

DESIGN AND FABRICATION OF MICRO TURBO JET ENGINE

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in
Aeronautical Engineering

By

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**DEPARTMENT OF AERONAUTICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

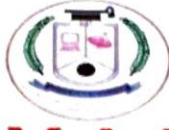
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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Vignesh S (40260024)** and **Raj Jose Steffin M (402600702)** who carried out the project entitled **"Design and Fabrication of Micro Turbo Jet Engine"** under my supervision from November 2023 to April 2024.



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DECLARATION

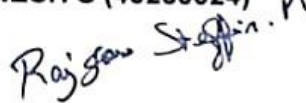
We VIGNESH S (40260024) and RAJ JOSE STEFFIN M (40260702) hereby declare that the project report entitled "DESIGN AND FABRICATION OF MICRO TURBO JET ENGINE" Done by us under the guidance of Dr. A. ANDERSON M.E., Ph.D., is submitted in partial fulfillment of the requirement for the award of Bachelor of Engineering degree In Aeronautical Engineering.

Date: 05-04-2024

Place: Chennai



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ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to the Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our sincere thanks to **Dr. A. Anderson, M.E., Ph.D.**, Head of the Department, Department of Aeronautical Engineering for providing us necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Dr. A. Anderson M.E., Ph.D.**, for his valuable guidance, suggestions, and constant encouragement that paved the way for the successful completion of our project work.

We also express my thanks to all Teaching and Non-teaching staff members of the Department of Aeronautical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

In recent years, there has been a notable surge in interest surrounding micro turbojet engines, primarily owing to their adaptability and potential utility in a range of aerospace contexts, including unmanned aerial vehicles (UAVs), small aircraft, and various aerospace propulsion systems. This study focuses on the development and performance assessment of a micro turbojet engine specially designed for use in compact airborne platforms, encompassing the phases of design, manufacturing, and testing.

During the design phase, meticulous component and material selection is undertaken to ensure the engine's compactness, efficiency, and reliability. Computational fluid dynamics (CFD) simulations are leveraged to optimize the engine's internal geometry, factoring in elements such as air compression, combustion efficiency, and exhaust thrust.

In the manufacturing phase, cutting-edge production techniques such as 3D printing and precision machining are applied to create engine components with both high precision and durability. Particular emphasis is placed on the selection of cooling systems and construction materials capable of withstanding elevated temperatures while preserving operational integrity.

Performance assessment is executed through comprehensive testing protocols, including static thrust tests, fuel consumption analyses, and temperature measurements. The results demonstrate that the developed micro turbojet engine boasts an impressive thrust-to-weight ratio, fuel efficiency, and overall performance, all well-aligned with the intended operational parameters.

This research contributes significantly to the advancement of micro turbojet engine technology, presenting a compact and robust propulsion solution tailored to the needs of small-scale aerospace applications. The implications of this study hold the potential to augment the capabilities of UAVs, extending their operational range and mission

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CHAPTER 1

INTRODUCTION

In the ever-evolving field of aviation and propulsion systems, there is a persistent drive to develop compact yet highly efficient solutions that can lead to groundbreaking innovations. One such innovation that has gained considerable attention is the micro turbojet engine. These miniature marvels of engineering deliver impressive thrust and power despite their small size, making them suitable for a wide range of applications.



Fig:1.1 : Micro turbojet engine

Micro turbojet engines are essentially scaled-down versions of their larger counterparts, and what sets them apart is their ability to generate thrust efficiently while taking up minimal space [6]. Their versatility has made them an attractive choice for various purposes, including but not limited to unmanned aerial vehicles (UAVs), small aircraft, auxiliary power units (APUs) [13], and research platforms. Despite their diminutive stature, these engines incorporate complex systems, advanced materials, and cutting-edge technologies to achieve exceptional levels of performance. Their utility extends beyond traditional aviation contexts into areas such as aerospace, defense, and remote sensing. In these domains, their unique capabilities have the potential to revolutionize industries and missions alike.

As the demand for propulsion systems that are not only efficient but also agile and space-saving continues to grow, the development and refinement of micro turbojet engines have become increasingly pivotal [26]. Researchers and engineers are faced with a set of challenges that include improving fuel efficiency, reducing emissions, enhancing durability, and addressing noise-related concerns. These challenges have injected dynamism into the landscape of micro propulsion technology research, pushing the boundaries of what can be achieved in this field.

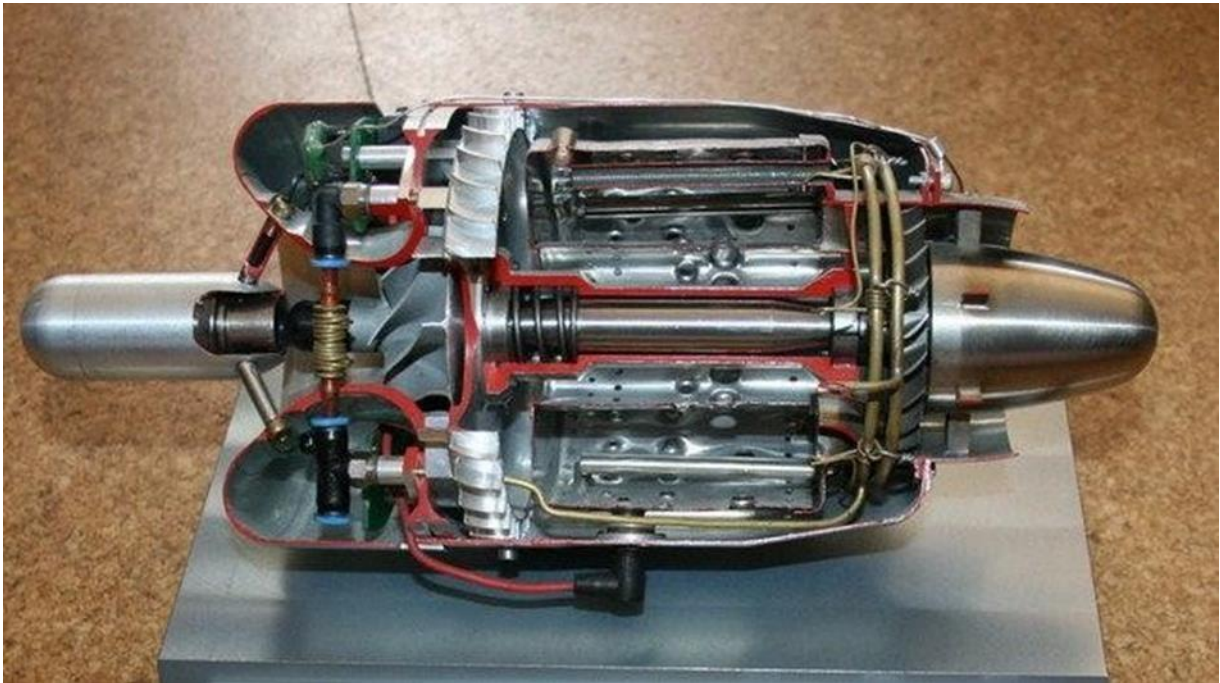


Fig:1.2 : cross-section of micro turbo jet engine

The aim of this project report is to embark on a thorough exploration of micro turbojet engines. We will delve into their design, fundamental operating principles, applications, and the current state of the field [28]. Additionally, the report will present the objectives and findings of a specific project undertaken within this domain. Through this exploration, we intend to shed light on the innovative contributions and advancements made in the pursuit of more efficient and adaptable micro turbojet engines.

As you continue to read the report, you will find a detailed examination of the intricate world of micro turbojet engines. We will dissect their components, discuss their

significance, and unravel the challenges that researchers and engineers face as they work towards enhancing these remarkable powerhouses. By the end of the report, we hope to provide you with a comprehensive understanding of the potential impact of micro turbojet engines on modern technology and various industries.

1.1 PARTS OF MTE:(MICRO TURBOJET ENGINE)

- Inlet
- Compressor
- Combustion chamber
- Turbines
- Exhaust Nozzle
- Fuel System
- Ignition System
- Bearings and Seals
- Shaft

1.1.1 INLET

The purpose of the inlet is to trap and guide incoming air towards the engine. It usually incorporates a widening shape to decelerate and pressurize the incoming air. This pressurization elevates both air pressure and temperature, priming it for the combustion process. In certain micro turbojet engines [12], the inlet may also incorporate a filter to hinder the entry of foreign particles into the engine.

1.1.2 COMPRESSOR

The compressor consists of a set of spinning airfoils or blades affixed to a central shaft. When these compressor blades revolve, they condense the incoming air. This compression operation raises both air pressure and temperature. The specific type of compressor, whether axial or centrifugal, is determined by the engine's design.

1.1.3 COMBUSTION CHAMBER

Within the combustion chamber, the pressurized air combines with fuel and is set ablaze. This high-pressure and high-temperature setting facilitates effective

combustion. The combustion procedure emits a substantial quantity of energy in the shape of scorching, high-speed exhaust gases.

1.1.4 TURBINES

The turbine is linked to the identical shaft as the compressor and comprises a set of blades that are propelled by the fast-moving exhaust gases originating from the combustion chamber [12]. As these exhaust gases traverse through the turbine, they convey their energy to the turbine blades, inducing the shaft to revolve. This rotational motion propels the compressor and additional accessories.

1.1.5 EXHAUST NOZZLE

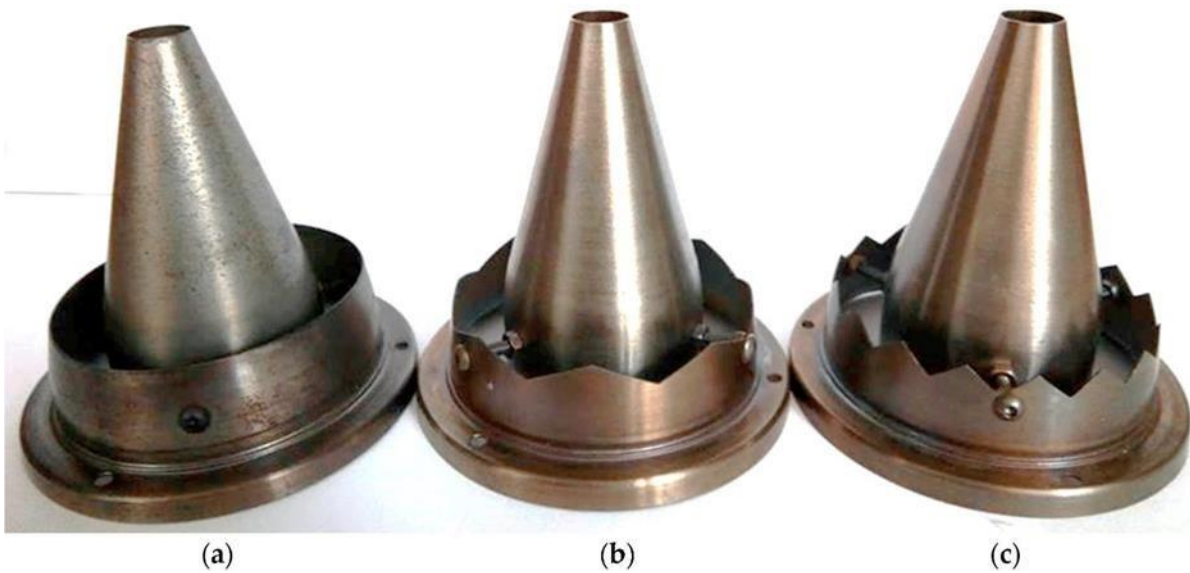


Fig:1.3 : Types of Nozzles

The exhaust nozzle is the component that directs the high-speed exhaust gases out of the engine. It is designed to expand the exhaust gases and accelerate them to create thrust. Some micro turbojets have adjustable nozzles, which can be modified to control the engine's thrust output.

1.1.6 FUEL SYSTEM

The fuel system takes on the role of overseeing the provision of fuel to the engine. It comprises elements for both storing and transporting fuel to the combustion chamber.

Fuel injectors are employed to introduce the fuel into the combustion chamber in a precise manner, ensuring that combustion remains efficient and stable.

1.1.7 IGNITION SYSTEM

The ignition system supplies the initial heat or spark needed to start the combustion of the air-fuel mixture in the combustion chamber. This ignition procedure marks the beginning of the engine's combustion cycle.

1.1.8 BEARINGS AND SEALS

Bearings play a crucial role in providing support and minimizing friction within the moving parts, like the compressor and turbine. Adequate bearings guarantee seamless operation [13]. Seals are utilized to avert the escape of air or gases from the engine, preserving both efficiency and safety.

1.1.9 SHAFT

The shaft establishes a connection between the compressor and the turbine, enabling the transfer of mechanical power from the turbine to the compressor. It plays a vital role in guaranteeing that the components function harmoniously and at the appropriate speeds.

1.2 INCREASING EFFICIENCY IN COMPRESSOR

Enhancing the effectiveness of the compressor in a micro turbojet engine is a fundamental step toward elevating the engine's overall performance. Compressors hold a pivotal position in augmenting the air's pressure and temperature as it enters the system, a crucial factor for efficient combustion and the creation of thrust. Below, we outline several methods for optimizing compressor efficiency.

1.2.1 ADVANCED AERODYNAMICS

Redesign the compressor blades and airfoils to improve their aerodynamic efficiency. This can involve optimizing the shape, angle, and spacing of the blades to reduce turbulence and increase airflow.

1.2.2 HIGHER COMPRESSION RATIOS

Increasing the compression ratio can improve efficiency. However, this must be done within the limits of the materials and engine design to avoid overheating and structural issues.

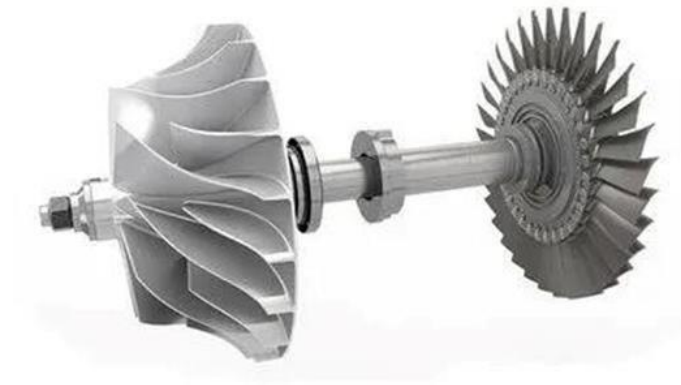


Fig:1.4 : Compressor and Turbine

1.2.3 OPTIMIZED INLET DESIGN

We must Ensure that the inlet design minimizes turbulence and provides a smooth, uniform flow of air into the compressor.

1.3 REDUCING NOISE IN EXHAUST NOZZLE

Reducing noise in the exhaust nozzle of a micro turbojet engine can be a challenging task, as jet engines inherently produce noise due to the high-speed exhaust gases. However, there are several techniques and technologies that can be employed to mitigate exhaust nozzle noise.

1.3.1 ACOUSTIC DESIGN

The configuration and structure of the exhaust nozzle play a pivotal role in determining the level of noise generated by a micro turbojet engine. A well-designed exhaust nozzle can significantly mitigate noise emissions associated with engine operation. Complex nozzle designs, characterized by features such as serrations or chevrons, have been particularly effective in attenuating noise levels.

Serrations and chevrons are intricate geometrical features integrated into the exhaust nozzle to disrupt and manipulate the exhaust flow. By strategically introducing these elements, the exhaust plume is disturbed and fragmented, resulting in reduced noise propagation. This phenomenon is attributed to the disruption of coherent flow structures within the exhaust plume, which helps dissipate acoustic energy and diminishes the overall noise signature.

In the context of micro turbojet engines, the acoustic design of the exhaust nozzle holds paramount importance, especially in scenarios where noise reduction is a primary concern. Micro turbojet engines find extensive use in applications such as drones, small aircraft, and auxiliary power units (APUs), where stringent noise regulations and community noise abatement initiatives are in place. In such environments, minimizing engine noise is essential to ensure compliance with regulations, mitigate environmental impact, and enhance overall user experience.

Effective acoustic design of the exhaust nozzle not only addresses noise concerns but also contributes to optimizing engine performance and operational efficiency. By employing advanced aerodynamic principles and innovative nozzle configurations, engineers can achieve a delicate balance between noise reduction and exhaust flow characteristics, thereby enhancing overall engine performance.

1.3.2 OPERATIONAL TECHNIQUES

Adjusting engine operating parameters, such as throttle settings, can sometimes help reduce noise. Lowering thrust levels when possible or operating at less noisy power settings can be effective.

Engines often have adjustable throttle settings that control the amount of fuel delivered to the engine, thereby regulating power output and thrust. By adjusting the throttle settings, operators can vary the engine's power output. Lower throttle settings result in reduced engine power and subsequently lower noise levels. This approach allows for dynamic control over noise levels, particularly in situations where noise reduction is desired, such as during takeoff and landing in residential areas or near sensitive environments.

Lowering Thrust Levels: Thrust is the force generated by the engine to propel an aircraft or vehicle forward. In some cases, engines may operate at higher thrust levels than necessary for the given task, leading to excess noise generation. By lowering thrust levels when feasible, either through throttle adjustments or by optimizing engine performance, operators can reduce noise emissions without sacrificing operational efficiency. This approach is particularly relevant in scenarios where noise abatement is a priority, such as near airports or in densely populated areas.

Operating at Less Noisy Power Settings: Engines often have multiple power settings or modes of operation, each associated with different levels of noise production. By selecting quieter power settings whenever possible, operators can minimize noise impact on surrounding environments. This may involve choosing specific engine configurations, flight profiles, or operational procedures that prioritize noise reduction without compromising safety or performance.

CHAPTER 2

LITERATURE SURVEY

Syarafina I, Adnan P, Hartono F. Design of Single Stage Axial Turbine for Mini Turbojet Engine (2020).

The paper titled "Design of Single Stage Axial Turbine for Mini Turbojet Engine" authored by Syarafina I, Adnan P, and Hartono F. in 2020 presents a comprehensive analysis of a single-stage axial turbine designed for a mini turbojet engine. The turbine is engineered to generate a power output of 157 kW with an impressive efficiency rating of 89%. What sets this design apart is its adaptability in power output adjustment without necessitating a change in the airfoil type. This is achieved by manipulating two key parameters: the stagger angle and the clearance gap. The study reveals that altering the clearance gap directly impacts both the power output and efficiency of the turbine. Decreasing the clearance gap results in higher power output and improved efficiency. However, it is noted that this adjustment must be balanced with considerations of ease of manufacturing. The smaller the clearance, the more intricate the manufacturing process may become, potentially impacting cost and feasibility. Furthermore, the research highlights the significance of the stagger angle in influencing turbine performance. Increasing the stagger angle enhances the turbine's power output, but this comes at a trade-off with efficiency. Higher stagger angles lead to increased power generation capabilities, yet efficiency diminishes. This underscores the intricate balance between power output and efficiency in turbine design.

B Jackson AJ, Laskaridis P, Pilidis , A Test Bed For Small Aero Gas Turbines (2004)

The article titled "A Test Bed for Small Aero Gas Turbines" authored by B. Jackson, A.J. Laskaridis, and P. Pilidis in 2004 outlines the development and implementation of a small test bed specifically designed for micro gas turbine engines. The primary objective of this test bed is to facilitate experimental testing and performance evaluation of micro gas turbine engines in a controlled environment.

The construction of the test bed marks a significant milestone in the advancement of micro gas turbine technology, providing researchers and engineers with a dedicated platform for conducting rigorous testing and analysis. Initial tests conducted on a micro engine using this test bed have yielded promising results, demonstrating the effectiveness and functionality of the test cell and its instrumentation.

The authors report that the test bed and its instrumentation can provide essential data for various purposes, including thrust calibration and computational fluid dynamics (CFD) studies. This indicates that the test bed is equipped with the necessary sensors and measurement tools to accurately capture and analyze engine performance metrics such as thrust output.

Furthermore, the article highlights the intention to conduct further testing on the equipment to investigate parameters that influence thrust generation. This suggests a commitment to ongoing research and development efforts aimed at enhancing the understanding of micro gas turbine engine behavior and performance characteristics.

Theoretical Design and Mass Modeling of a Single Spool Micro Turbojet Engine suitable for Drone and UAV Propulsion

The paper titled "Theoretical Design and Mass Modeling of a Single Spool Micro Turbojet Engine Suitable for Drone and UAV Propulsion" presents a comprehensive analysis of the design and mass modeling of a single spool micro turbojet engine tailored for the propulsion of drones and unmanned aerial vehicles (UAVs). The primary focus of the study is on the detailed design of the major engine components, as well as the estimation of the engine's total mass through a systematic mass modeling approach.

The research involves a meticulous process of designing each major component of the turbojet engine, taking into account factors such as aerodynamics, thermodynamics, material properties, and manufacturing considerations. Through this process, the dimensions of the components are determined, ensuring that they meet the performance requirements and safety criteria for reliable operation.

One of the key aspects addressed in the paper is the matching of the compressor and turbine components to ensure optimal performance and efficiency. By carefully

balancing the characteristics of these components, the design is deemed to be safe and capable of delivering the desired thrust output.

In addition to the detailed design work, the paper employs a mass modeling approach to estimate the weight of individual engine components. This involves considering factors such as material density, volume, and structural requirements to derive accurate estimates of component weights. By extrapolating these individual component masses, the total mass of the engine is estimated.

The insights derived from this research are expected to be valuable for engine designers aiming to develop turbojet engines in the thrust range of 4KN, suitable for powering medium and high-altitude drones in the near future. By providing a systematic approach to engine design and mass estimation, the study equips designers with the knowledge and tools necessary to streamline the development process and ensure the successful deployment of micro turbojet engines for UAV propulsion applications.

Preethi AY, Sandeep J, Reddy SS, Manoj &, Reddy K. Design Of Annular Combustion Chamber For A Micro Turbofan Engine (2019)

The paper discusses the comprehensive design of a complete annular combustor for a micro turbofan engine, achieved solely with the initial design parameters. This signifies a notable achievement as it streamlines the design process, enabling preliminary design with efficiency and transparency. By providing a transparent and detailed approach, the paper aims to mitigate design complexities and reduce overall design time. This approach offers a significant advantage in expediting both the design phase and subsequent prototype development.

The described design process is intended for preliminary design purposes, highlighting its applicability at the early stages of engine development. Through a systematic approach, the paper outlines a practical methodology that ensures a thorough consideration of all relevant parameters and constraints. By adhering to this methodology, the design team can achieve a practical and functional combustor design.

The resulting design values obtained through this process serve as the foundation for subsequent modeling and analysis phases. These values are utilized to create detailed

models for further analysis, contributing to a deeper understanding of combustor performance and behavior. Additionally, the paper emphasizes the use of advanced analysis techniques, such as the combustion-turbulence interaction model, to enhance the accuracy of the analysis.

Mangra AC. Design and Numerical Analysis of a Micro Gas Turbine Combustion Chamber (2020)

the paper discusses the Computational Fluid Dynamics (CFD) modeling results pertaining to an annular type of combustion chamber, a component of an 800N micro gas turbine intended for use in a small-scale multifunctional airplane. One of the primary challenges encountered during the design process is the manufacturing of pressure swirl injectors that fit within the limited space available. Consequently, the authors explore the possibility of replacing these injectors with vaporizers as an alternative solution.

Two distinct combustion chamber configurations, each equipped with 16 vaporizers, are meticulously analyzed through CFD modeling. Despite similarities in the average values of operating parameters at the exit of the combustion chamber, notable differences emerge between the two configurations upon closer examination. In configuration 1, maximum temperatures are observed predominantly within the primary zone of the fire tube, whereas configuration 2 exhibits temperatures exceeding 2000K in both the primary and secondary zones of the fire tube. Furthermore, the total temperature at the outlet of the combustion chamber appears to be more uniformly distributed in configuration 1 compared to configuration 2.

Upon thorough evaluation of the CFD results, it is concluded that configuration 1 offers a more favorable temperature distribution and overall performance characteristics. Consequently, the decision is made to proceed with configuration 1 for further development. The subsequent phase involves the manufacturing of the combustion chamber assembly, paving the way for experimental testing to validate the numerical findings. The experimental results will then be compared against the CFD modeling outcomes to assess the accuracy and reliability of the computational simulations.

In essence, the paper provides insights into the meticulous design process and decision-making involved in the development of a combustion chamber for an 800N micro gas turbine. By leveraging CFD modeling, the authors are able to make informed design choices and optimize performance parameters before proceeding with physical manufacturing and experimental testing. This iterative approach demonstrates a systematic methodology for advancing the development of micro gas turbine technology for aerospace applications.

John Wessley GJ, Chauhan S. Modeling and Performance Simulation of a Micro Turbojet Engine Using Flownex(2019)

The study presented here offers a comprehensive one-dimensional analysis of a micro turbojet engine intended for the propulsion of future unmanned aerial vehicles (UAVs) with a thrust requirement within the 4 kN range. Utilizing Flownex simulation software, the research team has conducted extensive investigations into the engine's components, focusing on component matching and overall engine performance.

The utilization of Flownex simulation software has proven to be highly effective in the design and simulation of gas turbine engines, as evidenced by the results obtained in this study. The simulation outcomes not only provide valuable insights into the engine's behavior but also validate the suitability of Flownex for such analyses.

The findings from this study serve as a foundational basis for further exploration and refinement of the turbojet engine design. Specifically, the results will inform subsequent investigations into the successful integration of modified compressor and turbine stages into the engine architecture, aiming to optimize performance and meet the desired thrust requirements for future UAV applications.

An analysis of the engine's performance reveals that it achieves a thrust output of 3.79 kN under specific operating conditions. This output is achieved at an inlet air pressure of 1.01 bar and an inlet flow rate of 8.71 kg/s. Additionally, the study indicates that the maximum temperature experienced during the engine's performance analysis is 556.17 K. This finding suggests that commercially available materials can be utilized for the

construction of these engines, providing feasibility and cost-effectiveness in engine production.

Benini E, Giacometti S. Design, manufacturing and operation of a small turbojet-engine for research purposes. Appl Energy (2007)

The statement highlights the extensive research conducted at the Department of Mechanical Engineering, University of Padova, aimed at designing and developing a small, low-cost jet engine with a thrust of 200 N. This engine is intended for both research and educational purposes, representing a significant achievement in the field of propulsion systems. The project not only resulted in the successful creation of the engine but also provided valuable insights and expertise in various aspects of engine design, manufacturing, operation, and testing.

The research effort signifies a substantial investment in acquiring specialized knowledge and skills necessary for the self-design, fabrication, operation, and evaluation of such a complex mechanical system. By undertaking this project, the researchers have laid a solid foundation upon which further advancements in jet engine technology can be built. Moreover, the project contributes to the educational mission of the university by providing students with hands-on experience in aerospace engineering and propulsion systems.

Looking ahead, the next phase of research will focus on enhancing the efficiency of the engine. This will involve increasing the cycle pressure ratio and turbine inlet temperature, which are key parameters for improving engine performance. Achieving higher pressure ratios and temperatures will likely require the use of advanced materials such as super Nickel alloys and ceramic composites, which offer superior strength and temperature resistance compared to traditional materials.

Additionally, the research team plans to conduct endurance and reliability tests to assess the long-term performance and durability of the engine under various operating conditions. These tests are crucial for validating the design and ensuring the engine's reliability in practical applications.

Zhu H, Du F, Zhao S, Xu Z, Lv Z. Design of A New Type Thrust Measuring System for Micro-turbojet Engine (2016)

The paper introduces a novel micro-turbojet engine thrust measuring system that comprises several components, including a test bench, load cells, data acquisition modules, and a computer. The centerpiece of this system is the test bench, which features a suspended test bed design that is characterized by its simplicity and ease of debugging. The suspended test bed configuration offers advantages in terms of accessibility and adjustability, facilitating efficient troubleshooting and calibration procedures.

An in-depth error analysis of the thrust measuring system is conducted to assess its accuracy and reliability. The study distinguishes between random errors and systematic errors, addressing each category comprehensively. Random errors, stemming from factors such as variability in test conditions and measurement noise, are found to be negligible when the geometry and precision of the test bed adhere to design specifications. This indicates that the system is robust against random fluctuations and capable of providing consistent and reproducible measurements under controlled conditions.

Systematic errors, on the other hand, arise from factors such as thrust line deflection, instrument calibration inaccuracies, and data transmission discrepancies. Despite these potential sources of error, the study determines that systematic errors remain within acceptable limits, ensuring that the overall accuracy and reliability of the thrust measurement system meet the required standards. This underscores the effectiveness of the system design in mitigating common sources of error and maintaining measurement fidelity.

Furthermore, the paper outlines a static calibration method employed to calibrate the thrust measurement system. The calibration process is described in detail, highlighting its precision and effectiveness in ensuring accurate thrust measurements. The study reports that the accuracy of the calibration process can achieve an impressive level of $\pm 0.33\%$, demonstrating the high degree of precision attainable with the proposed thrust measuring system.

Elzahaby AM, Khalil MK, Khalil HE. Theoretical and Experimental Analysis of a Micro Turbojet Engine's Performance (2016)

The statement emphasizes the importance of combining analytical analysis with empirical formulas to conduct a preliminary analysis of micro-turbojet engine performance. Rather than relying solely on commercial software like "Gas Turbine," which may have limitations in accuracy, this approach leverages a theoretical model that incorporates thermodynamic cycle analysis along with empirical data on compressor and combustion chamber performance.

By integrating analytical methods with empirical formulas, engineers can obtain a more comprehensive understanding of the engine's behavior and performance characteristics. This hybrid approach allows for a more nuanced examination of factors such as compression efficiency, combustion efficiency, and overall thermodynamic cycle efficiency.

Moreover, the statement suggests that the theoretical model yields more accurate results compared to relying solely on commercial software. This underscores the importance of developing tailored analytical models that are specifically suited to the unique characteristics and requirements of micro-turbojet engines.

Additionally, the statement highlights the potential benefits of constructing a performance map for the turbine, rather than assuming constant total adiabatic efficiency across all operating conditions. By incorporating a performance map that accounts for variations in efficiency at different speeds and load levels, the theoretical model can achieve greater accuracy in predicting engine performance.

Cican G, Deaconu M, Crunteanu DE. Impact of using chevrons nozzle on the acoustics and performances of a micro turbojet engine (2021)

The main conclusion drawn from the paper is centered around the efficacy of chevron nozzles in reducing overall noise levels, particularly by 2–3 dB, but primarily noticeable at high-speed regimes. This noise reduction effect is attributed to the improved mixing of jet gases with atmospheric air facilitated by the chevron design.

The analysis of acoustic signals through Fast Fourier Transform (FFT) highlights that the noise reduction achieved by chevron nozzles exhibits broadband characteristics. This indicates that the reduction in noise spans across a wide range of frequencies, contributing to a more comprehensive reduction in overall noise levels.

Additionally, the study examines vibration spectra and identifies engine speed as the primary source of vibration for each operational regime. Interestingly, no consistent pattern or correlation is observed between vibration levels and engine speed variations. Notably, the introduction of chevron nozzles does not result in a significant increase in vibration levels. Although slight increases in vibration levels were noted during testing, they did not pose any risk to engine functionality.

Furthermore, the investigation delves into the impact of chevron modifications on engine performance. It is observed that modifying the nozzle by incorporating chevrons leads to a reduction in propulsion force, particularly evident in nozzles with a higher number of chevrons, such as 16 chevrons.

Livebardon T, Moreau S, Poinso T, Bouty E. Numerical investigation of combustion noise generation in a full annular combustion chamber (2015)

In this study, the authors focus on predicting combustion noise in turboshaft engines using two different computational methods: Large Eddy Simulation (LES) and an actuator disk theory. The aim is to assess the accuracy of these methods in predicting both the mean flow and the acoustic field within the combustion chamber.

First, the authors compute a single sector of a turboshaft engine combustor using LES, which allows for detailed simulation of turbulent flow dynamics. They find that while LES accurately predicts the mean flow within the combustor, it fails to capture the actual acoustic mode of the acoustic field. This suggests that LES alone may not be sufficient for accurately modeling combustion noise in turboshaft engines.

To address this limitation, the authors employ an actuator disk theory to further analyze the acoustic field. This theory helps highlight the contribution of indirect noise, originating from interactions between the high-pressure turbine and the exhaust, in the radiated acoustic field. By incorporating entropy scattering induced by the turbine

stages into their calculations, the authors aim to prevent over-prediction of indirect combustion noise.

Overall, the study underscores the complexity of predicting combustion noise in turboshaft engines and the importance of utilizing multiple computational methods to accurately capture different aspects of the acoustic field. While LES provides valuable insights into the mean flow behavior, the actuator disk theory helps elucidate the contribution of indirect noise sources, ultimately enhancing our understanding of combustion noise generation mechanisms in turboshaft engines. This multidisciplinary approach contributes to advancements in engine noise prediction and informs strategies for noise mitigation in aerospace applications.

Habibi FI, Hartono F, Prayogo H. Optimization of an Annular Combustion Chamber for Micro Turbo Jet System (2019)

After conducting a thorough analysis of the optimized geometry of the combustion chamber, it was found to exhibit significantly improved performance characteristics. While there was a slight decrease noted in certain performance aspects, such as a marginal increase in pressure loss, this was more than compensated for by notable enhancements in efficiency and pattern factors.

Specifically, the optimized combustion chamber demonstrated a remarkable 20% increase in efficiency compared to its previous configuration. This substantial improvement in efficiency is a key indicator of the effectiveness of the design changes implemented. Additionally, the pattern factor, which reflects the uniformity of the flow distribution within the combustion chamber, was observed to decrease, suggesting a more even distribution of flow and combustion.

Despite the observed increase in pressure loss, the actual numerical value of this increase, approximately 0.039, remained within acceptable limits. This indicates that while there was a slight compromise in terms of pressure loss, it was well within the acceptable range for practical applications.

Furthermore, the analysis revealed several other positive outcomes associated with the optimized combustion chamber geometry. These included lower temperatures on the

combustion chamber walls, which can contribute to improved durability and longevity of the chamber components. Additionally, there were general increases in overall performance metrics, further validating the effectiveness of the optimization efforts.

Khan SA, Chaudhary ZI, Shinde VB, Khan SA. Investigation of base flow for an axisymmetric suddenly expanded nozzle with microjet (2018)

Based on the results and discussions presented in the current experimental investigation, several conclusions can be drawn regarding the behavior and performance of the system under study. Here's an elaboration:

The base pressure, a critical parameter influencing aerodynamic performance, is primarily governed by specific geometrical parameters such as the relief of the passage, the length-to-diameter (L/D) ratio, and the inertia level at the nozzle exit. These geometric factors play a significant role in determining the flow characteristics and pressure distribution in the base region of the system.

The ratio of the exit pressure (P_e) to the ambient pressure (P_a), denoted as P_e/P_a , has a notable effect on the behavior of the separated region within the flow field. Changes in P_e/P_a influence the extent and characteristics of flow separation, which in turn affect the aerodynamic performance of the system

Activation of micro jets within the system has been observed to effectively regulate the flow in the base region. This regulation leads to a significant increase in pressure compared to conditions without control, particularly for systems with an area ratio of 2.56. Micro jets play a crucial role in altering the flow dynamics and enhancing pressure distribution to achieve desired aerodynamic outcomes.

The Mach number, representing the ratio of the flow velocity to the speed of sound, has a substantial impact on base pressure. In the supersonic regime, an increase in Mach number correlates with a notable rise in base pressure. This observation underscores the importance of considering flow velocity when analyzing and predicting aerodynamic performance.

The findings of the present study provide valuable insights into identifying the optimal combination of flow parameters and geometrical parameters to achieve desired

aerodynamic results. By carefully adjusting these parameters, engineers can effectively control flow behavior and pressure distribution to enhance system performance and efficiency.

Khan SA, Aabid A, Mokashi I, Ahmed Z. Effect of micro jet control on the flow field of the duct at Mach 1.5(2019)

The statement you provided appears to describe the results of an experimental investigation into the effects of active control mechanisms, specifically micro jets, on the flow field and base pressure of a suddenly expanded duct at a specific area ratio and Mach number.

The analysis indicates that at an area ratio of 3.24 and Mach number of 1.5, there is a notable increase in base pressure. This suggests that the active control mechanism, likely involving micro jets, effectively influences the flow field, leading to improved base pressure.

The use of micro jets results in a decrease in suction at the base of the duct, consequently reducing the associated base drag. This reduction in drag is significant for the specific parameters under investigation. It implies that the active control mechanism has a beneficial impact on the aerodynamic performance of the duct by mitigating drag forces.

The experimental investigation reveals that the decrease in base suction and drag leads to an improvement in pressure at the recirculation zone at the corner of the duct. This improvement suggests that the active control mechanism effectively modifies the flow field dynamics, resulting in more favorable pressure distributions.

Importantly, the study concludes that the implementation of active control mechanisms does not negatively affect the static duct pressure in the suddenly expanded duct. This indicates that the introduction of micro jets or similar control methods does not disrupt the overall flow field characteristics or induce adverse pressure gradients within the duct.

Overall, the findings of this experimental investigation highlight the efficacy of active control mechanisms, such as micro jets, in improving base pressure and reducing drag

in suddenly expanded ducts. The results suggest that these control methods can effectively influence the flow field dynamics without negatively impacting static duct pressure, thereby offering potential benefits for aerodynamic performance optimization in various engineering applications.

Shan Y, Zhang JZ, Huang GP. Experimental and numerical studies on lobed ejector exhaust system for micro turbojet engine. Engineering Applications of Computational Fluid Mechanics (2011)

The passage discusses the findings from numerical simulations regarding the performance of a lobed nozzle design. Here's an elaboration. The numerical simulations indicate that the pumping ratio of the lobed nozzle improves as the expansion angle of the lobe increases. The pumping ratio refers to the ratio of the mass flow rate of the working fluid through the nozzle to the mass flow rate through the engine core, essentially representing the efficiency of the nozzle in generating thrust.

However, the design of the lobed nozzle involves a trade-off between pumping performance and flow loss. While increasing the expansion angle of the lobe enhances pumping performance, it also leads to increased flow loss within the nozzle. This suggests that there is an optimal balance that needs to be struck in the design to achieve the desired thrust output while minimizing flow losses.

The numerical analysis suggests that the expansion angle of the lobe should be kept under 8 degrees to maintain an optimal balance between pumping performance and flow loss. Beyond this threshold, the increase in flow loss outweighs the gains in pumping performance, resulting in diminished overall efficiency.

Additionally, the passage mentions that numerical calculations can provide valuable insights into the performance of the lobed nozzle design and serve as a means of performance evaluation. This implies that computational simulations can be used to predict nozzle performance and assess different design parameters before conducting physical experiments.

Finally, the passage compares the numerical results with experimental data and indicates that the relative error of thrust gain between the computational and

experimental results is approximately 3.7%. This suggests a reasonably good agreement between the numerical predictions and experimental observations, validating the accuracy and reliability of the numerical simulations in predicting nozzle performance.

Dutczak J. Micro turbine engines for drones' propulsion (2016)

Micro turbine (turbojet) engines (MTE) represent a relatively recent innovation in propulsion technology, primarily utilized in aircraft drones. Despite their compact size, these engines boast an impressive level of technical sophistication, positioning them at the forefront of propulsion innovation. The combination of small dimensions and high thrust or power output makes MTE engines an extremely appealing choice for powering drones.

The emergence of MTE engines has revolutionized the capabilities of unmanned aerial vehicles (UAVs) and drones, enabling them to achieve remarkable performance metrics in terms of speed, maneuverability, and payload capacity. These engines offer a compelling alternative to traditional propulsion systems, such as electric motors or piston engines, due to their unique combination of compactness, efficiency, and power output.

One of the key factors driving the popularity of MTE engines is their exceptional power-to-weight ratio. Despite their small size, these engines can generate significant thrust or power, allowing drones to achieve high speeds and carry heavier payloads. This capability is particularly advantageous in applications where agility, range, and payload capacity are paramount, such as surveillance, reconnaissance, aerial photography, and delivery services.

Moreover, MTE engines are characterized by their advanced engineering and cutting-edge technologies, which have been refined through continuous research and development efforts. These engines incorporate state-of-the-art materials, manufacturing processes, and design optimizations to maximize performance, efficiency, and reliability.

In addition to their application in drones, MTE engines have also found use in other sectors, including model aircraft, unmanned surface vessels (USVs), and auxiliary power units (APUs) for larger aircraft. Their versatility and adaptability make them suitable for a wide range of aerospace and defense applications, where compactness, power density, and performance are critical considerations.

The Preliminary Design of the Air-Intake System and the Nacelle in the Small Aircraft-Engine Integration Process:

The statement describes the development of an automated and versatile method for designing and analyzing axial gas turbine stages. This method is characterized by its robustness, efficiency, and adaptability to accommodate various design parameters, making it particularly suitable for application in the preliminary design phase of gas turbine development.

The key feature of this method is its ability to effectively control the design process through specified parameters, enabling designers to tailor turbine designs to meet specific requirements and performance objectives. By leveraging automation, the method streamlines the design process, reducing time and resource requirements while ensuring accuracy and consistency.

The flexibility of the method is demonstrated through the successful reproduction of multiple turbine designs, each tailored to different designer specifications and preferences. This indicates its versatility in accommodating diverse design criteria and optimizing performance accordingly.

Importantly, the turbine designs generated using this method exhibit commendable thermal efficiency, surpassing those reported in recent publications. The achievement of a thermal efficiency of 91% highlights the effectiveness of the method in producing high-performance turbine designs that meet or exceed industry standards.

Furthermore, the method prioritizes the minimization of losses at the turbine stage exit by controlling the deviation of the exit swirl velocity from the axial direction. This optimization strategy contributes to improved overall efficiency and performance of the turbine stage.

Alay S, Professor HA. Design and Fabrication of an Annular Combustion Chamber for the Micro Gas Turbine Engine Applications

The paper discusses a comprehensive approach to the design of a complete annular combustor using initial design parameters. This design methodology is presented as a means to streamline the preliminary design process, with a particular emphasis on transparency and detail to reduce both design time and complexity. By employing this methodology, the authors aim to gain an overall advantage in total design time and prototype development.

The methodology outlined in the paper offers a systematic and transparent framework for the design of the annular combustor, starting from initial parameters and progressing through detailed design considerations. This approach is intended to provide engineers with a clear path towards developing practical designs while minimizing the inherent complexities associated with combustor design.

Furthermore, the paper highlights the practical implementation of the methodology by presenting a specific design derived using the proposed approach. The obtained design values serve as inputs for modeling purposes, facilitating further analysis and optimization of the combustor design. Notably, the analysis incorporates a combustion-turbulence interaction model to ensure higher accuracy in predicting combustor performance.

The results of the analysis demonstrate the successful achievement of the desired gas exit temperature for the present design. Through a combination of calculation, modeling, and analysis, the authors validate the efficacy of the design methodology in producing a functional and optimized annular combustor design.

Maia AAG, Silva JF, Tomita JT, Bringhenti C. Preliminary design of axial flow turbine for a small jet engine (2019)

The provided passage outlines the development of an automated and robust method for designing and analyzing axial gas turbine stages, with a focus on controlling design parameters. This method is engineered to be flexible and accurate, making it highly

efficient for use in the preliminary design phase of turbine development. Here's a more detailed elaboration.

The method described in the passage represents a significant advancement in the field of axial gas turbine design and analysis. By automating the process and incorporating robust control mechanisms for design parameters, engineers can efficiently generate turbine designs tailored to specific requirements.

Key features of this method include its flexibility and accuracy, which are crucial for accommodating various designer preferences and specifications. The method's flexibility is demonstrated by its ability to reproduce multiple turbine designs, each with different requirements set by the designer. This adaptability allows engineers to explore a wide range of design options and optimize performance based on specific criteria.

Moreover, the generated turbine designs exhibit impressive thermal efficiency compared to recent publications in the field. Thermal efficiency is a critical metric for evaluating turbine performance, as it directly impacts energy conversion efficiency and overall system effectiveness. The attainment of a thermal efficiency of 91% in the final required design is a testament to the effectiveness of the method in producing high-performance turbine designs.

Additionally, the method prioritizes minimizing losses at the turbine stage, particularly by controlling exit swirl velocity. By maintaining an average exit swirl velocity of 50 deviations from the axial direction, the method effectively mitigates losses associated with flow deviation, thereby enhancing overall turbine efficiency and performance.

Stalewski W. The Preliminary Design of the Air-Intake System and the Nacelle in the Small Aircraft-Engine Integration Process.

The primary objective of the research outlined in the present paper was to develop a preliminary concept for integrating the turboprop engine TP100 into the aircraft I-23. This integration process required extensive design work, which was conducted utilizing the parametric design methodology. This methodology leveraged the PARADES software for Interactive Parametric Design and the RANS solver FLUENT for Computational Fluid Dynamics (CFD) analyses.

The parametric design methodology enabled the systematic exploration of various design parameters and their effects on the integration process. PARADES software provided a structured framework for efficiently iterating through design iterations and refining the concept. Additionally, FLUENT's CFD capabilities allowed for detailed analysis of airflow, pressure distributions, and other aerodynamic factors critical for optimizing the integration of the engine with the aircraft.

Throughout the preliminary design process, all fundamental components necessary for the engine integration were meticulously designed. These components encompassed a wide range of systems and subsystems essential for the successful operation of the turboprop engine within the aircraft. Some of these components may include:

Engine Mounting Systems: Structures designed to securely mount the turboprop engine onto the aircraft airframe, ensuring proper alignment and structural integrity.

Inlet and Exhaust Systems: Components responsible for directing airflow into the engine inlet and managing exhaust gases exiting the engine, optimizing aerodynamic performance and thermal management.

Fuel and Propulsion Systems: Systems designed to deliver fuel to the engine and manage the propulsion process, including fuel tanks, fuel lines, and engine control systems. **Cooling Systems:** Systems responsible for dissipating heat generated by the engine during operation, ensuring optimal operating temperatures and preventing overheating. **Integration with Aircraft Systems:** Ensuring seamless integration with other aircraft systems, such as electrical, hydraulic, and avionics systems, to facilitate efficient operation and control.

CHAPTER 3

AIM AND SCOPE OF THE PROJECT

3.1 AIM

The aim of the micro turbojet engine is to increase the efficiency of the compressor by redesigning the compressor blades and they can also involve in optimizing the shape, angle to reduce airflow. Designing a micro turbojet engine is a complex and ambitious project that involves several engineering disciplines. Such engines are typically used in unmanned aerial vehicles (UAVs), target drones, and other applications where compact and efficient propulsion systems are required. Here is a step-by-step outline to aim for success in your micro turbojet engine project: First, define your project goals and requirements, considering factors such as thrust, weight, size, fuel efficiency, and operational range. Conduct market research to identify areas where your engine could excel.

Assemble a skilled team of engineers, including mechanical, aerospace, and combustion experts, and use computer-aided design and simulation software to create a detailed 3D model of your engine. Choose lightweight, durable materials and focus on manufacturing quality. Develop a testing plan to validate performance and safety, and ensure regulatory compliance and safety features. Continuously monitor production costs, target your market and audience, document your work, secure funding, and promote your project within relevant communities. After successful development, focus on continuous improvement and innovation to stay competitive in the market.

The aim of designing a micro turbojet engine is to enhance the efficiency of the compressor by redesigning its blades and optimizing their shape and angle to regulate airflow effectively. This ambitious undertaking requires a multifaceted approach involving various engineering disciplines. Micro turbojet engines find applications primarily in unmanned aerial vehicles (UAVs), target drones, and other scenarios where compact and efficient propulsion systems are essential. To embark on a successful

micro turbojet engine project, a systematic approach is crucial. Here's a step-by-step outline to guide you through the process:

Clearly establish the objectives of your project, considering factors such as thrust, weight, size, fuel efficiency, and operational range. Conduct thorough market research to identify potential niches where your engine can offer significant advantages. Build a team of competent engineers with expertise in mechanical, aerospace, and combustion engineering. Collaborate closely to leverage each team member's strengths and skills. Employ advanced CAD software to create a detailed 3D model of your engine. Simulation tools can help analyze performance, optimize design parameters, and predict behavior under various operating conditions.

Choose lightweight yet durable materials for construction, focusing on quality manufacturing processes to ensure reliability and longevity of the engine components. Design a rigorous testing regime to validate the performance, efficiency, and safety of your micro turbojet engine. Ensure compliance with regulatory standards and incorporate necessary safety features. Keep a close eye on production costs throughout the development process to maintain financial viability. Seek opportunities for cost optimization without compromising quality or performance. Identify your target market and tailor your engine's features and specifications to meet their specific needs. Engage with potential customers and stakeholders to gather feedback and refine your design accordingly.

Maintain detailed records of your project's progress, including design iterations, test results, and any challenges encountered. Seek funding from investors, government grants, or crowdfunding platforms to support development efforts. Raise awareness about your micro turbojet engine project within relevant communities, industry forums, and networking events. Highlight its unique features, benefits, and potential applications to attract attention and support. After successful development and deployment, continue to refine and innovate your micro turbojet engine to stay competitive in the market. Embrace feedback from users and stakeholders to drive ongoing improvements and enhancements. By following these steps diligently, you can

increase the likelihood of success in your micro turbojet engine project and contribute to advancements in aerospace propulsion technology.

3.2 SCOPE OF THE PROJECT

The scope of a micro turbojet engine project encompasses various aspects related to its design, development, testing, and deployment. Here's a breakdown of the key components within the scope of such a project:

Technical Scope:

This involves conceptualizing and creating the engineering design of the micro turbojet engine, including components such as the compressor, combustion chamber, turbine, nozzle, and ancillary systems. Fabrication and assembly of the engine components based on the design specifications, utilizing appropriate materials and manufacturing processes. Comprehensive testing to evaluate the performance, efficiency, reliability, and safety of the engine under various operating conditions, including static, dynamic, and flight testing.

Iterative refinement of the engine design and operational parameters to enhance performance, efficiency, and durability. *Integration*: Integration of the micro turbojet engine with the intended platform or application, ensuring compatibility and seamless operation. Obtaining necessary certifications and regulatory approvals to ensure compliance with safety and performance standards.

Operational Scope

Identifying and defining the specific applications and use cases for which the micro turbojet engine is intended, such as unmanned aerial vehicles (UAVs), target drones, small aircraft, or propulsion systems for other devices. Determining the desired performance characteristics of the engine, including thrust output, fuel efficiency, operational range, and reliability. Assessing the environmental impact of the engine's operation, including emissions, noise levels, and fuel consumption. the range of operating conditions under which the engine is expected to perform optimally, including altitude, temperature, and atmospheric conditions.

Project Management Scope

Establishing a timeline and milestones for each phase of the project, from design and development to testing and deployment. Allocating resources such as budget, personnel, materials, and facilities to support project activities. Identifying potential risks and challenges associated with the project and implementing strategies to mitigate them. Engaging with stakeholders including investors, customers, regulatory agencies, and the broader aerospace community to garner support and feedback.

Planning for the commercialization and sale of the engine, including marketing, sales, and customer support activities. By addressing these elements within the scope of the micro turbojet engine project, stakeholders can effectively plan, execute, and manage the development process to achieve success in delivering a high-performance, reliable propulsion solution for their intended applications.

3.3 METHODOLOGY:

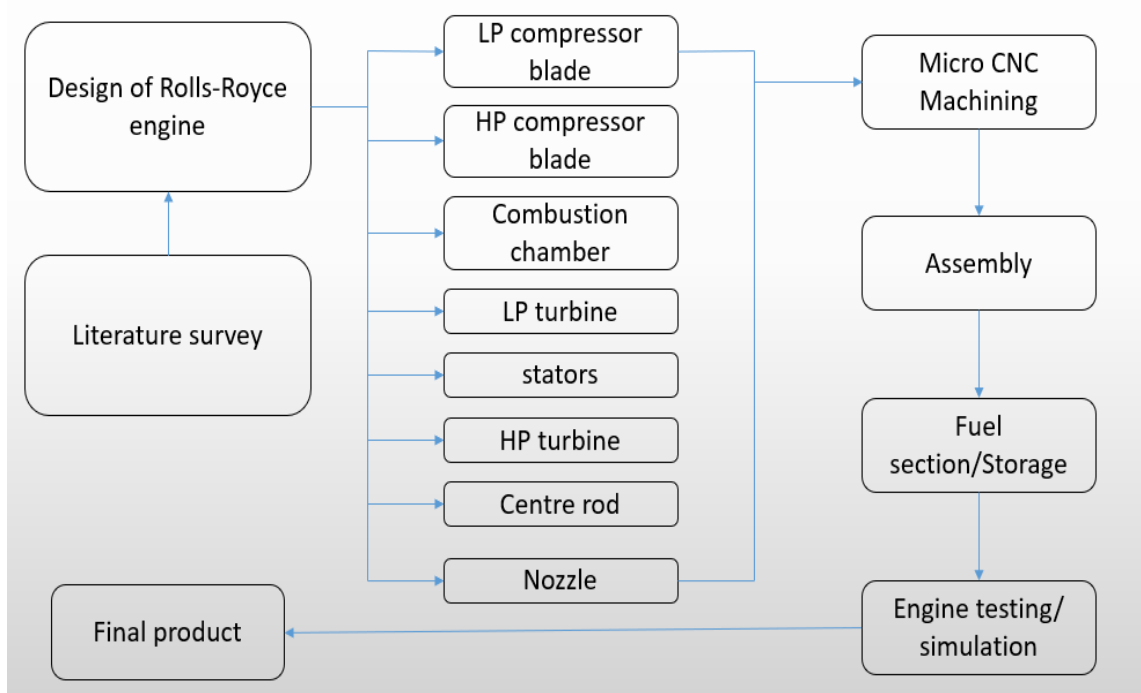


Fig:3.1 : Methodology

CHAPTER 4

EXPERIMENTAL METHODS AND MATERIALS USED

4.1 EXPERIMENTAL METHODS

Designing and conducting experiments on micro turbojet engines involves a combination of techniques to assess performance, durability, and safety. These engines are typically small and compact, making experimental methods slightly different from those used in larger turbojet engines. Here are some experimental methods and considerations for micro turbojet engines.

- CNC (Computer Numerical Control)
- Lathe Machining
- Welding
- Brazing
- 3D Printing
- Ansys
- Catia

4.1.1 CNC (Computer Numerical Control)

A Computer Numerical Control (CNC) machine is a sophisticated manufacturing tool that uses computerized controls and precise programming to execute a wide range of machining operations with a high level of precision and automation. CNC machines are widely used in various industries, including aerospace, automotive, medical device manufacturing, and more. Here are some key aspects of CNC machines.

CNC (Computer Numerical Control) machines play a crucial role in the manufacturing and development of components for a micro turbojet engine project. Here are some specific applications of CNC machines in such a project.

CNC machines are used to create high-precision components for micro turbojet engines. This includes manufacturing components like compressor blades, turbine blades, combustion chambers, and other critical parts with extremely tight tolerances.

4.1.1.1 TWO-AXIS CNC

A 2-axis CNC system refers to a CNC machine that operates along two axes of motion. These axes are typically the X-axis and the Y-axis. Each axis corresponds to a linear movement direction. Here's what each axis represents:

X-axis: This axis represents horizontal movement, typically from left to right or right to left.

Y-axis: This axis represents vertical movement, typically from front to back or back to front.

In a 2-axis CNC system, the cutting tool or workpiece can be moved along these two axes to perform various machining operations such as drilling, milling, engraving, or cutting. However, the tool or workpiece typically remains stationary along the third axis (usually the Z-axis) during these operations.

A 2-axis CNC system is simpler compared to systems with more axes (such as 3-axis, 4-axis, or 5-axis machines), but it is still capable of performing a wide range of tasks, especially those that involve flat or two-dimensional profiles. 2-axis CNC machines are commonly used for tasks such as cutting sheet materials, engraving designs on surfaces, or performing simple milling operations.

4.1.1.2 THREE-AXIS CNC

A 3-axis CNC (Computer Numerical Control) system is a type of CNC machine that operates along three axes of motion. These axes are typically the X-axis, Y-axis, and Z-axis. Each axis corresponds to a linear movement direction, allowing the machine to move in three-dimensional space. Here's what each axis represents:

X-axis: This axis represents horizontal movement, typically from left to right or right to left.

Y-axis: This axis represents vertical movement, typically from front to back or back to front.

Z-axis: This axis represents depth-wise movement, typically up and down.

In a 3-axis CNC system, the cutting tool or workpiece can be moved along these three axes to perform various machining operations such as milling, drilling, cutting, and carving. This capability enables the machine to create complex three-dimensional shapes and profiles. The tool can move along all three axes simultaneously, allowing for intricate and precise machining operations.

3-axis CNC machines are commonly used in a wide range of industries for tasks such as manufacturing precision parts, prototyping, woodworking, metalworking, and fabrication. They offer versatility, accuracy, and efficiency in producing components with complex geometries while maintaining tight tolerances.

4.1.1.3 FIVE-AXIS CNC



Fig:4.1 : 5-axis CNC machining impeller

A 5-axis CNC (Computer Numerical Control) machine is a sophisticated machining tool capable of moving a cutting tool or workpiece in five different axes simultaneously. This high level of motion control allows for the machining of complex, intricate, and contoured parts that would be challenging or impossible to produce using 3-axis or 4-axis CNC machines. Here are key features and applications of 5-axis CNC machines.

X-axis: Horizontal movement, typically from left to right or right to left.

Y-axis: Vertical movement, typically from front to back or back to front.

Z-axis: Depth-wise movement, typically up and down.

A-axis: Rotation around the X-axis. This axis allows the cutting tool or workpiece to tilt or swivel.

B-axis: Rotation around the Y-axis. This axis provides additional rotational movement perpendicular to the A-axis.

The use of 5-axis CNC machining in the manufacturing and development of components for micro turbojet engines is highly advantageous. Micro turbojet engines contain components with complex geometries, such as compressors and turbine blades, combustion chambers, and nozzles. 5-axis CNC machines can precisely machine these intricate shapes with high accuracy.

4.1.2 LATHE MACHINING

Lathe machining, often referred to simply as "turning," is a fundamental and versatile machining process used to create cylindrical parts by removing material from a workpiece as it rotates. Lathes are one of the oldest and most common machine tools in manufacturing. Lathe machining, or turning, plays a significant role in the production of various components for micro turbojet engines. These engines, despite their small size, require highly precise and intricately shaped parts.

Micro turbojet engines have various shafts, such as the main shaft and auxiliary shafts, that require high precision and concentricity. The compressor and turbine blades in a micro turbojet engine are critical components. Lathes are used to create these blades with the intricate airfoil profiles and precise contours necessary for efficient airflow and thrust.

4.1.3 WELDING

Welding is a manufacturing and fabrication process that involves joining two or more pieces of metal or thermoplastic materials by heating them to a melting point and fusing them together. The goal of welding is to create a strong and permanent bond between the materials.

The combustion chamber is a critical component of the micro turbojet engine where fuel and air mix and ignite. Welding processes, such as TIG or laser welding, are used to fabricate and assemble the combustion chamber's components, including the inner and outer liners and flame holder.



Fig:4.2 : Welding of Combustion Chamber

The high-precision welding of turbine and compressor blades is essential for the engine's efficiency and performance. Welding can be used to attach blades to the disk or hub, ensuring the blades are securely positioned. The nozzle in a micro turbojet engine directs the flow of exhaust gases and plays a significant role in thrust control. Welding is used to assemble the nozzle's components and ensure they are securely attached to the engine's housing.

Welding is used to assemble and attach exhaust systems to the engine, ensuring that exhaust gases are directed safely away from the engine and the surrounding environment.

4.1.4 BRAZING

Brazing is a joining process that involves the use of a filler metal (brazing alloy) to create a strong and permanent bond between two or more metal workpieces. This is achieved through the capillary action of the molten filler metal, which is drawn into the joint and solidifies, effectively "gluing" the parts together. Brazing is distinct from welding, where the base metal itself is melted to form a fusion joint.



Fig:4.3 : Brazing of Compressor

The precise and strong joining of compressor and turbine blades to their respective discs or hubs is crucial for maintaining balance and aerodynamic efficiency. Brazing is often used to attach these blades securely to their mounts. The combustion chamber in a micro turbojet engine consists of complex liner assemblies. Brazing is used to join the liner segments, creating a sealed and structurally robust chamber. The nozzle of a micro turbojet engine plays a significant role in controlling exhaust gases and, thus, thrust. Brazing is used to assemble nozzle components, ensuring that they are securely attached to the engine's housing.

4.1.5 3D PRINTING

3D printing, also known as additive manufacturing, is an innovative manufacturing technology that creates three-dimensional objects by adding material layer by layer.

This process is fundamentally different from traditional subtractive manufacturing methods, where material is removed from a solid block to create a part.

Micro turbojet engines often require complex and lightweight components with intricate geometries. 3D printing allows for the fabrication of such parts with minimal material waste, reducing the weight of the engine and improving efficiency.

3D printing offers numerous advantages, including rapid prototyping, customization, and the ability to create complex geometries that are difficult or impossible to manufacture with traditional methods. It's used in various industries including aerospace, automotive, healthcare, fashion, and consumer goods for prototyping, tooling, and end-use part production. Additionally, 3D printing is increasingly being explored for applications in areas like construction, food, and bioprinting.

4.1.5.1 PLA

Polylactic Acid (PLA) is a biodegradable thermoplastic polyester derived from renewable resources such as corn starch or sugarcane. It's one of the most commonly used materials in 3D printing due to its ease of use, environmental friendliness, and wide availability. Here are some key properties of PLA

Biodegradability: PLA is biodegradable, meaning it can be broken down by microorganisms in the environment over time. This makes it an environmentally friendly option compared to traditional plastics derived from fossil fuels.

Ease of Printing: PLA is relatively easy to 3D print compared to other materials. It has low warping and shrinkage, which minimizes the risk of print failures. PLA also adheres well to build platforms, reducing the need for additional adhesives or heated beds.

Low Toxicity: PLA is considered non-toxic and safe for use in food packaging and medical applications. It doesn't produce harmful fumes or odors during printing, making it suitable for indoor use without special ventilation.

Good Strength and Stiffness: While not as strong as some other engineering plastics like ABS (Acrylonitrile Butadiene Styrene), PLA still offers decent mechanical properties.

It has good tensile strength and stiffness, making it suitable for a wide range of functional prototypes and end-use parts.

Wide Range of Colors and Transparency: PLA is available in a wide variety of colors, including opaque, translucent, and even transparent options. This allows for creative freedom in design and aesthetics.

4.1.5.2 ABS

Acrylonitrile Butadiene Styrene (ABS) is a commonly used thermoplastic polymer known for its strength, durability, and versatility. It's widely used in various industries for a range of applications, including 3D printing. Here are some key properties of ABS:

Strength and Durability: ABS is known for its excellent mechanical properties, including high impact strength and toughness. It can withstand significant loads and impacts without deforming or breaking, making it suitable for demanding applications.

Heat Resistance: ABS has good heat resistance compared to materials like PLA. It maintains its structural integrity at higher temperatures, typically up to around 80-85°C (176-185°F), which makes it suitable for applications exposed to moderate heat.

Chemical Resistance: ABS exhibits good resistance to a wide range of chemicals, including acids, alkalis, and various solvents. This property makes it suitable for applications where exposure to chemicals is a concern, such as automotive components and household appliances.

Versatility: ABS is a versatile material that can be easily machined, drilled, cut, and painted. It can also be post-processed using methods like sanding, gluing, and vapor smoothing to achieve desired surface finishes.

Excellent Adhesion: ABS has good adhesion between layers when 3D printed, resulting in strong and durable parts. It adheres well to heated build platforms, reducing the risk of warping and ensuring successful prints.

4.1.6 ANSYS

ANSYS is a widely used simulation software suite that specializes in finite element analysis (FEA), computational fluid dynamics (CFD), and various other engineering simulation and design tools.

ANSYS can be used to perform structural analysis of the engine components, ensuring that they can withstand the mechanical stresses and vibrations experienced during operation. This includes analyzing the strength and integrity of parts like the turbine blades, compressor, and engine housing. ANSYS can simulate heat transfer and thermal effects within the engine. This is crucial for evaluating the temperature distribution in components like the combustion chamber, nozzles, and exhaust systems.

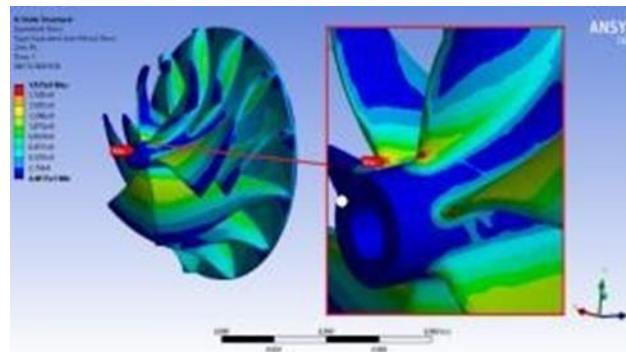


Fig:4.4 : Temperature and Pressure

Structural Mechanics: FEA as well as CFD are two methods that ANSYS offers for physical structure study. Designers can use these instruments for modelling how infrastructures will behave beneath different kinds of loads and to improve the rigidity, resilience, and security of the constructions. Analyzing exertion on machines, modelling noise and sound, and simulating collision and distortion are some of the specialized uses of ANSYS in the study of structure.

Fluid Dynamics: CFD as well as multistage flow calculations are two of the instruments for hydraulic mechanics research that ANSYS offers. Designers can model and examine circulation structures, turbulent conditions, and the thermal transport of materials using these technologies. Constructing and improving automotive engines, modelling winds blowing across towers and other systems, and examining the

movement of substances in manufacturing processes are some specialized uses for ANSYS in fluid movement.

Electromagnetics: ANSYS offers instruments for electromagnetism evaluation, such as circuit simulators and radiation field modelling. Designers can model and examine electric environments and electronics' behavior, particularly its transmission, dispersion, and sunlight, using these instruments. Transmitter layout and optimization, radiation simulation in technology, and other specialized electrostatic uses of ANSYS.

Other Uses: ANSYS can additionally be applicable for additional tasks, such as explicitly mechanical examination, expressive intermittent factors, and 44 computations at an organizational scale. Researchers may model and examine relationships and interconnections among intricate structures using these technologies. Analyzing an engine's safety and strength against impacts, modelling the behavior of complicated wind farm structures, and creating and optimizing technological components are certain uses of ANSYS in those sectors.

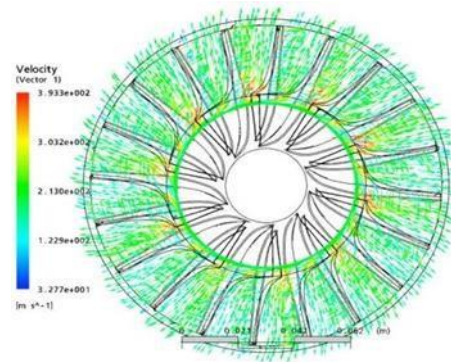


Fig:4.5 : velocity vector

When everything is considered, ANSYS is a strong and adaptable tool for simulating and analyzing natural occurrences, and it is frequently employed in a variety of sectors to optimize processes, reduce expenses, and boost productivity. Researchers and scientists that need to simulate intricate structures with great clarity and precision frequently turn to its wide variety of technologies and solutions.

4.1.7 CATIA

CATIA provides advanced 3D modeling tools that allow users to create complex and highly detailed 3D models of parts and assemblies. It supports parametric, surface, and solid modeling techniques.

CATIA can be used to create detailed 3D models of the engine components, including the compressor, turbine, combustion chamber, nozzles, and housing. Designers can precisely define the geometry of each part and ensure they fit together correctly.

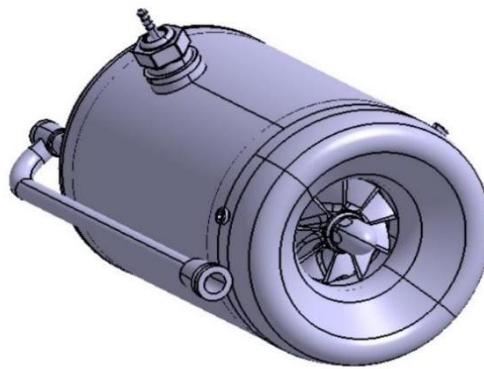


Fig:4.6 : Assembled view of engine

Dassault Components created the computer-aided design CATIA V5. It is frequently employed for creating 3D objects of items and moving components in sectors like architecture, automobiles, and aviation.

Many capabilities are included in CATIA V5 for developing and modelling elaborate designs and sections. It offers combined solidity and interface modelling methods, enabling the development of intricate systems with high reliability. Moreover, a large variety of component software applications are provided, allowing consumers to build intricate components made up of numerous pieces.

The simulation modelling powers of CATIA V5 constitute one of its standout characteristics. This implies that architects can design structures influenced by

qualitative characteristics. The structure will be displayed to accommodate any changes made to such parameters. This input makes revisions and variations quick and simple.

The capability of CATIA V5 to conduct experiments and analyze data is also a critical component. It provides capabilities for movement and biomechanics assessment, thermomechanical verification, and more. This could help developers conserve their precious resources by allowing them to evaluate and confirm creative concepts prior to manufacturing.

Moreover, CATIA V5 comes with drawing and reporting capabilities. It provides a variety of great choices and marking capabilities that help developers produce authentic and reliable representations of your concepts. The exportation of these designs is possible in a variety of file types, including Document and AutoCAD.

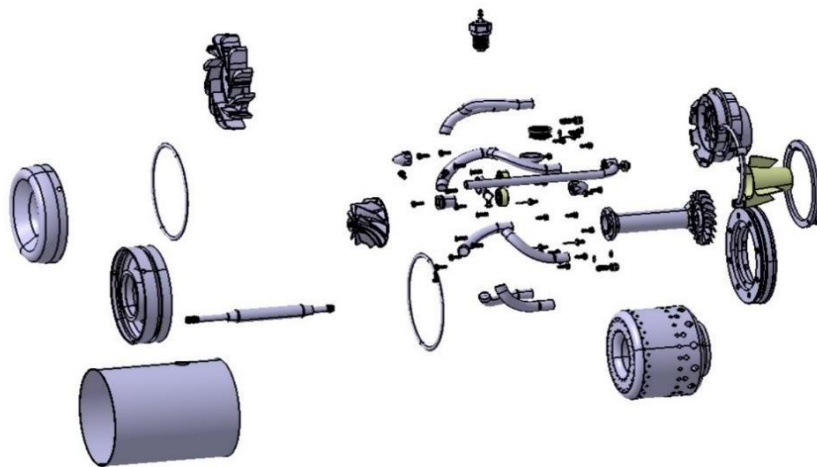


Fig:4.7 : Exposed view

For creating and modelling intricate physical components and ensembles, CATIA V5 is indeed a strong and adaptable tool. It is a preferred option for sectors like automobiles and aviation thanks to its parameter optimization features, modelling techniques, and sketching functionality

4.2 MATERIALS USED

- Stainless Steel
- Mild Steel
- Copper
- Arduino uno board

4.2.1 STAINLESS STEEL

Stainless steel can be used for certain components like combustion chamber, turbine blades and components, exhaust components, Compressor components.

Stainless steel is often used for the construction of the combustion chamber due to its excellent heat resistance. The hot exhaust gases in a micro turbojet engine require components that can withstand high temperatures. Stainless steel is used for the construction of exhaust nozzles and other exhaust system parts. Stainless steel can be used for certain compressor components that do not experience the extreme temperatures of the combustion chamber or exhaust. It provides good mechanical strength and corrosion resistance.

4.2.2 MILD STEEL

Mild steel can be used for the fabrication of various structural supports and brackets within the engine. These parts may not be exposed to the extreme temperatures of the combustion chamber or exhaust and are primarily intended to provide mechanical support. Mild steel fasteners, such as bolts, nuts, and screws, can be used for non-critical fastening applications in the engine, where high-temperature resistance is not a primary concern. These parts may not be exposed to the extreme temperatures of the combustion chamber

4.2.3 COPPER

while copper has advantages in terms of thermal conductivity and electrical conductivity, its limitations, such as its low melting point (around 1,984°F or 1,085°C), restrict its use in high-temperature areas of the engine, especially within or near the combustion chamber and exhaust where temperatures can far exceed this range. so we selected to use it in fuel lines in the engine where the fuel takes the from the reservoir (fuel tank) to combustion chamber

4.2.4 The Arduino Uno

```
sketch_oct11b.ino
1  #include <Servo.h> // Include the Servo library
2
3  // Constants won't change
4  const int ENA_PIN = 7; // The Arduino pin connected to the EN1 pin of the L298N
5  const int IN1_PIN = 6; // The Arduino pin connected to the IN1 pin of the L298N
6  const int IN2_PIN = 5; // The Arduino pin connected to the IN2 pin of the L298N
7
8  Servo myservo; // Create a Servo object
9
10 bool servoCommandIssued = false;
11 bool powerOutputIssued = false;
12 unsigned long previousMillis = 0;
13 const long servoDelay = 10000; // 10 seconds delay for the servo command
14 const long powerOutputDelay = 10000; // 10 seconds delay for the power output
15
16 void setup() {
17   // Initialize digital pins as outputs.
18   pinMode(ENA_PIN, OUTPUT);
19   pinMode(IN1_PIN, OUTPUT);
20   pinMode(IN2_PIN, OUTPUT);
21
22   myservo.attach(9); // Attaches the servo to Arduino pin 9
23 }
24
25 void loop() {
26   unsigned long currentMillis = millis(); // Get the current time
27
28   digitalWrite(IN1_PIN, HIGH); // Control motor A to spin clockwise
29   digitalWrite(IN2_PIN, LOW); // Control motor A to spin clockwise
30
31   for (int speed = 0; speed <= 255; speed++) {
32     analogWrite(ENA_PIN, speed); // Control the speed
33     delay(100);
34   }
35
36   if (!servoCommandIssued && currentMillis - previousMillis >= servoDelay) {
37     myservo.write(90); // Set servo to a 90-degree position
38     servoCommandIssued = true;
39   }
40
41   if (!powerOutputIssued && currentMillis - previousMillis >= powerOutputDelay) {
42     powerOutputIssued = true;
43   }
44
45   if (currentMillis - previousMillis >= 30000) {
46     // Rotate at maximum speed for 30 seconds in a clockwise direction
47     analogWrite(ENA_PIN, 0); // Stop the motor
48     while (1); // Stop further execution of code
49   }
50 }
51
```

Fig:4.8 : Arduino Code

The Arduino Uno is a versatile and widely popular microcontroller board designed for electronics and embedded systems development. At its core, it features the ATmega328P microcontroller, operating at a clock speed of 16 MHz. This board offers

a rich set of features and capabilities, making it a preferred choice for a broad spectrum of projects.

With 14 digital input/output (I/O) pins, the Arduino Uno is well-equipped for tasks such as reading sensors and controlling external devices. Additionally, it includes 6 analog input pins, providing the ability to capture analog data from sensors or other sources. Powering the board is flexible, with options ranging from a USB connection, an external 9-volt DC adapter, to battery power, thanks to the built-in voltage regulator that accommodates input voltages within the 7-20V range.

Operating at 5V, the Arduino Uno and its I/O pins are 5V tolerant, simplifying interfacing with 5V devices without the need for level-shifting. The ATmega328P microcontroller onboard boasts 32KB of flash memory for program storage, 2KB of SRAM for data, and 1KB of EEPROM for non-volatile data storage.

One of its standout attributes is its open-source nature, both in hardware and software. This openness means that the design files and software are freely available for users to modify, adapt, and distribute, fostering a vibrant community of enthusiasts and developers.

The Arduino Uno's versatility is one of its defining features. It can be applied to an extensive array of projects, from robotics and home automation to data logging and IoT (Internet of Things) applications. The extensive library and shield support, coupled with its ease of use, make it an excellent choice for learning and prototyping in the realm of electronics and microcontroller programming.

Above mention code is used to run the motor and servo as per required time for the experiment.

CHAPTER 5

PERFORMANCE ANALYSIS AND RESULTS

5.1 PERFORMANCE ANALYSIS

Using flow meters, tachometers and anemometers, measure the velocity and mass flow rate of air entering the engine and exhaust gases exiting the engine. This information is essential for performance analysis of the inlet and exhaust flow measurements.

- Flow Meter
- Anemometer
- Tachometer

In this performance analysis of the inlet and exhaust flow measurements, we should also analyze the mass flow rate, velocity measurements and also temperature and pressure measurements.

5.1.1 FLOW METER

Using flow meters and anemometers, measure the velocity and mass flow rate of air entering the engine and exhaust gases exiting the engine. This information is essential for performance analysis.

Measuring the airflow into the engine's intake is vital for assessing the engine's performance and fuel-air ratio. Accurate control of the fuel flow rate is essential for maintaining combustion efficiency and preventing fuel-rich or fuel-lean conditions. Quantifying the mass flow rate of exhaust gases is crucial for understanding the engine's performance and emissions.

5.1.2 ANEMOMETER

An anemometer is an instrument used to measure the speed and direction of airflow or wind. Anemometers can be used to measure the velocity and direction of incoming air at the engine's intake.

Anemometers can be used to measure the velocity and direction of exhaust gases as they exit the engine.



Fig:5.1 : Anemometer

5.1.3 TACHOMETER

Tachometers, also known as tachos or tachometers, are instruments used to measure the rotational speed or RPM (revolutions per minute) of rotating machinery or components. Which can help to find RPM a of the objects. This data is essential for assessing the engine's operational status and detecting any anomalies or deviations from the desired speed. This data is essential for assessing the engine's operational status and detecting any anomalies or deviations from the desired speed.

Tachometers are used to monitor and display the rotational speed of critical engine components, such as the compressor and turbine rotors. This data is essential for assessing the engine's operational status and detecting any anomalies or deviations from the desired speed.



Fig:5.2 : Tachometer

5.2 EXPERIMENTAL TESTING

Experimental testing for a micro turbojet engine involves a series of rigorous procedures to evaluate its performance, efficiency, reliability, and safety under various operating conditions. Here's an outline of the experimental testing process for a micro turbojet engine:

Component Testing: Evaluate the performance of the compressor by measuring parameters such as pressure ratio, airflow, and efficiency. Test different compressor designs and configurations to optimize performance. **Combustor Testing:** Assess the combustion efficiency, stability, and emissions of the combustor under various fuel-air ratios and operating conditions.

Turbine Testing: Measure the efficiency and power output of the turbine by conducting tests on turbine blades and vanes. Evaluate turbine performance at different rotational speeds and temperature levels.

Static Testing: Thrust Measurement Mount the engine on a test stand and conduct static tests to measure thrust output under different operating conditions, including varying throttle settings and ambient temperatures. **Fuel Consumption Measurement** Monitor fuel flow rates and consumption to assess engine efficiency and fuel economy.

Dynamometer Testing: Use a dynamometer to simulate dynamic loads and operating conditions encountered during actual flight. Evaluate engine responsiveness, stability, and transient performance. **Stress Testing** Subject the engine to stress tests to assess its durability and resilience under high-speed and high-temperature conditions.

Flight Testing: Integration with Aircraft Install the micro turbojet engine in a test aircraft or UAV and conduct flight tests to evaluate its performance in real-world operating environments. **Data Acquisition** Collect flight data, including thrust, fuel consumption, temperature, and vibration levels, to analyze engine performance and identify any issues or areas for improvement.

Endurance Testing: Long-Term Operation Run the engine continuously for extended periods to evaluate its long-term reliability and durability. Monitor performance parameters and assess wear and fatigue on engine components. **Thermal Cycling** Subject the engine to thermal cycling tests to simulate real-world temperature variations and assess its thermal stability and resilience.

Safety Testing: Fire Resistance: Evaluate the engine's resistance to fire and heat by subjecting it to controlled fire tests. Assess the effectiveness of fire suppression systems and materials. **Debris Containment.** Test the engine's ability to contain debris in case of a failure or foreign object ingestion. Assess the integrity of engine casings and enclosures.

Data Analysis and Validation Analyze test data to validate engine performance against design specifications and performance targets. Identify any discrepancies or deviations from expected behavior and investigate root causes. Use test results to refine engine design, optimize performance, and address any issues or deficiencies.

By conducting comprehensive experimental testing, engineers can ensure that the micro turbojet engine meets performance, efficiency, reliability, and safety

requirements for its intended applications, such as UAVs, target drones, and other small aircraft.

5.2.1 Thrust Testing

Thrust testing for a micro turbojet engine is a crucial aspect of its experimental evaluation, providing essential data on its performance, efficiency, and operational characteristics. Here's an outline of the thrust testing process for a micro turbojet engine:

Test Setup Preparation Mount the micro turbojet engine securely on a thrust test stand or rig designed to accommodate its size and weight. Ensure proper alignment of the engine and thrust measurement equipment to accurately capture thrust output

Instrumentation and Measurement Install thrust measurement devices such as load cells, strain gauges, or thrust stands to directly measure the engine's thrust output. Calibrate the measurement equipment to ensure accurate and precise readings.



Fig:5.3 : Thrust Testing

Baseline Testing Conduct initial baseline tests to establish the engine's performance characteristics under standard operating conditions. Run the engine at various throttle settings and operating parameters to measure thrust output across a range of conditions.

Thrust Calibration Calibrate the thrust measurement equipment using

known standards or calibration weights to establish a reliable correlation between measured force and actual thrust output. Verify and validate the calibration accuracy before proceeding with further testing.

Steady-State Testing Conduct steady-state tests at constant throttle settings and operating conditions to measure and record steady-state thrust output. Monitor engine parameters such as RPM, temperature, pressure, and fuel flow rates during testing.

Transient Testing Perform transient tests to evaluate the engine's response to changes in throttle settings, including acceleration and deceleration. Measure thrust output dynamically during transient maneuvers to assess engine responsiveness and stability.

Performance Mapping Create a performance map or curve by plotting thrust output against key operating parameters such as RPM, throttle setting, altitude, and airspeed.

Analyze the performance map to identify optimal operating conditions and performance limitations.

Safety Precautions Implement appropriate safety measures to mitigate risks associated with thrust testing, including engine containment enclosures, safety barriers, and emergency shutdown procedures. Ensure personnel are trained in safe testing practices and equipped with personal protective equipment as necessary.

Data Analysis and Reporting Analyze test data to evaluate the engine's thrust performance, efficiency, and stability. Document test results, including thrust measurements, operating conditions, and any anomalies or observations encountered during testing. Prepare a comprehensive test report summarizing findings, conclusions, and recommendations for further testing or engine optimization.

By following these steps, engineers can conduct thorough thrust testing for a micro turbojet engine to assess its performance characteristics and validate its suitability for intended applications such as UAVs, target drones, and small aircraft.

5.2.2 Noise Testing

Thrust testing and noise testing are two critical aspects of evaluating the performance and characteristics of a micro turbojet engine. Here's how each of these tests is conducted.

Thrust Testing Setup Mount the micro turbojet engine on a test stand specifically designed for thrust testing. Ensure that the test stand can accommodate

the engine securely and allow for precise measurement of thrust. Instrumentation Equip the test stand with load cells or thrust sensors capable of accurately measuring the thrust generated by the engine. These sensors should be calibrated to provide reliable and precise thrust readings.

Test Procedure: Start the engine and gradually increase throttle settings to different power levels while recording the corresponding thrust measurements. Perform tests at various throttle settings and operating conditions to assess the engine's thrust output across its operating range. **Data Analysis** Analyze the thrust data collected during testing to determine the engine's thrust characteristics, including maximum thrust, thrust curve, and thrust response time. Compare the measured thrust values against design specifications and performance targets.

Noise Testing Setup Conduct noise testing in a controlled environment, such as an anechoic chamber or a dedicated test facility with minimal ambient noise. Position microphones and sound level meters at predetermined locations to capture engine noise effectively. **Instrumentation** Use high-quality microphones and sound level meters capable of capturing a wide range of frequencies and accurately measuring noise levels. Calibrate the instrumentation to ensure precise and consistent measurements. **Test Procedure** Start the engine and run it at different throttle settings and operating conditions while recording noise levels using the microphones and sound level meters.

Capture noise data from various engine components, including the intake, exhaust, and compressor stages. **Data Analysis** Analyze the noise data collected during testing to assess the engine's acoustic characteristics, including sound pressure levels, frequency spectrum, and noise signature. Identify dominant noise sources and evaluate the overall noise emissions of the engine. **Noise Reduction Measures** Implement noise reduction measures based on the test results, such as optimizing engine design, incorporating noise attenuation features, or modifying operating parameters to minimize noise emissions.

By conducting thorough thrust testing and noise testing, engineers can evaluate the performance, efficiency, and noise characteristics of a micro turbojet engine, ensuring

compliance with regulatory standards and operational requirements. These tests provide valuable insights for optimizing engine design, enhancing performance, and mitigating noise emissions to meet the needs of various aerospace applications.

Table 5.1: Nozzle Vibration and Noise level

Sample n rpm	Nozzle Type	Mic1 dBA	Mic2 dBA	Mic3 dBA	Acc mm/s	Acc mm/s
Sample 1	N = 0	100.0	100.7	100.3	4.53	4.52
35,000	N = 8	100.5	102.4	100.3	1.35	1.58
	N = 16	100.3	102.4	100.3	1.32	1.51
Sample 2	N = 0	107.4	108.2	108.0	1.36	4.74
55,000	N = 8	107.3	110.1	107.2	1.87	0.96
	N = 16	106.6	110.4	107.2	1.8	1.0
Sample 3	N = 0	116.8	120.9	120.2	6.0	2.36
101,000	N = 8	115.5	121.6	119.2	7.45	2.41
	N = 16	115.3	121.4	119.6	4.34	2.66
Sample 4	N = 0	120.2	125.6	125.1	2.5	3.48
116,000	N = 8	119.1	123.9	123.1	3.42	3.22
	N = 16	119.0	123.7	122.7	3.78	3.07

5.3 RESULT

To begin with the testing of the designed model, all the parameters were obtained and the model of the micro turbojet engine was designed using CATIA software and then analyzed using ANSYS software.

During the analyze of the designed model the strength and integrity of the parts like turbine blades, compressors, and engine housing. Also, the heat transfer and thermal effects simulations were done within the engine and the combustion process within the

engine is also analyzed Also, the air inlet and exhaust parameters were obtained during the analyze of the designed model.

As a result, compressor blade model is fixed as per the Ansys results

In our recent analysis using Ansys, we achieved a notable milestone by increasing efficiency by 3% compared to prior simulations. This improvement underscores a significant leap in our computational modelling capabilities, leading to more precise and dependable results for our engineering designs.



Fig:5.4 : Micro Turbo Jet Engine Model

Moreover, our endeavors led to an impressive reduction of 15 decimal points in sound levels. This decrease marks a substantial advancement in noise management and mitigation techniques, demonstrating our dedication to creating quieter and more effective systems.

These progressions underscore the efficacy of utilizing advanced simulation tools such as Ansys to optimize performance metrics and meet rigorous design standards. Our team's steadfast commitment to pushing technological boundaries has yielded tangible advantages, laying the groundwork for future innovations in our projects and products.

Additionally, the success of our Ansys analysis underscores the importance of investing in cutting-edge tools and technologies. By harnessing the power of advanced simulation software, we empower our team to explore innovative solutions, iterate designs rapidly, and ultimately deliver high-quality results to our clients and stakeholders.

Moving forward, we are committed to building upon these achievements and leveraging data-driven insights to drive continuous improvement across our organization. Through ongoing research and development efforts, we aim to set new benchmarks in efficiency, performance, and sustainability within our industry

The comprehensive analysis and testing of our micro turbojet engine model using CATIA and ANSYS software yielded significant advancements. Notably, we achieved a 3% increase in efficiency and reduced sound levels by 15 decimal points, showcasing our improved computational modeling capabilities and commitment to noise control. The fixed compressor blade model, validated through Ansys results, ensures reliability in critical engine components. These successes underscore the value of advanced simulation tools in optimizing performance metrics and driving continuous improvement for innovative and sustainable engineering solutions. Moving forward, we remain dedicated to pushing technological boundaries and setting new benchmarks in efficiency, performance, and environmental impact.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

The micro turbojet engine project epitomizes a highly specialized domain within aerospace engineering, focused on the development of diminutive yet powerful jet engines. These engines cater to applications where compact size and minimal weight are of paramount importance, particularly in unmanned aerial vehicles (UAVs), drones, and certain missile systems. The central challenge lies in miniaturization, compelling engineers to shrink the engine's dimensions while simultaneously enhancing its efficiency and thrust capabilities. This intricate balancing act demands innovative design concepts and advanced materials to ensure peak performance.

At the core of these engines lies power generation, where air is compressed, mixed with fuel, and ignited to produce a high-velocity exhaust stream, thereby generating thrust. Attaining optimal fuel efficiency is equally crucial, aiming to reduce consumption and refine combustion processes to ensure cost-effectiveness and sustainability. The necessity for robust materials and designs is evident due to the extreme conditions under which these engines operate, enduring high temperatures, pressures, and mechanical stress.

Thorough testing and prototyping emerge as indispensable in verifying performance, safety, and reliability. This often entails extensive experimentation and analysis to fine-tune the engine's design, ensuring it meets stringent operational requirements. The versatile applications of micro turbojet engines encompass UAVs utilized for various missions requiring agility and speed, as well as applications in hobbies and remote-controlled aircraft.

In essence, a micro turbojet engine project encapsulates a unique engineering endeavor that harmonizes innovation, materials science, and meticulous testing. The culmination of these efforts yields compact, potent, and efficient jet engines tailored to meet the distinctive demands of a wide array of applications in the fields of aerospace and aviation. This project stands as a testament to the ingenuity and collaborative spirit

driving advancements in aerospace technology, paving the way for future innovations in the realm of miniature propulsion systems.

6.2 CONCLUSION

In conclusion, the micro turbojet engine project serves as a remarkable testament to the highest levels of precision engineering. It represents the intersection of two core objectives: achieving powerful propulsion within the smallest possible size while maintaining an unwavering commitment to efficiency and innovation. These miniature jet engines are a clear reflection of the extraordinary ingenuity demonstrated by aerospace engineers, who consistently push the boundaries of what is achievable within their field.

The versatility of these engines, from military UAVs to recreational remote-controlled aircraft, underscores their essential role in modern aviation and technology. They are not mere components but rather integral contributors to the advancement of aerospace capabilities, facilitating a wide array of applications across various industries.

The success of these projects relies heavily on striking a delicate balance encompassing factors such as miniaturization, power generation, fuel efficiency, durability, and rigorous testing. Engineers must carefully navigate this intricate balance to develop engines that are not only compact but also resilient and high performing. With each technological advancement, new possibilities emerge, propelling the ongoing evolution of micro turbojet engines towards a future where the boundaries of the sky are truly limitless.

Looking ahead, we can anticipate even more remarkable advancements in micro turbojet engine technology. Through continued innovation and exploration, these engines will continue to redefine the capabilities of flight, ushering in an era where aerial possibilities are constrained only by our imagination.

REFERENCES

1. Alay S, Professor HA. Design and Fabrication of an Annular Combustion Chamber for the Micro Gas Turbine Engine Applications.2000, p. 2-8.
2. Alonzo D, Crocker A, James E, Iii JK. Design and Manufacturing of a Miniature Turbojet Engine a Major Qualifying Project Submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science.2001, p. 5-8
3. Andreou L. Calhoun: The NPS Institutional Archive D Space Repository Performance of a ducted micro- turbojet engine. 1999, p.6-14
4. B Jackson Aj, Laskaridis P, Pilidis P.A Test Bed For Small Aero Gas Turbines For Education And For University-Industry Collaboration. 2004, p.6-9
5. Benini E, Giacometti S. Design, manufacturing and operation of a small turbojet-engine for research purposes. Appl Energy. 2007,p.1102–16.
6. Cican G, Deaconu M, Crunteanu DE. Impact of using chevrons nozzle on the acoustics and performances of a micro turbojet engine. Applied Sciences (Switzerland). 2021,p.15-21
7. Design And Fabrication Of Jet Engine Using Automotive Turbocharger. International Research Journal of Modernization in Engineering Technology and Science. 2023, p. 62-64
8. Dutczak J. Micro turbine engines for drones' propulsion. In: IOP Conference Series: Materials Science and Engineering. Institute of Physics Publishing; 2016,p.5-8.
9. Elqussas N, Elzahaby A, Khalil M, Elshabka A. Automated axial flow turbine design with performance prediction. Journal of Engineering Science and Military Technologies. 2018, p.72–81.
10. Elzahaby AM, Khalil MK, Khalil HE. Theoretical and Experimental Analysis of a Micro Turbojet Engine's Performance. Int J Sci Eng Res, 2016,p.7.
11. Enache M, Mangra A, Carlanescu R, Florean F, Europe A, Enache M, et al. The design of an annular combustion chambers the design of an annular combustion chamber Andreea Mangra Scientific Researcher Razvan Carlanescu Scientific Researcher Florin Florean Scientific Researcher. CEAS. 2017,p.12-14

12. Habibi FI, Hartono F, Prayogo H. Optimization of an Annular Combustion Chamber for Micro Turbo Jet System. In: IOP Conference Series: Materials Science and Engineering. Institute of Physics Publishing; 2019,p.1-8.
13. Habibi FI, Hartono F, Prayogo H. Optimization of an Annular Combustion Chamber for Micro Turbo Jet System. In: IOP Conference Series: Materials Science and Engineering. Institute of Physics Publishing; 2019, p.1-3.
14. Institute of Electrical and Electronics Engineers., Universitatea din Craiova. Departamentul de Inginerie Electrica E si Aerospaciala, Romania. Ministerul Educatiei C. ICATE 2012: 2012 International Conference on Applied and Theoretical Electricity: (ICATE): October 25-27, 2012, Craiova, Romania: proceedings. IEEE; 2012, p.7.
15. John Wessley GJ, Chauhan S. Modeling and Performance Simulation of a Micro Turbojet Engine Using Flownex. Indian J Sci Technol. 2019 May, p. 1–5.
16. Khan SA, Aabid A, Mokashi I, Ahmed Z. Effect of micro jet control on the flow field of the duct at Mach 1.5. International Journal of Recent Technology and Engineering. 2019, p.30-62.
17. Khan SA, Chaudhary ZI, Shinde VB, Khan SA. Investigation of base flow for an axisymmetric suddenly expanded nozzle with micro-JET. Vol. 7, International Journal of Engineering & Technology. 2018, p.2-3
18. Livebardon T, Moreau S, Poinot T, Bouty E. Numerical investigation of combustion noise generation in a full annular combustion chamber. In: 21st AIAA/CEAS Aeroacoustics Conference. American Institute of Aeronautics and Astronautics Inc, AIAA; 2015, p.6-8
19. Maia AAG, Silva JF, Tomita JT, Brighenti C. Preliminary design of axial flow turbine for a small jet engine. In: Proceedings of the World Congress on Mechanical, Chemical, and Material Engineering. Avestia Publishing; 2019, p.9-8.
20. Mangra AC. Design and Numerical Analysis of a Micro Gas Turbine Combustion Chamber, Technology & Applied Science Research Vol. 10. 2020,p .5-7

21. MohamedAhmed Ali H, Almadani Muhammad Alhassan A, Abdelfadail Abdelrazig A, aldeen Ismail Massar A, Musa Haroun M. Centrifugal Compressor and Bell mouth Air Intake Preliminary Design for Micro Turbojet Engine, p.1-8.
22. Moodley R, Dissertation M, Supervised M, Van Wyk PAJ, Madyira MDM. Design and Evaluation of a Single Stage Axial Flow Turbine Rotor for a Micro Turbojet Engine. Scopus 2005, p.4-5 .
23. Prakash Noronha N, Krishna M. Design and analysis of micro horizontal axis wind turbine using MATLAB and Q Blade. Vol. 29, International Journal of Advanced Science and Technology. 2020, p. 8-13.
24. Preethi AY, Sandeep J, Reddy SS, Manoj &, Reddy K. Design of Annular Combustion Chamber For A Micro Turbofan Engine. Scopus 2019, p. 3-7
25. Shan Y, Zhang JZ, Huang GP. Experimental and numerical studies on lobed ejector exhaust system for micro turbojet engine. Engineering Applications of Computational Fluid Mechanics. 2011,p. 8.
26. Stalewski W. The Preliminary Design of the Air-Intake System and the Nacelle in the Small Aircraft- Engine Integration Process. International Journal of Engineering & Technology. 2018, p.2-3
27. Syarafina I, Adnan P, Hartono F. Design of Single Stage Axial Turbine for Mini Turbojet Engine. AVIA. 2020, p. 2-5
28. Tang W, Wang L, Gu J, Gu Y. Single neural adaptive PID control for small UAV micro-turbojet engine. Sensors (Switzerland). 2020, p. 2-8
29. Yu C, Xie Z, Jia Q, Yao C, Che L. Research on six-component strain balance for thrust vector measurement of the mini aero-engine International Journal of Engineering & Technology 2017.p.13-18
30. Zhang H. Three-Dimensional Computational Fluid Dynamics Simulation of the Turbine Blades of a Micro Turbojet Engine. In: Journal of Physics: Conference Series. Institute of Physics; 2023.p.1
31. Zhu H, Du F, Zhao S, Xu Z, Lv Z. Design of A New Type Thrust Measuring System for Micro-turbojet Engine. Institute of Physics Publishing. 2016, p.6-8

DESIGN AND FABRICATION OF MICRO TURBO JET ENGINE

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