International Journal of Scientific and Research Publications, Volume 6, Issue 8, August 2016
ISSN 2250-3153

AUTOMOTIVE-TURBOCHARGER BASED GAS TURBINE ENGINE USED TO PRODUCE ELECTRICITY

Shreyas Ramanagara Sridhara, Vishan Ravi Tejaas, Varun Kumar R, Nagarjun RK

Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University
Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University
Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University
Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University

Abstract- Miniaturized gas turbine generator made using automotive turbo charger, by using optimized combustion camber design. The fuel being used here to power the gas turbine is Bio-Diesel which is one of the eco friendly fuel available .The engine can run on any eco friendly fuels .Here the power is been extracted by using impulse turbine at the exhaust of the engine. The combustion camber is optimized in such a way that the efficiency is more than 90%.

Index Terms- Miniaturized Gas Turbine Generator Using Automotive Turbo Charger, Eco-Friendly Power Generator, Bio-Diesel Gas Turbine Generator, Optimized Combustion Chamber design of a Gas Turbine

I. INTRODUCTION

A gas turbine engine finds applications in a jet propulsion system in aircrafts and as a prime mover in industries for power generation. It consists of three core components:

1.Compressor

2.Combustor

3.Turbine

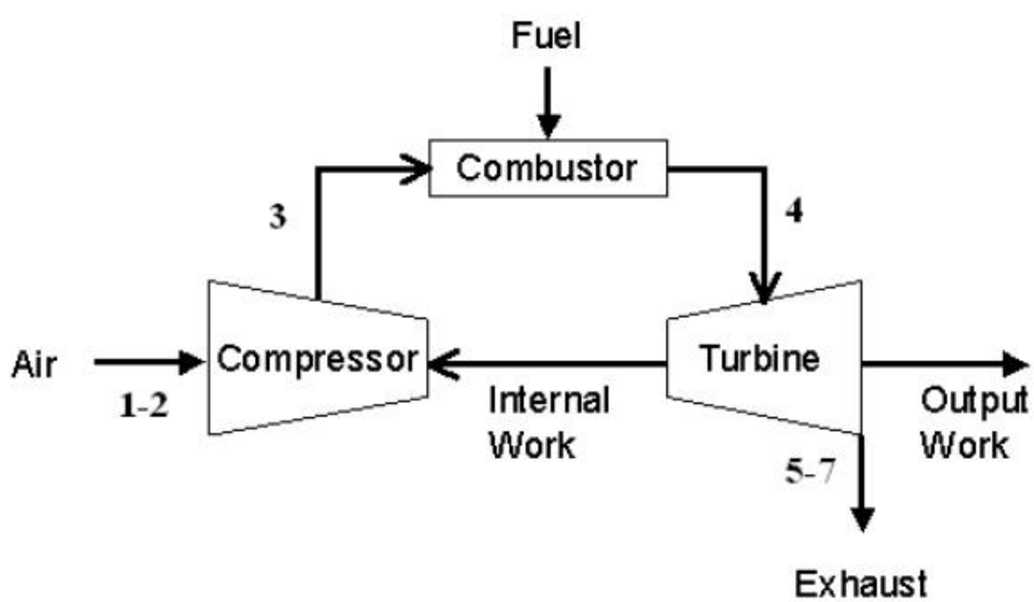


Figure 1.1

Compressor consists of Inlet (Diffuser) and Compressor Section.

- Inlet - Inlet is just a diverging duct (called a diffuser), which means that the area does affect the flow. As the molecules rush inside, they realize that the cross-sectional area starts increasing. So, they slow down and start bunching up together. It's quite obvious that the static pressure is increased as the molecules come out through the exit of the inlet.
  The dynamic pressure goes down since the flow is getting decelerated as a result of the area gradient. Intuitively, the velocity should decrease as the area increases.
  The mass flow rate of the incoming air is approximately a constant. Air doesn't flow as per our own desires. Mathematically, the mass flow rate is given by $\dot{m}=\rho A\upsilon$

  It can be easily seen that as the area increases, the velocity should decrease, if the mass flow rate is constant. Thus, the dynamic pressure decreases while the static pressure increases. As long as we don't do any external work on the fluid, the total pressure remains the same. Thus, as static pressure increases, dynamic pressure decreases.

- Compressor Section - Inside the compressor, there are rotor blades which compresses the air. It pushes the air normal to its blade. In order to make the flow direction along the line, there's another component called stator blades. It doesn't move. Its blades are attached to the engine frame (cantilevers). But, they're inclined in such a way that they direct the flow in straight line (parallel to the axis).

Combustion Camber the compressed air which enters the combustion chamber is mixed with fuel and ignited when the combustion process begin it releases heat which increases the total energy in of the fluid

Turbine - Turbine is designed to produce more power than required to drive the compressor the excess power can be used to run a shaft power. And if the gases are not fully expanded in the turbine, their remaining energy can be used to produce thrust in jet propulsion by further expansion through a nozzle

An automotive turbocharger also consists of a compressor and a turbine mounted on the same shaft. Energy available in the exhaust gases of an Internal Combustion (IC) engine is used to drive the turbocharger-turbine, which in turn drives its compressor to raise the density of the air supplied to the IC engine.

The energy in the exhaust gas is utilized in running the impulse turbine where in turn it is connected to gear box. Here the gear box is connected to A.C Generator to produce power(electrical energy).

II. DESIGN CONCEPT

An automotive turbocharger provides a pre-packaged system of a compressor and turbine operating on a common shaft. So the idea is to build a gas turbine engine by adding the third core component, the combustor.
The first step is to choose a turbocharger with the key requirement available. Then based on these specifications a combustor is to be designed and developed suitably for the chosen turbocharger. The combustor in combination with the turbocharger would then perform as a gas turbine engine. And the last component being the impulse turbine and gear box assembly (which includes A.C Generator) is connected to the exit of the nozzle , to obtain electrical energy as the final output.

III. Study And Findings

3. The Ideal Brayton Cycle

For the ideal case, depicted in Figure 3.1, the Brayton Cycle consists of four reversible thermodynamic processes, with a gas (usually air) as the working fluid. The process involves work being done on the system, resulting in isentropic compression. Next, constant pressure combustion occurs and heat is added. Work is then output by the system through isentropic expansion. Often, part of this work is internal work used to carry out the isentropic compression of the earlier stage, with the remainder of the produced work providing usable work output. The final process to complete the cycle is constant pressure "heat rejection", where heat is expelled to return the fluid to the initial state. This last process does not actually occur in reality.

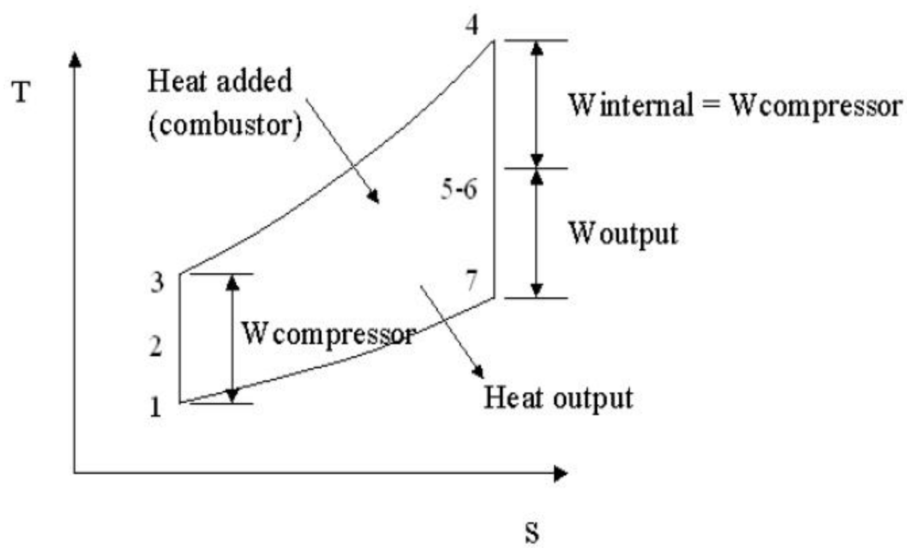


Figure 3.1: Temperature –enthalpy diagram depicting the four process of ideal Brayton cycle.

Gas turbine engine

The original general purpose gas turbine engine design, known as the turbojet, was developed independently by two engineers, Frank Whittle of the United Kingdom, and Hans von Ohain of Germany, in the 1930's. The turbojet has since been modified into a number of variants, including turboprop, turbo shaft, turbofan, and the more recent propfan (also known as open rotor or unducted turbofan). Although each type of turbine engine has very unique purposes and performances, they each operate on the same basic principles, which in the thermodynamics discipline are known collectively as the Brayton Cycle.

As stated before, all gas turbine engines operate on the Brayton Cycle. Each component of the engine is specifically designed to fulfil a necessary step in this cycle. To begin, incoming air travels through a diffuser inlet, which slows down the air and attempts to isentropically recover as much stagnation pressure as possible. This corresponds to the change from state 1 to 2 in the Brayton Cycle. The air then enters the compressor, where rotating compressor blades increase the pressure adiabatically, exiting in state 3. The compressor pressure ratio is a key performance parameter and helps characterize the engine. Two types of compressors are in use today, the axial flow and the radial (or centrifugal) flow compressor. A parallel to the drive shaft, keeping the flow stream in one direction. The flow is compressed as it passes through alternating stages of compressor (rotor) and diffuser (stator) blades. These types of compressors are used on high speed jet aircraft, so that the high velocity flow can be kept in one direction. Radial compressors, on the other hand, accelerate flow perpendicular to the drive shaft. This process requires a larger frontal compressor face, but achieves high compression across each stage. For these reasons, as well as their simplicity and robustness, radial compressors are used for low speed applications.

The high pressure air from the compressor flows into the combustor, where fuel is injected and ignited. The burning fuel-air mixture provides heat energy input to the flow. After the igniter first starts the combustion, the flame must be self-sustaining. This task is complicated by the incoming high pressure air from the compressor, which can extinguish the flame. To help alleviate this effect, a flame tube is inserted into the main combustion chamber. The flame tube serves two purposes, one being protection of the flame and the other is to allow the proper amount of air into the combustion area to create a stoichiometric balance between the air and fuel. This is accomplished by placing holes of a calculated area around the fuel injector, where primary combustion occurs.

Additional holes are placed in the flame tube further downstream to complete the combustion in the secondary zone.

Lastly, several holes are added close to the combustor exit, known as the dilution zone, in order to mix the cold outer air with the hot combustion gases and thus lower the overall exhaust gas temperature and protect the turbine blades from too much heat stress.
The high energy flow, state 4 in the Brayton Cycle, continues out of the combustion chamber and is allowed to expand adiabatically through the turbine blades. The expanding gases rotate the turbines, which are attached to a shaft that powers the compressor; additionally the turbine blades can also power additional components such as propellers or fans. The temperature that the turbine blades can withstand is one of the main factors in the capabilities of the engine. After the turbine, some engines will inject and ignite additional fuel in the flow to increase exit velocity and provide more thrust. This stage is known as an afterburner, and is labelled as state 6.

With or without the afterburner, flow finally reaches the exhaust nozzle, which can adiabatically accelerate the gases out of the engine to provide thrust. The gas turbine engine cycle is outlined in Figure 3.1, with labels corresponding to those of the Brayton Cycle of Figure 3.1. Details of the specific engine components chosen for this project, as well as the reasons for each choice, can be found later in this research paper.

Automotive turbocharger

A turbocharger consists of a compressor and turbine operating on a single common shaft. These are often designed for use on automobile internal combustion engines. When installed, the hot exhaust gases exiting the cylinders pass through the turbine side of the turbocharger, spinning the turbine blades, and thus the shaft. The shaft then transmits power to drive the compressor. The exhaust gases then continue out to the exhaust manifold and continue as usual.

As the compressor spins, it raises the pressure of the incoming air from the air intake. The high pressure air is often directed through a charged air cooler (also known as an intercooler) to further raise the density of the air. The high density air is then ducted into the cylinder and combustion occurs as normal. The larger mass of air, however, allows for more fuel to be burned in the same volume, and thus more power to be extracted by the piston during the power stroke, transmitting more power to the crankshaft and eventually the wheels. The cycle of an automotive turbocharger follows closely to that of an aircraft turbine engine and thus allows for the correlation between an aircraft engine and that of the automotive based turbine engine to be created.

A depiction of the operation of a turbocharger is shown in Figure 3.1 .spinning the turbine blades, and thus the shaft. The shaft then transmits power to drive the compressor. The exhaust gases then continue out to the exhaust manifold and continue as usual.

Turbocharger Selection

Almost any automotive turbocharger can be converted into a self-sustaining gas turbine engine. However, depending on the application, some are better suited than others. For this project, it was desired to use a larger turbocharger that had an established history of reliability. Diesel engine turbochargers are typically manufactured for maximum service life given their application. In years past, turbocharger performance was not heavily emphasized on diesel engines, as long as point performance was satisfied by the manufacturer. Recently however, the increase in federal emissions regulations coupled with rising fuel costs have pushed the development of extremely reliable high
performance turbochargers for diesel engine applications. One of the most effective ways to cut emissions on diesel engines and improve performance is to maintain the proper fuel-to-air ratio.

In the past, "turbo lag" was characteristic of turbo diesel engines during acceleration. "Turbo lag" is a condition that results from the turbocharger's inability to quickly increase airflow rate with increasing fuel flow rate. Because airflow lagged behind the increase in fuel flow, a fuel-rich condition occurred, causing incomplete combustion. This is characterized by heavy black smoke exiting the exhaust and is often observed by motorists on the highway. Turbocharger manufacturers have greatly reduced this problem by implementing mechanisms on turbochargers to make them spool quicker. This enables the turbocharger to increase manifold pressure much faster and therefore, be much more sensitive to changes in fuel flow rate. Huge increases in engine efficiency and drastically reduced emissions have resulted from the implementation of such mechanisms.

These mechanisms all simply function to make the turbocharger more responsive to throttle input. Waste gates and variable vane geometries are the two primary mechanisms currently in use, and simply make use of the continuity equation. By decreasing flow area, flow velocity increases. This increase in velocity causes the turbine wheel to spool faster, which makes it more responsive to changes in flow rate. Wastegates were the first solution and simply divert excess exhaust flow around the turbine, and feed it directly into the exhaust pipe. This allows the use of a smaller turbine which is more sensitive to the exhaust flow rate.

However, the disadvantage to this type of design is that the small turbine housing is often prone to “surging”. If the wastegate is not precisely controlled, the small turbine will over-speed the compressor for a given engine operating condition, and feed too much air to the engine. The rapid change in speed of the compressor or “surge” is the end result and can be damaging to the turbocharger. Although wastegates have been successfully used on many engines, the use of variable vane geometries has recently replaced wastegates since they offer much more precise control over the flow in the turbocharger, and tend to eliminate surging problems. Instead of permanently making the turbine smaller as done with wastegates, vanes in the turbine or compressor are moved to restrict or open up airflow as needed.

By doing this, the effective size of the turbocharger can be varied based on the amount of exhaust flow, and the turbocharger does not have to be designed for single point performance as done in the past. For the gas turbine constructed in this project, we wanted to have the ability to evaluate the engine’s performance as a function of several different variables; one of which was turbine geometry.

After researching and pricing several different turbochargers (K27) was chosen. It has an excellent history of reliability, and should work well as a gas turbine. One of the characteristics of this turbocharger that makes it desirable for this project is the variable vane geometry mechanism in the turbine housing and it is a non waste gated turbocharger. Using this mechanism, turbine performance can be evaluated for different vane settings, which was one of the original goals of this project

The vane system is relatively simple, and consists of a set of fins that slide axially on two shafts. The fins can be positioned around the outside of the turbine wheel to restrict flow, or completely retracted to allow maximum flow rate through the turbocharger under high engine load situations.

4. TURBOCHARGER CAD DESIGN

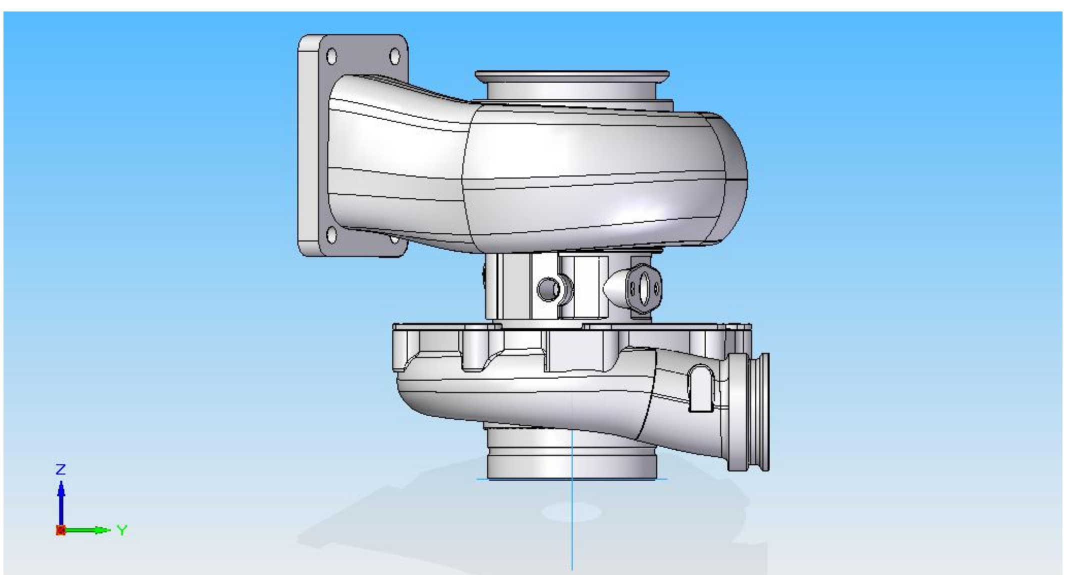


Figure 4.1: Diametric view

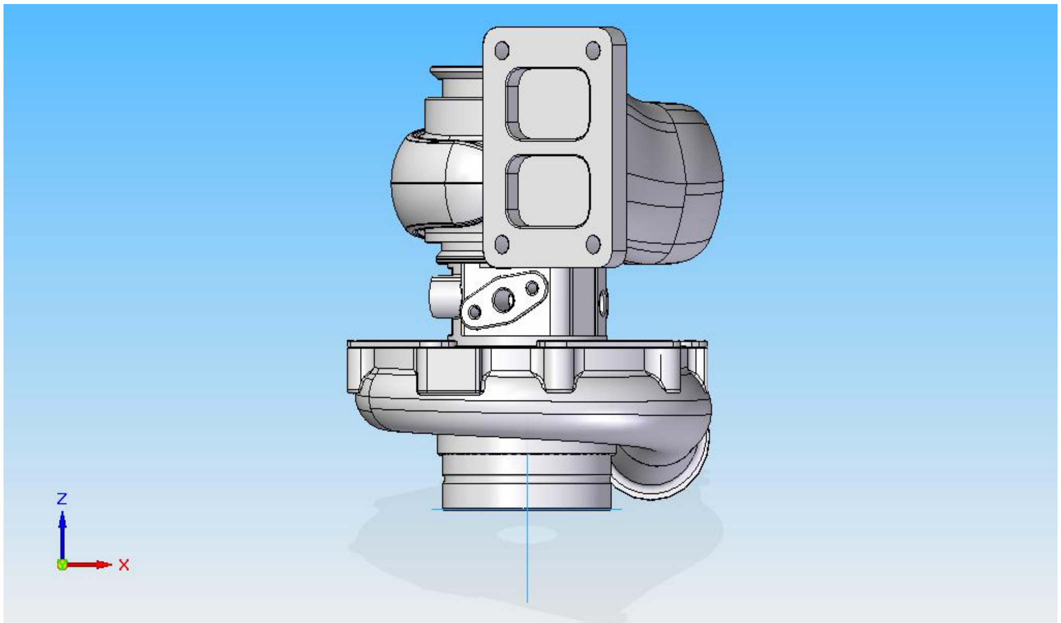


Figure 4.2 : Front view

5. COMBUSTION CHAMBER

5.1 Introduction

A combustor is a component or area of a gas turbine, ramjet, or scramjet engine where combustion takes place. It is also known as a burner, combustion chamber or flame holder. In a gas turbine engine, the *combustor* or combustion chamber is fed high pressure air by the compression system. The combustor then heats this air at constant pressure. After heating, air passes from the combustor through the nozzle guide vanes to the turbine. In the case of a ramjet or scramjet engines, the air is directly fed to the nozzle. A combustor must contain and maintain stable combustion despite very high air flow rates. To do so combustors are carefully designed to first mix and ignite the air and fuel, and then mix in more air to complete the combustion process

5.2 Types of combustion chamber

5.2.1 Can Type

Can combustors are self-contained cylindrical combustion chambers. 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 their shared exhaust is fed to the turbine(s). Can type combustors were most widely used in early gas turbine engines; owing to their ease of design and testing (one can test a single can, rather than have 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%). Most modern engines that use can combustors are turbo shaft featuring centrifugal compressors.

5.2.2 CANNULAR

The next type of combustor is the *cannular* combustor; the term is a portmanteau of "can annular". Like the can type combustor, can annular 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 generally has 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.

5.2.3 ANNULAR

The final, and most commonly used, the 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 temperatures. They also have the lowest pressure drop of the three designs (on the order of 5%). The annular design is also simpler, although testing generally requires a full size test rig. Most modern engines use annular combustors; likewise, most combustor research and development focuses on improving this type.

5.3 Functions of combustion chamber

The objective of the combustor in a gas turbine is to add energy to the system to power the turbines, and produce a high velocity gas to exhaust through the nozzle in aircraft applications. As with any engineering challenge, accomplishing this requires balancing many design considerations, such as the following:

1. Completely combust the fuel. Otherwise, the engine is just wasting the unburnt fuel.
2. Low pressure loss across the combustor. The turbine which the combustor feeds needs high pressure flow to operate efficiently.
3. The flame (combustion) must be held (contained) inside of the combustor. If combustion happens further back in the engine, the turbine stages can easily be damaged. Additionally, as turbine blades continue to grow more advanced and are able to withstand higher temperatures, the combustors are being designed to burn at higher temperatures and the parts of the combustor need to be designed to withstand those higher temperatures.
4. Uniform exit temperature profile. If there are hot spots in the exit flow, the turbine may be subjected to thermal stress or other types of damage. Similarly, the temperature profile within the combustor should avoid hot spots, as those can damage or destroy a combustor from the inside.
5. Small physical size and weight. Space and weight is at a premium in aircraft applications, so a well designed combustor strives to be compact. Non-aircraft applications, like power generating gas turbines, are not as constrained by this factor.
6. Wide range of operation. Most combustors must be able to operate with a variety of inlet pressures, temperatures, and mass flows. These factors change with both engine settings and environmental conditions (I.e., full throttle at low altitude can be much different than idle throttle at high altitude).
7. Environmental emissions. There are strict regulations on aircraft emissions of pollutants like carbon dioxide and nitrogen oxides, so combustors need to be designed to minimize those emissions.

5.4 Combustor Chamber Components

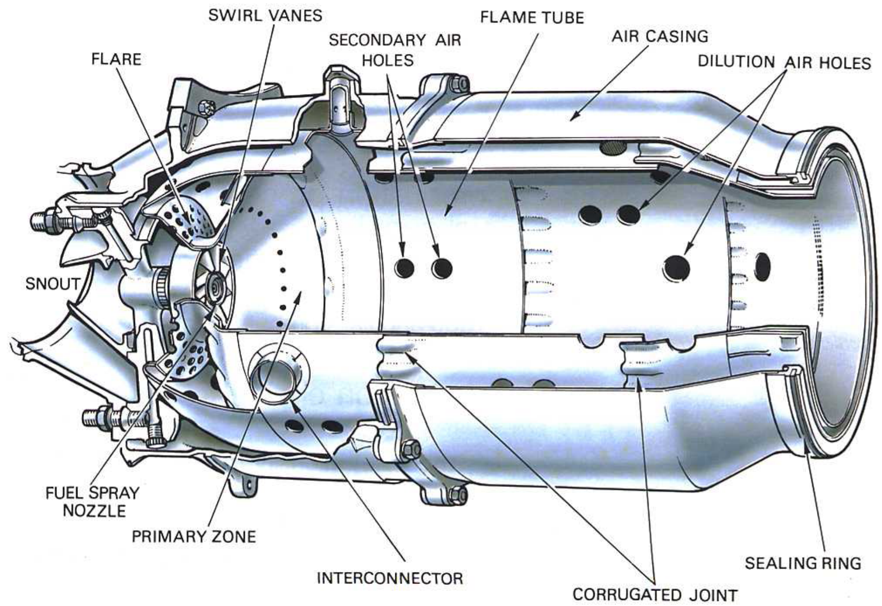


Figure 5.4.1: Combustion chamber components

Outer Case

The case is the outer shell of the combustor, and is a fairly simple structure. The casing generally requires little maintenance. The case is protected from thermal loads by the air flowing in it, so thermal performance is of limited concern. However, the casing serves as a pressure vessel that must withstand the difference between the high pressures inside the combustor and the lower pressure outside. That mechanical (rather than thermal) load is a driving design factor in the case.

Diffuser

A diffuser is designed so as to reduce the airflow velocity that enters the diffuser inlet after getting compressed .The airflow velocity is reduced so as to avoid blowout which is a condition in which the flame in the combustion chamber is blown away because of velocity of air thus making the combustion chamber less self-sustaining. The purpose of the diffuser is to slow the high speed, highly compressed, air from the compressor to a velocity optimal for the combustor. Reducing the velocity results in an unavoidable loss in total pressure, so one of the design challenges is to limit the loss of pressure as much as possible. Furthermore, the diffuser must be designed to limit the flow distortion as much as possible by avoiding flow effects like boundary layer separation. Like most other gas turbine engine components, the diffuser is designed to be as short and light as possible.

Liner

The liner contains the combustion process and introduces the various airflows (intermediate, dilution, and cooling, see *Air flow paths* below) into the combustion zone. The liner must be designed and built to withstand extended high temperature cycles. For that reason liners tend to be made from super alloys like Hastelloy X . Furthermore, even though high performance alloys are used, the liners must be cooled with air flow. Some combustors also make use of thermal barrier coatings. However, air cooling is still required. In general, there are two main types of liner cooling; film cooling and transpiration cooling. Film cooling works by injecting (by one of several methods) cool air from outside of the liner to just inside of the liner. This creates a thin film of cool air that protects the liner, reducing the temperature at the liner from around 1800 Kelvin (K) to around 830 K, for example. The other type of liner cooling, transpiration cooling, is a more modern approach that uses a porous material for the liner. The porous liner allows a small amount of cooling air to pass through it, providing cooling benefits similar to film cooling. The two primary differences are in the resulting temperature profile of the liner and the amount of cooling air required. Transpiration cooling results in a much more even temperature profile, as the cooling air is uniformly introduced through pores. Film cooling air is generally introduced through slats or louvers, resulting in an uneven profile where it is cooler at the slat and warmer between the slats. More importantly, transpiration cooling uses much less cooling air (on the order of 10% of total airflow, rather than 20-50% for film cooling). Using less air for cooling allows more to be used for combustion, which is more and more important for high performance, high thrust engines.

Snout

The snout is an extension of the dome (see below) that acts as an air splitter, separating the primary air from the secondary air flows (intermediate, dilution, and cooling air; see *Air flow paths* section below).

Fuel Injector

The fuel injector is responsible for introducing fuel to the combustion zone and, along with the swirler (above), is responsible for mixing the fuel and air. There are four primary types of fuel injectors; pressure-atomizing, air blast, vaporizing, and premix/prevaporizing injectors. Pressure atomizing fuel injectors rely on high fuel pressures (as much as 500 pounds per square inch (psi) to atomize the fuel. This type of fuel injector has the advantage of being very simple, but it has several disadvantages. The fuel system must be robust enough to withstand such high pressures, and the fuel tends to be heterogeneously atomized, resulting in incomplete or uneven combustion which has more pollutants and smoke.

Igniter

Most igniters in gas turbine applications are electrical spark igniters, similar to automotive spark plugs. The igniter needs to be in the combustion zone where the fuel and air are already mixed, but it needs to be far enough upstream so that it is not damaged by the combustion itself. Once the combustion is initially started by the igniter, it is self-sustaining and the igniter is no longer used. In can-annular and annular combustors (see

Types of combustors below), the flame can propagate from one combustion zone to another, so igniters are not needed at each one. In some systems ignition-assist techniques are used. One such method is oxygen injection, where oxygen is fed to the ignition area, helping the fuel easily combust. This is particularly useful in some aircraft applications where the engine may have to restart at high altitude.

5.5 AIR FLOW IN COMBUSTION CHAMBER

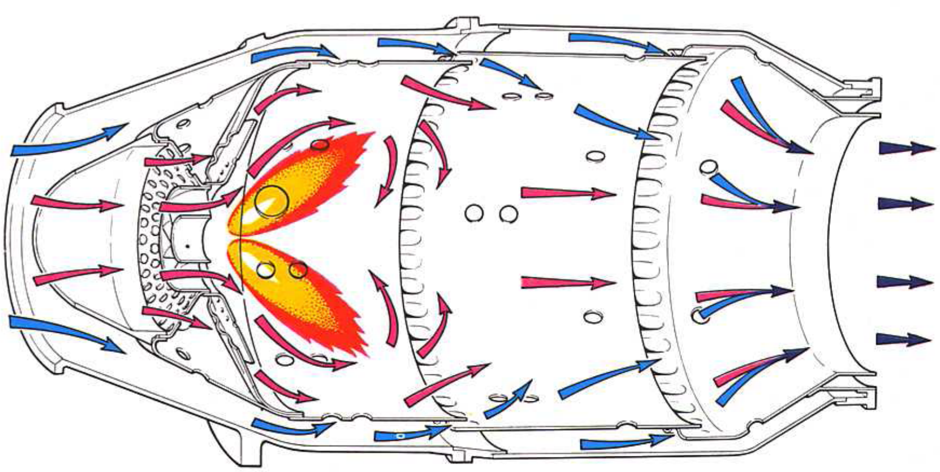


Figure 5.5.1 : Air flow pattern

Primary air

This is the main combustion air. It is highly compressed air from the high pressure compressor (often decelerated via the diffuser) that is fed through the main channels in the dome of the combustor and the first set of liner holes. This air is mixed with fuel, and then combusted

Intermediate air

Intermediate air is the air injected into the combustion zone through the second set of liner holes (primary air goes through the first set). This air completes the reaction processes, cooling the air down and diluting the high concentrations of carbon monoxide (CO) and hydrogen (H_2).

Dilution air

Dilution air is airflow injected through holes in the liner at the end of the combustion chamber to help cool the air to before it reaches the turbine stages. The air is carefully used to produce the uniform temperature profile desired in the combustor.
However, as turbine blade technology improves, allowing them to withstand higher temperatures, dilution air is used less, allowing the use of more combustion air.

Cooling air

Cooling air is airflow that is injected through small holes in the liner to generate a layer (film) of cool air to protect the liner from the combustion temperatures. The implementation of cooling air has to be carefully designed so it does not directly interact with the combustion air and process.

6. ENGINE CYCLE ANALYSIS

6.1 Introduction of Brayton Cycle

First purposed by George Brayton for use in reciprocating oil burning engines in the year 1870. Current usage for gas turbines where both compression and expansion process takes place. A gas turbine is a type of internal combustion engine. It has rotating compressor coupled to a turbine, and a combustion chamber in-between.

Energy is added to the gas stream in the combustor, where fuel is mixed with air and ignited, combustion of the fuel increases the temperature. The products of the combustion are forced into the turbine section. There, the high velocity and volume of the gas flow is directed through a nozzle, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. It works on open version of Brayton cycle, therefore analysis of this cycle is required so as to obtain the temperature and pressure

Brayton cycle phases

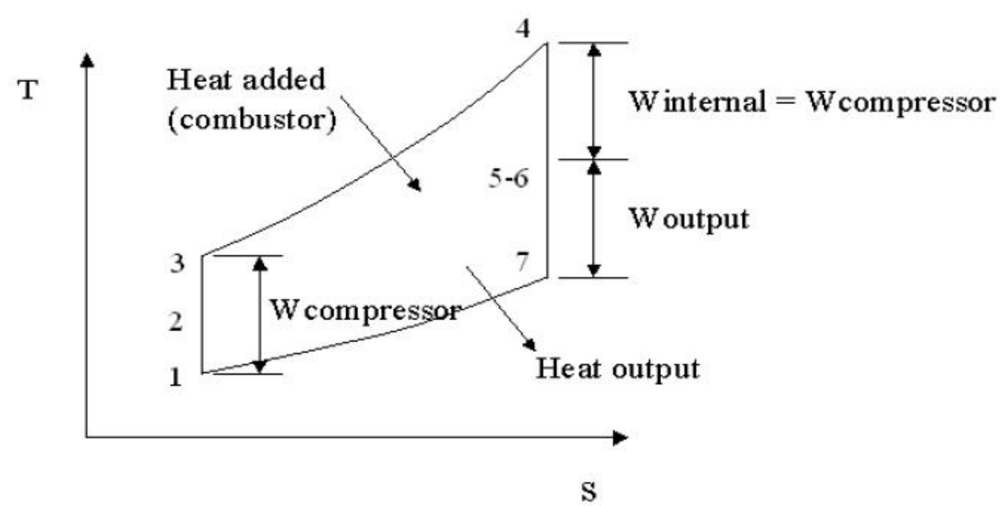


Figure 6.1.1

Open cycle gas turbine engine: air at ambient condition drawn into the compressor temperature and are raised high pressure and high temperature are mixed with fuel and burnt at constant pressure, the resulting high temperature gases enter the turbine and expand to the atmospheric pressure while producing power.

Notations to be taken into account :

A	Chamber casing area, m^2
A_2	Compressor outlet area, m^2
A_a	Annulus area, m^2
A_d	area of dilution holes, m^2
C_D	Discharge coefficient
d_f	Flame Tube diameter, m
d_h	Dilution hole diameter, m
d_j	Dilution jet diameter, m
g	Constant in Newton`s Law, m/s^2
k	Ratio of flame tube area to casing area
kA	Flame-tube area, m^2
M	Chamber air mass flow rate, kg/s
m_g	Ratio of hot combustion products entering dilution zone to total chamber mass flow
m_p	Ratio of primary zone air flow t total chamber air mass flow
m_s	Ratio of air entering snout to total chamber air mass flow
n	Number of dilution holes
P	Total Pressure, kg/m^2
p	Static Pressure, kg/m^2
q	Dynamic Pressure, kg/m^2
r	Area Ratio, A/A_2
R	Gas Constant Of Air
T	Temperature °K
U	Velocity, m/s
λ	Diffuser pressure loss coefficient
ρ	Density, kg/m^3

Suffixes

a	Annulus
diff	Diffuser
f	Flame Tube
g	Hot gas Dilution Hole
h	Diltion Holes
opt	Optimum value

6.2 Calculation of Combustion Camber

$$\text{Area of combustion camber}_{(\text{Reference Area})} = \left(\left(\frac{R}{2}\right)\left(\frac{\dot{m}_3 T_3^{0.5}}{P_3}\right)^2\left(\frac{\Delta P_{2-3}}{q_{ref}}\right)\left(\frac{\Delta P_{2-3}}{P_2}\right)^{-1}\right)^{0.5}$$

$$q_{ref} = \frac{\rho_2 U_{ref}^2}{2}$$

where R = 286.9Nm/KgK
$\dot{m}_3$ = ? (found later in the following steps)
T_3 = ? (found later in the following steps)
P_3 = ? (found later in the following steps)

$$\frac{\Delta P_{2-3}}{q_{ref}} = 40$$

$$\frac{\Delta P_{2-3}}{P_2} = ?$$

a). $\frac{P_3}{P_2} = \left(\frac{T_3}{T_2}\right)^{\frac{\gamma}{\gamma-1}}$

$\frac{P_3}{P_2} = 3$; $P_3 = 3atm = 3.0397 * 10^5\ N/m^2$

$$\frac{T_3}{T_2} = 1.368$$

$$T_3^{`} = T_2 * 1.368$$

$$T_3^{`} = 407.883K$$

$$\eta_c = \left(\frac{T_3^{`} - T_2}{T_3 - T_2}\right) = ?$$

$$\eta_c = 0.8$$

$$\frac{\eta_c}{T_3^{`} - T_2} = \frac{1}{T_3 - T_2}$$

$$T_3 - T_2 = 138.6\ 0$$

$$T_3 = 436.60K$$

6.3 Calculation of Mass Flow Rate

BMEP(brake mean effective pressure) is in the range 1250 to 1700 kPa. For turbocharged 4 stroke diesel engines, max BMEP values are typically in the range 1000-1200 kPa

MEP (kPa)=P(kW)x n_Rx 10^3 / V_d(dm^3) x N (rev/sec)

$n_{R\,=}$ number
n_R is 2 for 4 Stroke and 1 for 2 Stroke

Consider MEP =700 (for T/C diesel engine)

BMEP = 1000 – 1200KPa

$$\text{Mep} = \frac{P(kw) * \eta_R * 10^{-3}}{V_d * N_{(rev/_{sec})}}$$

η_R = no. of crack reduced

MEP = 700 for T/C diesel engine

$$700 = \frac{103 * 2 * 10^3}{V_d * \left(\frac{2600}{60}\right)}$$

$$V_d = \frac{103 * 2}{700 * \left(\frac{2600}{60}\right)}$$

$V_d = 0.00629m^3$

$\frac{\rho_3}{\rho_2} = \left(\frac{P_3}{P_2}\right)^{\frac{1}{2}}$

$\frac{\rho_3}{\rho_2} = 2.191$

$\rho_3 = 2.68495$ kg/m^3

Volumetric efficiency $(\eta_v) = \frac{2*\dot{m}}{\rho_a * V_d * N}$

$\eta_v = 98.1$

$\dot{m} = \frac{0.95*2.68495*0.00679*2600}{2*60}$

$\boldsymbol{\dot{m}_{in}}$ **= 0.3752 Kg/sec**

$T_3 - T_2 = 138.6\ 0$

$T_3 = 436.60K$

WC =WT

$C_p(T_3\text{-}T_2) = C_p(T_4\text{-}T_5)$

$T_3\text{-}T_2 = T_4\text{-}T_5$

$\left(\frac{T_4}{T_5}\right) = \left(\frac{P_4}{P_5}\right)^{\frac{\gamma-1}{\gamma}}$

$\left(\frac{T_4}{T_5}\right) = \left(\frac{P_3}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$

$T_5 = \left(\frac{P_2}{P_3}\right)^{\frac{\gamma-1}{\gamma}} * T_4$

$T_5 = \left(\frac{1}{3}\right)^{0.287} * T_4$

$T_5 = 0.730611 * T_4$

$T_3 - T_2 = T_4 - 0.730611 * T_4$

$T_4 = \frac{16860}{0.2693} = 625.861$

$T_5 = 457.27908$

6.4 Calculation of Area Of Combustion Camber.

Now,

Area of combustion camber$_{\text{(Reference Area)}} = \left(\left(\frac{R}{2}\right)\left(\frac{\dot{m}_3 T_3^{0.5}}{P_3}\right)^2\left(\frac{\Delta P_{2-3}}{q_{ref}}\right)\left(\frac{\Delta P_{2-3}}{P_2}\right)^{-1}\right)^{0.5}$

Area of combustion camber$_{\text{(Reference Area)}}$ = $\left(\left(\frac{287}{2}\right)\left(\frac{0.3752*(436.6)^{0.5}}{3.0397*10^{5}}\right)^{2}(40)(0.07)^{-1}\right)^{0.5}$

Area of combustion camber$_{\text{(Reference Area)}}$ = $\left((143.5)(0.1234*10^{-5}*21.58)^{2}\left(\frac{40}{0.07}\right)\right)^{0.5}$

Area of combustion camber$_{\text{(Reference Area)}}$ = 0.007384 m^2

Area of combustion camber$_{\text{(Reference Area)}}$ = 73.384 cm^2

Area of combustion camber$_{\text{(Reference Area)}}$ = (πr^2)

$r^2_{\text{(Reference Area)}}$ = 24.305

$r_{\text{(Reference Area)}}$ = 4.848

$d_{\text{(Reference Area)}}$ = 9.696300 cm ← diameter of Combustion Camber

6.5 Mass Flow rate through Snout

Consider T4 = 800k (material constrains)

$$\dot{m}_{in}\ (Cp_4\ T_4 - Cp_3\ T_3) = \dot{m}_f Q_u$$

$$0.3752(1.098*800 - 1.020*436.6) = \dot{m}_f*37270$$

$$\dot{m}_f = 0.00436\ \text{Kg/sec}$$

$$\phi_4 = \frac{\dot{m}_4}{\dot{m}_{in}\, fst} = \frac{0.00436}{0.3752*0.07246} = 0.1605$$

$$\Delta T_{max} = \frac{T_4 - T_5}{\phi_4}$$

$$= \frac{1075.88-466.6}{0.1605} = 2264.17\text{k}$$

$$\emptyset_{pz} = \frac{T_g - T_3}{\eta_{p_3}*\Delta T_{max}} = \frac{1800-436.6}{0.7*2264.17} = .86023$$

$$\frac{\dot{m}_f}{\dot{m}_{sn}} = \emptyset_{pz}\ \text{fst}$$

$$\dot{m}_{sn} = \frac{0.00436}{.8602*0.07246}$$

$$\dot{m}_{sn} = 0.06994\text{kg/sec}$$

6.6 Area Of Liner

A_L = kopt * Area of combustion Camber$_{ref}$

$$K_{opt} = 1\text{-}\left(\frac{(1-\dot{m}_{sn})^2-\lambda}{\left(\frac{\Delta P_{3-4}}{q_{ref}}-\lambda r^2\right)}\right)^{1/3}$$

r = ratio of outer casing area of the compressor area

But,

$A_{comp} = \pi * r^2$

$= \pi * (0.0215)^2$

$A_{comp} = 0.00145\ m^2$

$r = \frac{A_{ref}}{A_{comp}}$

$r = \frac{0.007335}{0.00145}$

r = 5.0924

$K_{opt} = 1\text{-}\left(\frac{(1-0.0699)^2-.3}{40-0.30*(5.0924)^2}\right)^{1/3}$

$K_{opt} = 1\text{-}\left(\frac{0.97412-0.30}{(40-8.3160)}\right)^{1/3}$

$K_{opt} = 1\text{-}\left(\frac{0.6746}{31.6839}\right)^{1/3}$

$K_{opt} = 0.74020$

$\pi * r_L^2 = 0.0054656$

$r_L^2 = 0.001856$

$r_L = 0.04171$

$D_L = 0.083425$ m

$D_L = 8.3425$ cm (Diameter of the liner)

6.7 Static Pressure in Combustor

$P_{3.1} - P_3 = q_3\left(1-\frac{1}{(Ar)^2}\right) - \Delta P_{diffar}$

$P_{3.1} = 3.0394 * 10^5 + 11416.64\left(1-\frac{1}{(5.0924)^2}\right) - 0.3$

$P_{3.1} = 3.034188 * 10^5 N/m^2$

6.8 Combustor volume :

Combustor Loading = 3Kg/atm m^3

Combustor Volume = $\frac{\dot{m}_{sn}}{Vol*P_3*10^{(0.00145(T_3-400))}}$

Combustor Volume = $\frac{0.0127}{3.106835*3*1.2490}$ = 0.00255 m^3

6.9 Length Of Liner

$\frac{Vol}{A_{sn}} = \frac{0.002855}{0.0054825} = 0.5223$

L_L = 52.23 cm

6.10 Length of diffuser

D_2 = Dia of Compressor outlet
D_1 = D_{ref} Of Combustion Camber
2θ = Cone Angle of Diffuser = 16

$\frac{D_3-D_2}{2L} = \tan\theta$
$\frac{(9.8600-4.3)}{2L} = \tan 8$

L_{diff} = 19.780cm

6.11 Exit Length Of Combustion Chamber

D_4 = Dia of Turbine Inlet
$2\theta_2$ = Cone Angle Of Combustor exit = 30
D_3 = 9.8600cm
D_4 = 7.62 cm

L = $\frac{D_3-D_4}{2\tan\theta_2}$

L = 4.1798cm

6.12 Dilution Holes :

Determination of flame tube pressure loss

$\frac{\Delta P_f}{q_p} = \frac{\Delta P_{3-4}}{q_{ref}} - \lambda\left(r^2 - \frac{1}{(1-k)^2}\right)$

$= 40 - 0.3\left(5.265 - \left(\frac{1}{(1-k)^2}\right)\right)$
$= 40 - 4.4281$

$\frac{\Delta P_f}{q_p}$ = 35.57187

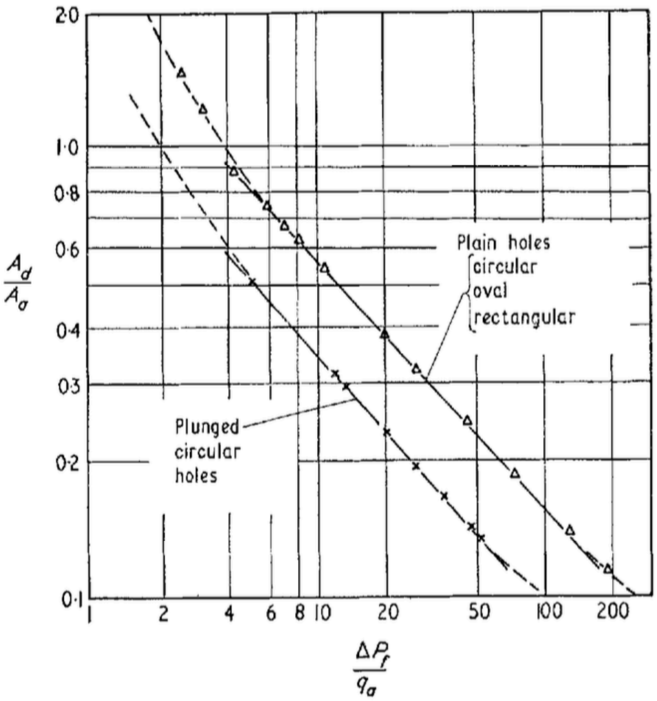


Figure 6.12.1 : Dilution Hole Flow Parameter

from graph : 6.12.1

$\frac{\Delta P_f}{q_p} = 35.57187$

So,

$\frac{A_d}{A_a} = 0.3$

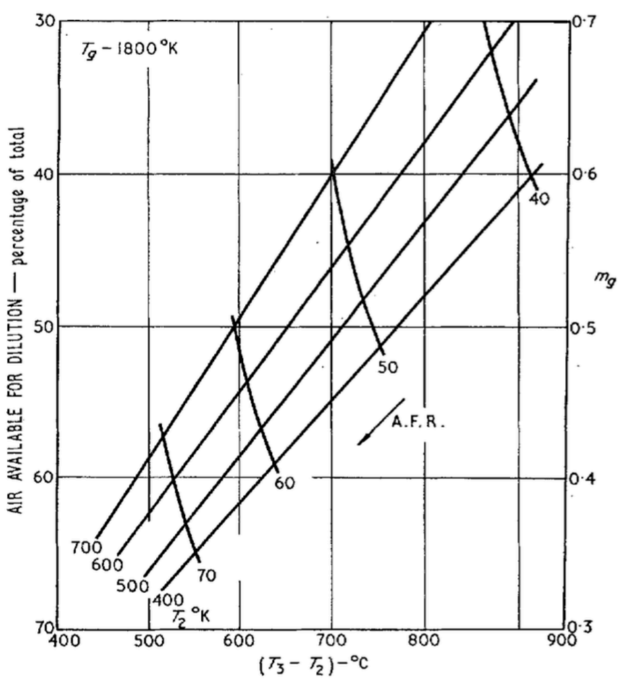


Figure 6.12.2 : Influence Of Combustor Temperature Rise on available dilution air

From Graph : 6.12.2

T_3-T_2 = 666.66 K

SO ,

$\dot{m}g$ = 0.465

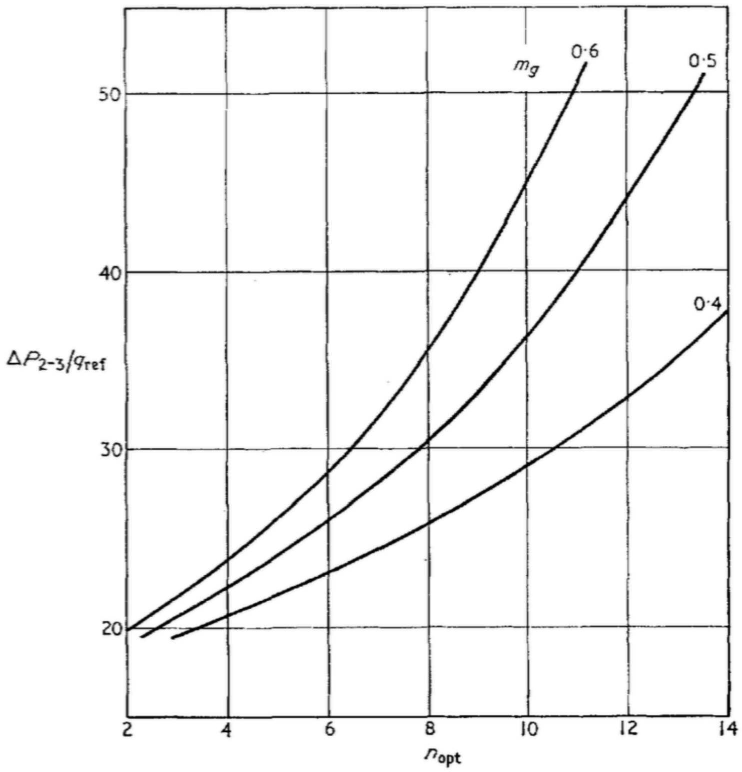


Figure 6.12.3 : Design Chart illustrating the variation of optimum number of dilution holes with airflow distribution and chamber pressure loss

6.13 Number of holes

From graph 6.12.3

Number of holes (optimum Number of dilution holes) (optimum Number of dilution holes) $\frac{\Delta P_{3-4}}{q_{ref}}$ = 40

$\dot{m}g = 0.465$

so, n_{opt} = 11

6.14 Diameter Of Dilution Holes

$$dh^2 = \frac{4(1-k_{qut})A\left(\frac{A_d}{A_a}\right)}{\pi n}$$

$$dh^2 = \frac{4(1-0.722)(0.007635)(0.3)}{\pi 11}$$

dh = 0.008585m

ISSN 2250-3153

dh = 0.8585 cm

6.15 Efficiency Calculation

$$\eta_c = \left(\frac{(\dot{m}_a+\dot{m}_f)h_4 - \dot{m}_a h_3}{\dot{m}_f * Q_R}\right) * C_{p_{(T)}}$$

here,

$\dot{m}_a$ = 0.3752
$\dot{m}_f$ = 0.00436

Let C_p be at Temperature T = 850k , $C_{p_{850}}$ = 1.11

Q_R = heat of reaction = 47270 KJ/Kg
h_4 = enthalpy at the exit of the combustion chamber = 800K
h_3 = enthalpy at the entry of the combustion chamber = 436.6k

$$\eta_c = \left(\frac{(0.3752+0.00436)800 - 0.375*436.6}{0.00436*47270}\right) * 1.11$$

η_c = 0.9547

η_c = 95.47%

CONCLUSION

As per the problem statement mentioned in the starting of the paper, we would like to conclude this paper by telling that a miniaturized gas turbine generator was made using automotive turbo charger, where the combustion chamber was optimized to yield better efficiency than the engines available in the current market. Indeed electricity is been generated by extracting power by using impulse turbine. To be noted that the fuel been used is one of the eco friendly fuel (Bio-Diesel). As said the efficiency is found to be 95.47% here by we conclude that this engine is the most efficient to produce electricity with a given quantity of fuel (Bio-Diesel).
One thing as to be taken into account as this is an air breathing engine, it as no moving parts inside the combustion camber.
In this particular engine we can use any fuel for combustion. The only thing that as to be looked into is the fuel injector, which as to be changed depending on the fuel being used for combustion (fuel injector depends on the fuel charactertictics).

ACKNOWLEDGMENT

We would like to thank our giude Dr. Allamaprabhu C.Y, Assistant Professor, Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University. for guiding us through writing this Scientific and research paper.

REFERENCES

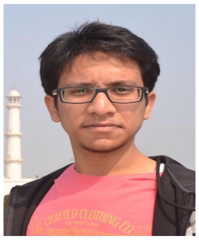
[1] Moran J.Micheal., Howard N Shapiro.,Daisie D.Boettner., Margaret B Bailey Fundamentals of engineering thermodynamics 7th ed, McGraw-Hill.
[2] Walsh, P. and Fletcher, P.*, Gas Turbine Performance,* 2nd ed., Black Well.
[3] *Gas turbine* A HANDBOOK OF AIR LAND AND SEA APPLICATION.
[4] Cengel, Yunus. and Boles, Micheal.*, Thermodynamics and engineering approach* , McGraw-Hill .
[5] Heywood, J.B., Internal Combustion Engine Fundamentals, McGraw-Hill.

[6] Lefebvre, A.H., *Gas Turbine Combustion* , 2nd ed., Taylor and Francis.

[7] VK.SANGVI.

[8] Mattingly, J.D., *Elements of Gas Turbine Propulsion*, chapter 9, McGraw-Hill.

AUTHORS



First Author – Shreyas Ramanagara Sridhara : Final Year B.Tech Student, Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University,shreyasrs36@gmail.com.

Second Author –Vishan Ravi Tejaas: Final Year B.Tech Student, Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University, ravitej28@gmail.com.

Third Author – Nagarjun RK: Final Year B.Tech Student, Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University.

Fourth Author – Varun Kumar R: Final Year B.Tech Student, Aerospace Department, International Institute For Aerospace Engineering And Management, Jain University.