical rotor spacer, a thermal shield, and a rear shaft make up the high-pressure turbine rotor. There are two seals on the shaft's front side. Pressurized air cannot escape the compressor discharge pressure (CDP) and enter the compressor rotor rear bearing drain casing because of the front seal. The other seal keeps the CDP inside the combustion chamber and rotor-formed housing. This shell functions as a balancing chamber, reducing the thrust stress on ball bearing N°4 by providing a binding force. To increase their resistance to oxidation, corrosion, and erosion, the turbine blades in both stages are strengthened and air-cooled internally. (Mohammed, 2024)

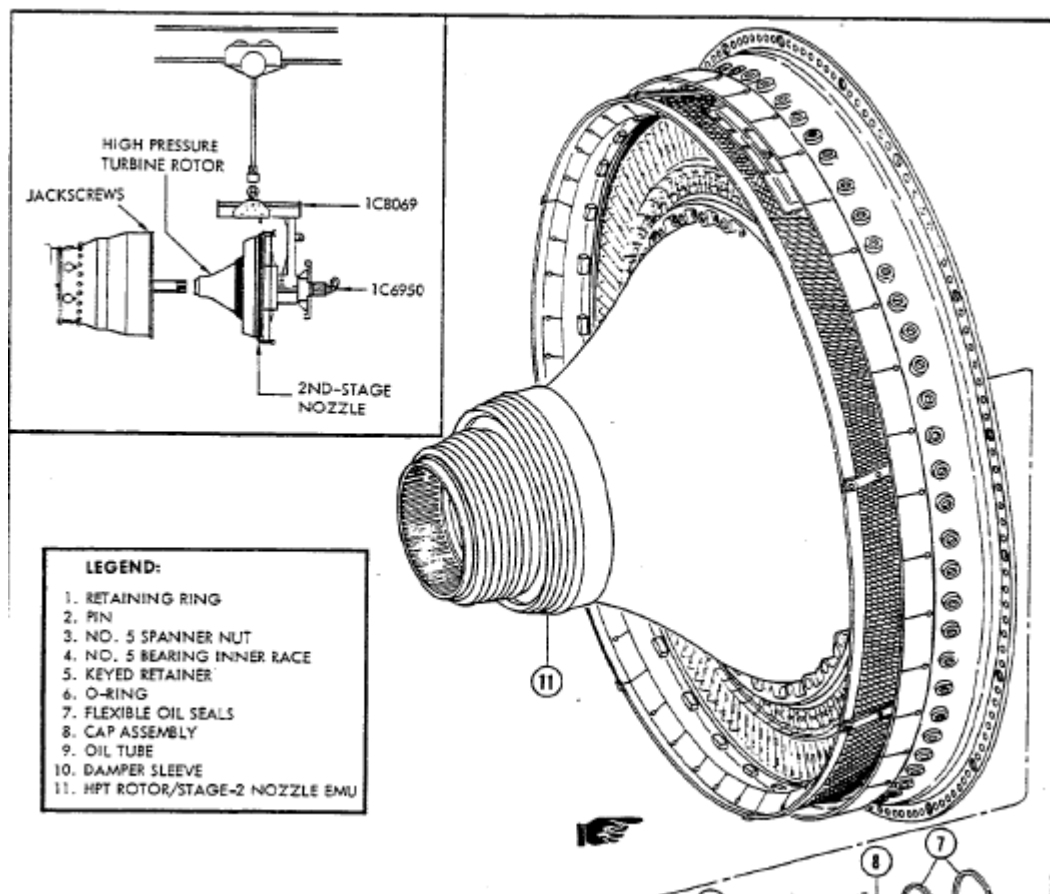


Figure II.21 High Pressure Turbine Rotor (PIGNONE, 2002)

II.3.1.6.2. High Pressure Turbine Blade

Cooling of Rotors The compressor's constant air discharge, which travels through the holes in the first-stage nozzle support and toward the turbine shaft, cools the high-pressure rotor. Prior to entering the dovetail slots, this air cools the rotor's interior as well as the two disks. **High-Pressure Turbine Blade Cooling:** The LM 2500 gas generator has a high-pressure turbine with single crystal blades that have a heat transfer technique that improves thermal transfer efficiency and improved internal cooling design. This raises the firing temperature to maximize power while enabling the blades to run at temperatures below the blade metal temperature. Air released from the compressor cools both stages of the high-pressure turbine blades as it passes through the blade roots and into the blades. Both external film cooling and internal convection are used to cool the first-stage blades. With air flowing through the labyrinth and then outward through the leading edge, tip, and fin holes, the leading-edge circuit provides internal convection cooling. Air passing via the trailing edge exit holes aids in trailing edge convection cooling. Convection cools the second-stage blades, and all of the cooling air is released at the blade tips. (PIGNONE, 2002)

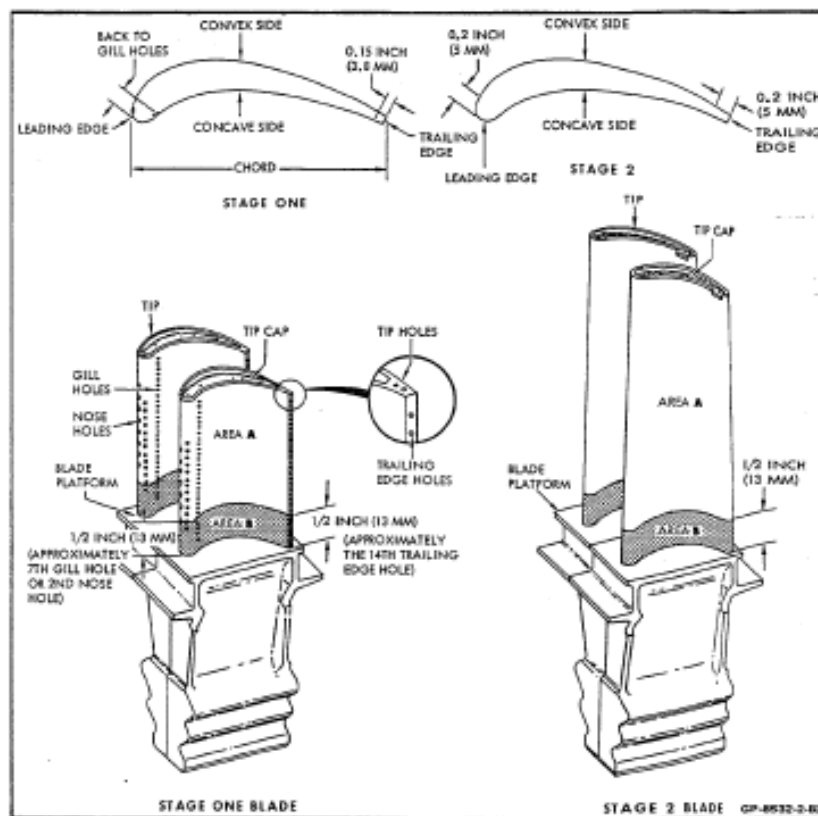


Figure II.22 High Pressure Turbine Blades (PIGNONE, 2002)

II.3.1.7. Power Turbine (Low Pressure Turbine)

The PGT 25 power turbine's components were designed with the help of a wealth of knowledge in the fields of axial/centrifugal compressors and high-efficiency gas turbines. The main goal of the blades' aerodynamic design was to achieve extremely high efficiency at both rated and lowered speeds. With a mild aerodynamic load and excellent expansion efficiency, the turbine stages can be reduced to two at the working speed of 6,500 rpm. The two expansion stages have a high energy level and a three-dimensional design. Cobalt-based for the

nozzle and nickel-based for the rotor blades, the precision casting superalloy is the same material used in high-performance gas turbines. The mild gas temperature at the power turbine inlet ensures a large safety margin with respect to bearing creep and blade life.

Longer maintenance intervals and lower maintenance costs are made possible by the construction's simplicity and the excellent quality of the materials utilized. (Mohammed, 2024)

II.3.1.7.1. Power Turbine Stator

The power turbine stator consists of the following main elements:

- First-stage casing assembly (casing, bandage sectors, and seals).
- First-stage nozzle assembly (nozzles, nozzle support ring, elliptical shield).
- Second-stage casing assembly (casing, bandage sectors, and seals).
- Second-stage nozzle assembly (nozzles and membrane).

The two casings form a single block and are paired by three cylindrical pins and connected by 72 tie rods. These casings are connected at the front to the transition casing and at the rear to the stator cone support.

Openings are provided on the casings to introduce endoscopes for inspecting the trailing edges of the nozzles and the leading edges of the rotor blades on both stages. (PIGNONE, 2002)

II.3.1.7.2. Power Turbine Rotor

- Comprises two blade discs, an intermediate spacer ring, and a hub.
- Assembly is secured by 16 tie rods, manipulated by hydraulic cylinders.
- Each disc accommodates 83 blades fixed by "fir-tree" root fittings.
- Blade tips feature dual sealing teeth to mitigate leakage.
- Blade design enables engagement of mounts via centrifugal force loosening.
- Blades are axially secured to the disc via a special locknut.
- Rotor cooling and hot gas buffering use air drawn from the axial compressor.
- Labyrinth seals direct cooling air to various rotor surfaces.
- Fins on the heads of the 16 tie rods activate cooling air circulation over the 2nd-stage turbine disc.
- Torque transfer from the discs to the shaft is facilitated by a mounting flange. (PIGNONE, 2002)

II.3.1.8. PGT25 Gas Turbine Bearings

Two journal-style bearings power the rotor. Tilted pads have been put on the journal bearing nearest the turbine crowns. Furthermore, the moving bearing uses direct lubrication, and the thrust bearing is journal-type. Low-pressure oil is used to lubricate the bearings, and it is delivered to them via pipes inside the transmission shaft housing. The flanged conduit behind the housing has a single intake line. The thrust

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bearing's fixed pivot is lubricated by the oil that escapes from its operational partner, and the oil is transferred to the support bearings via calibrated orifices. The oil released by the nearby bearing lubricates the coupling to the driven machine. Three sets of labyrinth seals and a threaded seal guarantee gas sealing between the inner bearing and the moving crown chamber. The air pushed out of the 16th stage of the gas generator's axial compressor powers an ejector that pressurizes the second sealing device (apart from the bearing) once all gaps between them have been drained. (Mohammed, 2024)

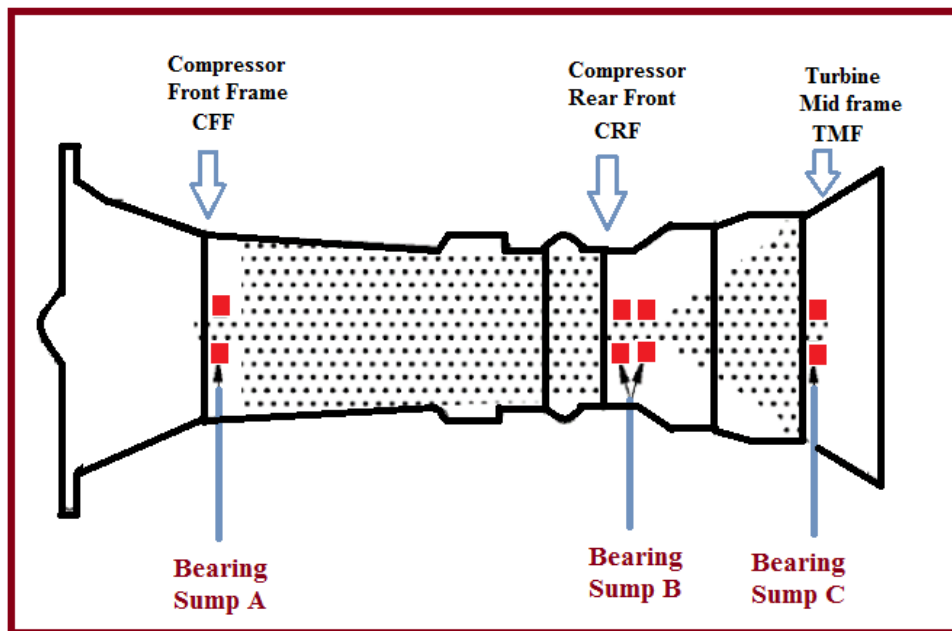


Figure II.23 PGT25 Gas Turbine Bearings (Mohammed, 2024)

II.3.1.9. Fuel Gas System

The system allows for stopping and controlling the flow that is conveyed to the combustion chamber during the different stages of start-up and under various operating conditions. After the fuel gas leaves the gas skid, it goes directly to the turbo compressor block and more precisely to the gas turbine. But before being injected into the combustion chamber, it passes through a regulation system, we call it the FSR Fuel Regulation System.

The system consists of three valves, two for regulation and one for safety:

GCV1: Gas Control Valve 1

GCV2: Gas Control Valve 2

FGS: Fuel Gas Stop Valve

When the fuel gas arrived to the FSR system with pressure of 30bar the GCV vanes will reduce his pressure on two steps the first one in GCV1 and the second one on the GCV2 to a pressure depend of the speed of the gas turbine.

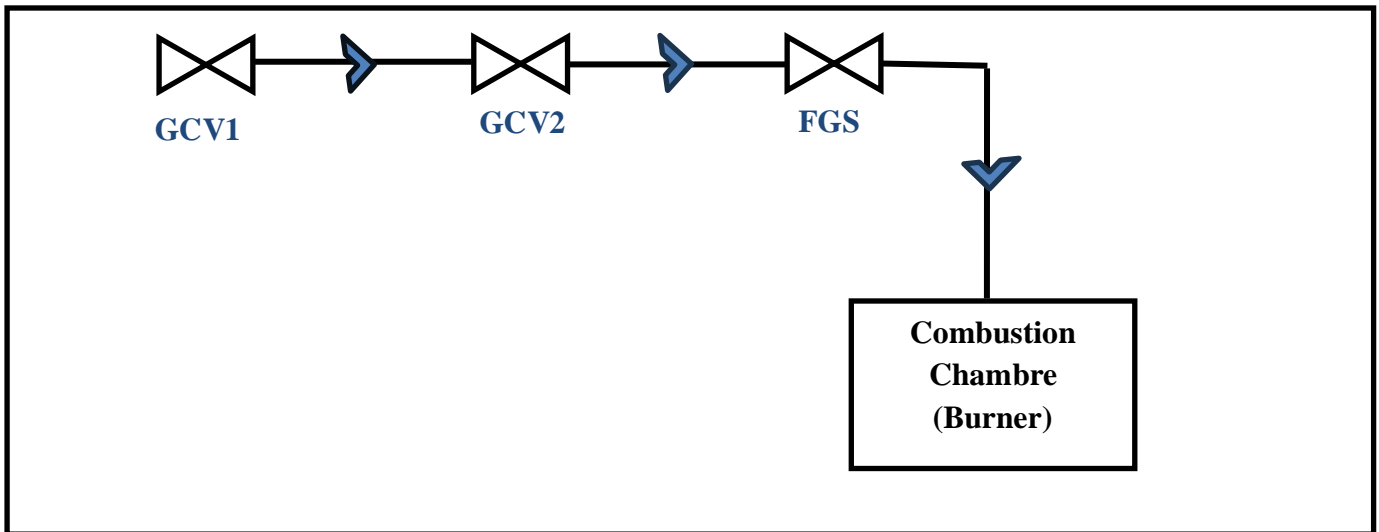


Figure II.24 Fuel Gas System Schematization

II.3.1.10. Burner

The burner is the final component of the fuel gas system. Its task is to distribute the gas uniformly within the combustion chamber, achieving the optimal air/fuel ratio for combustion and creating a flame with a geometry designed to prevent any potential damage to the cover, liner, and gas collection chamber.

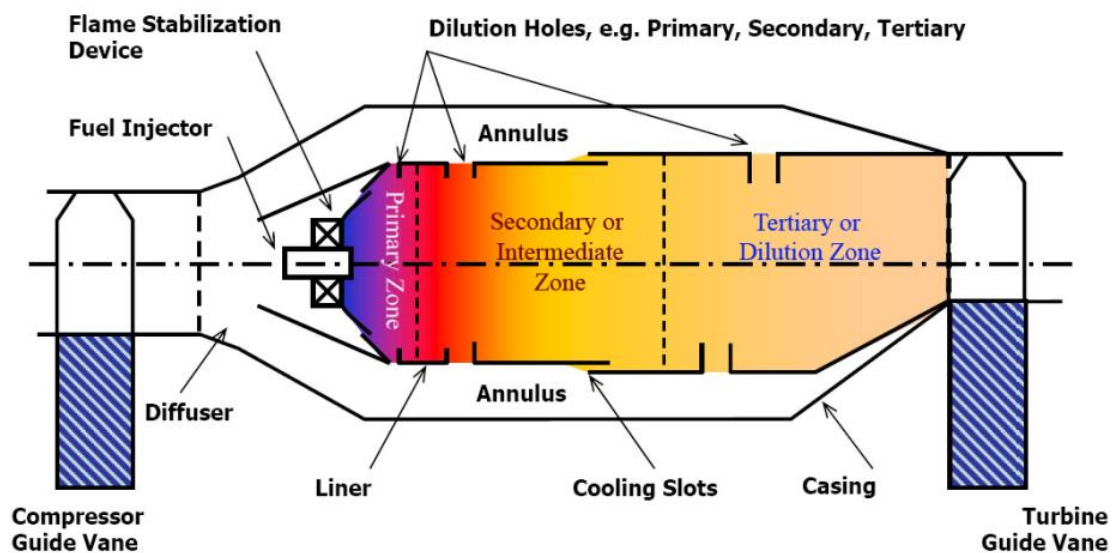


Figure II.25 PGT25 Burner Schematization

Conclusion

The PGT25 gas turbine is a machine that was developed and produced through a collaboration between Baker Hughes and Nuovo Pignone. It is used in several industrial sectors such as the oil and gas industry, where we saw the different parts of the machine (compressor, combustion chamber, turbine, carburetion system, etc.).

Chapter III

Mathematical Model and Simulation Parameter

III.1. Introduction

In this chapter we will see the different steps and parameters used to carry out the CFD simulation. At the beginning the mathematical model and the different equations included in the simulation, then the calculating domain mesh and the boundary conditions.

III.2. Simulation

Engineering simulation uses advanced software to visualize, analyze, and predict the result of processes and the behavior of 2D, 3D product designs while those products and systems are still in development. The insights gained from engineering simulation software help stakeholders make critical product design decisions in the digital phase, before moving to physical testing and prototyping—saving money, encouraging innovation, and accelerating time to market. (Ansys, 2016)

III.3. Computational Fluid Dynamic

Computational fluid dynamics (CFD) is the science of using computers to predict liquid and gas flows based on the governing equations of conservation of mass, momentum, and energy. Fluids are all around us and sustain our lives in endless ways. The vibrations in your vocal cords generate pressure waves in the air that make speech possible, as well as hearing the spoken words. Without fluids, your tennis ball's topspin would be meaningless, and your airplane wouldn't generate any lift. Through CFD, we can analyze, understand, and predict the fluids that make up nearly every part of our world. (Ansys, 2016)

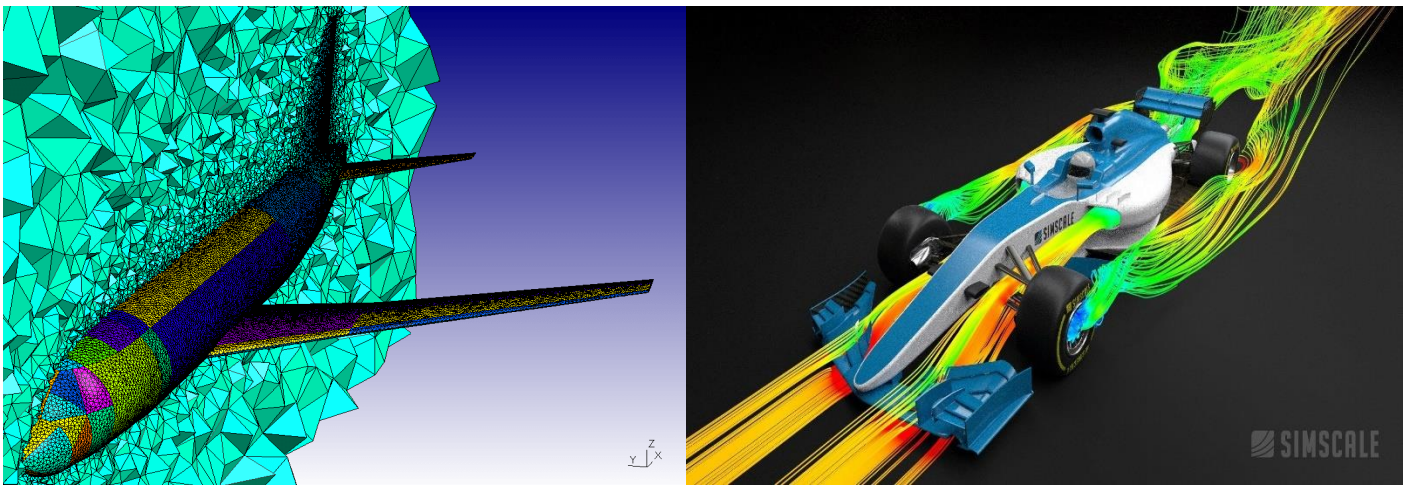


Figure III.1 Computational Fluid Dynamic (Ansys, 2016)

III.3.1. Steps for a CFD Calculation

The CFD process consists of three main stages: the pre-processor, the solver, and the post-processor.

1)preprocessor: Construct the geometry of the computational domain, Subdivide the domain into small control volumes (mesh), Define the boundary conditions.

2) Solver: Numerically define the operating conditions (gravity, pressure, etc.), Specification of boundary conditions, it allows the choice of the iterative process.

3) post processor: Display the results obtained, View fields (pressure, velocity, temperature, etc.) as well as all calculated quantities, also offers the ability to plot and visualize streamlines.

III.3.1. Computational Fluid Dynamic Application

III.3.1.1 Aerospace

CFD makes it possible to model the airflow around aircraft to predict lift and drag, known as external aerodynamics. This is important as companies look to optimize aircraft designs for improved performance and decreased fuel usage. CFD can also simulate complex systems within the aircraft's interior, such as cabin air circulation, to predict air quality. Key applications include Avionics cooling, aero-optics, external aerodynamics, cabin HVAC, and propulsion.

III.3.1.2. Automotive

CFD enables us to perform in-depth temperature investigations across the Multiphysics system in electric vehicles, where e-motors and battery electrochemistry produce intricate intersections between mechanical, chemical, and electrical engineering. This can lessen battery thermal runaway, which can result in fires, and let engineers forecast how well the motor is cooled. Gearbox lubrication, autonomous sensors, battery modeling, external aerodynamics, aeroacoustics, and electric motor cooling are some of the main uses.

III.3.1.3. Energy

As an enabler for decarbonization, hydrogen is a valuable fuel in creating a cleaner planet. CFD allows us to model the full hydrogen value chain—from production to storage, transportation, and consumption. CFD can conduct exploratory studies to learn how hydrogen and other alternative fuels can be used in conventional engines and determine the efficacy of alternative fuel options. Key applications include PEM electrolysis, hydrogen production, transportation, storage, and consumption, and fuel cell utilization.

III.3.1.4. Healthcare

In the biomedical domain, CFD is capable of analyzing bodily fluid flows, including blood flow via the circulatory system and airflow via the respiratory system. It can also be used to assess the possible effectiveness of novel drugs and expedite the development of medical devices. The respiratory system, cardiovascular flow, and biopharmaceuticals are important uses. (Ansys, 2016)

III.4. Ansys Fluent 6.3.26

Fluent is a computer program for calculating fluid dynamics (also known as computational fluid dynamics, or "CFD") that has two features:

- **Solver:** By offering a number of digital simulations, SOLVEUR enables the specification of operating circumstances (such as pressure) and their parameters, as well as the digital definition of operating conditions. It also enables the selection of the optimal procedure. For the spatial and temporal discrepancy and the coupling of pressure and speed.

-post processor: allows you to visualize the geometry and mesh of the domain, but above all, to display the results obtained. It is thus possible to visualize the fields (speed, temperature, as well as all the calculated quantities). It also offers the possibility to plot and visualize the streamlines. (Ansys, 2016)

III.5. Simulation of Reactive Flows

Reactive flows are flows that are chemically reactive. All types of fluid flows with chemical reactions occurring within the fluid phase, at the interphase between different fluid phases or at interphases to solids. Reactive flow finds its applications in many areas including catalytic cracking in chemicals process, combustion in IC engine, CO₂ capture process, polymerization, etc. Simulation of reactive flows is becoming increasingly important because it allows researchers to gain insight into processes with difficult conditions, such as high temperature and pressure. In this way, the effort and costs for prototypes and field test can be reduced to a minimum.

III.5.1. Continuous Non-Premixed Turbulent Combustion in Annular Combustion Chamber

Nowadays approximately 80% of consumed global energy comes from combustion processes. In addition, compared to the amount corresponding to 2011, global energy demand is expected to increase near one-third by 2040. However, in spite of the rapid growth in the use of renewable energies, fossil fuels - oil, gas and coal - will remain the main sources for global energy supply in the next few years. However, due to the associated emission of greenhouse gases, particulate matter and soot, the wide use of combustion systems has a significant impact on both health and environment. Therefore, in order to increase fuel efficiency and to reduce pollutant emissions, continuous design improvements in combustion systems need to be introduced. Annular combustion chamber like configurations featuring strong turbulence-chemistry interactions is typically used as a means of flame stabilization in both gas turbine combustors and industrial burners. The characteristic recirculating flow regions formed in such configurations have a significant influence on both flame stabilization mechanisms and residence time distributions, which subsequently affect soot and NO_x formation in flames. Previous studies have shown that the peak of soot volume fraction is associated with the low strain rates, high temperature regions of the flame, whereas advection processes can explain the presence of soot in high local strain rates shear layer regions unfavorable for soot to form. Both time and length scales characterizing turbulent reacting flows control indeed the pollutant formation in flames. An adequate treatment of the turbulence-chemistry interactions usually presents in annular combustion chamber configurations is therefore needed in order to improve existing combustion systems. Combustion processes and flame behavior in particular are highly sensitive to inflow conditions. This means that accurate modelling of turbulent transport of momentum, energy and species mass is paramount to obtaining reliable simulation results. Non-reactive and reactive flow studies show that, compared to Reynolds-averaged Navier-Stokes (RANS) approaches, large-eddy simulations (LES) based ones predict scalar mixing processes and dissipation rates with considerably improved accuracy, especially in complex flows.

The main objective: this work is to assess the FPV model capabilities to predict turbulent non-premixed flames in annular combustion chamber configurations featuring strong turbulence-chemistry interactions [Methane-Air, Hydrogen-Air]. In addition, it is of particular interest to determine whether the modeling approaches employed are able to capture the fundamental reactive flow features characterizing the studied burners.

III.6. Mathematical Model

The main features of the mathematical model utilized in this work are briefly described in this section. A particular emphasis is put on the flow governing equations and the combustion modeling approach employed here.

III.6.1. Masse Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0 \dots \dots \text{(III.1)}$$

Y_i : Mass fraction of Species D_i : Diffusion Coefficient

S_i : Source Terme (e.g. chemical reactions)

III.6.2. Momentum Equation

$$\frac{\partial(\rho u)}{\partial t} + \nabla \cdot (\rho \mathbf{U} \cdot \mathbf{U}) = -\nabla p + \nabla \cdot \boldsymbol{\tau} + \rho \mathbf{F} \dots \dots \text{(III.2)}$$

\mathbf{U} : Velocity Vector

ρ : Fluid Density

P : Pressure

$\boldsymbol{\tau}$: Viscous Stress Tensor

g : Gravitational Acceleration

F : Externe Body Forces

III.6.3. Conservation of Energy Equation

$$\frac{\partial(\rho E)}{\partial t} + \nabla \cdot (\rho \mathbf{U} E) = -\nabla(p \mathbf{U}) + \nabla \cdot (\boldsymbol{\tau} \cdot \mathbf{U}) + \nabla \cdot (K \nabla T) + \rho \mathbf{U} \cdot \mathbf{g} + Q \dots \dots \text{(III.3)}$$

\mathbf{U} : Velocity Vector ρ : Fluid Density

P : Pressure

$\boldsymbol{\tau}$: Viscous Stress Tensor

g : Gravitational Acceleration

F : Externe Body Forces

K : Thermal Conductivity

$E = e + (1/2) \mathbf{U} \cdot \mathbf{U}$

Q : Heat Source Term

III.6.4. Chemical Conservation Equations

$$\frac{\partial(\rho Y_i)}{\partial t} + \nabla \cdot (\rho U Y_i) = \nabla \cdot (\rho D_i \nabla Y_i) + R_i + S_i \dots \dots \text{(III.4)}$$

Y_i : Mass fraction of species.

ρ : Fluid density

U : Velocity Vector

D_i : Diffusion Coefficient

R_i : Reaction Rate

S_i : Additional Source Term

III.6.5. Turbulence Equation (k), (ϵ)

Turbulence Kinetic Energy (k) Equation:

$$\frac{\partial(\rho k)}{\partial t} + \nabla \cdot (\rho U k) = \nabla \cdot \left(\left(\mu + \frac{\mu_t}{\sigma_k} \right) \nabla k \right) + Pk - \rho \epsilon \dots \dots \text{(III.5)}$$

k : Turbulent kinetic energy ρ : Fluid density u : Mean velocity μ : Dynamic viscosity μ_t : Turbulent viscosity

σ_k : Turbulent Prandtl number Pk : Production term ϵ : Dissipation rate

Dissipation Rate (ϵ) Equation:

$$\frac{\partial(\rho \epsilon)}{\partial t} + \nabla \cdot (\rho u \epsilon) = \nabla \cdot \left(\left(\mu + \frac{\mu_t}{\sigma_\epsilon} \right) \nabla \epsilon \right) + C_{1\epsilon} \frac{\epsilon}{K} Pk - C_{2\epsilon} \rho \frac{\epsilon^2}{k} \dots \dots \text{(III.6)}$$

σ_ϵ : turbulent Prandtl number for ϵ (typically 1.3)

$C_{1\epsilon}, C_{2\epsilon}$: model constants.

$C_{1\epsilon}$: 1.44

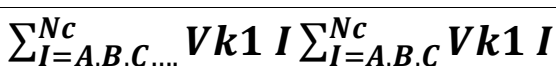
$C_{2\epsilon}$: 1.92

C_μ : 0.09

Chapter III: Mathematical Model and Simulation Parameter

III.6.6. Combustion Modeling Using the EDM (Eddy Dissipation Model)

In general, chemical reactions can be represented by a number K of elementary reactions involving N_c species we write:

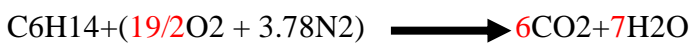
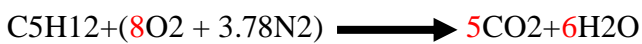
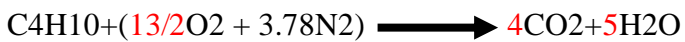
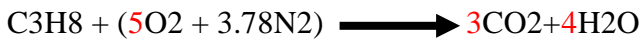
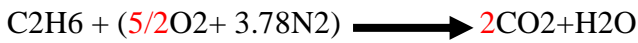
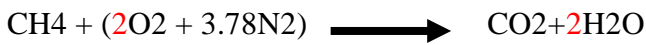


$K=1, 2, \dots, K$

V_{K1} et V_{K2} : Are the stoichiometric coefficient of species in the elementary reaction.

-In this work we took the following chemical equations:

1) Fuel Gas Combustion Simulation:



2) Hydrogen Combustion:



III.6.6.1. Reagent Limiter

This limiter checks the existence of reactants to have a reaction (a reaction rate) these reactants must be in flammable proportions.

$$R_k = A \frac{\varepsilon}{k} \min\left(\frac{I}{V_{K1}}\right)$$

Where A is a coefficient to be adjusted according to the geometry and the fuel, I is the molar concentration of species with k only passing through the reactants.

III.6.6.2. Product Limiter

The purpose of this limiter is to check for the presence of combustion products; the reaction rate will be zero if there are no combustion products.

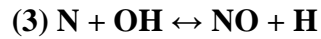
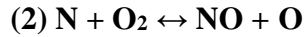
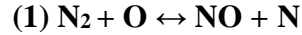
$$R_K = A B \frac{\varepsilon}{k} \min\left(\frac{\sum_p I W_1}{\sum_p V_{K1} W_1}\right)$$

B is a coefficient; the index P runs through all the products in the elementary reaction k.

III.6.7. Thermal Nox Formation Mechanism [Zeldovitch Mechanism]

Thermal NO formation mechanism is the dominant source of NO_x in combustion system. It is formed by the reaction of atmospheric nitrogen with oxygen due to combustion at elevated temperatures (above 1800 K).

The three reactions producing thermal NO proposed by Zeldovich are:



Due to high activation energy requirement of Reaction (1), NO production by thermal mechanism proceeds at a slower rate than the oxidation of hydrocarbons. The NO formation rate can be approximated by:

$$(4) [\text{NO}] = k e^{-K/T} [\text{N}_2] [\text{O}_2]^{1/2} t$$

where k and K are reaction constants, T is absolute temperature, and t is time [10]. Eq (4) indicates that thermal NO formation is an exponential function of temperature. The other factors that influence thermal NO formation rate are oxygen, nitrogen concentrations and residence time of reaction products.

III.7. Chemical Species Proprieties

III.7.1. Reagents

	Molecular Weigh (kg/kg.mol)	Conductivity λ (w/m.k)	Density ρ (J/kg.k)	Viscosity σ (kg/m.s)	δh of Reaction Kj/mol
CH4	16.04303	0.0332	0.6679	1.087e-05	-802
C2H6	30.07012	0.0207	1.263	9.29e-06	-1560
C3H8	44.09	0.0177	1.91	7.95e-06	-2220
C4H10	58.1243	0.0159	2.46	7e-06	-2877
C5H12	72.1539	3.05	3.05	7.2e10-06	-3298.4
C6H14	86.17848	0.0138	0.0138	7.6e10-06	-4163
H2	2.016	0.1815	0.09		-286
Air	28.966	0.0242	Ideal gas	1.7894e-05	/

Table III.1 Reagent Chemical Species Proprieties

III.7.2. Product

	Molecular Weigh (kg/kg.mol)	Conductivity λ (w/m.k)	Density ρ (J/kg.k)	Viscosity σ (kg/m.s)	δh of Reaction Kj/mol
CO2	44.00995	0.0145	1.7878	1.37e-05	-393.5
H2O	18.01534	0.0261	0.5542	1.34e-05	-285.8

Table III.2 Product Chemical Species Proprieties

III.7.3. Comburant (Air)

	Molecular Weigh (kg/kg.mol)	Conductivity λ (w/m.k)	Density ρ (J/kg.k)	Viscosity σ (kg/m.s)	δh of Reaction Kj/mol
O2	31.998	0.0246	1.2999	1.919e-05	/
N2	28.0134	0.0242	1.138	1.66e-05	-92.4

Table III.3 Comburant Chemical Proprieties

III.7. Simulation Parameters

III.7.1. Calculation Domain

The burner of the PGT25 gas turbine consist of an annular combustion chamber:

Combustion Chamber Length: 850mm

Maximum Hight: 250mm

Compressed Air Inlet Section: 0.078 m^2

Fuel Inlet Section: 0.01177 m^2

Burnt Gas Outlet Section: 0.01356 m^2

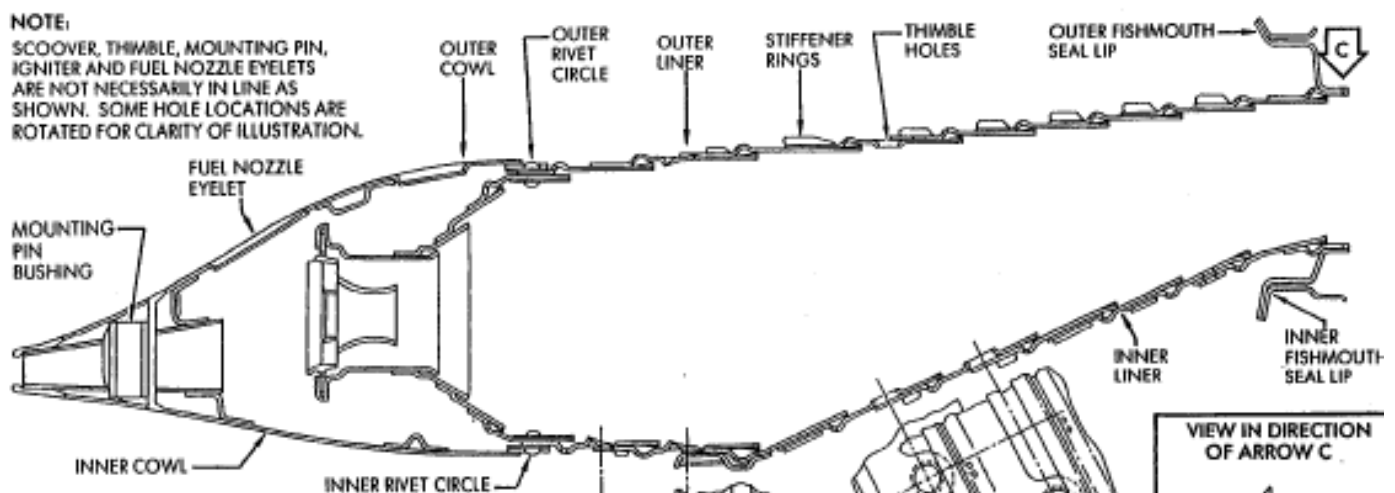
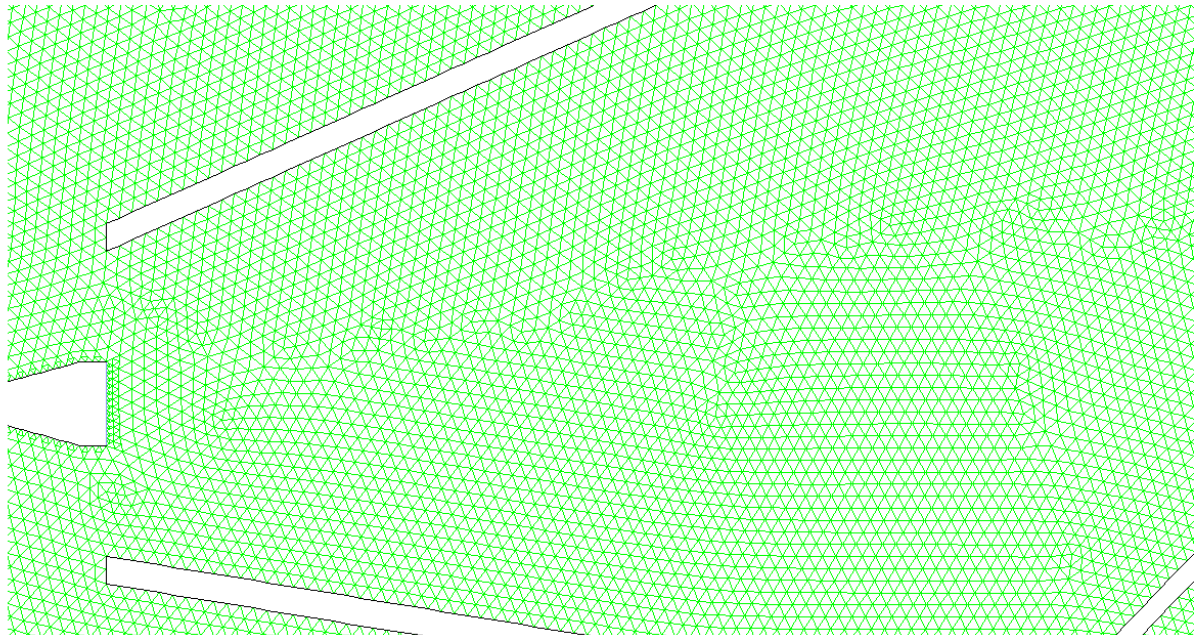


Figure III.2 Calculation Domaine [PGT25 Combustion Chambre]

III.7.2. Simulation Mesh

The geometry of the calculation domain and the mesh was generated using gambit software, after testing several different meshes in terms of the number of nodes, an unstructured mesh was consisting of 360 nodes.

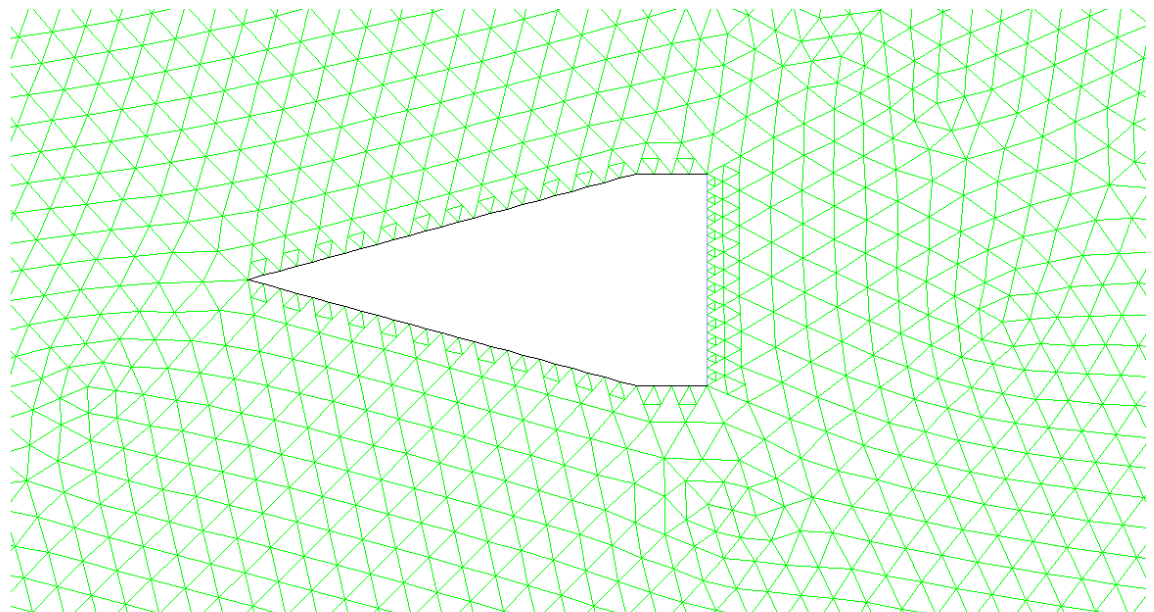
with a refinement of the fuel injection surface were chosen this choice is justified by the independence of the mesh solution.



Grid

Jun 09, 2025
FLUENT 6.3 (2d, dp, pbns, spe, rke)

Figure III.3 Calculation Domain Mesh



Grid

Jun 05, 2025
FLUENT 6.3 (2d, dp, pbns, spe, rke)

Figure III.4 Calculation Domain Mesh Zoom $\times 70$

III.7.2. Boundary Conditions

	Mass Flow (Kg/s)	Temperature (°C)	Turbulence Intensity (%)
Air Inlet	28	399.85	10
Carburant Inlet	0.1	14.85	10

Table III.4 Fuel Gas Combustion Boundary Conditions

	Mass Flow (Kg/s)	Temperature (°C)	Turbulence Intensity (%)
Air Inlet	28	399.85	10
Carburant Inlet	0.1	14.85	10

Table III.5 Hydrogen Combustion Boundary Conditions

Conclusion

This mathematical model and these equations constitute the tool that was used by the Ansys software to resolve the different parameters of the numerical simulation

Chapter IV

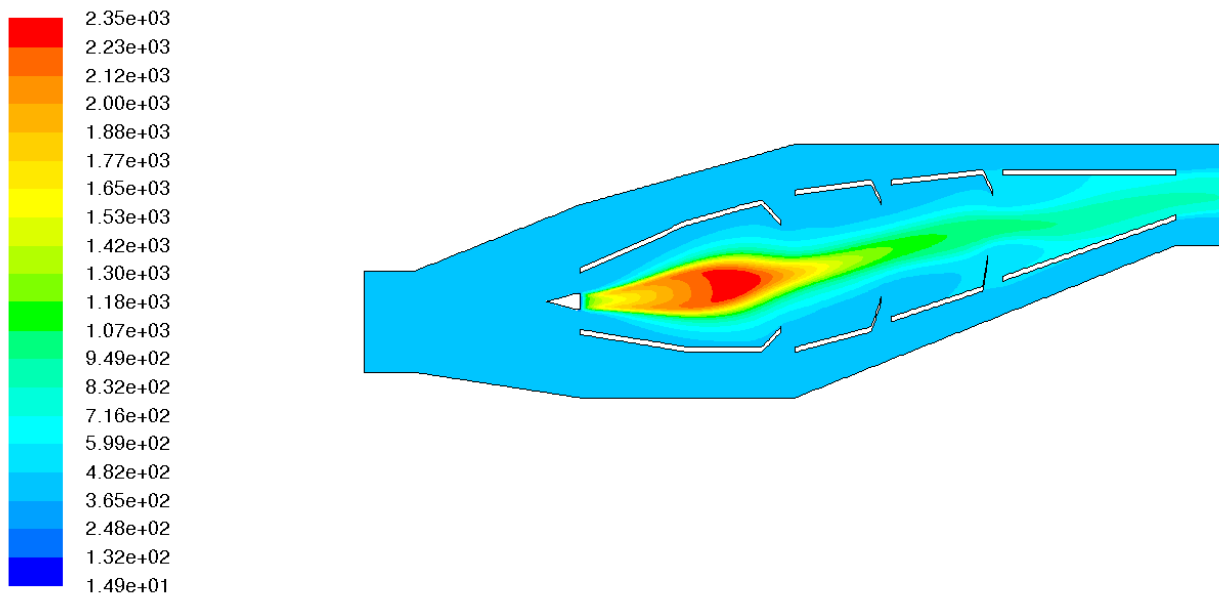
Presentation and Interpretation of Numerical Results

IV.1. Introduction

After solver step, we pass to the post processor step where we present our results and analyzing the different details in each one, like contours temperature and velocity histograms etc. ..., and finally we will see the global difference between the hydrogen and the fuel gas flames.

IV.2. Fuel Gas Result Simulation

IV.2.1. Temperature



Contours of Static Temperature (c)

FLUENT 6.3 (2d, dp, pbns, spe, rke) Jun 03, 2025

Figure IV.1 Temperature Contour for (Fuel Gas-Air)Flame

The contour (Figure IV.1) represents the distribution and variation of temperature at the level of the combustion chamber, where the red zone symbolizes the maximum temperature of the flame which is approximately 2350°C. The temperature declines progressively and this can be observed according to the colors (red the hottest to the coldest blue color).

The combustion chamber is composed of two parts: the first is the cooling space where the dilution air circulates, and the second is the flame tube that envelops the flame. The flame tube is divided into three parts: the first is the mixing zone where the fuel (natural gas) is mixed with the combustion air (compressed air), and the perimeter where the temperature is optimal thanks to a mixture close to stoichiometry.

The temperature gradually decreased in the intermediate zone to about 1100 °C and then to 850 °C in the dilution zone. This temperature decrease is due to the cooling air, which increases the curvature of the mixture, thus reducing the stoichiometry ratio (air flow) and consequently the temperature, (See Figure IV.2).

Chapter IV: Presentation and Interpretation of Numerical Results

We can therefore say that the temperature at the combustion chamber is influenced by several parameters such as the type of fuel, the stoichiometry rate, the percentage of compressed air that is evacuated by the swirl valve, etc.

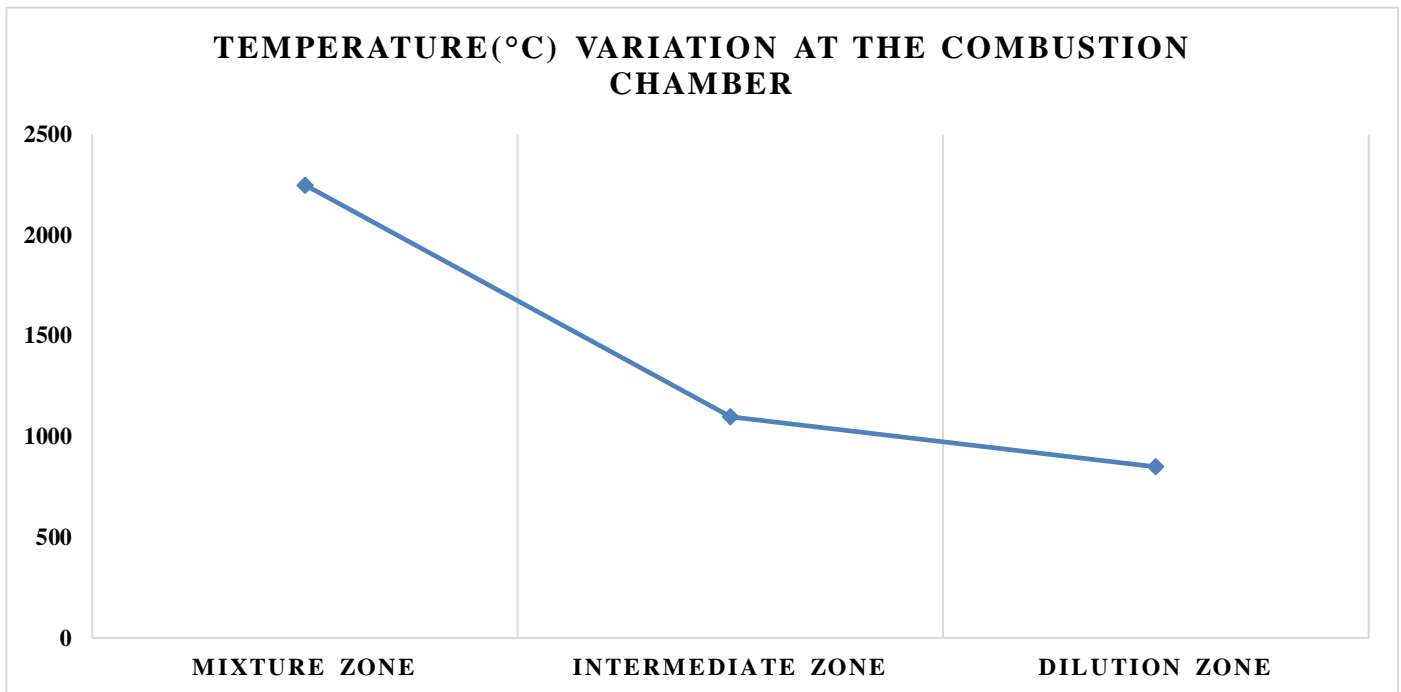
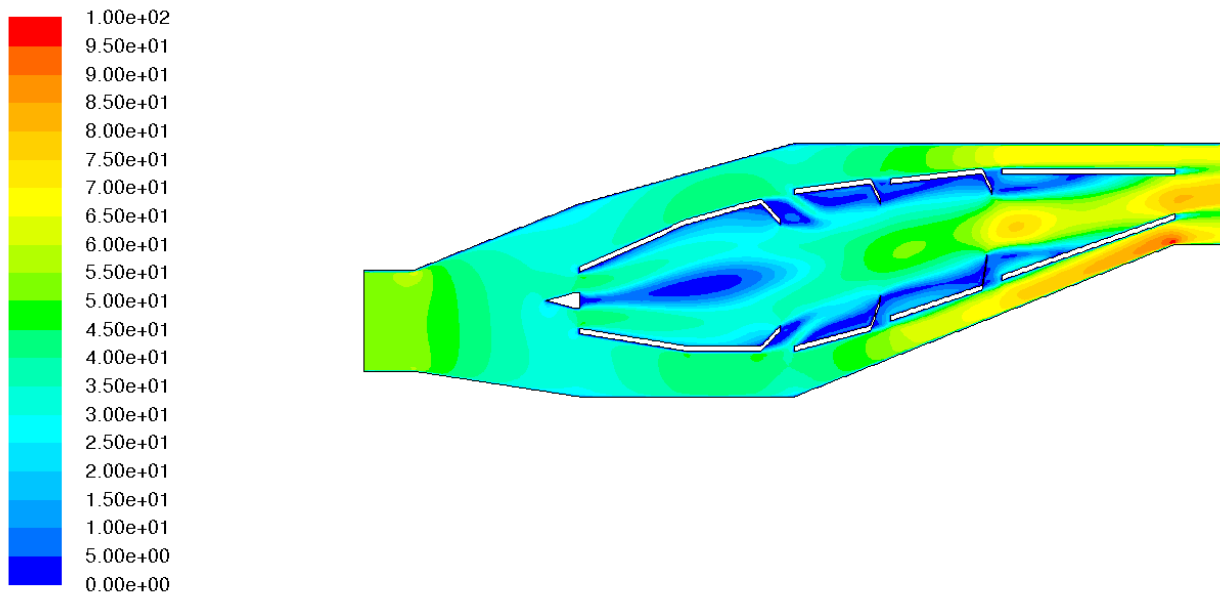


Figure IV.2 Representation of Temperature Change in the Combustion Chamber

According to industrial law, the temperature must be divergent from a maximum value to a value that must not exceed the thermal resistance limit of the metallurgy and at the same time keep a margin of profitability to reach the volute regime by the machine.

IV.2.2. Velocity



Contours of Velocity Magnitude (m/s)

FLUENT 6.3 (2d, dp, pbns, spe, rke) Jun 03, 2025

Figure IV.3 Velocity Contour (Natural Gas -Air) Flame

The contour (Figure IV.3) represents the flame speed variation in the burner of the PGT25 gas turbine. We can see the flame speed converging from the minimum speed which is about 5 m/s to a maximum speed of 75 m/s in flame tube.

Three flame speed profiles are distinguished in the flame tube:

- The laminar speed profile in the mixing zone, where the speed is between 5 m/s and 20 m/s: the mixing zone is designed to ensure perfect homogenization of fuel and air, so that a laminar velocity allows for a more controlled and stable mixture.
- The turbulent velocity profile in the intermediate zone where the velocity is between 40 m/s and 65 m/s: The intermediate zone is designed to ensure the start of dilution by secondary air (cooling air) through the dilution ports and where the flame velocity enters the turbulence profile.
- The turbulent velocity profile in the dilution zone where the velocity is between 70 m/s and 90 m/s: In the dilution zone, the flow velocity becomes turbulent so that mixing between the cooling air and the flue gases is better and local temperature gradients that could damage the turbine are avoided. Good turbulence in the dilution zone allows complete post-combustion of unburned materials (CO, hydrocarbons), thus reducing emissions and also avoiding the formation of NO_x by limiting high-temperature stagnation zones, (see Figure IV.4).

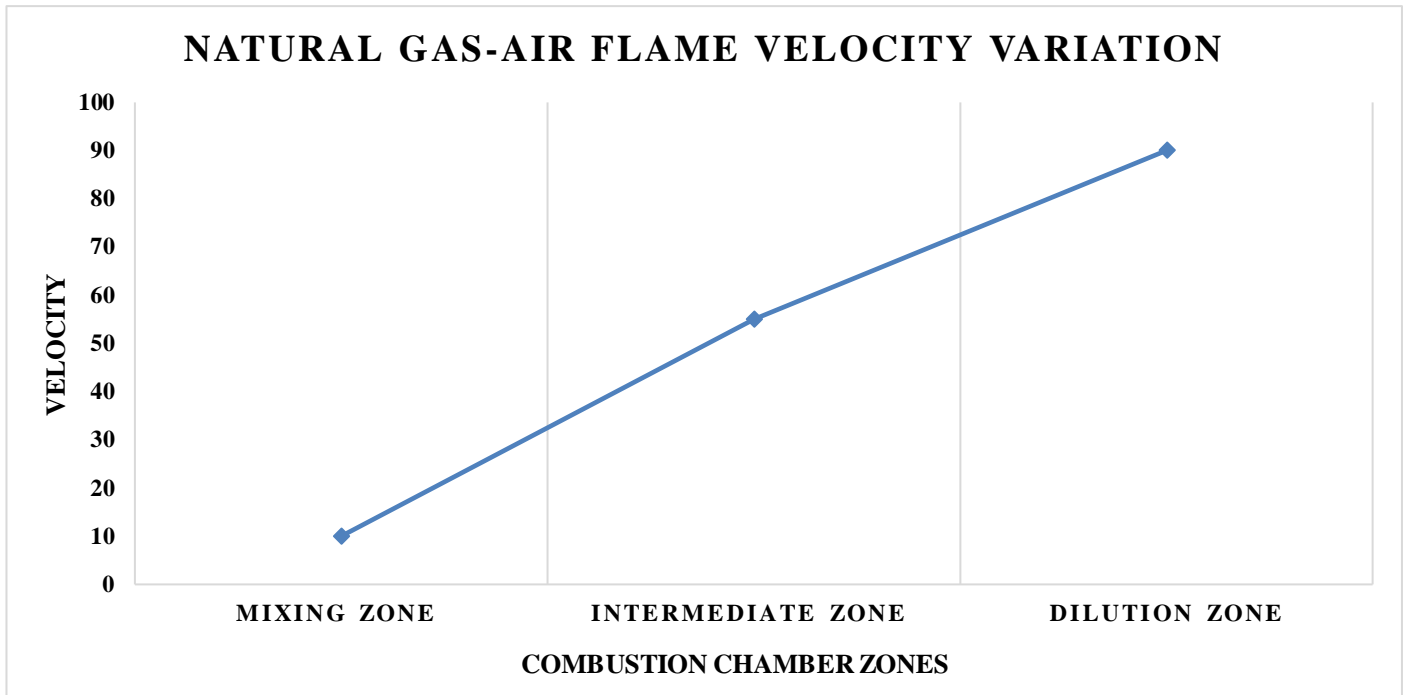
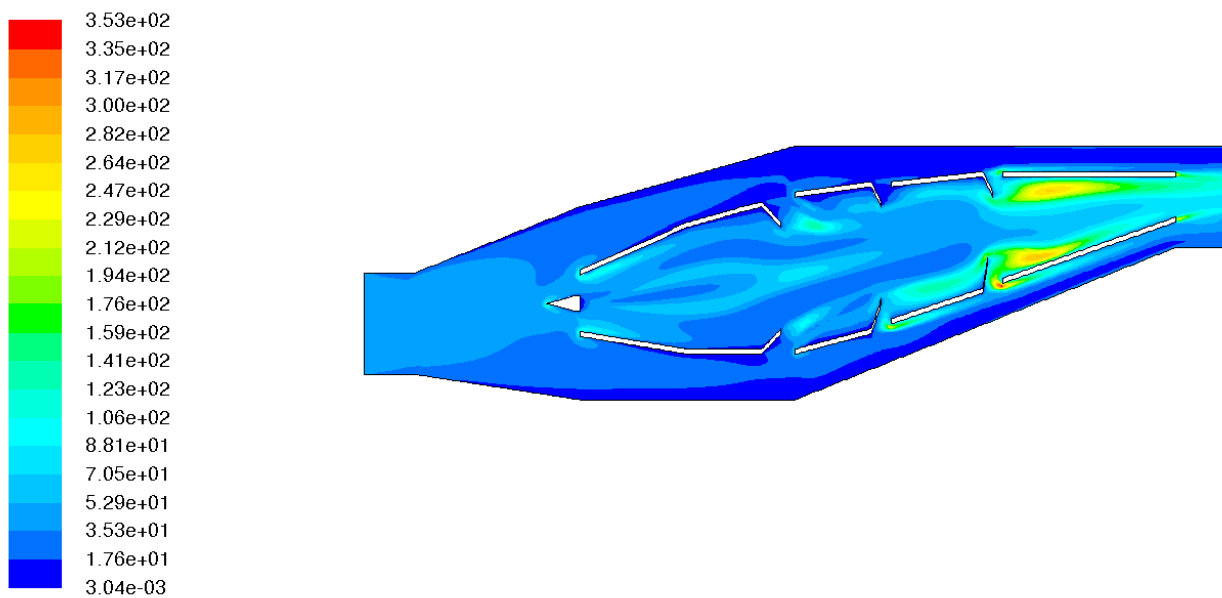


Figure IV.4 Flame Velocity Variation

IV.2.3. Turbulence



Contours of Turbulent Kinetic Energy (k) (m2/s2)

FLUENT 6.3 (2d, dp, pbns, spe, rke) Jun 03, 2025

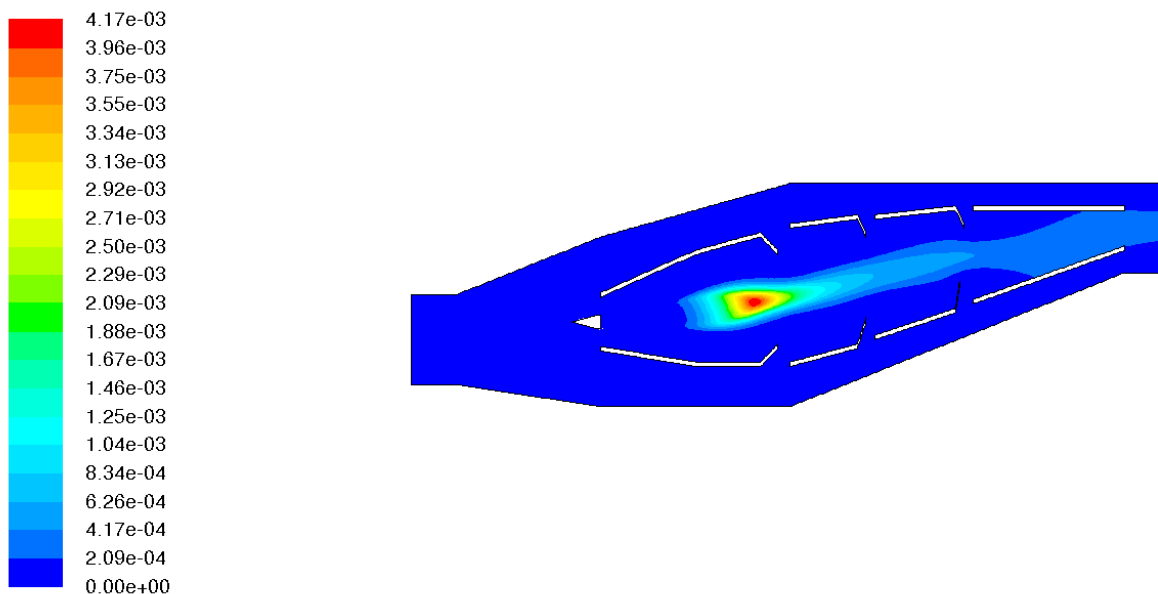
Figure IV.5 Turbulence Contour (fuel Gas - Air) Flame

Chapter IV: Presentation and Interpretation of Numerical Results

In this contour (Figure IV.5), we observe the distribution of turbulence in the burner. we find that the turbulence increases from a minimum value of $3.04 \times 10^{-3} \text{ (k)(m}^2/\text{s}^2)$ to a maximum value of $300 \text{ (k)(m}^2/\text{s}^2)$ at the flame tube outlet, the turbulence in the mixing zone is about $35.3 \text{ (k)(m}^2/\text{s}^2)$ or this can be considered as moderate turbulence for the fuel jet injected into the primary zone. In the intermediate zone, the turbulence is about $52.9 \text{ (k)(m}^2/\text{s}^2)$ where the turbulence has the role of accelerating the flame and increasing the reaction rate. The turbulence explodes in the dilution zone at a value of $264 \text{ (k)(m}^2/\text{s}^2)$, the high intensity of the turbulence aims to maximize the chemical mixing rate between the dilution air and the burnt gases for improving the combustion efficiency and especially to homogenize the temperature before the flow diffuses towards the turbine. So, we can say that Turbulence Generation Mechanisms is created by:

- Injector geometry (orifices, swirlers, cross jets).
- Injection velocity (high Reynolds number promotes turbulence).
- Swirl systems that induce flow rotation to improve mixing.

IV.2.4. Mass Fraction of Pollutants Nox



Contours of Mass fraction of Pollutant no

Jun 07, 2025
FLUENT 6.3 (2d, dp, pbns, spe, rke)

Figure IV.6 Mass Fraction of Pollutants Nox (Fuel Gas- Air) Flame

In this contour (Figure IV.6) we have the representation of the Nox distribution in the PGT 25 gas turbine burner, the red zone in the mixture zone represents the maximum rate of Nox in our calculate domain with an approximate value of $4.17 \times 10^{-3} \text{ ppm}$, the rate of nitrogen oxide decreases gradually in the Intermediate zone and the dilution zone until reaching a value approximate of $4.17 \times 10^{-4} \text{ ppm}$. It has already been mentioned that the mixing zone is the area where the fuel (natural gas) mixes with the oxidant (air). This is the hottest area of

Chapter IV: Presentation and Interpretation of Numerical Results

the burner, with a temperature ranging between 2230 and 2300°C, which directly influences the increase of NO_x in this area.

Therefore, according to the Zeldovich mechanism, the relationship between NO_x formation and temperature is direct. Other factors directly influence NO_x formation in the burner, such as pressure and fuel type.

The mechanism reaction is thermally activated exponentially (endothermically) or the dissociation of O₂ and H₂O produces more free radicals (O, OH) which fuel the mechanism.

-2300°C: maximum formation of NO_x.

-850°C: Minimum NO_x formation.

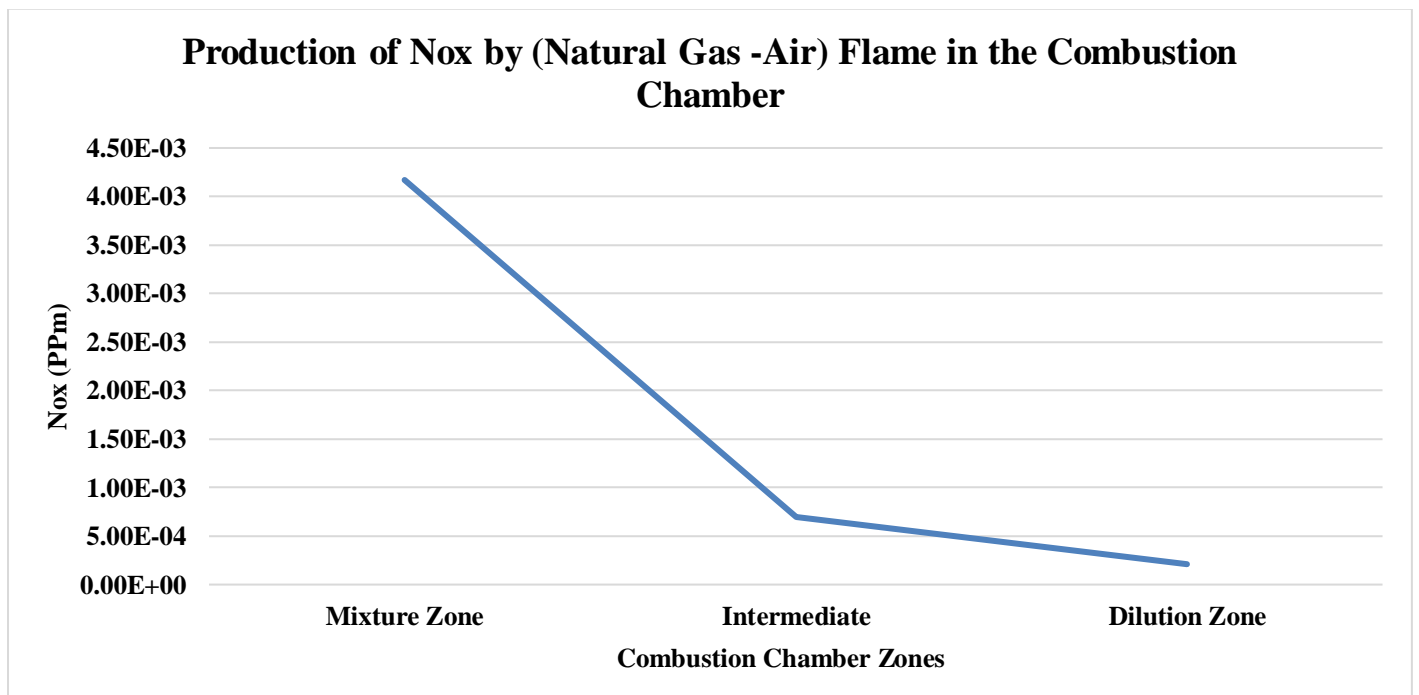
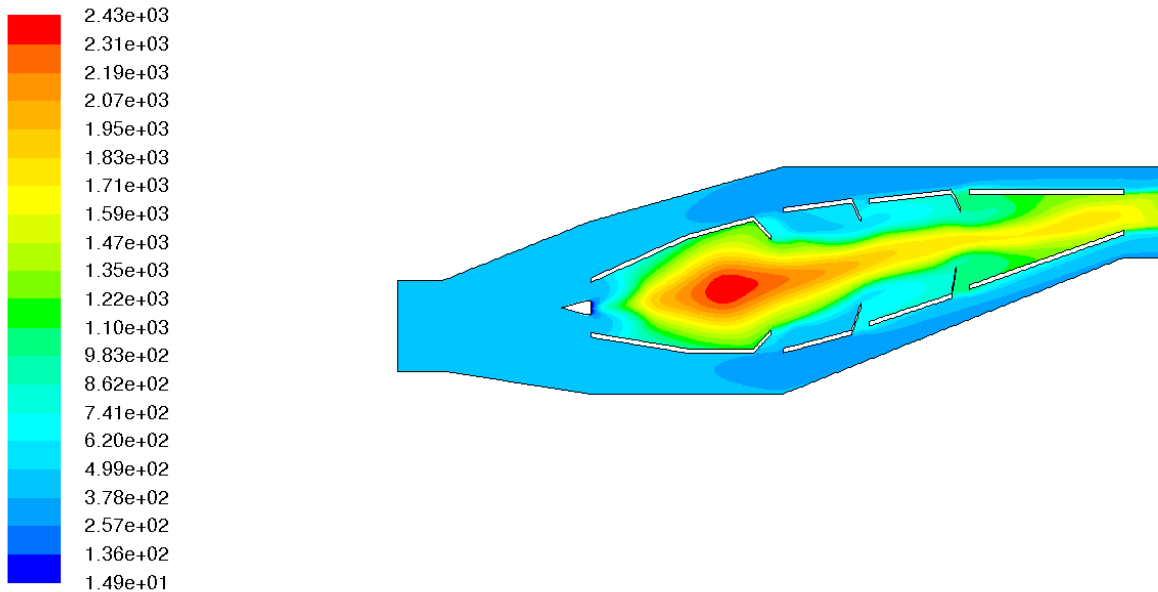


Figure IV.7 Production of Nox by (Natural Gas-Air) Flame in the Combustion Chamber

IV.3. Hydrogen Result Simulation

IV.3.1. Temperature



Contours of Static Temperature (c)

Jun 04, 2025
FLUENT 6.3 (2d, dp, pbns, spe, rke)

Figure IV.8 Temperature Contour for (Hydrogen-Air) Flame

This contour (Figure IV.8) shows the thermal distribution in the combustion chamber of a PGT25 gas turbine, using hydrogen as fuel. Where the red zone in the mixing perimeter represents the maximum flame temperature with an approximate value of 2430°C, the temperature gradually decreases through the intermediate zone and the dilution zone until reaching a temperature of 1500°C at the burner outlet. The mixing zone experienced a maximum temperature and thermal contour due to the mixture (air-hydrogen) which is close to the stoichiometric condition. As the cooling air flows to the intermediate zone, the temperature drops and begins to decrease as the mixture begins to contain excess air. The temperature at the burner outlet decreases to a value of 1500°C thanks to the maximum dilution by air, where the stoichiometry is minimal. So, hydrogen burns hotter thanks to its lower calorific value 33.33 Kwh/Kg and its low molar mass (2g/mol), more reactive molecules per kg, therefore more energy released, (See Figure IV.9).

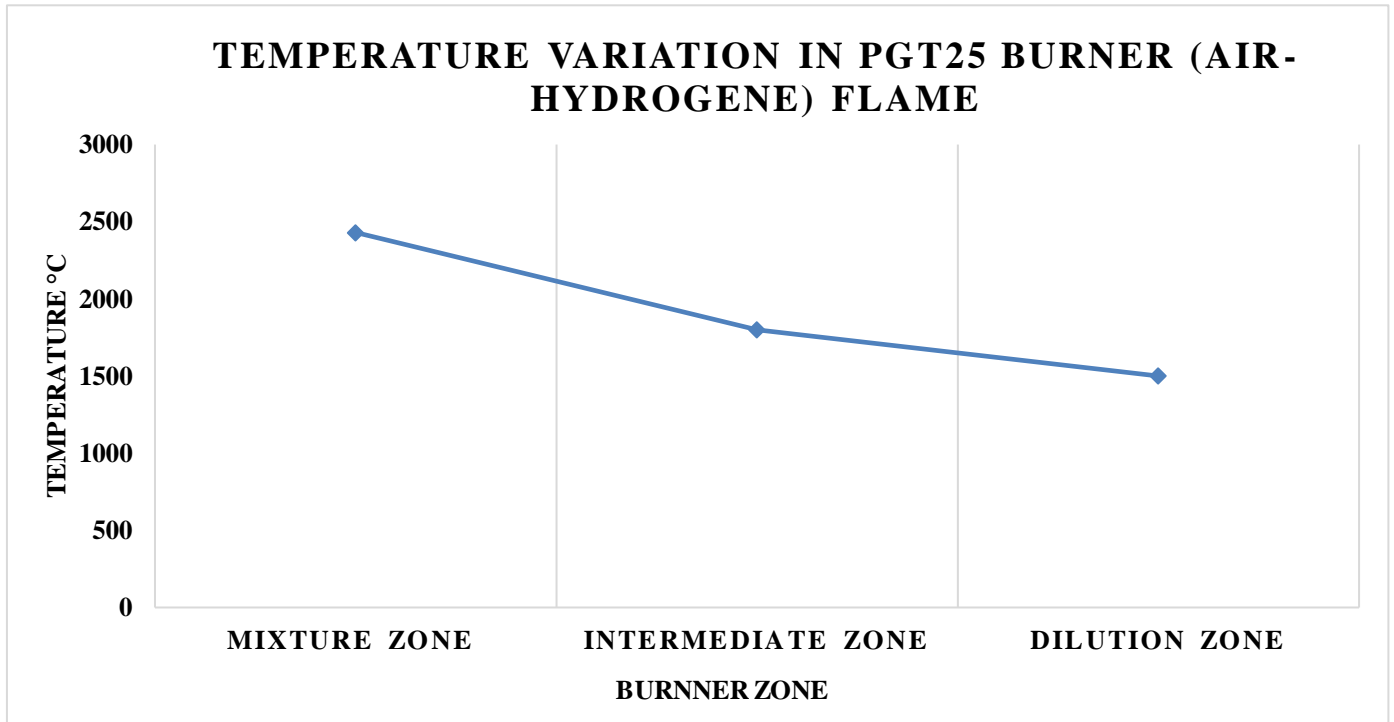
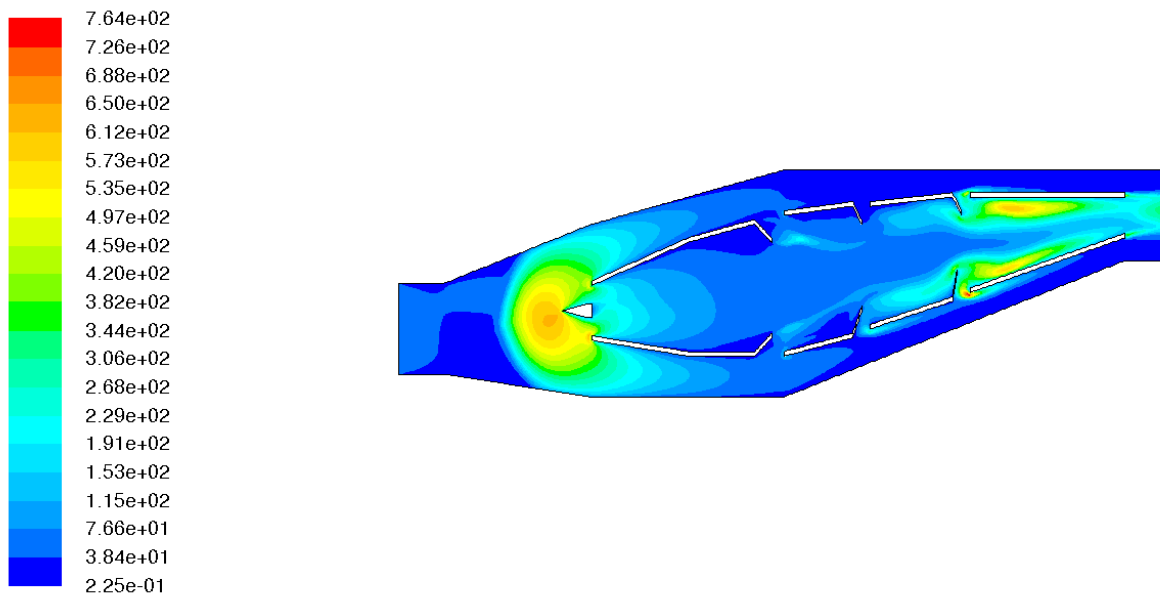


Figure IV.9 Temperature Variation in PGT 25 Burner (H2 Carburant)

IV.3.2. Turbulence



Contours of Turbulent Kinetic Energy (k) (m2/s2)

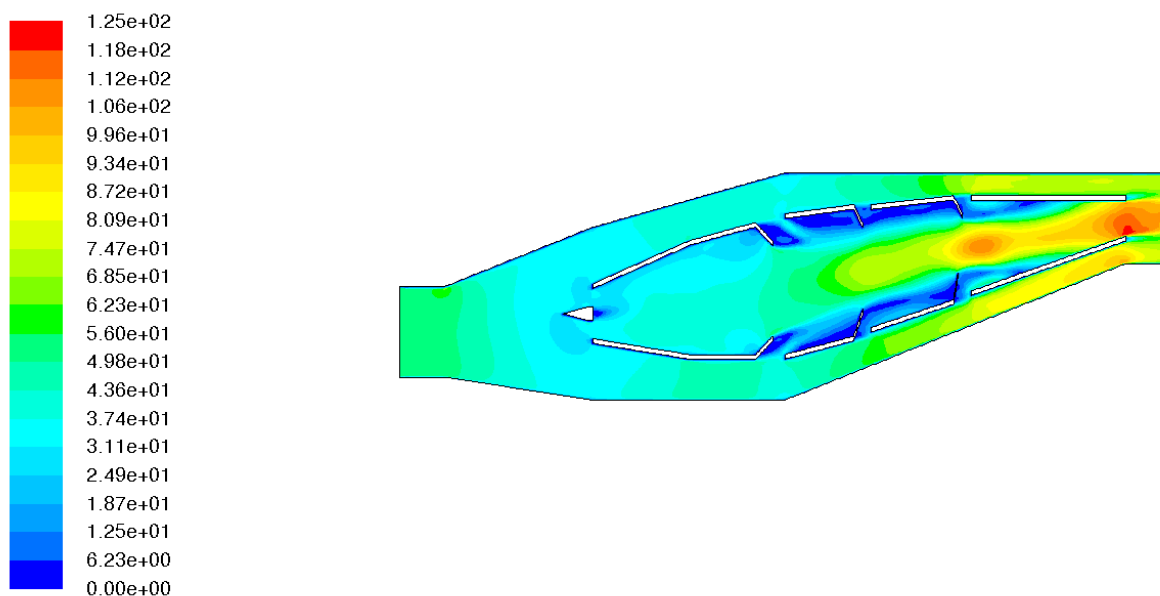
FLUENT 6.3 (2d, dp, pbns, spe, rke) Jun 04, 2025

Figure IV.10 Turbulence Contour (Hydrogen-Air) Flame

Chapter IV: Presentation and Interpretation of Numerical Results

The contour (Figure IV.10) represents the variation of turbulence intensity throughout the combustion chamber of the PGT25 turbine where the coldest areas express low intensity and the hottest areas represent the highest intensity. A turbulence zone with an intensity of about $612 \text{ (kJ)(m}^2/\text{s}^2)$ can be observed in the upstream of the fuel injector. In the mixing zone there is a slight intensity generated by the injection effect at about $268 \text{ (kJ)(m}^2/\text{s}^2)$. The turbulence rate explodes in the delirium zone by the effect of the delirium air passing through the delirium orifices towards the flame tube to delirium the burnt gases. or the turbulence at the burner outlet to perfect the thermal homogeneity. Turbulence increases in the flame tube, but with higher values than other fuels, which can be explained by the specific characteristics of hydrogen, such as its very high flammability, which can amplify turbulent interactions. The aerodynamics of the combustion chamber plays a crucial role in the recirculation of burnt gases and the stabilization of the flame.

IV.3.3. Velocity



Contours of Velocity Magnitude (m/s)

FLUENT 6.3 (2d, dp, pbns, spe, rke) Jun 04, 2025

Figure IV.11 Velocity Contour (Hydrogen-Air) Flame

The contour (Figure IV.11) represents the speed variation in the combustion chamber of the PGT25 gas turbine using hydrogen as fuel. The flame speed increases or is about 30 m/s in the mixing zone and about 75 m/s in the intermediate zone then the speed gradually increases up to a value of 115 m/s at the outlet of the combustion chamber. Flame speed increases due to several factors related to the fuel property, such as very high thermal diffusivity which means that it quickly transfers heat and free radicals to fresh combustion zones, accelerating flame propagation. In a system without premixing, combustion occurs by diffusion. Hydrogen diffuses very quickly into the air, which accelerates the flame speed. and finally, hydrogen requires very little energy to ignite, which facilitates flame initiation and propagation. (see Figure IV.12)

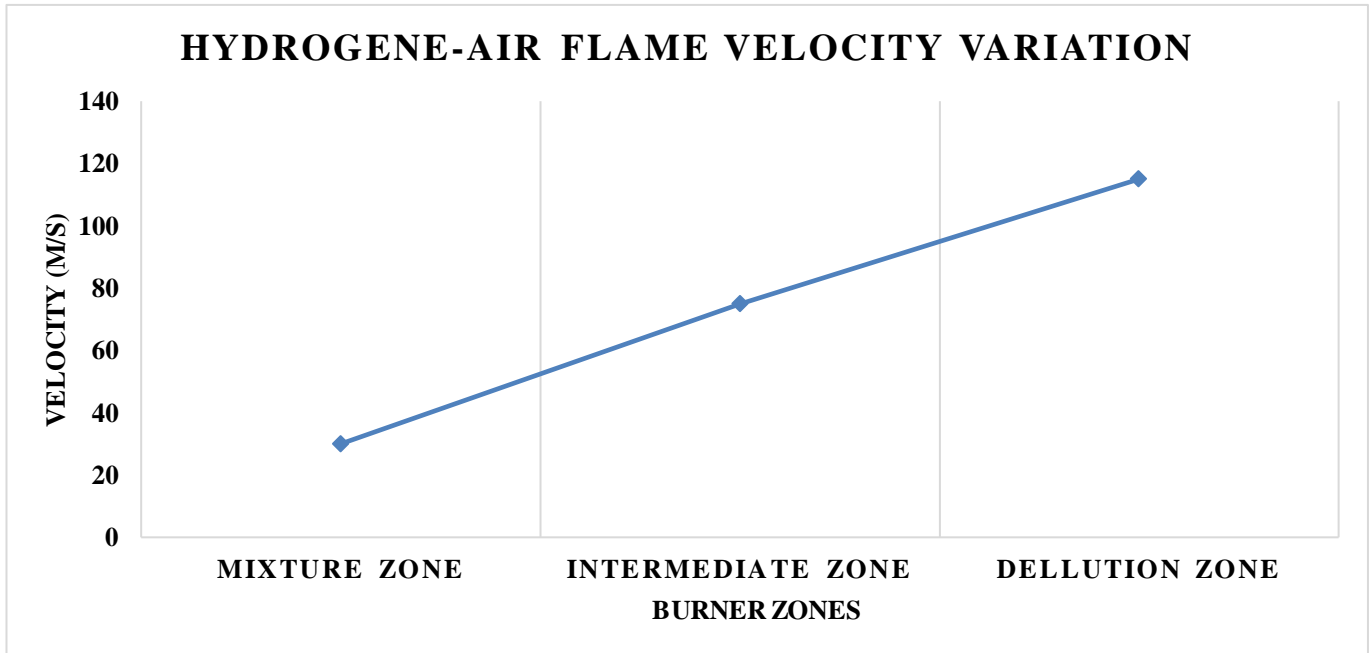
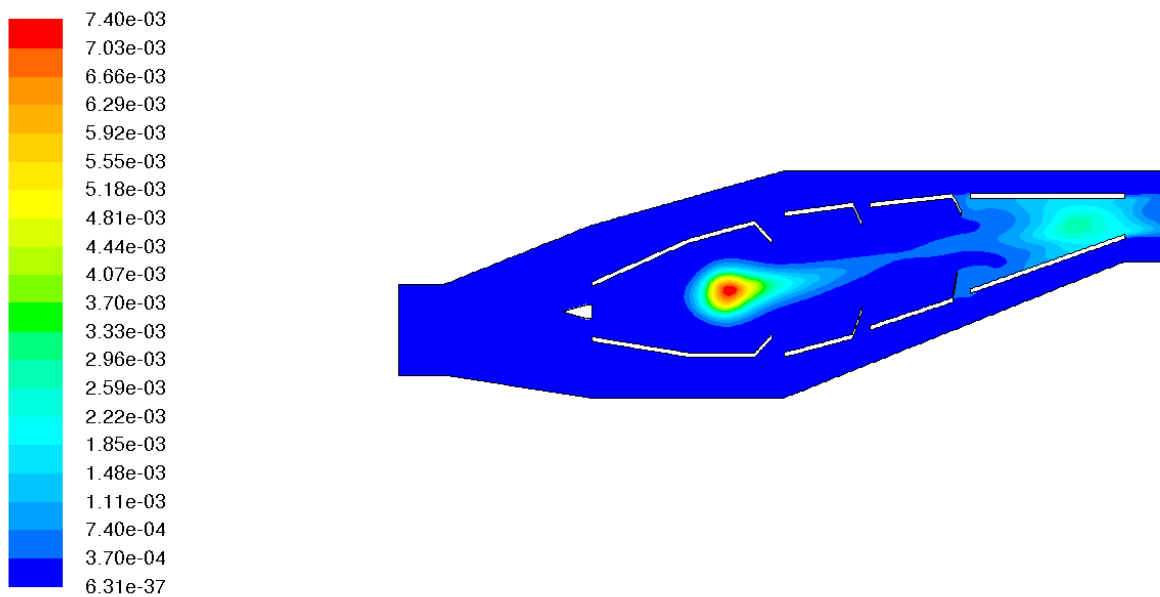


Figure IV.12 Hydrogen-Air Flame Velocity Variation

IV.3.4. Mass Fraction of Pollutants Nox



Contours of Mass fraction of Pollutant no

Jun 04, 2025
FLUENT 6.3 (2d, dp, pbns, spe, rke)

Figure IV.13 Nox Contour (Hydrogen-Air) Flamme

The contour (Figure IV.13) represents the formation of NO_x by the hydrogen flame in a burner of a PGT25 gas turbine. NO_x formation is concentrated in the hottest areas, where the maximum formation of nitrogen oxides (7.40e-03ppm) is found in the mixing perimeter (hydrogen-air) and this is the area where the highest

Chapter IV: Presentation and Interpretation of Numerical Results

temperature was detected. the formation is focused with less intensity in the dilution zone more precisely at the exit of the combustion chamber (2.50×10^{-3} ppm). As previously stated, NO_x formation is directly related to flame temperature (the higher the temperature, the greater the formation of nitrogen oxides) because the Zeldovitch mechanism is exponentially temperature dependent. Hydrogen does not contain carbon. Therefore, there is no formation of CH radicals or other intermediate species that could reduce some of the NO_x by reflux reactions. In a diffusion flame (where the fuel and oxidant are not premixed), areas near the flame front reach very high local temperatures because the fuel/air mixture is not homogeneous. This creates "hot spots" where NO_x production is intense, (see Figure IV.14)

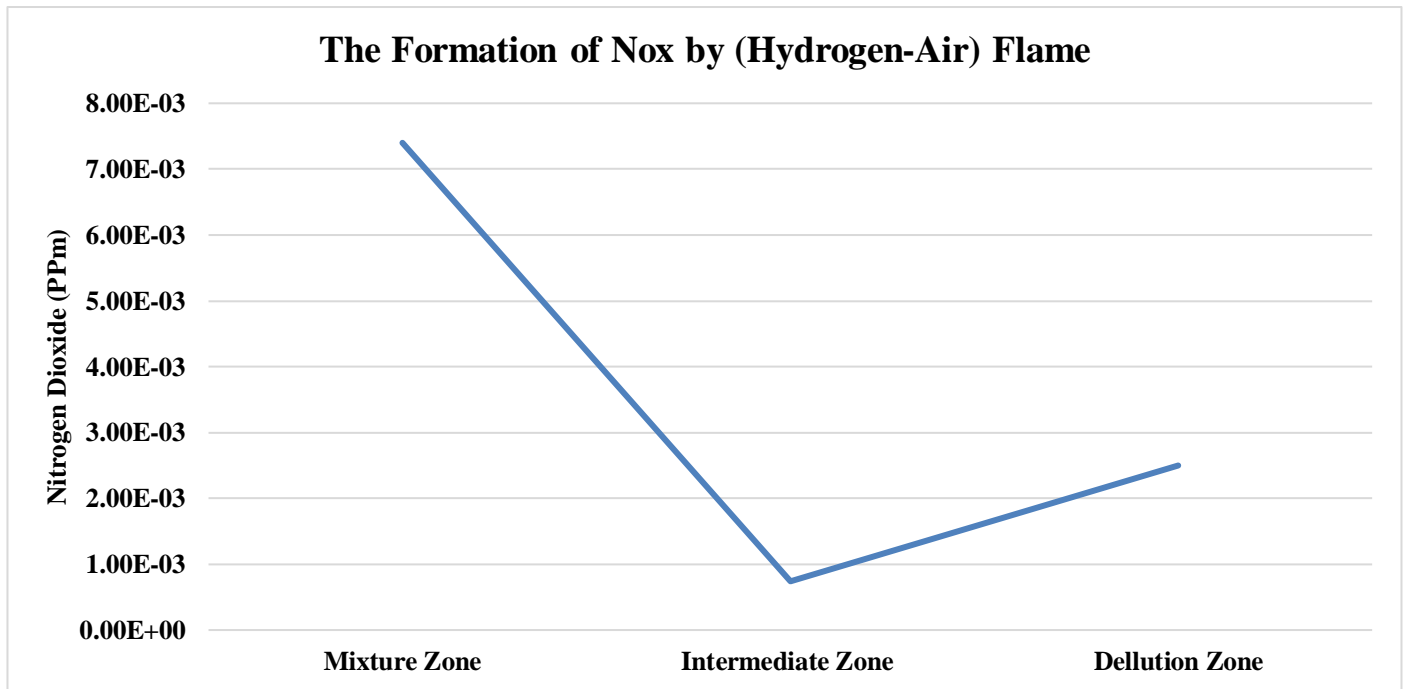


Figure IV.14 NO_x Formation by (Hydrogen-Air) Flame in PGT25 Gas Turbine Burner

Comparison of the Flame Temperature Between Hydrogen and Natural Gas

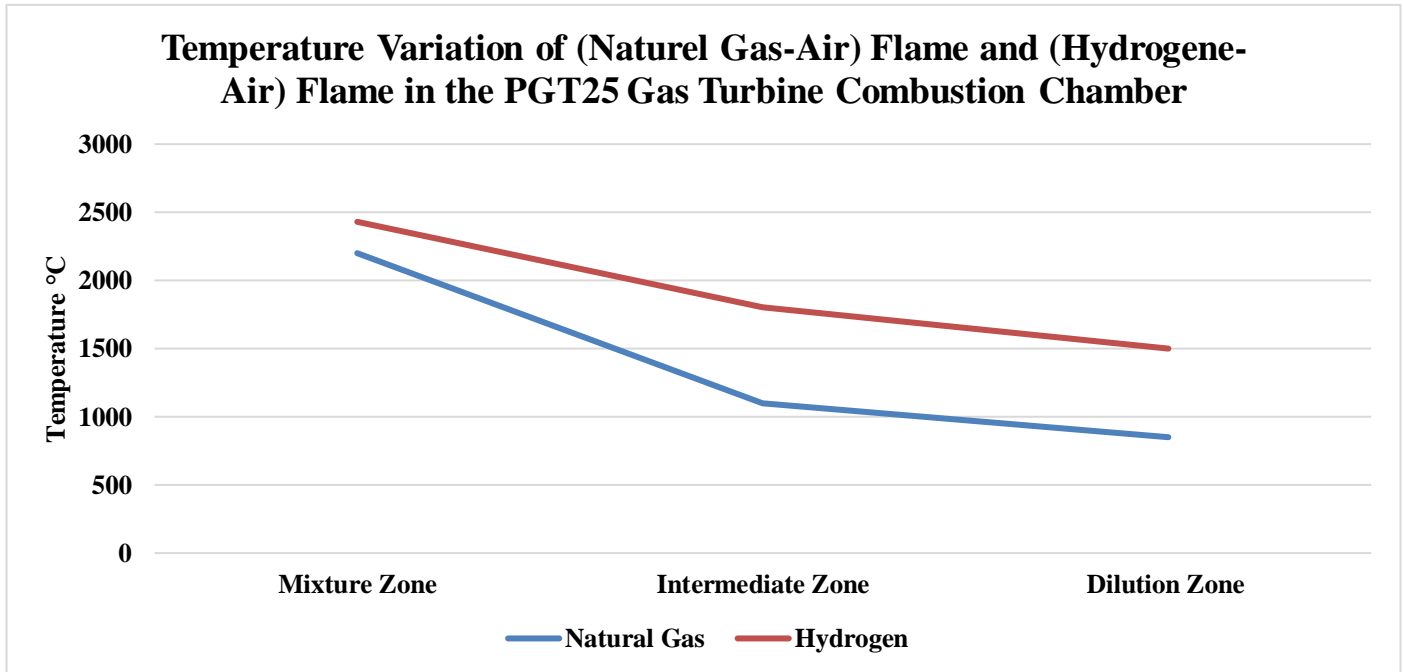


Figure IV.15 Comparison of the Flame Temperature Between Hydrogen Natural Gas

The graph(Figure IV.15) represents two thermal variation curves for the two flames studied: natural gas and hydrogen. As previously indicated, the temperature of both flames decreases throughout the combustion chamber, but the temperature value indicated by the hydrogen flame is always higher than that of the natural gas. (see the table)

	Natural Gas Flame	Hydrogen Flame
Mixture Zone	2300 °C	2430 °C
Intermediate Zone	1100 °C	1800 °C
Dilution Zone	850 °C	1500 °C

TableIV.1 (Natural Gas -Air) and (Hydrogen-Air) Flame Temperature

Hydrogen Flame

- The flame temperature of hydrogen in air is higher than that of natural gas reaching about 2430 °C.
- Hydrogen requires materials resistant to higher temperatures (ceramic coatings, increased cooling).

Natural Gas Flame

- The flame temperature of methane is generally lower, around 2300°C.
- The combustion chamber materials can withstand the temperature released by the natural gas flame and do not require any material modifications.

Comparison of Nox Production between the Hydrogen and Natural Gas Flame

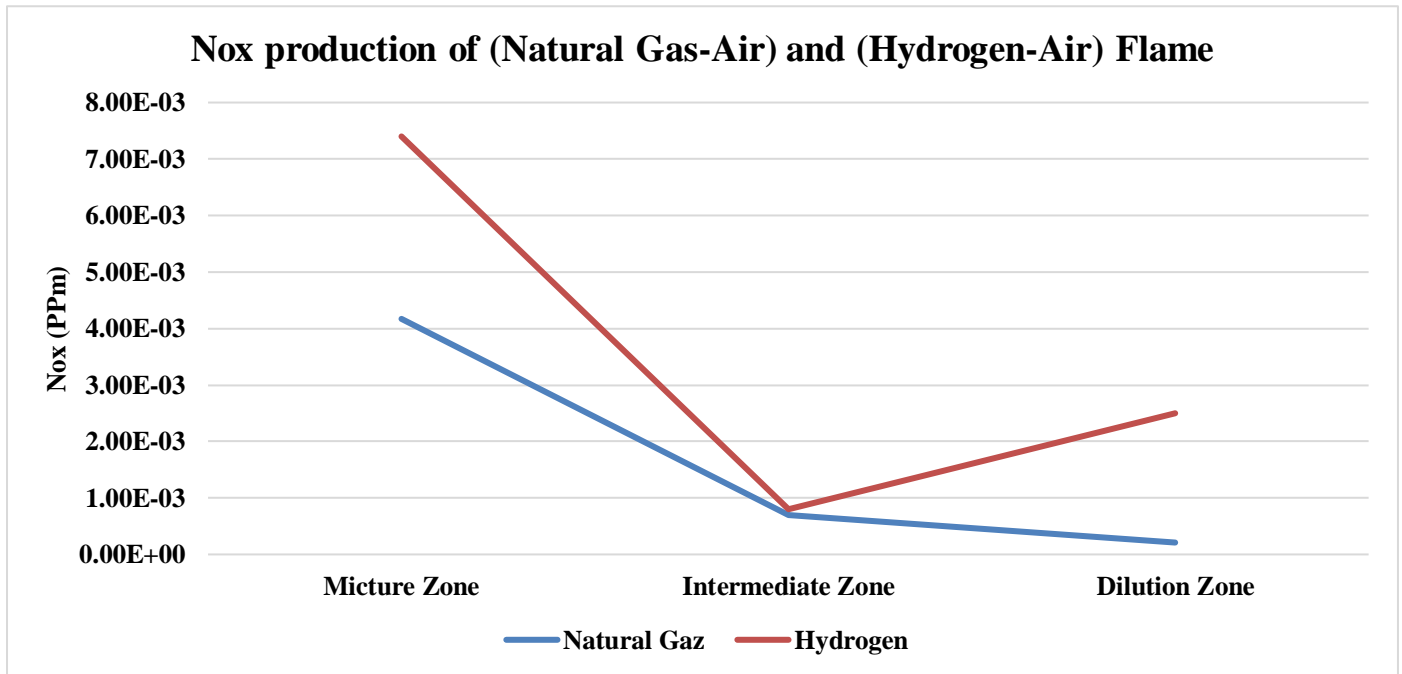


Figure IV.16 Comparison of Nox Production between the Hydrogen and Natural Gas Flame

The graph (Figure IV.16) shows us two curves of variation of NO_x production by the natural gas flame and the hydrogen flame. The formation of NO_x by hydrogen flame is higher than that of natural gas and as said before the formation of NO_x is directly linked to the temperature of the flame, and as the temperature of the hydrogen flame is high (2000°C-2340°C) the formation of NO_x is higher than that of natural gas.

	Natural Gas Flame	Hydrogen Flame
Mixture Zone	4.17e-03 ppm	7.40e-03 ppm
Intermediate Zone	7e-04 ppm	7.40e-04 ppm
Dilution Zone	2.10-04 ppm	2.50e-03 ppm

Table IV.2 Nox Formation of (Natural Gas-Air) and (Hydrogen-Air) Flame

Hydrogen Flame

- very high NO_x formation compared to that of natural gas according to the Zelodovich mechanism
- low carbon production
- To limit NO_x in hydrogen-powered gas turbines:
 - 1) Diluted combustion (injection of steam or N₂ to reduce the maximal temperature)
 - 2) Stratification of the mixture (avoid areas that are too hot).
 - 3) Rich-lean combustion (staged combustion).

Natural Gas Flame

- Natural gas remains less emitting of Nox.
- Emission of carbon more than hydrogen (presence of CH radicals).

General Conclusion

The final conclusion drawn from this work is that hydrogen is a fuel with special characteristics compared to natural gas. Hydrogen can be used as an alternative fuel for gas turbines, but under certain conditions, to adapt the gas turbine combustion chamber to use hydrogen as fuel, several major modifications are necessary due to the specific properties of H₂. Here are the main modifications to consider:

1)Modification of the fuel injection system:**-Suitable Injectors:** Hydrogen has a much lower volumetric energy density than natural gas, Injectors must be resized for a higher mass flow rate and better homogenization of the air-fuel mixture.

-Dilution Strategy:To avoid excessively high flame temperatures, staged injection or dilution by water/steam injection may be necessary.

-Flashback Resistance: Since hydrogen has a very wide flammability range (4–75% in air), flashback prevention systems (such as fast flow orifices) must be incorporated.

2)Thermal coating and resistant materials:**-Higher Temperatures:** The combustion of H₂ generates higher adiabatic temperatures which requires: Improved ceramic coatings (TBC) on the walls,Improved ceramic coatings (TBC) on the walls.

-Increased cooling: Optimization of cooling systems (by air film, transpiration, etc.) is essential to avoid premature degradation.

3)NOx Emission Control: Combustion of hydrogen (without carbon) does not produce CO₂, but generates more NO_x due to thermal peaks. Possible solutions:

-Advanced downstream catalyst systems (SCR).

-Water vapor injection or exhaust gas recirculation (EGR) to reduce temperature.

4)Changes to the regulation system:The combustion dynamics change radically (flame speed ~3× higher than that of methane). It is necessary to adapt:

-Control laws to avoid combustion instabilities (flashback, pressure oscillations).

-Ignition and fuel transition sequences (if dual-fuel turbine).

The switch to hydrogen requires a partial redesign of the combustion chamber, with a focus on injection, cooling and NO_x reduction.

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