جامعة الأمير محمد بن فهد
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

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Senior Design Project Report

Design of Radial Jet Engine Using Automotive Turbocharger

In partial fulfillment of the requirements for the

Degree of Bachelor of Science in Mechanical Engineering

Group Members

Student				
Name	ALI ALMUTAWA*	NASSER ALMASHAME	SAUD ALOTIBI	HUSSAIN ALMASHAME
ID	201403646	201502695	201400389	201502158

Project Advisor: Dr. Panagiotis Sphicas

Abstract

This project is about researching, designing and building jet-engines. A simpleturbojet engine was designed, and construction in this project using a large diesel car turbocharger on a small-scale level. The turbocharger serves as an integrated compressor & turbine assembly that is suitably manipulated and carefully convertedinto an open cycle constant pressure gas turbine. The design was made bystudying the work done by industry and researchers over the course of the history ofjet engines. The project mainly involves modelling and designing of combustion chamber using software packages likeAutoCAD, SolidWorks etc.; and then complete fabrication of the same by us.The methods were then discussed and chosen in a way that wouldsimplify the design work as well as the construction of the engine.

In this research, our main objective is to design, develop and manufacturea self-sustaining combustion within the engine. The design settled uponconsists of a radial compressor, an annular combustion chamber and an axial turbine.Since the compressor would have been the most difficult part to machine, the decision was made early on to use the compressor from a turbocharger out of an automotiveengine. Turbocharger consists of two chambers that are connected by center housing and the two chambers contain a turbine wheel and a compressor wheel connected by a shaft which passes through the center housing.

In this research, we will apply our mechanical engineering understanding to design, analyze and correct the problems with jet engines. We will also calculate the RPM of the jet engine and efficiency of the jet engine. Finally, we will provide suggestion to develop the jet engines to increase the efficiency.

Keywords– Jet engine, turbocharger, compressor, turbine, internal combustion engine, combustion chamber, efficiency.

Acknowledgment

We are extremely beholden and own an irredeemable dept, of gratitude to our project advisor **“Dr. Panagiotis Sphica”**for their valuable guidanceand help extended tous in our project.We consider it as a great opportunity to do project under his guidance and to learn from his research expertise. It was incredible to get his professional direction that positively impacted work on a major deal. We thank you for all your contributions of time, insightful discussions, instructions, reviews and recommendations about the project.

Our hearty gratitude extends to the officials of the PMU for the help we received from the faculty and staff of the PMU. They helped us to effectively use the various facilities of the university. They also allowed us to use the library and the industrial facilities available. We would like to thank them for all non-technical and technical support to carry out our project work.

On the other hand, the efforts of the team members were tremendous. The division of work among the team members was clear, remarkable and productive too. Every team member has been helped to carry out their functions efficiently and effectively. It was a great time to work with team members. The leader of the group addresses his strongest gratitude to each of the members of the team**NASSER ALMASHAME**, **SAUD ALOTIBI**, and **HUSSAIN ALMASHAME**.

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List of Acronyms (Symbols)

C_p	Specific heat capacity at constant pressure
C_v	Specific heat capacity at constant volume
W	Work interaction
w	Specific work
F	Force
h	Specific enthalpy
h_o	Specific stagnation enthalpy
LHV	Fuel heating value
$\dot{m}$	Mass flow rate
P	Static pressure
P_0	Stagnation pressure
Q	Heat interaction
q	Specific heat
R	Gas constant
r	Radius
s	Specific entropy
T	Static temperature
T_0	Stagnation temperature
V	Absolute flow velocity
[illegible]	Specific heat ratio
η	Efficiency
π	Pressure ratio
ρ	Density
τ	Temperature ratio

Subscript

a	Air
c	Compressor
f	Fuel
o	Overall
p	Propulsive
t	Turbine
th	Thermal

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CHAPTER 1

INTRODUCTION

OJECT DEFINITION

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Introduction

A jet engine is a type of reaction engine discharging a fast-moving jet that generates thrust by jet propulsion. This broad definition includes airbreathing jet engines i.e. turbojets, turbofans, ramjets, and pulse jets.

A modern jet engine is truly a miracle ofengineering.Jet engines see wide use in many applications, aviation and energy production amongmany others.Thedesign and construction of a jet engine requires a great deal ofknowledgefrom many different fields, thermodynamics and fluid mechanics tomechanical engineering.From fine tolerance in space to resilience to high temperatures and stress, the jet engine has gone through a revolution over the years, with greatimprovements in performance, efficiency and reliability.The most commonly known jet engines are the turbojet engine, the turboprop engine,the turbofan engine, the turboshaft and the ramjet engine. The major principle in allthese engines are the same and they work according to similar concepts as the internalcombustion engine:

- Suck: This part is focused on the inlet, the air is sucked in.
- Squeeze: The second part is focused on the compression of the air, where the inlet airis compressed to a higher pressure.
- Bang: The third part is focused on the combustion chamber, where the compressed airis mixed with fuel and then ignited bang.
- Blow: The fourth part is focused on the outlet of the engine, where the ignited air and fuel-mixture exits at a high velocity.

Starting out with a compressor, a combustion chamber and a turbine, we can tell the difference from the turbojet, turboprop, turboshaft and turbofan on where the power is transferred from the turbine.

- In a turbojet, the turbine is connected to the compressor.

- In a turboprop, the turbine is connected to the compressor and a propeller.
- In a turbo shaft, the turbine is connected to the compressor and a power shaft.
- In a turbofan, the turbine is connected to the compressor and a fan that blows air through a duct around the engine.

The thrust of a typical jetliner engine went from 5,000 lbf (22,000 N) (de Havilland Ghost turbojet) in the 1950s to 115,000 lbf (510,000 N) (General Electric GE90 turbofan) in the 1990s, and their reliability went from 40 in-flight shutdowns per 100,000 engine flight hours to less than 1 per 100,000 in the late 1990s. This, combined with greatly decreased fuel consumption, permitted routine transatlantic flight by twin-engine airliners by the turn of the century, where before a similar journey would have required multiple fuel stops [1].

1.1 Project Definition

This project consists of Design, fabrication, assembly and testing of a Jet Engine, using a large diesel car turbocharger, on a small-scale level. The turbocharger serves as an integrated compressor & turbine assembly which is suitably manipulated and carefully converted into an open cycle constant pressure gas turbine. The project mainly involves complex modeling, designing and analysis of combustion chamber using software packageslike AutoCAD, SolidWorks etc.; and then complete fabrication of the same completely by us.

The engine chosen for this project is the simplest type, the turbojet engine. They work in a way where the incoming airiscompressed by the inlet enough to sustain combustion when fuel is added.And the force of the air exiting the engine is propelling the aircraft forward, making the engine compress even more air, repeating the cycle. In a simple way as can be intake of the compressor runs down here spiral around the flame tube and propane is injected into the flame tube. There are lots of holes in the flame tube.

Compressed air speeding in goes with the propane busting chamber and spools up the turbine which runs the compressor rails. Then it comes in easy to the top of the bearing moves the heat out of the bearing and lubricates it dumps back out the discharge nozzle.

1.2 Project Objectives

Our objective is to construct a working scaled model of a turbojet engine using diesel car turbocharger which will be self-sufficient and requiring no separate power sources to operate thus allowing the unit to be mobile. This project consists of design, fabrication, assembly and testing of a Jet Engine, using a diesel car turbocharger. This project is replica of actual working of the jet engine on a small-scale level. The turbocharger serves as an integrated compressor & turbine assembly which is suitably manipulated into an open cycle constant pressure gas turbine. The project mainly involves complex modeling, designing and analysis using software packages like AutoCAD, SolidWorks etc.; and then complete fabrication of the samecompletely by us.

1.3 Project Specifications

The procedure that will be adopted in designing the turbojet engine is outlined below:

- Define the system and its components.
- Build up the physical/Block model describing all the components.
- Obtain the equivalent diagrammatic representation of the block model.
- Formulate the mathematical model and describe the assumptions made.
- Write down the equations describing the model.
- Solve the equations for desired output variables.
- Examine the solution and variables.

- Apply the necessary corrections to subvert the idealized corrections made in both the physical and the mathematical model.
- Reanalyze and Redesign till the solutions obtained are compatible with the results expected of the actual system.
- Detailed Design and selection of the various components based on the results obtained in the analyses of the mathematical model.

CHAPTER 2

LITERATURE REVIEW

2.1 PROJECT BACKGROUND

2.2 PREVIOUS WORK

2.3 COMPARATIVE STUDY

2.1 Project Background

In this section history of jet engines, applications, working principle and types of jet engines are discussed.

2.1.1History of jet engine

The basic principle used in jet engines has been known for a long time. It dates to around150 BC when the principle was used in the Aeolipile as shown in figure 2 [2], which is a simple construction using aradial steam turbine. The steam exits through a nozzle creating aspinning motion of a ball. Allaccording to Newton's third law.

The key to a practical jet engine was the gas turbine, extracting power from the engine itself to drive the compressor. The gas turbine was not a new idea: the patent for a stationary turbine was granted to John Barber in England in 1791.The first gas turbine to successfully run self-sustaining was built in 1903 by Norwegian engineer Ægidius Elling. The interest continued during the 1800s. But it wasn't until Sir FrankWhittle of the Royal Air Force in the 1930s made the first patent for the jet engine andshowed the possibilities through reliable energy conversion. He made the first static testin 1937. Two years later, in 1939, it was a German physicist named Hans von Ohain whomade the first jet-powered-flight and demonstrated the possibilities of the jet engines.The ideas came about improving the propeller driven aircrafts of the time, where themain problem was the speed of the aircraft. The aircraft of the time were closing in onthe speed of sound, and sometimes getting too close, which would result in shockwavesbeing created, causing the propeller to shatter.

The jet engine allowed a continuous combustion and airflow. It was a big changefrom thepiston engines dominating the industry. At the time, the greatest struggle the engineershad was to create a material that could withstand the temperatures generated in thecombustion chamber, since it would often lead to the turbines melting. The developmentof the jet engine took off during World War II and performance was quickly raised becauseof the efforts made to try to get any advantage possible. Thus, paving the way for themodern jet engines.

Figure 2.1: Hero’s Aeolipile (Source: Knight’s American Mechanical Dictionary, 1876).

Following the end of the war the German jet aircraft and jet engines were extensively studied by the victorious allies and contributed to work on early Soviet and US jet fighters. The legacy of the axial-flow engine is seen in the fact that practically all jet engines on fixed-wing aircraft have had some inspiration from this design.By the 1950s the jet engine was almost universal in combat aircraft, except for cargo, liaison and other specialty types.The efficiency of turbojet engines was still rather worse than piston engines, but by the 1970s, with the advent of high-bypass turbofan jet engines fuel efficiency was about the same as the bestpiston and propeller engines.

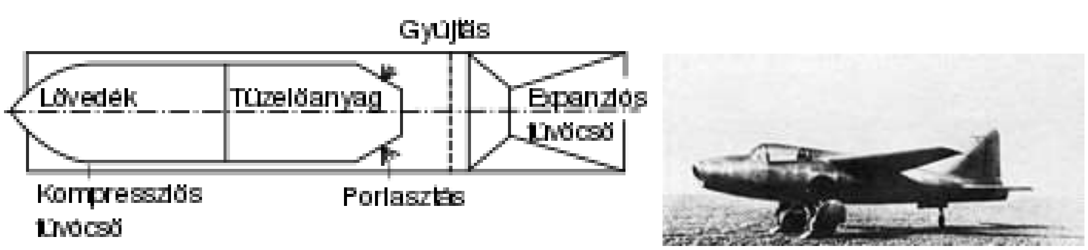


Figure 2.2: (a) Albert Fonó's ramjet-cannonball from 1915. **(b)** Heinkel He 178, the world's first aircraft to fly purely on turbojet power.

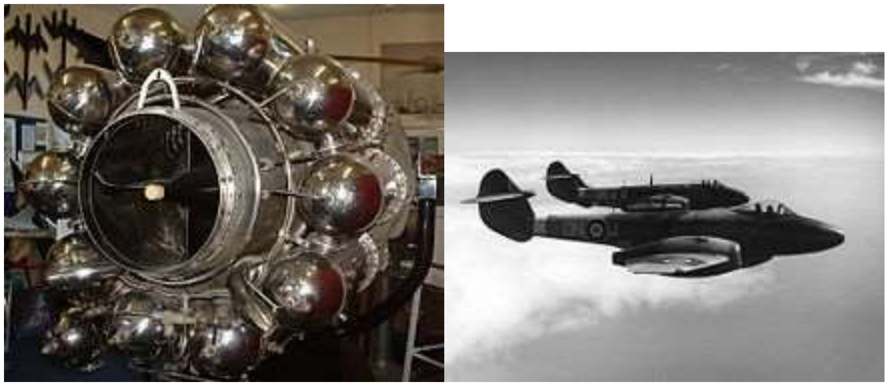


Figure 2.3: (a) The Whittle W.2/700 engine flew in the Gloster E.28/39. **(b)** GlosterMeteor F.3s.

2.1.2Application of jet engine

Jet engines power jet aircraft, cruise missiles and unmanned aerial vehicles. In the form of rocket engine,jet engine power fireworks, model rocketry, spaceflight, and military missiles.Jet engine designs are frequently modified for non-aircraft applications, as industrial gas turbines or marine powerplants. These are used in electrical power generation, for powering water, natural gas, or oil pumps, and providing propulsion for ships and locomotives. Industrial gas turbines can create up to 50,000 shaft horsepower.

Jet engines are also sometimes developed into, or share certain components such as engine cores, with turboshaft and turboprop engines, which are forms of gas turbine engines that are typically used to power helicopters and some propeller-driven aircraft.

Figure 2.4: A JT9D turbofan jet engine installed on a Boeing 747 aircraft.

2.1.3Working Principle of Jet Engine

All jet engines work on the same principle. The engine sucks air in at the front with a fan. A compressor made with many blades attached to a shaft spin at high speed and raises the pressure of the air by compress or squeeze the air. The compressed air is then sprayed with fuel and an electric spark lights the mixture. The burning gases expand and blast out through the nozzle, at the back of the engine. The engine and the aircraft get thrust forward as the jets of gas shoot backward. As the hot air is going to the nozzle, it passes through another group of blades called the turbine.The turbine is attached to the same shaft asthe compressor. Spinning the turbine causes the compressor to spin. Figure 2.1 shows the air flow through the engine.

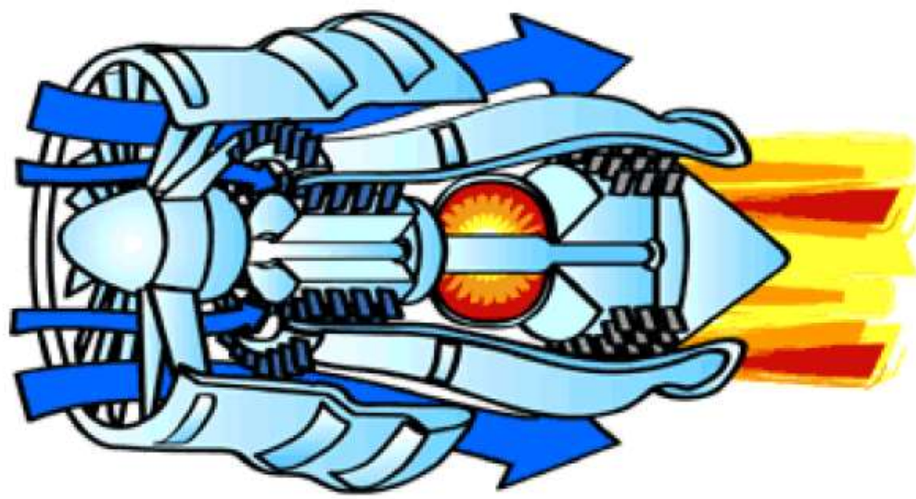


Figure 2.5: Air flow through the Jet engine.

2.1.4Parts of jet engine

Following are the parts of jet engine:

- Fan - The fan is the first component in a turbofan. The large spinning fan sucks in large quantities of air. Most blades of the fan are made oftitanium. It then speeds this air up and splits it into two parts. One part continues through the "core" or center of the engine, where it isacted upon by the other engine components.

- Compressor - The compressor is the first component in the engine core. The compressor is made up of fans with many blades andattached to a shaft. Thecompressor squeezes the air that enters it into progressively smaller areas, resulting in an increase in the airpressure. This results in an increase in the energy potential of the air. The squashed air is forced into the combustion chamber.
- Combustor - In the combustor the air is mixed with fuel and then ignited. There are as many as 20 nozzles to spray fuel into the airstream.The mixture of air and fuel catches fire. This provides a high temperature, high-energy airflow. The fuel burns with the oxygen in thecompressed air, producing hot expanding gases. The inside of the combustor is often made of ceramic materials to provide a heat-resistantchamber. The heat can reach 2700°.
- Turbine - The high-energy airflow coming out of the combustor goes into the turbine, causing the turbine blades to rotate. The turbines arelinked by a shaft to turn the blades in the compressor and to spin the intake fan at the front. This rotation takes some energy from the highenergyflow that is used to drive the fan and the compressor. The gases produced in the combustion chamber move through the turbine andspin its blades. The turbines of the jet spin around thousands of times. They are fixed on shafts which have several sets of ball-bearing in between them.
- Nozzle - The nozzle is the exhaust duct of the engine. This is the engine part which produces the thrust for the plane. The energydepleted airflow that passed the turbine, in addition to the colder air that bypassed the engine core, produces a force when exiting thenozzle that acts to propel the engine, and therefore the airplane, forward. The combination of the hot air and cold air are expelled andproduce an exhaust, which causes a forward thrust.

The velocity of the air entering the nozzle is low, about Mach 0.4, a prerequisite for minimizing pressure losses in the duct leading to the nozzle [4]. The temperature entering the nozzle may be as low as sea level ambient for a fan nozzle in the cold air at cruise altitudes. It may be as high as the 1000K exhaust gas temperature for a supersonic afterburning engine or 2200K with afterburner lit [5]. The pressure entering the nozzle may vary from 1.5 times the pressure outside the nozzle, for a single stage fan, to 30 times for the fastest manned aircraft at mach 3.[6]

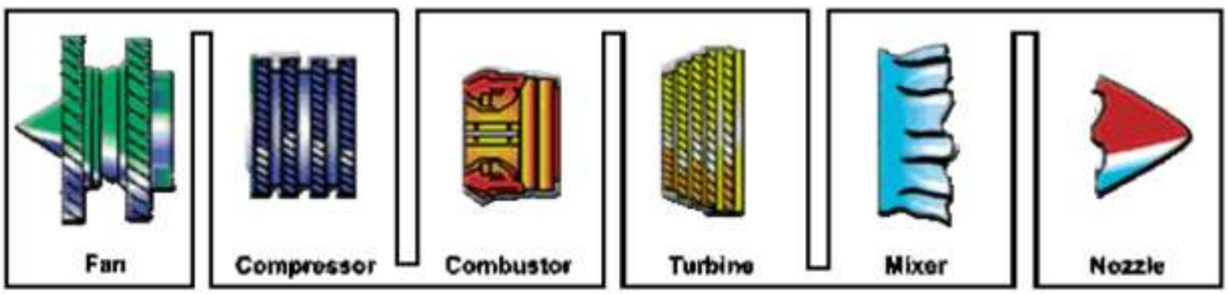


Figure 2.6: Parts of jet engine.

2.1.5Types of Jet Engine

Following are the types of jet engine:

- **Turbojets:** The basic idea of the turbojet engine is simple. Air taken in from an openingin the front of the engine is compressed to 3 to 12 times itsoriginal pressure in compressor. Fuel is added to the air and burned in a combustion chamber to raise the temperature of thefluid mixtureto about 1,100°F to 1,300° F. The resulting hot air is passed through a turbine, which drives the compressor.

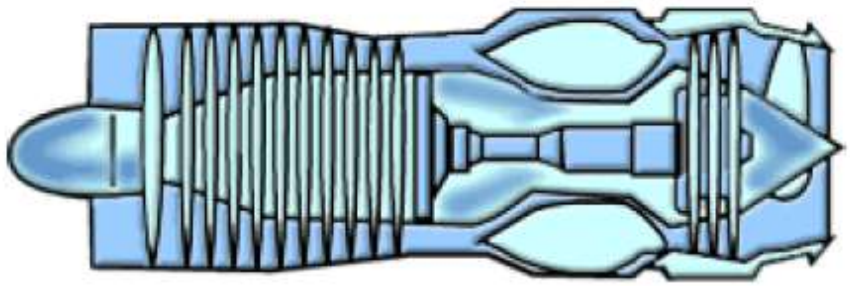


Figure 2.7: Turbojet engine.

- **Turboprops:** A turboprop engine is a jet engine attached to a propeller. The turbine at the back is turned by the hot gases, and this turns a shaft thatdrives the propeller. Some small airliners and transport aircraft are powered by turboprops.

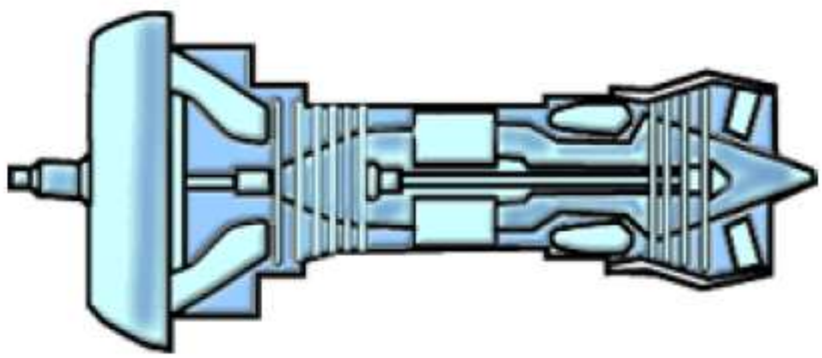


Figure 2.8: Turboprop engine.

- **Turbofans:** A turbofan engine has a large fan at the front, which sucks in air. Most of the air flows around the outside of the engine, making it quieterand giving more thrust at low speeds. In a turbojet all the air entering the intake passesthrough the gas generator, which is composed of the compressor, combustion chamber, and turbine. In a turbofan engine only a portion ofthe incoming air goes into the combustion chamber. Theremainder passes through a fan, or low-pressure compressor, and is ejected directly as a "cold" jet or mixed with the gas-generator exhaust to produce a "hot" jet. The objective of this sort of bypass system is toincrease thrust without increasing fuel consumption. It achieves this by increasing the total air-mass flow and reducing the velocity withinthe same total energy supply.

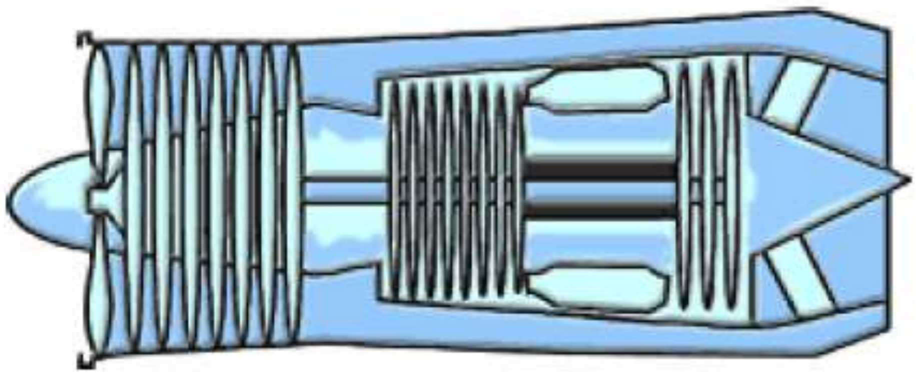


Figure 2.9: Turbofan engine.

- **Turboshafts:** This is another form of gas-turbine engine that operates much like aturboprop system. It does not drive a propeller. Instead, it providespower for a helicopterrotor. The turboshaft engine is designed so that the speed of the helicopter rotor isindependent of the rotating speedof the gas generator.

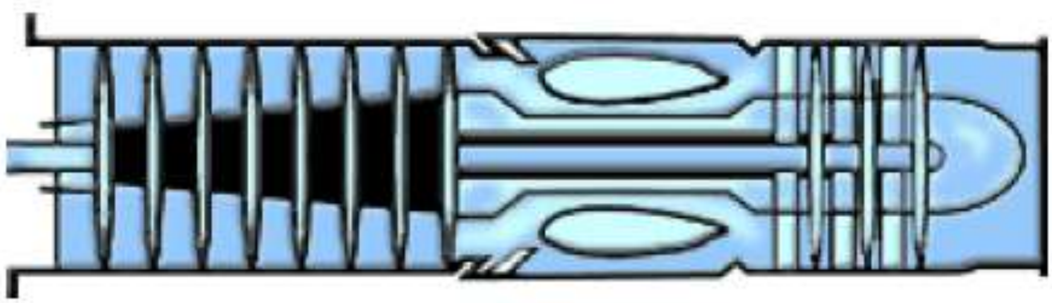


Figure 2.10: Turboshaft engine.

- **Ramjets:** The ramjet is the simplest jet engine and has no moving parts. The speed of the jet "rams" or forces air into the engine. It is essentiallya turbojet in which rotating machinery has been omitted. Its application is restricted by the fact that its compression ratio depends wholly onforward speed.

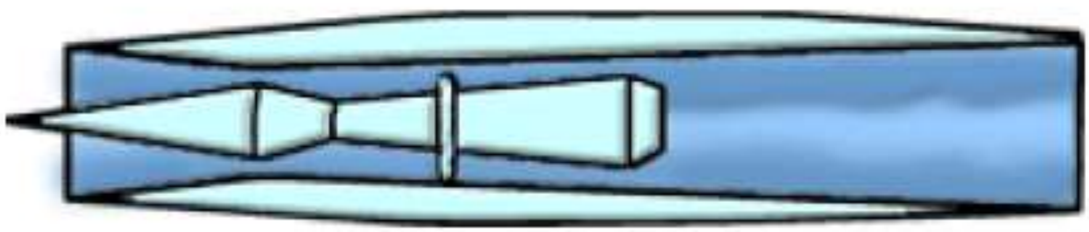


Figure 2.11: Ramjets engine.

3

SYSTEM DESIGN

3.1 DESIGN CONSTRAINTS

3.2 DESIGN METHODOLOGY

3.3 THEORETICAL CALCULATIONS & DESIGN

3.4 PRODUCT SUBSYSTEMS & COMPONENTS

3.5 MANUFACTURING & ASSEMBLY

3.1Design Constraints

Following are the design constraints in this project:

3.2 Design Methodology

Figure 3.1 shows the first cad model design of combustion chamber. It was made by analyzing common jet engines andfiguring out the most suitable design for this project. The design consists of a radialcompressor, an annular combustion chamber and an axial turbine.

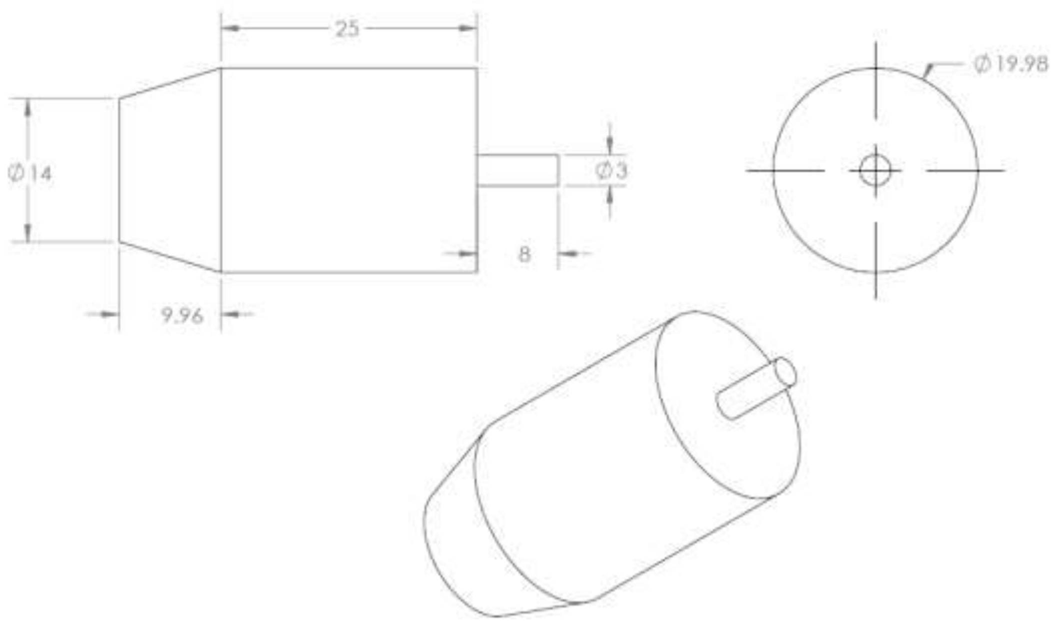


Figure 3.1: First CAD Design of combustion chamber.

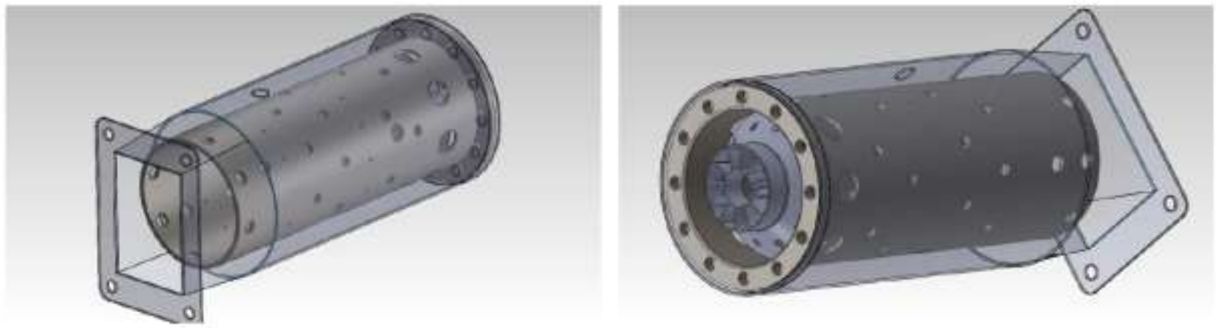
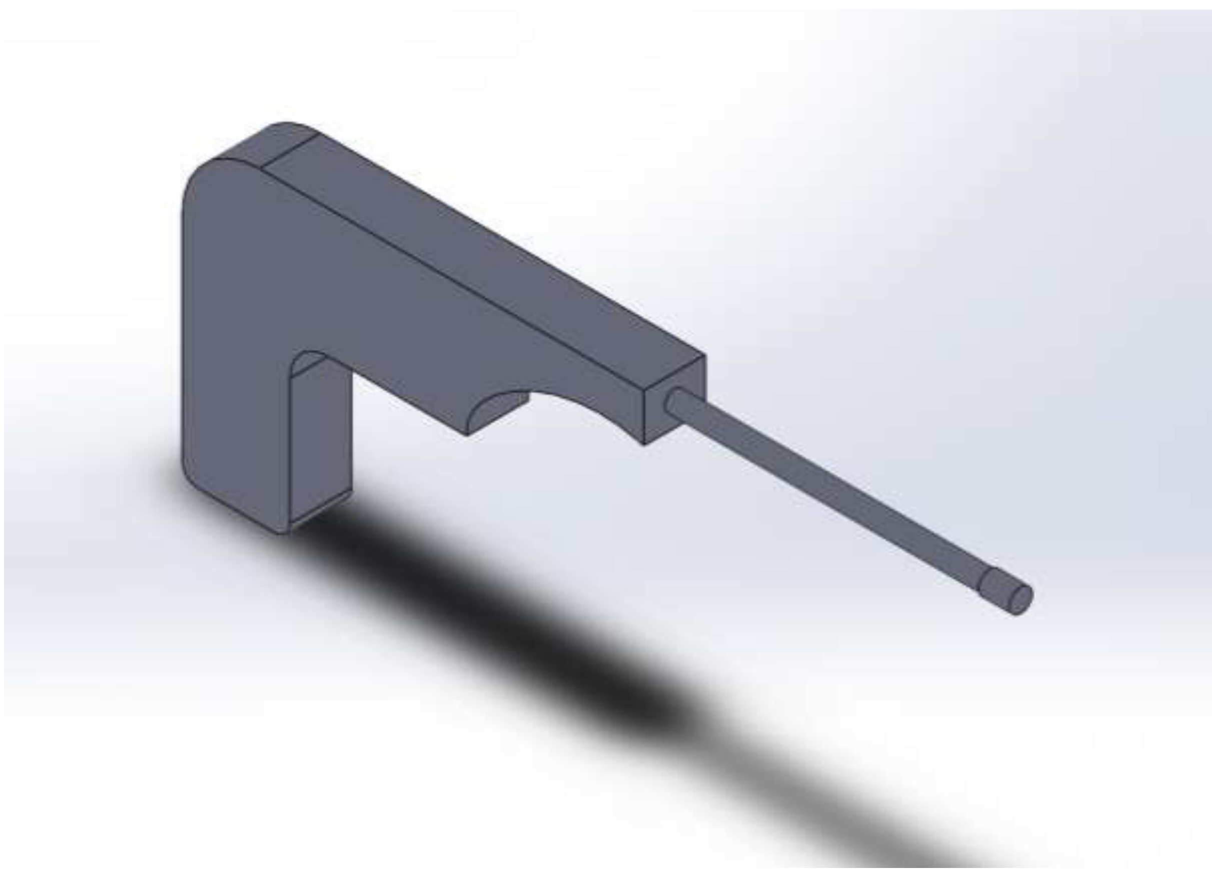


Figure 3.2: Final assembly of combustion chamber.

CAD Model



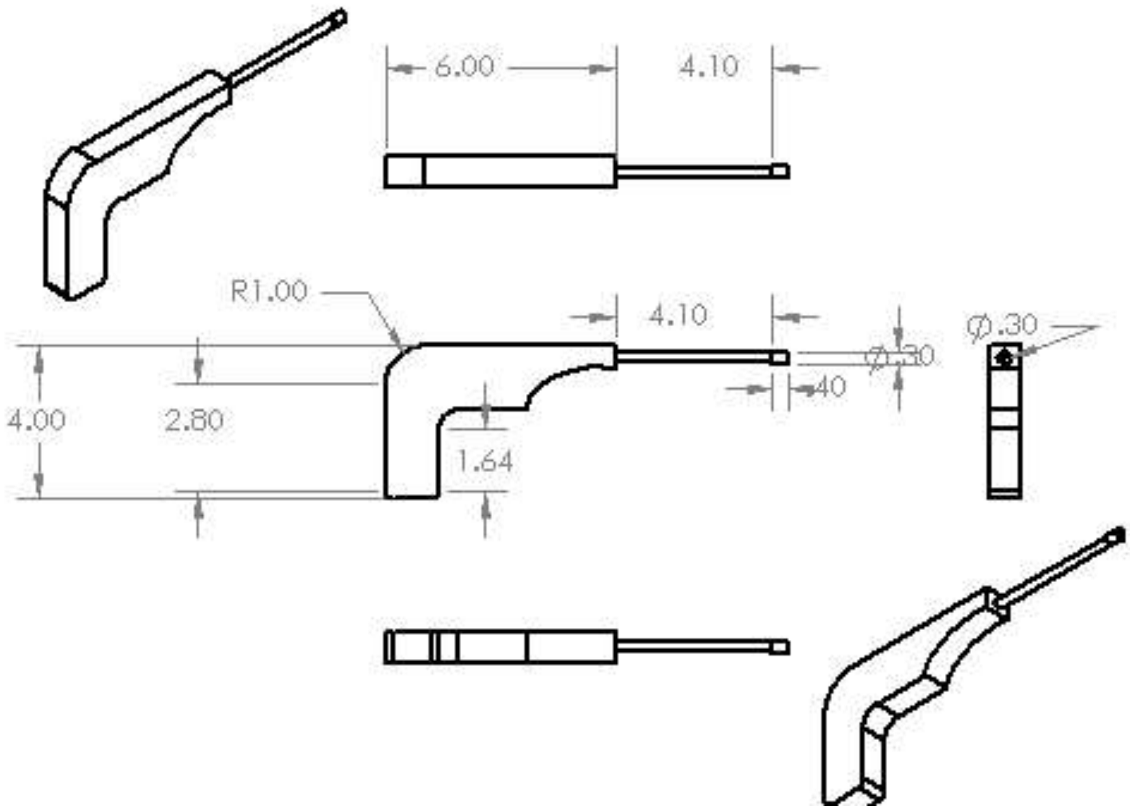


Figure 3.3: CAD Model of Spark Gun.

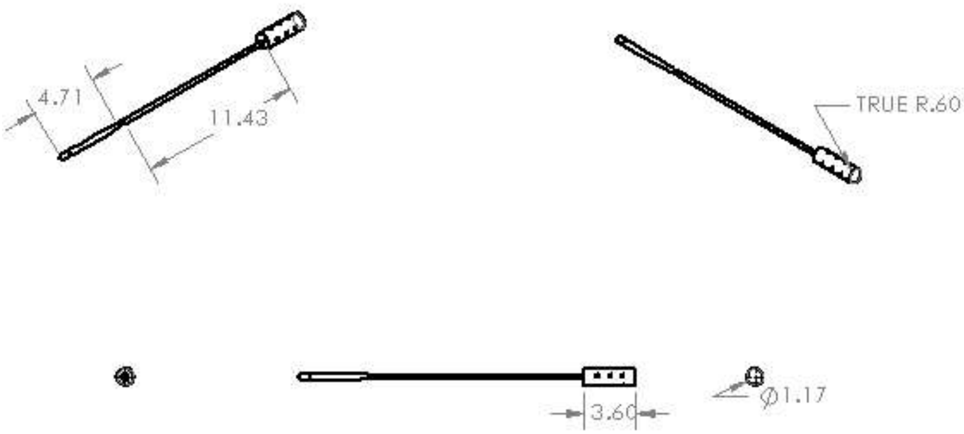


Figure 3.4: CAD Model of Stove fire.

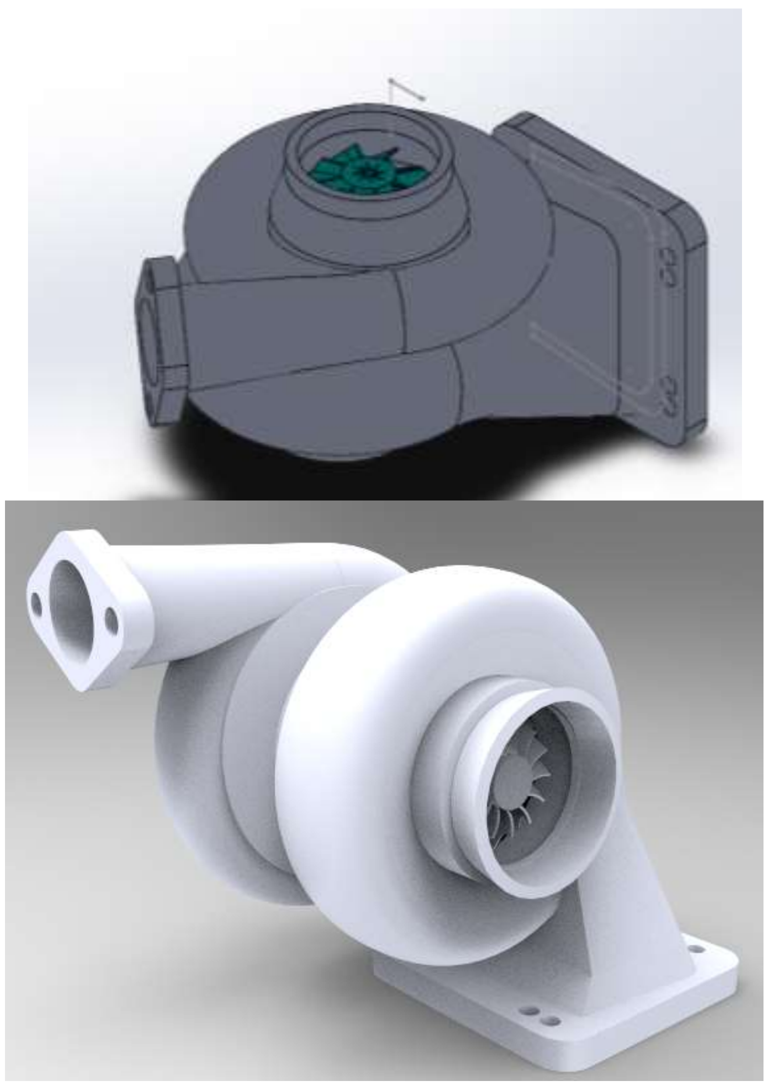


Figure 3.5: CAD Model of turbocharger used from car.

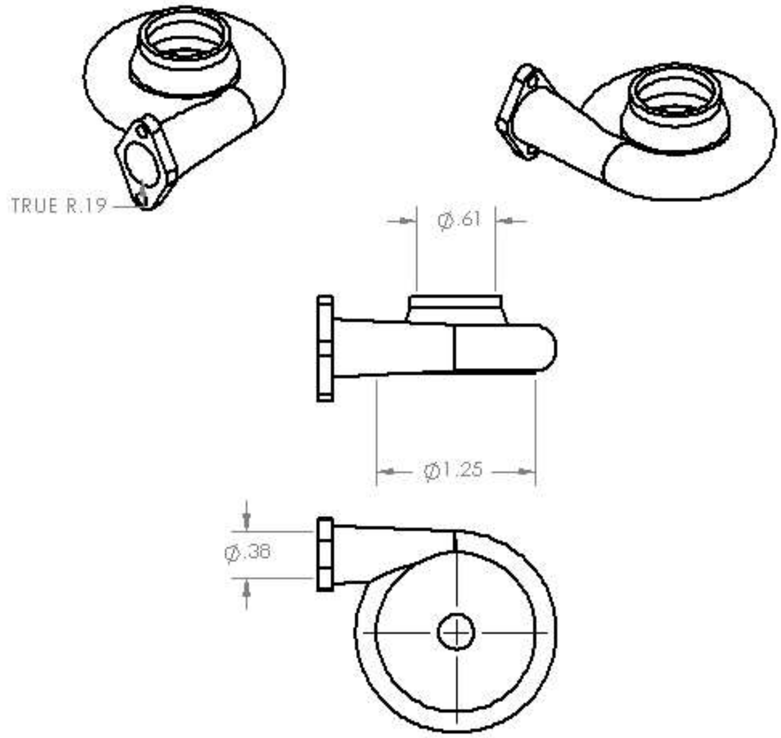


Figure 3.6: CAD Model of propeller housing of Turbocharger.

3.3 Theoretical Calculations and Design

Net thrust generated for jet engine is given by the equation:

$$F_N = (\dot{m}_{air} + \dot{m}_f)V_j - \dot{m}_{air}V$$

$\dot{m}_{air}$: Rate of flow of air through engine

$\dot{m}_f$: Rate of flow of fuel entering the engine

V_j: Speed of jet

V: True air speed of the aircraft

The research presentedin this paper is focused on the thermo-dynamical analysis of a small sized turbojet.

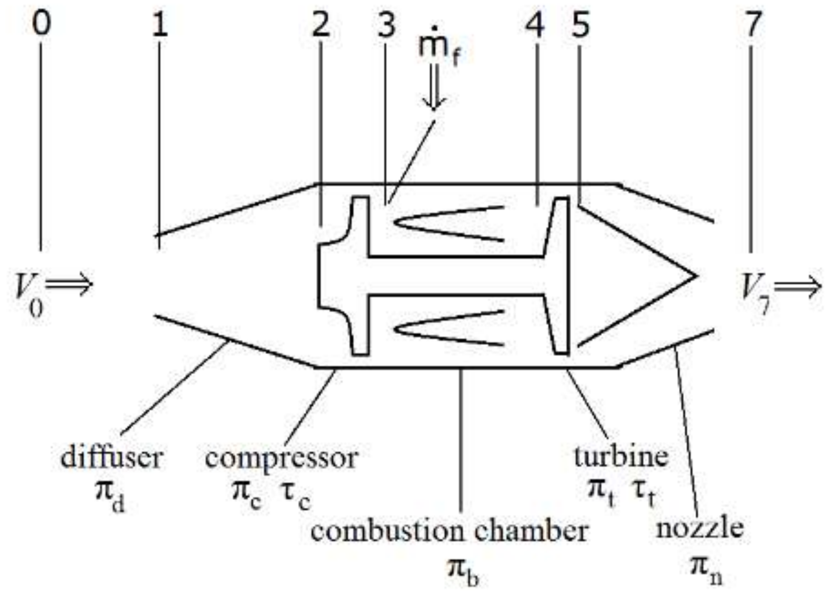


Figure 3.7: Turbojet engine parameter for analysis.

Assumptions for Analysis

1. Each component is analysed as a control volume at steady state.
2. The diffuser, compressor, turbine, and nozzle processes areisentropic.
3. No pressure drops for flow through the combustor.
4. The turbine work output equals the work required to drivethe compressor.
5. Kinetic energy effects are ignored except at the inlet and exit of the engine.
6. Potential energy effects are negligiblethroughout.
7. The working fluid is air modelled as an ideal gas.

Diffuser:

By applying mass and energy rate balances:

$$h_1 + \frac{V_1^2}{2} = h_a + \frac{V_a^2}{2}$$

$$h_1 = h_a + \frac{V_a^2}{2}$$

Compressor:

The pressure at the exit of compressor or combustor inlet:

Using compressor ratio:

$$\frac{p_2}{p_1} = \pi_c$$

Turbine:

$$\frac{\dot{W}_t}{\dot{m}} = \frac{\dot{W}_c}{\dot{m}}$$

$$h_3 - h_4 = h_2 - h_1$$

$$h_4 = h_3 + h_1 - h_2$$

Nozzle:

By applying energy balance at nozzle exit:

$$h_4 + \frac{V_4^2}{2} = h_5 + \frac{V_5^2}{2}$$

Neglecting velocity at nozzle inlet: $V_4 = 0$

$$V_5 = \sqrt{2(h_4 - h_5)}$$

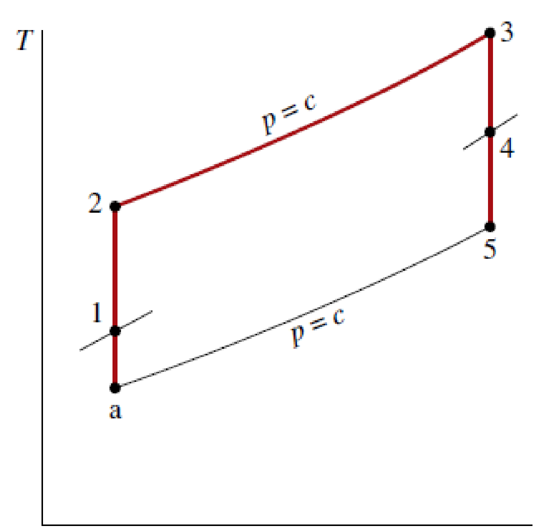


Figure 3.8: T-s diagram for ideal turbojet engine cycle.

Following theoretical formulas are used:

The Brake Mean Effective Pressure $\boldsymbol{bmep}$

$$bmep = \frac{4\pi\tau}{V_d}$$

bmep:The Brake Mean Effective Pressure

τ:Torque

Vd:Volume Displacment.

The Brake Power, $\boldsymbol{\dot{W} b}$

$$\dot{W}_b = 2\pi\tau N$$

Where:

Wb:Brake Power

τ:Torque

N:Mean Speed(rpm)

The Mean Piston Speed ($\boldsymbol{\bar{U} P}$)

$$\bar{U}_P = 2NS$$

Where:

ŪP:Mean Piston Speed

N:Mean Speed (rpm)

S:Stroke (four Strok)

The mass Airflow rate ($\boldsymbol{\dot{m}a}$)

$$\dot{m}_a = e_v \rho_i V_d \left(\frac{N}{2}\right)$$

where:

ṁa: Air flow rate

ev: Volumetric Efficiency

ρi: Density of the air

Vd:VolumeDisplacment N: Mean Speed(rpm)

Density of the air

$$\rho_i = \frac{P_i}{RT_i}$$

Where:

Pi: Density of the air

Pi: Pressure inlet

R: Gas constant

Ti: Inlet temperature

Mass flow rate ($\dot{\boldsymbol{m}}$)

$$\dot{m} = \rho_i A_f c_o \left[\frac{2}{\gamma - 1}\left(\left(\frac{P_2}{P_1}\right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma+1}{\gamma}}\right)\right]^{\frac{1}{2}}$$

where: P2/P1:pressure ratio

Af :effective area

γ:1.4

ρi :Density of the air.

co:sound speed

Speed of sound$\boldsymbol{sound}$

$$c_o = \sqrt{\gamma RT_i}$$

where: γ:1.4

Ti:Inlet temperature

R:Gas constant

$\boldsymbol{Effectivearea}$

$$A_f = C_f A_v = C_f \frac{\pi}{4} d^2 (seat)$$

Where:

Cf: Flow coefficient

AV:Valve area

d:Diameter

The Mach number (M):

$$\frac{P_1}{P_2} = \left[1 + \left(\frac{\gamma - 1}{2}\right) M^2\right]^{\frac{\gamma}{\gamma-1}}$$

where: P1/P2=Plow/Phigh

The critical mass (***ṁcr***)

$$\dot{m}_{cr} = \rho_I A_f c_o \left(\frac{2}{\gamma + 1}\right)^{\frac{(\gamma+1)}{2(\gamma-1)}}$$

where:

ṁcr: Mass critical

Af: Effective area

ρI: Density of the air.

γ=1.4

co: sound speed

3.4 Product Subsystems and Components

This section discusses about components of the turbojet engine used in this project.

3.4.1Block diagram of turbojet engine

The entire block circuit of the engine has been divided into three major units which are listed below:

1. The Turbocharger unit
2. The Hydrostatic lubrication unit and

3. The Combustion system

Each of these three units is further sub divided into sub-units.

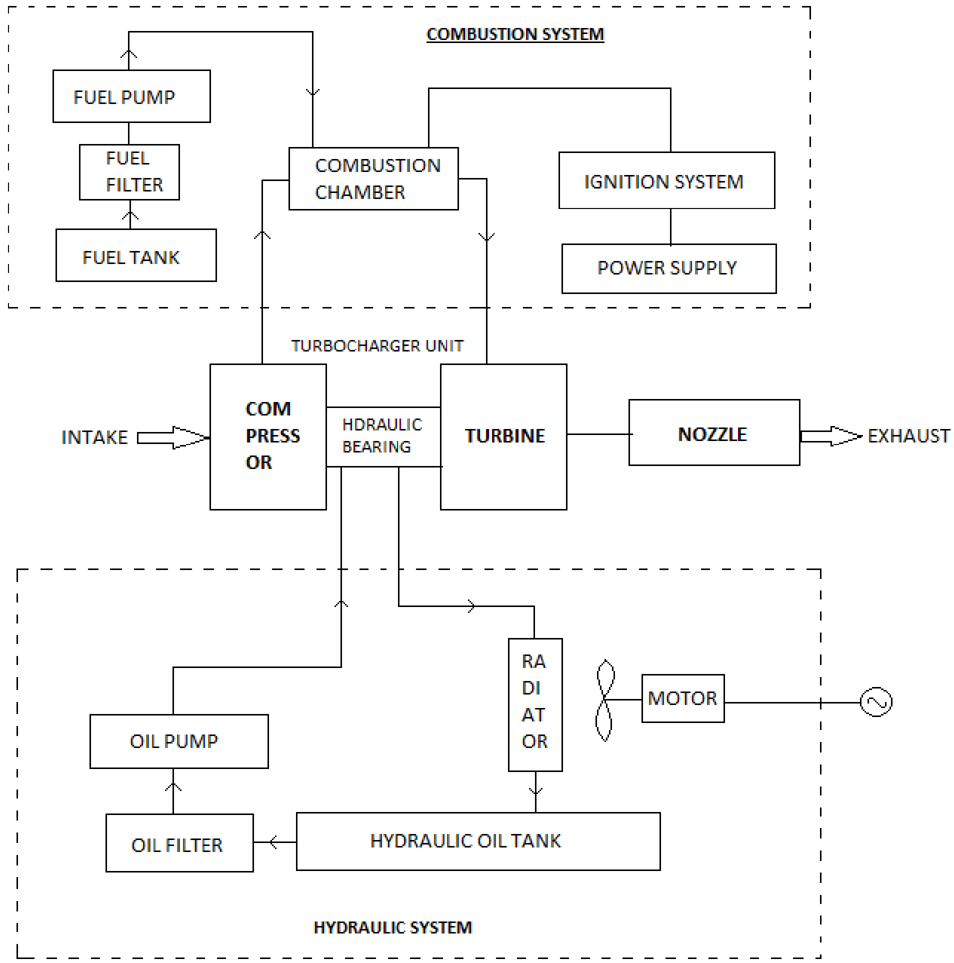


Figure 3.9: Block diagram of turbojet engine.

1. **The Turbocharger unit:**This unit is an assembly of an inlet diffuser, a huge diesel carturbocharger and an exhaust nozzle.

   Turbocharger: A turbocharger is a centrifugal compressor powered by a turbine that is driven by an engine's exhaust gases. A turbocharger's purpose is to compress the oxygen entering a car's engine, increasing the amount of oxygen that enters and thereby increasing the power output. The turbocharger is powered by the car's own exhaust gases. In other words, a turbocharger takes a by-product of the engine that would otherwise be useless and uses it to increase the car's horsepower.

Turbocharger compressor: Turbocharger compressors are generally centrifugal compressors consisting of three essential components: compressor wheel, diffuser, and housing. With the rotational speed of the wheel, air is drawn in axially, accelerated to high velocity and then expelled in a radial direction.

Turbocharger turbine: The turbocharger turbine, which consists of a turbine wheel and turbine housing, converts the engine exhaust gas into mechanical energy to drive the compressor. The gas, which is restricted by the turbine's flow cross-sectional area, results in a pressure and temperature drop between the inlet and outlet. This pressure drop is converted by the turbine into kinetic energy to drive the turbine wheel.

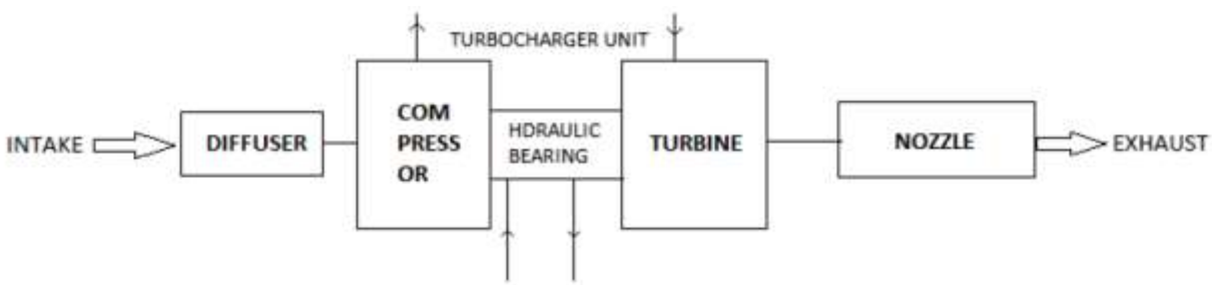


Figure 3.10: The turbocharger unit.

Propelling Nozzle: The propelling nozzle is the key component of all jet engines as it creates the exhaust jet. Propelling nozzles turn pressurized, slow moving, hot gas, into lower pressure, fast moving colder gas by adiabatic expansion. Propelling nozzles can be subsonic, sonic, or supersonic, but in normal operation nozzles are usually sonic or supersonic. Nozzles operate to constrict the flow, and hence help raise the pressure in the engine, and physically the nozzles are very typically convergent, or convergent-divergent. Convergent-divergent nozzles can givesupersonic jet velocity within the divergent section, whereas in a convergent nozzle the exhaustfluid cannot exceed the speed of sound of the gas within the nozzle. The nozzle shown in the figure is a convergent type nozzle.

2. **The Hydrostatic unit:**The hydraulic system consists of an oil pump, oil filter, oil storagetank and an air-cooled radiator.

Hydraulic oil pump: An oil pumps function is to supply the oil to the turbocharger's hydrostatic bearing at considerable pressure. An external gear pump is most suitable for medium flows and pressures. An external gear pump consists of two meshing gears. The driver gear rotates the driven and while meshing low pressure zone is created and the downstream which sucks in the fluid. The fluid flows past the casing and the teeth surface and at the upstream the squeezing action produces high pressure.

Oil filter: An oil filter is a filter designed to remove contaminants from engine oil, transmission oil, lubricating oil, or hydraulic oil. Oil filters are used in different machinery. A chief use of the oil filter is in internal-combustion engines. Gas turbine engines, such as those on jet aircraft, require the use of oil filters. Oil filter consists of an element made of bulk material (such as cotton waste) or pleated Filter paper to entrap and sequester suspended contaminants. As material builds up on (or in) the filtration medium, oil flow is progressively restricted. This requires periodic replacement of the filter element

Oil storage tank: Gas turbines will have integral lubricating systems to prevent damage caused by excessive friction. Often a portion of the lubricating oil is used in the hydraulic oil systems for hydraulic control devices. Lubricating oil is typically stored in integral stainless steel and carbon steel tanks that are monitored for level

Radiator: Radiators are heat exchangers used to transfer the thermal energy from one medium to another for the purpose of cooling and heating. To cool down the engine, coolant heated from flowing through the engine is fed into the header of the radiator via the inlet and then cools down as it circulates through the tubes to the opposite header and cold coolant exits back into the engine via the outlet, and the cycle is repeated. As it circulates through the tubes, the coolant transfers its heat to the tubes which, in turn, transfer the heat to the fins that are lodged between each row of tubes. The fins then radiate the heat transferred by the tubes to the surrounding air, hence the term radiator

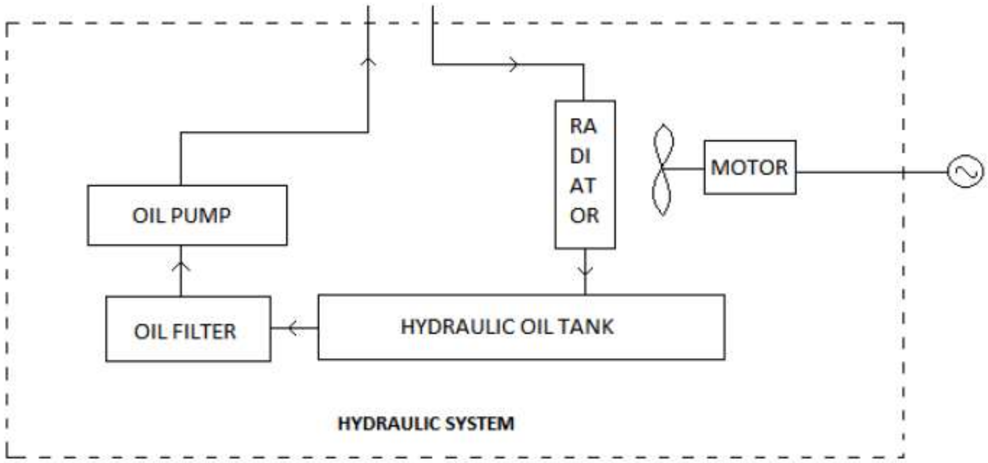


Figure 3.11: The hydraulic system.

3. **The combustion system:**The combustion system consists of the combustion chamber, the ignition system, and the fuel pumping system which consists of fuel pump, fuel filter and fuel tank.

   Combustion chamber: A gas turbine combustion chamber can be defined as a chamber which provides a space for formation of air fuel mixture, its combustion and thus formation of high temperature gases at highest combustion efficiency with minimum loss of chamber pressure.The figure shows the cross-sectional view of the combustion chamber. It consists of the outer cylinder called casing and the inner cylinder called flame tube. The casing and the flame tube are both made up of the sheet metal. The flame tube is supported in the outer casing. The flame tube consists of the holes which are symmetrically drilled on the surface of the flame tube. The fuel nozzle situated at the center of the snout sprays the pressurized fuel into fine droplets. The flame tube is divided into three zones based on the functionality of each zone. The three zones are primary, secondary and tertiary zones. These zones contain primary, secondary and tertiary holes respectively.

   The combustor is a critical component since it must operate at reliably high temperatures and provide suitable temperature distribution of hot gases at the entry to the turbine and create a minimum amount of pollutants over a long operating life. The operational requirement of a gas turbine combustion chamber is that even if the atmospheric conditions change, the combustor must deal with continuously varying fuel flow without allowing the engine to flame out or exceed temperature limits. The size and the design of the gas turbine combustion chamber are very critical for the efficient operation of the combustion chamber and it varies with the requirements.

Ignition system: The ignition system consists of 230V AC supply, an ignition coil, ignition coil driver circuit and a spark plug. The function of an ignition system is to produce high intensity spark at equal intervals of time. The 230V AC acts as a power source. 230V AC voltage is applied to the ignition coil which is transformer. The ignition coil transforms the 230V AC into 15,000V AC. This temporary surge of high voltage is enough to produce high intensity spark.

Fuel pumping system

Fuel tank: A fuel tank is safe container for flammable fluids. Though any storage tank for fuel may be so called, the term is typically applied to part of an engine system in which the fuel is stored and propelled into an engine.

Fuel filter: A fuel filter screens out dirt and dust particles from the fuel, normally made into cartridges containing a filter paper. They are found in most internal combustion engines. Unfiltered fuel may contain several kinds of contamination, for example paint chips and dirt that has beenknocked into the tank while filling, or rust caused by moisture in a steel tank. If these substances are not removed before the fuel enters the system, they will cause rapid wear and failure of the fuel pump and injectors, due to the abrasive action of the particles on the high-precision components used in modern injection systems. Fuel filters also improve performance, as the fewer contaminants present in the fuel, the more efficiently it can be burnt.

Fuel pump: A fuel pump for jet engine is required to deliver fuel in small quantities at extremely high pressures to achieve the required atomization. An internal gear pump is most suitable for such application. An internal gear pump functions in the similar way as that of external gear pump except that the meshing gears are internal rather than external.

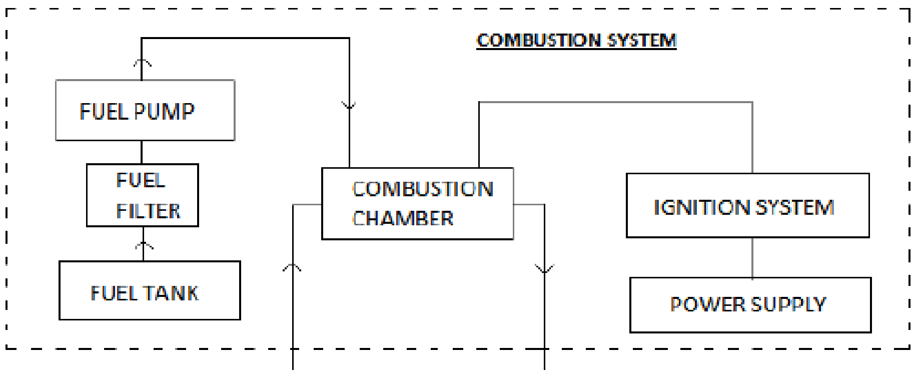


Figure 3.12: The combustion system.

3.4.2Equivalent Diagrammatic Representation of the physical model

The equivalent diagrammatic representation of the physical model is nothing but representation with the blocks replaced by the equivalent symbols for each component. It helps in easy understanding of the circuit diagram. The main feature of the diagrammatic representation is the elimination of the need to label the components, once the symbols for each component is known no further aid is required for understanding the circuit diagram. The diagrammatic model for the above block model is constructed below.

3.4.3Theoretical working of the model

In order to understand the working of the jet engine model one has to know the principle of working of the gas turbine. A gas turbine consists of three basic units' viz. a compressor (radial/axial), a turbine (impulse/reaction) and a combustion chamber.

In order to produce an expansion through a turbine a pressure ratio must be provided and the first necessary step in the cycle of the gas turbine plant must therefore be compression of the working fluid. If after compression, the working fluid was to be expanded directly in the turbine and there were no losses in either of the component, the power developed by the turbine would just equal that absorbed by the compressor. Thus, if the two were coupled together the combination would do no more than turn itself round. But the power developed by the turbine can be increased by addition of the energy to raise the temperature of the working fluid priorto expansion. Since the working fluid is air a very suitable means of doing this is by the combustion of the fuel in the air which has been compressed. Expansion of the hot working fluid then produces greater power output from the turbine, so that it can provide a useful output in addition to driving compressor. This represents the gas turbine or internal combustion turbine in its simplest form. The three components viz. compressor, turbine and the combustion chamber connected are shown diagrammatically in fig. 3.9 below.

Having understood the working of a simple gas turbine, understanding the working of the jet engine project shouldn't be difficult because the working cycle of the model is same as that of simple gas turbine. For the sake of simplicity, the working of the model is explained in three stages again on the basis of the functionality.

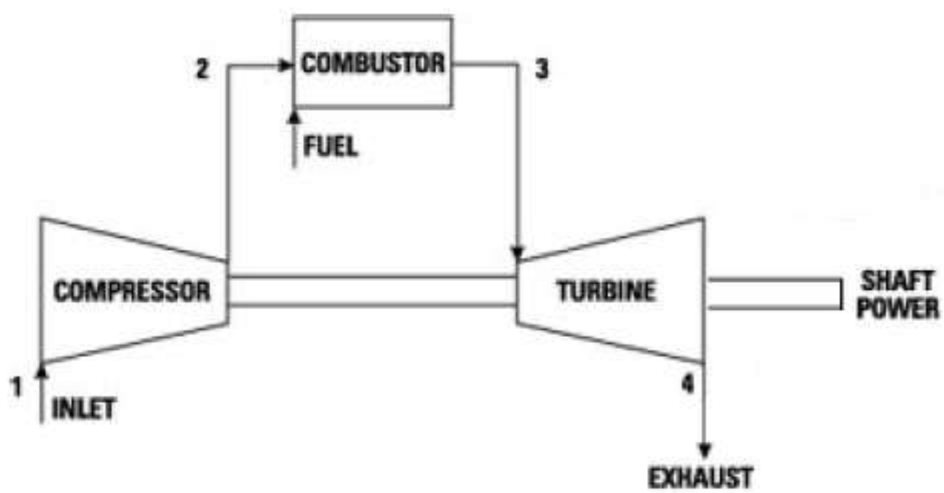


Figure 3.13: Simple gas turbine system.

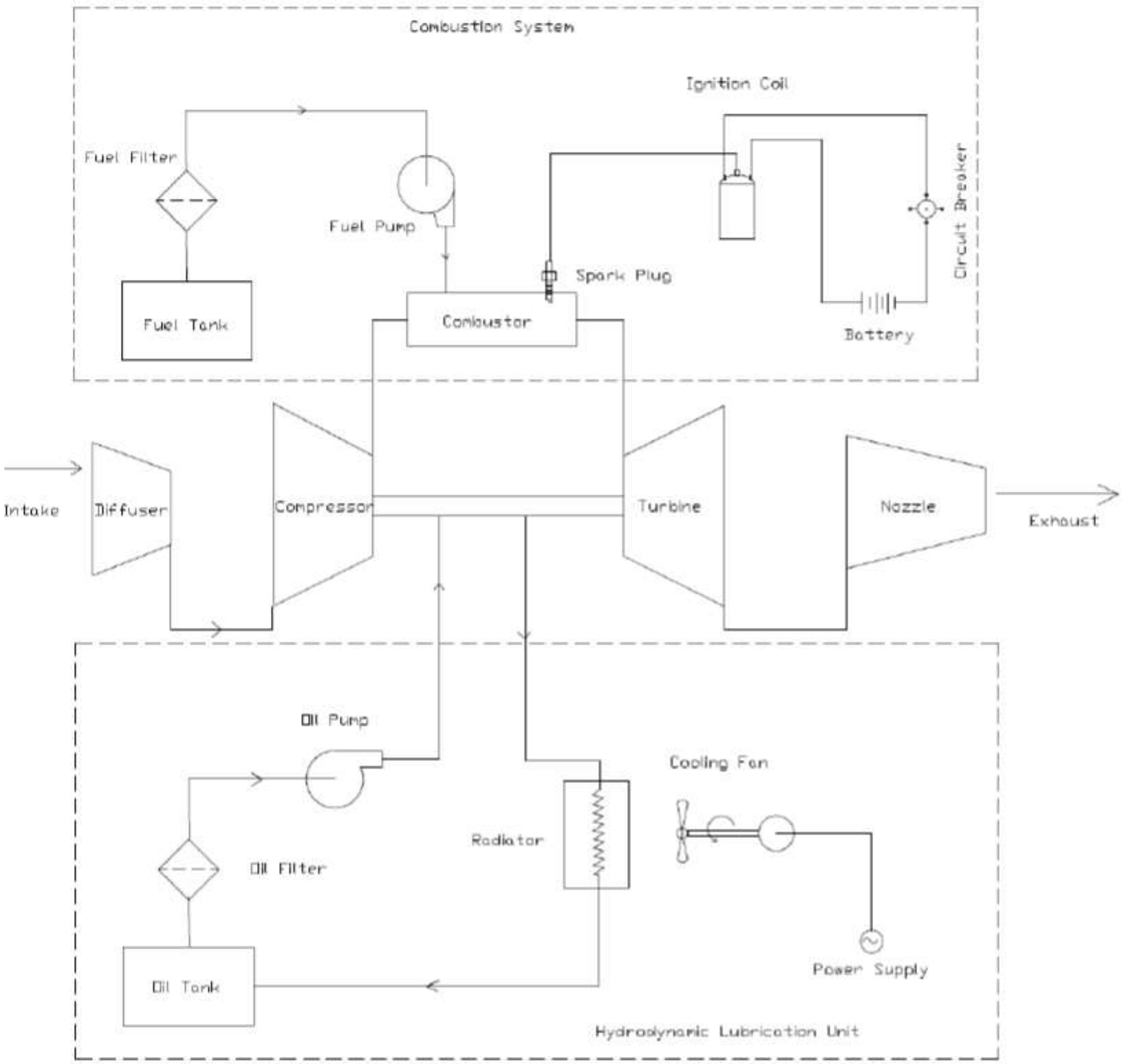


Figure 3.14: Equivalent Diagrammatic Representation of the physical model.

3.5 Manufacturing and Assembly

Figure 3.15: Image of Turbocharger used.

Figure 3.16: Parts used to manufacture combustion chamber.

4

ESTING and ANALYSIS

4.1 EXPERIMENTAL SET-UP

4.2 SUBSYSTEM 1

4.3 SUBSYSTEM 2

ULTS, ANALYSIS and DISCUSSION

4.1Subsystem 1

Figure 4.1: Actual Design of Radial Jet Engine.

4.2 Subsystem 2

Figure 4.2: Set up of Radial Jet Engine.

4.3 Results Analysis and Discussion

Data assumption taken for analysis:

$$\gamma_a = 1.4$$

$$\eta_c = 77\%$$

$$\gamma_g = 1.33$$

$$\eta_T = 78\%$$

$$C_{pa} = 1.005\_KJ/Kg/K$$

$$\eta_{noz} = 85\%$$

$$C_{pg} = 1.147\_KJ/Kg/K$$

$$\eta_{Tran} = 92\%$$

$$\eta_{comb} = 85\%$$

$$T_{amb} = T_0 = 293K$$

$$P_{amb} = P_0 = 0.98bar$$

$$Q_f = 43\_MJ$$

$$Pressure\_Ratio = \frac{P_{02}}{P_{01}} = 2.5$$

Output Variables required:

1. Compressor outlet temperature
2. Turbine inlet temperature
3. Turbine pressure ratio
4. Nozzle outlet temperature
5. Jet speed
6. Intake air mass flow rate
7. Air-fuel ratio
8. Fuel flow rate
9. Exhaust gases mass flow rate

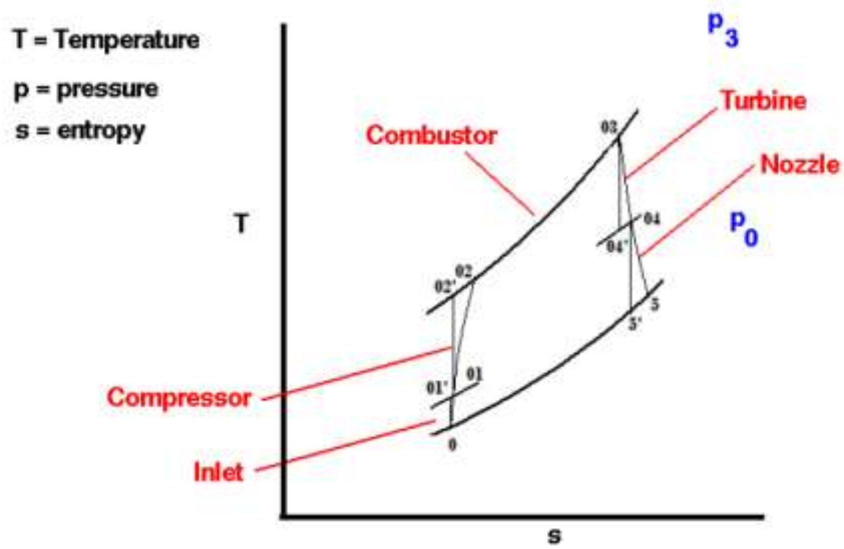


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Figure 4.3: T-S Diagram of Radial Jet Engine Cycle.

Sr. No.	Output Variable	Calculated Values	Expected Values	Comment on calculated Values	Status of acceptance
1	Compressor outlet temperature T_{02}	407.15K	425K	OK	Acceptable
2	Turbine inlet temperature T_{03}	1028.7K	1060K	OK	Acceptable
3	Turbine pressure ratio $\frac{P_{03}}{P_{04}}$	1.8	2	OK	Acceptable
4	Nozzle outlet temperature T_{05}	855.96K	850K	OK	Acceptable
5	Jet speed C_5	383.27m/s	416m/s	LESS	Acceptable
6	Intake air mass flow rate $\dot{m}_a$	0.39kg/s	0.85kg/s	LESS	Acceptable
7	Air-fuel ratio $\frac{\dot{m}_a}{\dot{m}_f}$	58.5:1	90:1	LESS	Acceptable
8	Fuel flow rate $\dot{m}_f$	0.4kg/min	0.56kg/min	OK	Acceptable
9	Exhaust gases mass flow rate $\dot{m}_g$	0.4kg/s	1.41kg/s	LESS	Acceptable

#	Variable	values
1	Ambient temp. T01	300K
2	Ambient pres. P01	1bar
3	Compressor Pres. Ratio $\frac{p02}{p01}$	1.3
4	Compressor Pres. P_{02}	1.3bar
5	Compressor Temp. T_{02}	407.15K
6	Turbine inlet Temp. T_{03}	1028.7K
8	Turbine outlet Temp. T_{04}	855.96K
9	Shaft rotational speed	382.27 rev/min
10	Intake mass flow rate M_a	0.39 kg/s
11	Fuel flow rate M_f	0.03 kg/s
12	Stoichiometric Air-fuel ratio $\frac{Ma}{Mf}$	15.44:1
13	Exhaust mass flow rate M_g	0.42 kg/s

Standard conditions assumption

Compressor Specification

From Compressor Pres. Ratio

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

Ideal Combustion assumption. Adiabatic temperature

Thermocouple at exit of turbine

Tachometer

Calculated from shaft RPM and compressor blade angle

Ideal Combustion. Stoichiometric air-fuel ratio

Ma + Mf

Table 4.1: Parameters measured and calculation using equations defined above.

5.1 PROJECT PLAN

5.2 CONTRIBUTION of TEAM MEMBER

5.3 PROJECT EXECUTION MONITORING

LLENGES and DECISION MAKIN

5.1 Project Plan

We worked as one team but to be run with the time for the course. Our leader**ALI ALMUTAWA**suggested todivide the team to two groups as field work group and writing and research group. Everygroup was working by all member advices. Every group used to exchange the ideas andinformation to support other group and work as team in the same time. This managementwas successful to finish the project which is not simple project for students.

5.2 Contribution of Team Member

All the members were effective, shared ideas, exchange ideas and opinions. Everymember tries to attempt to work in all sections but because of the pressure of the Semesterand the division member to two groups we work as below table 5.1 to show exact workfor each member:

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1-	**Writing and researching chapter 4**			
2	**Writing and researching chapter 5**			
3	**Following up with the 3D Drawing**			
4	**Ordering material and financial**			

Table 5.1: List the tasks and the team member assigned to conduct these tasks.

#	Task description	Team member/s assigned
1	**Wiring up and finishing assembling component**	all
2	**Conducting tests**	
3	**MAKING FINAL PRESENTATION POWER POINT**	
4-	**FINAL PRESENTATION PREPERATIONS**	ALL

Table 5.2: List the tasks planned the team member/s assigned to conduct these tasks.

5.3 Project Execution Monitoring

The team meet twice every week to discuss the updated progress. The leader **ALI ALMUTAWA**manages the meetings.All meeting was to review theprevious work and planning for next part. All meetings were helpful for each memberbecause every member try to exchange his own idea with others. Field group and writinggroup were trying to work smoothly together not just focusing on their part. Every group support the other. When we face any problem, we try our best solution to ask our advisorabout it. The advisor was successful to help us to work as engineers and find the solutionby ourselves.

5.4 Challenges and Decision Making

The main challenge we got in this project while doing experiments. It was very tough to perform an experiment because of the class schedule and availability of all group member. Assembly of the setup was also on task which we did with the help of coordination between our team members. Overall the project got completed on time.

CHAPTER 6
PROJECT ANALYSIS

6.1 LIFE LONG LEARNING

6.2 IMPACT of ENGINEERING UTION

6.3 CONCLUSION

6.4 FUTURE RECOMENDATION

6.1 Lifelong Learning

Fascinated by turbojet engine, we decided to learn all that we can about jet engines. We figured that the best way to explore the principles of a turbojet engine is to build one. Like us thrilled by the gas turbine propulsion, quite a few experimenters have gone to the extent of building their own custom gas turbine engines. The first military gas turbine engine was constructed by Garrett/ Aires each on experimental basis using a simple turbocharger. It was built as a research project for US government. Many experimenters have uploaded their experimented gas turbine-based projects on the internet. There is good amount of the information available on the subjects with all kinds of designs being employed. We want to use these ideas to study how actual gas turbines operate, what variables go into picture while designing a working gas turbine and what sort of difficulties are encountered while construction of an actual working gas turbine from a scrap turbocharger, this encouraged us to build our own turbocharger based turbojet engine that will be a research test bed for our project.

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