TITLE OF PROJECT

Turbocharger based thrust generating DEVICE

A Final Year Project Report

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In Partial Fulfillment

of the Requirements for the Degree of

Bachelors of Mechanical Engineering

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ABSTRACT

This project aims to repurpose standard turbochargers into thrust-generating devices by integrating them with a combustion chamber and nozzle. The concept involves utilizing the compressed air generated by the turbocharger's compressor section to produce thrust through controlled combustion. By directing the resulting gases to the turbine segment of the turbocharger and then through a specifically designed nozzle, thrust is generated.

The primary objective is to showcase the versatility of turbochargers beyond their conventional role of enhancing engine performance. This modification demonstrates their potential to power diverse propulsion systems, opening up new avenues for creative engineering solutions. By harnessing the energy of compressed air in a controlled combustion process, this project seeks to explore alternative methods of propulsion, moving beyond traditional internal combustion engines.

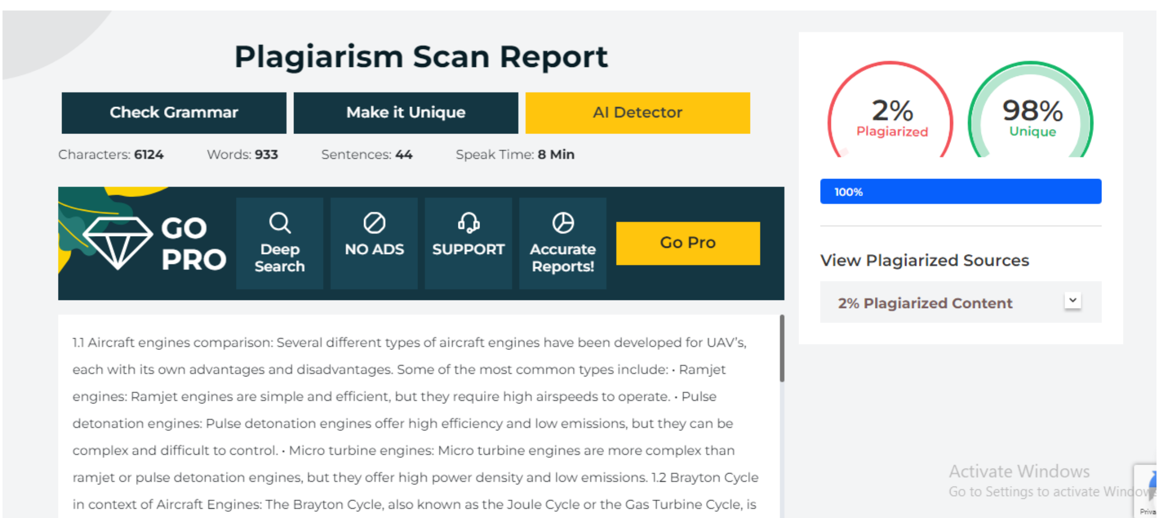
The integration of a combustion chamber and nozzle with the turbocharger offers a novel approach to propulsion system design. It highlights the adaptability of turbocharger technology and its potential applications across various engineering domains. This initiative not only explores innovative propulsion techniques but also encourages creativity in engineering solutions.

Through this project, turbochargers are transformed into dynamic components capable of driving different mechanisms forward, particularly suited for applications requiring low thrust, such as unmanned aerial vehicles (UAVs). By repurposing turbochargers in this manner, the project not only demonstrates their adaptability but also addresses the specific needs of UAVs and similar devices.

ACKNOWLEDGMENTS

We extend our sincere appreciation to our supervisor, Dr. Asad Javed, Assistant Professor at the School of Mechanical & Manufacturing Engineering, NUST, Islamabad, and our co-supervisor, Dr. Saad Ayub, Assistant Professor at the same institution, for their invaluable guidance and support throughout this project. Their expertise and encouragement, combined with the collaborative efforts of our team, were instrumental in achieving our objectives. We also express gratitude to the faculty and staff of the School of Mechanical & Manufacturing Engineering, NUST, Islamabad, for their assistance and cooperation.

ORIGINALITY REPORT



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ABBREVIATIONS

CAD: Computer Aided Design

BC: Brayton Cycle

TE: Thrust Engine

BWR: Back Work Ratio

CR: Compression Ratio

ND: Nozzle Diameter

Chapter 1: Introduction

1.1 Motivation of Work:

The aviation industry is continuously striving for advancements in propulsion systems to enhance efficiency and reduce costs. However, the high production costs associated with manufacturing internal assemblies for Thrust engines, particularly the compressor and turbine components, pose significant challenges. This limitation impedes innovation and obstructs progress in developing more accessible propulsion solutions. Therefore, the motivation behind this project lies in bridging this gap by leveraging preexisting assemblies found in turbochargers. By utilizing turbocharger components, which offer comparable functionalities at a fraction of the cost, we aim to provide a cost-effective alternative to traditional Thrust engine components, thereby facilitating advancements in propulsion technology.

1.2 Problem Statement:

The inability to manufacture internal assemblies of Thrust engines, primarily the compressor and turbine components, due to high production costs, presents a significant obstacle in the aviation industry. This limitation inhibits the development of efficient propulsion systems and restricts access to advanced technology. To overcome this challenge, we aim to utilize pre-existing assembly within turbocharger, which offers comparable functionalities at a fraction of the cost. By repurposing turbocharger components, we seek to provide a viable solution to the manufacturing constraints hindering progress in propulsion system development.

1.3 Objectives of the Project:

The primary objective of this project is to explore the feasibility of using pre-existing assemblies from turbochargers as substitutes for the internal components of jet engines, specifically the compressor and turbine. To achieve this overarching goal, the following specific objectives have been outlined:

- Investigate the design and functionality of turbocharger assemblies to assess their suitability for integration into jet engine systems.
- Develop a method for adapting turbocharger components to fulfill the roles of compressor and turbine within a jet engine framework.
- Conduct experimental testing and performance analysis to evaluate the effectiveness and efficiency of the repurposed turbocharger assemblies in generating thrust.
- Assess the economic and practical feasibility of utilizing turbocharger components as substitutes for internal jet engine assemblies, considering factors such as cost, reliability, and scalability.
- By addressing these objectives, this project aims to demonstrate a novel approach to propulsion system development, offering a cost-effective alternative to traditional manufacturing methods while maintaining performance standards and fostering innovation in the aviation industry.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A review of the literature on aircraft engine design is presented. This chapter summarizes the existing knowledge in aircraft engines with a particular focus on the design of the combustion chamber, turbocharger, and converging nozzle. The chapter also highlights the necessity of the project in the context of previous works.

2.2 Combustion Chamber Design

Combustion chambers are critical components of aircraft engines, as they are responsible for converting fuel into usable thrust. Several factors need to be considered when designing a combustion chamber for an aircraft engine, including:

- Size and weight: The combustion chamber must be small and lightweight to minimize the overall weight of the aircraft engine.
- Efficiency: The combustion chamber must be designed to efficiently convert fuel into heat, as aircraft engines have limited fuel capacity.
- Emissions: Aircraft engines are often operated in close proximity to people and sensitive environments, so it is important to minimize emissions from the combustion chamber.
- Durability: The combustion chamber must be able to withstand the high temperatures and pressures that occur during combustion.

2.3 Aircraft engines comparison:

Several different types of aircraft engines have been developed for UAV's, each with its own advantages and disadvantages. Some of the most common types include:

- Ramjet engines: Ramjet engines are simple and efficient, but they require high airspeeds to operate.
- Pulse detonation engines: Pulse detonation engines offer high efficiency and low emissions, but they can be complex and difficult to control.
- Micro turbine engines: Micro turbine engines are more complex than ramjet or pulse detonation engines, but they offer high power density and low emissions.

2.4 Brayton Cycle in context of Aircraft Engines:

The Brayton Cycle, also known as the Joule Cycle or the Gas Turbine Cycle, is a thermodynamic cycle that describes the operation of a gas turbine engine, commonly used in aircraft propulsion systems. Named after George Brayton, who first proposed the concept in the late 19th century, the Brayton Cycle is a fundamental framework for understanding the energy conversion processes within gas turbine engines. The Brayton Cycle consists of four main processes: compression, combustion, expansion, and exhaust. Here's a brief overview of each phase in the context of an aircraft engine:

Compression:

The incoming air is compressed by the compressor, typically consisting of multiple axial or centrifugal stages. Compression raises the pressure and temperature of the air, preparing it for the combustion process. The compressor is a critical component in enhancing the overall efficiency and performance of the engine.

Combustion:

The compressed air enters the combustion chamber, where it is mixed with fuel and ignited. This process releases a significant amount of energy, leading to a rapid increase in temperature and pressure. The combustion products, now at high temperature and pressure, are directed to the turbine for the next phase.

Expansion:

The high-temperature, high-pressure gases from combustion drive the turbine, extracting energy to power the compressor and other accessories. As the gases expand through the turbine, they lose energy, resulting in a decrease in temperature and pressure. The turbine is connected to the compressor through a shaft, forming a linked system that efficiently transfers energy from the combustion to the compression phase.

Exhaust:

The remaining exhaust gases exit the turbine and are expelled from the engine at high velocity through the nozzle. This high-speed exhaust jet creates a forward thrust, propelling the aircraft forward according to Newton's third law of motion.

In the context of aircraft engines, the Brayton Cycle offers several advantages, such as high power-to-weight ratios, efficiency at high altitudes, and the ability to operate in a wide range of conditions. Turbojet, turbofan, and turboprop engines are common types of aircraft engines that utilize variations of the Brayton Cycle.

Continuous advancements in materials, aerodynamics, and control systems have led to improvements in the efficiency, reliability, and performance of aircraft engines based on the Brayton Cycle, contributing significantly to the aviation industry's progress.

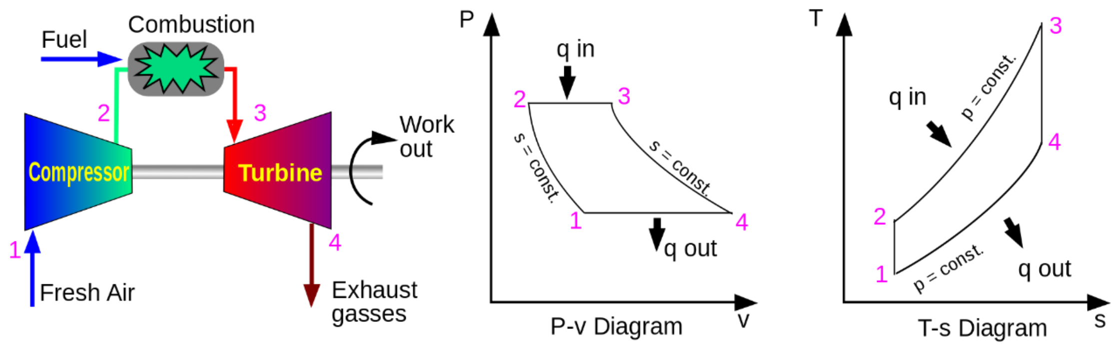


Figure 7: Brayton Cycle in context of Aircraft engines

2.5 Necessity of the Project

Up till now we have gone through conventional aircraft engines. Most of which are very bulky and large in size and are not suitable for a small-scale fixed wing UAV's. We also know that turbocharger has a built-in turboshaft with turbine and compressor mounted on it. Therefore, by simply designing and manufacturing the combustion chamber and nozzle we can make a thrust creating device that is similar to an aircraft engine except for that fact that combustion chamber position varies. Following table shows the research papers that we studied:

Table 1: Research Papers and Key Findings

Paper name	Key Findings
Paper 1 (Combustion Chamber Design)	Exploring the intricacies of combustion chambers, including their design, operational mechanisms, material choices, diverse types, and methods of air distribution, constitutes a vital area of research in this field
Paper 2 (Thermal behavior of Turbocharger)	This paper outlines the thermal characteristics and constraints associated with every element of a turbocharger system.
Paper 3 (Thermodynamic Processes of Turbojet Engine)	A comprehensive examination of thermodynamic cycles and processes occurring within the turbojet engine is provided in this detailed analysis.
Paper 4 (Nozzle Study)	Design and Calculations of a Converging Nozzle for Engine Back Pressure and Thrust Control to provide optimum engine performance.

CHAPTER 3: METHODOLOGY

After thoroughly reading the previously mentioned research papers we were able to finalize down the design approach. The starting point that we selected for our design was the finalizing the thrust output we must achieve at nozzle output. This gave the combustion mixture flow rate and respective diameters of the nozzle. The combustion mixture mass flow largely depends on the pressure ratios of the turbocharger's compressor section and the fuel inlet flow rate. Based on these parameters and market considerations we narrowed down the turbochargers that we could use for this project. Throughout the design process use of modern tools like CAD (SolidWorks), CAE(Ansys fluent) and Mathcad was vital

3.1 <u>Repurposing the turbocharger:</u>

We know that turbocharger is primarily used for providing a boosted air into the engine manifold. It enhances the pressure of intake air by using the energy of the engine's exhaust gases. Now look at the figure below:

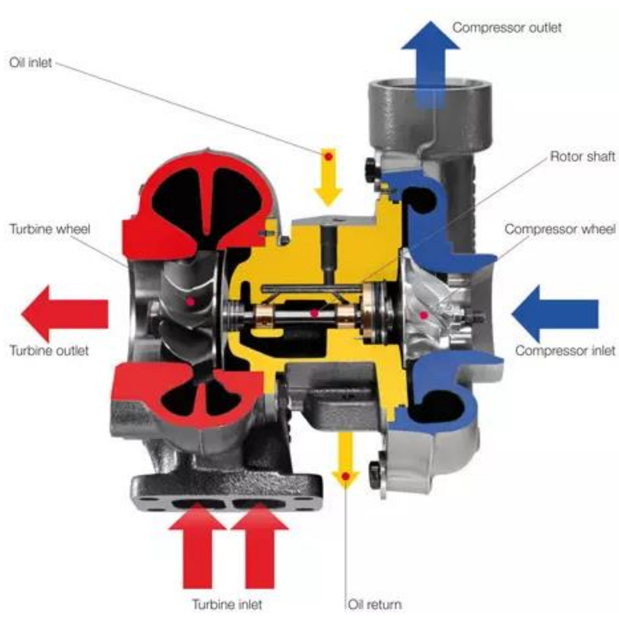


Figure 8: Turbocharger Cross sectional view

If compressed air outlet is directed into a combustion chamber, where combustion takes place under extreme conditions of pressure, the gases will gain the energy. If these gases are directed into the turbine section instead of leaving them to atmosphere, their useful energy can be harnessed to drive the turbine. The excess of energy can be used as a thrust, which is our goal. Hence in theory, we can create a gas turbine engine by simply repurposing the turbocharger.

3.2 Selection of Turbocharger

When selecting the turbochargers, the marketing research allowed us to know the available options, i.e. **Tob4**, **Tbp4**, and **Garette GT2052**. Only models that meet leading parameters being availability, affordability, and the ability to run effectively under the pressure and sustain the temperature conditions were considered for the evaluation.

Upon comparison, the Garette GT2052 model was chosen for several reasons: Upon comparison, the GT2052 model was chosen for several reasons:

Cost-effectiveness:

The GT2052 made by GT has this unique capability of giving us the best value for money. GT2052 is the best among the available options.

Lubrication:

The lubrication system of the GT2052 was thus found to be a proper match for the project's needs, with the right features to deliver top performance regardless of the conditions the engine must operate in.

Durability:

GT2052 showed a functional design which was approved to the actual operation of temperature and pressure in space, which means the gear can be applied in actual space mission.

3.3 Combustion Chamber

Combustion chamber is the most critical component of the system. The highest of the temperature and pressures are reached inside it. It has to be capable of maintaining its structural integrity under the extreme heat. The combustion chamber is many of 5 parts. Inlet port coming from the compressor, external casing or enclosure, fuel inlet tube, flame tube (the annulus) and the exhaust port.

The pressurized air from the turbocharger's compressor outlet enters into the combustion chamber annulus which has a hole to pass it into the inner cavity. Holes have different diameters based on their position in the flame tube. The inner region is divided into primary, secondary and tertiary zones. The fuel enters directly into the flame tube and gets mixed with incoming air. The spark plug then fires and rapid expansion of gases takes place which rush out leaving from the chamber's exit port.

Combustion chamber geometry:

The geometry of the combustion chamber was constructed in SolidWorks and its cross sectional view is shown. The division of air among the primary, secondary and tertiary holes is also shown:

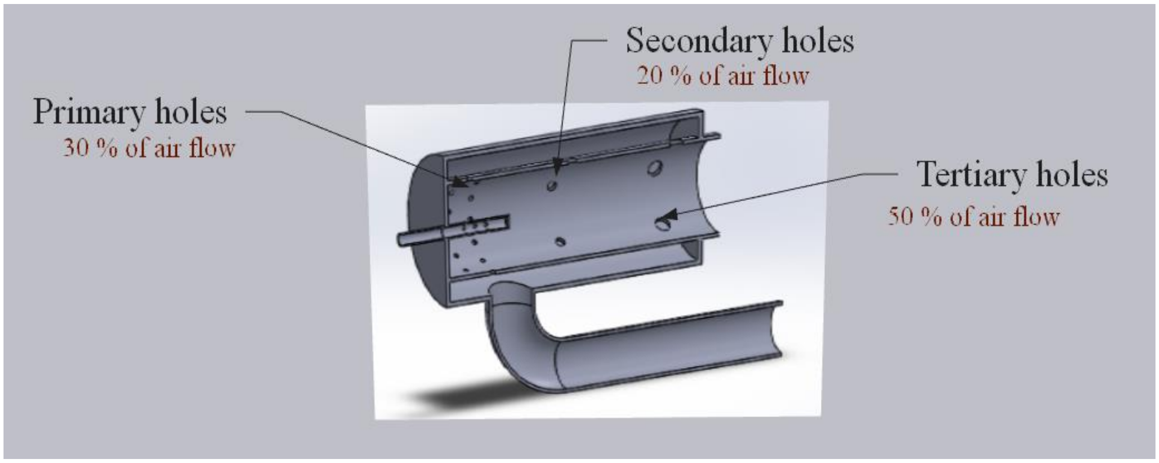


Figure 9 Combustion Chamber Geometry

Combustion Chamber Calculations:

The sizes of the holes, lengths of tubes and their diameters were calculated imperially as learned from the research papers. The Mathcad calculations are attached in the appendix whereas the results of calculations are as follows:

Table 2: Results of combustion chamber calculations.

Sr.	Parameter	Value
1	Diameter of flame tube	76 mm
2	Length of flame tube	228 mm
3	Flame tube inlet position from left end	57 mm
4	No. of primary holes	26
5	No. of secondary holes	5
6	No of tertiary holes	5
7	Diameter of primary holes	4.08 mm

8	Diameter of secondary holes	7.6 mm
9	Diameter of tertiary holes	12 mm

Combustion Chamber Simulations:

The combustion chamber was simulated in ANSYS to get the insights into our design feasibility. For this purpose, at first a STEP file was exported from SolidWorks to ANSYS workbench. In the ANSYS design modeler a compliment body was created to fill in the vacant space inside the combustor. This was done to simulate the fluid. After that it was taken to mesh workspace. The default settings of mesh were used and a triangular variable mesh was created that was neither too coarse neither too fine to cause the software lag. Finally, ANSYS fluent was started and following initial and boundary conditions were given:

Table 3: Simulation parameters

Sr.	**Parameter**	**Value**
1	Mode of combustion	Non-premixed
2	Air inlet pressure	2 bars
3	Air mass flow rate	0.1209 kg/s
4	Fuel type	Methane
5	Fuel inlet pressure	2 bars
6	Fuel mass flow rate	0.0012 kg/s
7	Turbulence model	SST k ω

8	Fluid boundary condition	No-slip
9	Combustor outlet gauge pressure	0 bars
10	Initialization	hybrid
11	Max. iterations to run	300

The figures below show the results after running the simulation study.

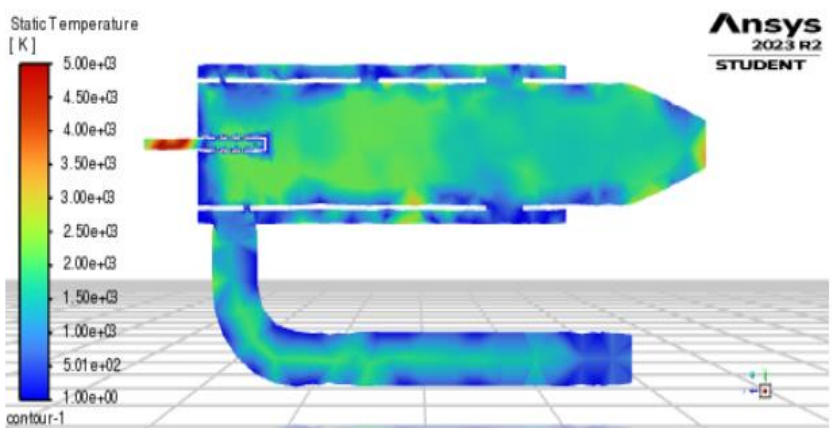


Figure 10: Temperature Analysis

Figure 4 clearly shows the cross-sectional view of combustor with temperature profile of the air-fuel mixture's gases after combustion. The temperature in the center of flame tube is maximum, roughly equal to the flame temperature of methane i.e., 2200 degrees Celsius. But near the boundaries where fluid contacts with the metal (stainless steel) enclosure, the temperature decreases less than 1000 degrees Celsius. This is due to the mixing of burnt mixture with the incoming unburnt air from secondary and tertiary holes. The mixing and controlling the temperature of burning was the real challenge. Because the melting point of stainless steel is near 1500 degrees Celsius, whereas the maximum temperature achieved was 2200 degrees Celsius. This meant the steel would melt away and cause the system to fail. But by efficiently distributing the air we have achieved the temperature less than 1000 degrees near the metal boundaries. This makes the system feasible.

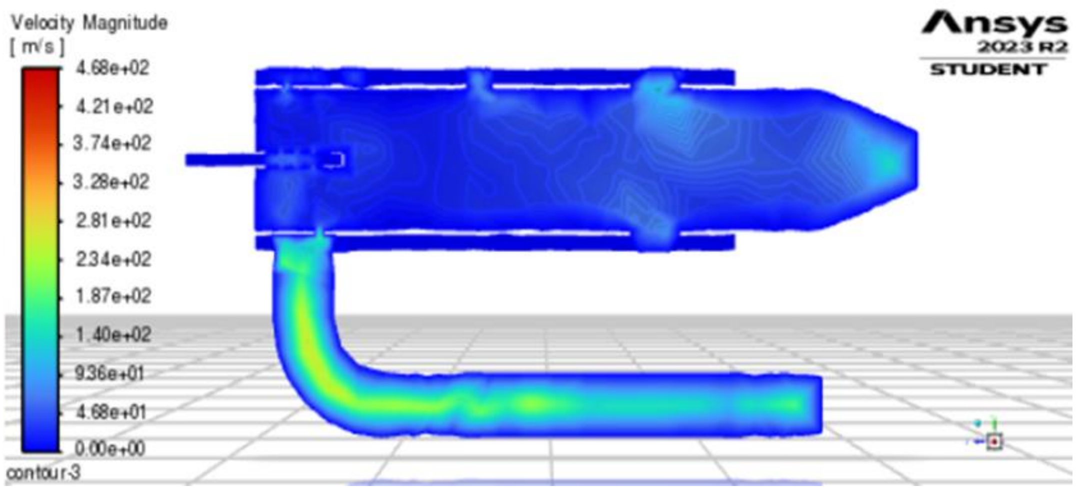


Figure 11: Velocity analysis.

Figure 5 represents the velocity analysis inside the combustor. The velocity is maximum in the pipe that is coming from the turbocharger's compressor. It has the value around 235 m/s in the pipe. However, inside the combustor's annulus, the velocity is much lower and is negligible. This is due to the existence of high pressure. When the air enters from the annulus to the flame tube through the holes, the velocity increases in the passage through the holes. Then it gradually decreases till the center of flame tube. An interesting fact to note is that, near the combustor's exit, the velocity is much higher. This is due to conical profile of the exit passage and expansion of gases due to combustion. Near the exit, velocity is approximately 150 m/s. Whereas average velocity inside the flame tube is about 50 m/s.

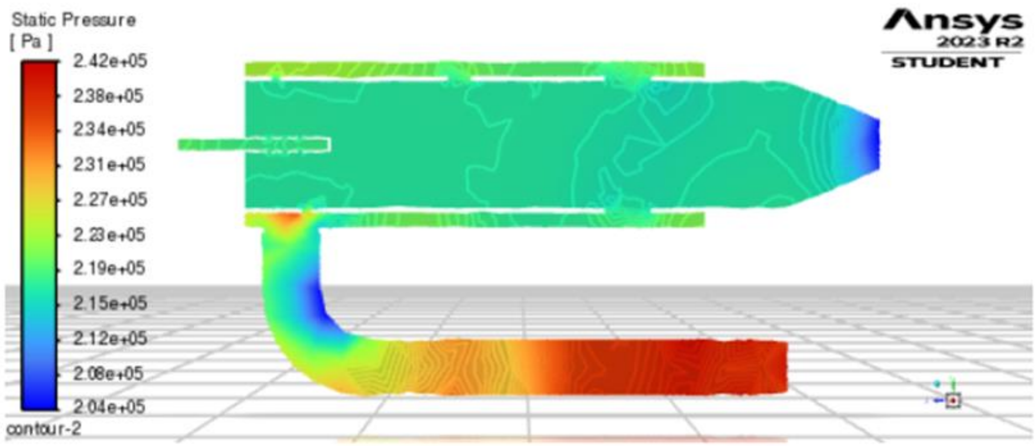


Figure 12: Pressure analysis.

Pressure profile shows variations due to high Reynolds number and a high turbulence. Maximum pressure observed at inlet is 2.42 bars. Average pressure in the annulus and inside flame tube is 2.25 bars and 2.16 bars.

After expansion in combustor gases exit into the turbine section of turbocharger. Portion of energy of burnt gases is used to drive the turbocharger's turbine while rest of energy appears as a the useful thrust when gases exit through nozzle

3.4 <u>Converging nozzle</u>

A converging nozzle is attached to the turbine outlet via flange. Its primary function is the production of thrust. The velocity of exhaust gases increases as they approach the converging section of the nozzle. We already know the mass flow rate of exhaust gases (the mass flow rate remains conserved). From mass flow rate, velocity of gasses at exit and cross-sectional area of converging point of nozzle, we calculated the thrust. The thrust we calculated amounts to 80N. This equates to 8 kgf. It means that sufficient thrust will be produced to propel 8 kg mass. Which is the quite reasonable mass for a small drone or fixed wing UAV.

Table 1: Nozzle specifications

Sr.	Parameter	Value
1	Converging Diameter	12 mm
2	Mass flow rate	0.12 kg/s
3	Nozzle exit velocity	257 m/s
4	Nozzle inlet velocity	155 m/s
5	Nozzle inlet pressure	1.64 bars
6	Nozzle exit pressure	1.01325 bars
7	Net thrust produced	80 kgf

Simulations of Nozzle

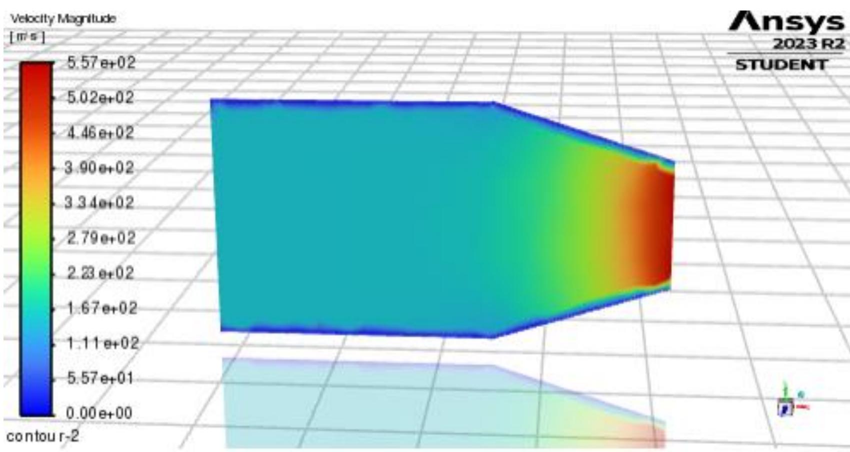


Figure 7: Velocity Analysis of Nozzle.

Figure 7 shows the velocity contour across the nozzle.

3.5 Material Procurement and Manufacturing

Turbocharger

Stainless steel Pipe

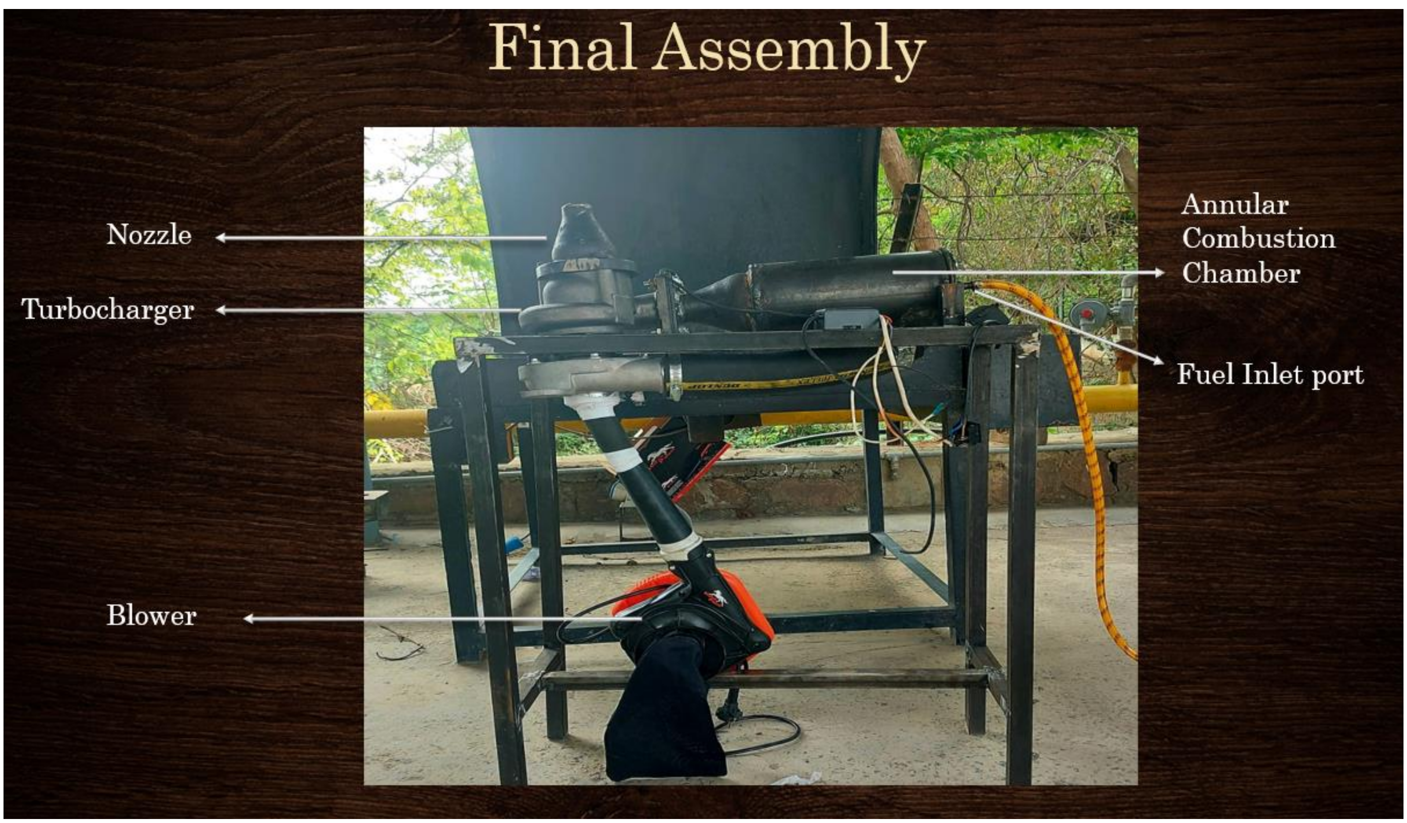
Fuel injector

Spark Plug

Flange

Machining for nozzle

Drilling of holes on combustor liner



BILL OF MATERIALS

S/No.	Material	Model No	UNIT COST	TOTAL AMOUNT
1	Turbocharger	GT 2052	29,500	29,500
2	Spark Plug module		1,400	1,400
3	Blower	ST-2230	4,800	4,800
4	Gaskets	Standard	1,000	2,000
5	Flanges		1,500	3,000
6	Outer Casing	ISO	2,000	2,000
7	Flame Tube	ISO	2,000	2,000
8	Nozzle		1,500	3,000
9	Stand		2,800	2,800
11	Inlet Pipe		2,300	2,300
12	Bolt + washer	ISO	40	640
13	Cylinder + LPG		2,800	2,800
14	Fuel Pipe		1,000	1,000
15	Fuel Injector Port		150	150
16	Machining		10,000	10,000
	GRAND TOTAL			67,390

CHAPTER 4: RESULTS and DISCUSSIONS

4.1 <u>Testing:</u>

Concept testing of the turbocharger focused on ensuring smooth operation of the internal compressor turbine assembly.

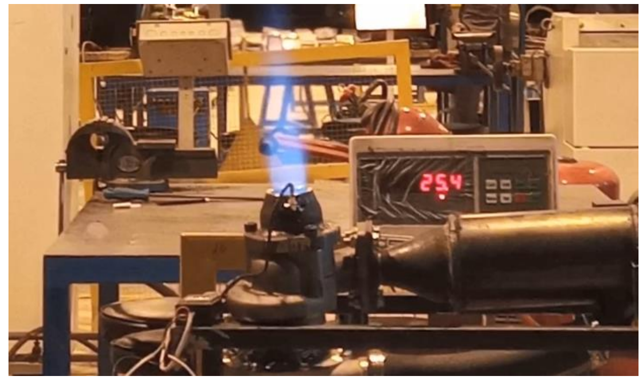
Concept testing of the simple combustion chamber aimed to identify and rectify any manufacturing flaws.

Final assembly testing validates the integration and functionality of all components.

Final assembly testing with nozzle evaluates the performance and efficiency of the complete thrust engine system.

Thrust Measuring

Initial Reading



Final Reading

4.2 Results:

Table 5: Theoretical Calculations:

Compressor Inlet Pressure P_1	**1 atm**
Compressor Outlet Pressure P_2	**2 atm**
Compression Ratio	**2**
Turbine Inlet Temperature T_3	**1300 K**
Turbine outlet Temperature T_4	**1100 K**
Back Work Ratio	**27.7 %**
Thermal Efficiency	**16.6 %**
Thrust Generation	**80 N**

Table 6: Practical Observations:

Thrust Generation	**41 N**
Mass flow rate of fuel	**0.00055 kg/s**
Mass flow rate of air	**0.06125 kg/s**
Air/fuel ratio	**122**

4.1 Discussion:

Design Parameters:

One of the most important aspects of this project involves assessing the suitability of turbocharger assemblies for integration into gas turbine engine. Turbochargers are traditionally designed for increasing the performance of internal combustion engines by compressing intake air. However, their repurposing into gas turbine engines requires evaluation of their structural integrity and material compatibility. The design parameters such as compressor size and turbine size play a crucial role in determining the performance of the converted system. The temperature at the end of combustion chamber is the highest temperature obtained during the whole cycle. This temperature is well within the operating temperature range of the material we are using i.e. structural steel.

The combustion chamber design is another important factor that affects the efficiency and effectiveness of thrust generation. Factors such as flame tube diameter, length, and inlet piston dimensions are carefully evaluated to ensure proper mixing of fuel and air, complete combustion, and efficient energy conversion. The calculation of hole sizes and distribution within the combustion chamber is based on empirical data and theoretical considerations to achieve desired combustion characteristics and temperature distribution. The number of primary holes is maximum as 30% of the air flow to the combustion chamber has to be through them. The number of secondary holes is quite less but they have comparatively large diameter than primary holes as 20% of the air flow to the combustion chamber has to be through them. The number of tertiary holes is same as secondary holes but they have significantly large diameter than as 50% of the air flow to the combustion chamber has to be through them.

Performance:

A turbocharger gas turbine engine undergoes assessment via Brayton cycle analysis, offering valuable insights into its efficiency and energy conversion processes. Parameters like back work ratio and thermal efficiency are key in evaluating the system's overall performance. The analysis indicates promising efficiency and thermal performance, suggesting its viability as a significant alternative for propulsion. The thermal efficiency signifies the engine's capability in converting fuel into useful work, while the back work ratio reflects the portion of turbine work utilized to run the compressor, crucial for increasing inlet air pressure. This leaves a substantial percentage of work available for thrust generation, emphasizing the engine's potential effectiveness in generating propulsion.

Thrust generation:

Despite meticulous optimization efforts in nozzle design and flow parameter control, achieving substantial thrust output remains a critical challenge in this project. The calculated thrust value of 80 N falls short of the actual results, which measured 41 N. Potential reasons for this disparity include losses in system components, inaccuracies in the air/fuel mixture, and incomplete combustion. Addressing these factors is crucial to improving overall engine performance and achieving desired thrust levels, particularly in applications such as UAVs.

Applications:

The versatility and adaptability of this method of making gas turbine engine make it suitable for a wide range of uses, including unmanned aerial vehicles (UAVs), small aircraft, and other propulsion systems requiring low to moderate thrust levels. The cost-effectiveness and relatively simple design make it an attractive option for less expensive jet engines.

4.4 Comparison against already existing similar works:

In this article (published by M Usman Butt of Mechanical Engineering Dept, University of Lahore, 1-km Raiwind road, Lahore, Pakistan)

https://www.e3sonferences.org/articles/e3sconf/pdf/2019/21/e3sconf_icpeme2018_02008.pdf, the thermal efficiency of turbocharger based gas turbine engine obtained is 6%. While our thermal efficiency is 16%. And their theoretical thrust generation is 90 N and practical thrust generation is 75 N, while our theoretical thrust generation is 80N. in comparison to the gas turbine engine built by publisher of this article, we have gas turbine engine with better performance. We couldn’t find the quantitative comparison for performance of turbocharger based gas turbine engine other than this article.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion:

Our project aimed to transform turbocharger components into a practical gas turbine engine suitable for small-scale applications like drones and UAVs. We meticulously designed the combustion chamber and nozzle configurations, prioritizing efficiency and thrust output through hands-on engineering rather than simulation-based analysis. This approach allowed us to explore the feasibility of jet engine concepts in real-world scenarios, leading to iterative design refinements based on tangible results. The outcome surpassed expectations, with the engine demonstrating impressive performance. This success highlights the adaptability of turbocharger technology, offering a cost-effective solution for propulsion needs in various industries. By showcasing the viability of our design for practical applications, we've paved the way for advancements in alternative propulsion systems and contributed to the evolution of aviation and engineering technologies.

5.2 Recommendations:

Design parameters:

Conducting further research and analysis to optimize the design parameters of turbocharger based gas turbine engine. This includes refining the geometry of the combustion chamber and nozzle to improve efficiency and performance.

Experimental Validation and Testing:

Performing comprehensive experimental validation and testing of the converted turbocharger gas turbine engine under real-world conditions to validate performance factors such as thrust output, thermal efficiency, and durability.

Usage of Advanced Materials and Manufacturing Techniques:

Usage of advanced materials such as lightweight alloys, composite materials and manufacturing techniques such as additive manufacturing, and advanced machining processes to enhance the performance i.e. Thrust/Weight ratio, reliability, and cost-effectiveness of the gas turbine engine.

Alternative Fuels and Combustion Technologies:

Investigation of the use of alternative fuels and combustion technologies to improve the environmental sustainability and fuel efficiency of gas turbine engine. Exploring the feasibility of utilizing biofuels, hydrogen or synthetic fuels to reduce emissions and minimize environmental impact. Exploring innovative combustion technologies such as staged combustion or lean-burn combustion for enhanced performance and efficiency.

Continued Research and Collaboration:

Engaging with academic institutions, research organizations, industry forums, and government agencies to exchange knowledge and leverage collective expertise.

5.3 **References:**

[1] Design and construction of a simple turbojet engine by Simon Fahlström, Rikard Pihl-Roos.

Retrieved from:

https://www.diva-portal.org/smash/get/diva2:974874/FULLTEXT01.pdf

[2] "Aeolus | Combustion Chambers." JetX Engineering.

Retrieved from:

www.jet-x.org/a4.html

[3] Nozzle selection and Design Criteria.

Retrieved from:

https://www.mssoy.org/uploads/files/nozzle-selection-vt.pdf

[4] Gas Turbine Theory By Hih Saravanamuttoo, H. Cohen & GFC Rogers.

[5] Gas Turbine Theory 7th Edition by H. Cohen, G.F.C. Rogers, Paul Straznicky.

[6] Article by M Usman Butt of Mechanical Engineering Dept, University of Lahore, 1-km Raiwind road, Lahore, Pakistan.

Retrieved from:

https://www.e3s-conferences.org/articles/e3sconf/pdf/2019/21/e3sconf_icpeme2018_02008.pdf

APPENDIX I: Calculations

Brayton Cycle:

$P_1 := 1\ \mathbf{atm}$ $P_2 := 2\ \mathbf{atm}$ $P_3 := 2\ \mathbf{atm}$

$T_1 := 300\ \mathbf{K}$ $T_3 := 1300\ \mathbf{K}$

$h_1 := 300.19 \cdot 10^3\ \frac{\mathbf{J}}{\mathbf{kg}}$ $P_{r1} := 1.386$

$$P_{r2} := \frac{P_2}{P_1} \cdot P_{r1}$$

$P_{r2} = 2.772$

From Thermal Properties Table

$T_2 := 365\ \mathbf{K}$

$h_2 := 365.27 \cdot 10^3\ \frac{\mathbf{J}}{\mathbf{kg}}$

$T_3 := 1300\ \mathbf{K}$

$h_3 := 1395.97 \cdot 10^3\ \frac{\mathbf{J}}{\mathbf{kg}}$

$P_{r3} := 330.9$

$P_4 := 1\ \mathbf{atm}$

$$P_{r4} := \frac{P_4}{P_3} \cdot P_{r3}$$

$P_{r4} = 165.45$

$T_4 := 1100\ \mathbf{K}$

$h_4 := 1161.07 \cdot 10^3\ \frac{\mathbf{J}}{\mathbf{kg}}$

Back Work Ratio

$W_{comp.in} := h_2 - h_1$

$W_{comp.in} = \left(65.08 \cdot 10^3\right) \frac{J}{kg}$

$W_{turb.out} := h_3 - h_4$

$W_{turb.out} = \left(234.9 \cdot 10^3\right) \frac{J}{kg}$

$r_{bw} := \frac{W_{comp.in}}{W_{turb.out}}$

$r_{bw} = 0.277$

Thermal Efficiency

$q_{in} := h_3 - h_2$

$q_{in} = \left(1.031 \cdot 10^6\right) \frac{m^2}{s^2}$

$W_{net} := W_{turb.out} - W_{comp.in}$

$W_{net} = \left(1.698 \cdot 10^5\right) \frac{J}{kg}$

$\eta_{thermal} := \frac{W_{net}}{q_{in}}$

$\eta_{thermal} = 0.165$

$\boxed{\eta_{thermal}} := 16.5\%$

Combustion Chamber

Reference Data for GT2052

Compressor	inducer diameter	exducer diameter	A/R
	38mm	52mm	0.51

Diameter of Compressor intake

$D_{comp.in} := 38\ mm$

Diameter of flame tube

$D_f := 2 \cdot D_{comp.in}$

$D_f = 0.076\ m$

Length of flame tube

$L_f := 6 \cdot D_{comp.in}$

$L_f = 0.228\ m$

Flame tube inlet piston

$X_{fi} := \frac{L_f}{4}$

$X_{fi} = 0.057\ m$

Calculation of holes

	primary	secondary	tertiary
air %	30%	20%	50%
no. of holes	26	5	5
		impirically determined	

Area of Compressor inlet

$A_{comp.in} := \pi \cdot \left(\frac{D_{comp.in}}{2} \right)^2$

$A_{comp.in} = \left(1.134 \cdot 10^{-3}\right)\ m^2$

Total Area of Primary Holes

$A_{p.t} := 0.3 \cdot A_{comp.in}$ no. of Primary Holes

$A_{p.t} = \left(340.234 \cdot 10^{-6}\right)\ \mathbf{m}^2$ $N_p := 26$

Area of Primary each hole

$$A_p := \frac{A_{p.t}}{N_p}$$

$A_p = \left(13.086 \cdot 10^{-6}\right)\ \mathbf{m}^2$

Radius of each Primary hole

$$r_p := \left(\frac{A_p}{\pi}\right)^{\frac{1}{2}}$$

$r_p = \left(2.041 \cdot 10^{-3}\right)\ \mathbf{m}$

Total Area of Secondary Holes

$A_{s.t} := 0.2 \cdot A_{comp.in}$ no. of Secondary Holes

$A_{s.t} = \left(226.823 \cdot 10^{-6}\right)\ \mathbf{m}^2$ $N_s := 5$

Area of Secondary each hole

$$A_s := \frac{A_{s.t}}{N_s}$$

$A_s = \left(45.365 \cdot 10^{-6}\right)\ \mathbf{m}^2$

Radius of each Secondary hole

$$r_s := \left(\frac{A_s}{\pi}\right)^{\frac{1}{2}}$$

$r_s = \left(3.8 \cdot 10^{-3}\right)\ \mathbf{m}$

Total Area of Tertiary Holes

$A_{t.t} := 0.5 \cdot A_{comp.in}$ no. of Tertiary Holes

$A_{t.t} = (567.057 \cdot 10^{-6})\ \mathbf{m}^2$ $N_t := 5$

Area of Tertiary each hole

$$A_t := \frac{A_{t.t}}{N_t}$$

$A_t = (113.411 \cdot 10^{-6})\ \mathbf{m}^2$

Radius of each Tertiary hole

$$r_t := \left(\frac{A_t}{\pi}\right)^{\frac{1}{2}}$$

$r_t = (6.008 \cdot 10^{-3})\ \mathbf{m}$

APPENDIX II: Definitions

Brayton Cycle: A thermodynamic cycle that describes the operation of certain heat engines that have air or some other gas as their working fluid.

Back work ratio: The ratio of compressor work to turbine work.

Thermal Efficiency: The thermal efficiency of a heat engine is the percentage of heat energy that is transformed into work.

Combustion Chamber: The area where fuel and an oxidizer are ignited.

Thrust: A reaction force described quantitatively by Newton's third law. When a system expels or accelerates mass in one direction, the accelerated mass will cause a force of equal magnitude but opposite direction to be applied to that system.

Nozzle: It converts the internal energy of a working gas into propulsive force by varying diameter along its length.

Self-sustained: A system which can maintain itself by independent effort to run in a healthy state.

Inducer diameter: The diameter where the air enters the compressor.

Exducer diameter: The diameter where the air exits the compressor.

A/R ratio: The inlet (or, for compressor housings, the discharge) cross-sectional area divided by the radius from the turbo centerline to the centroid of that area.