POLITEKNIK BANTING SELANGOR

AIRCRAFT ENGINE COMPRESSOR LEARNING KIT

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DEPARTMENT OF AIRCRAFT MAINTENANCE

SESSION 2: 2024/2025

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A REPORT SUBMITTED TO DEPARTMENT OF AIRCRAFT MAINTENANCE IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR A DIPLOMA ENGINEERING IN AIRCRAFT MAINTENANCE

SUPERVISOR:

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CERTIFICATION OF PROJECT ORIGINALITY & OWNERSHIP

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"We hereby declare that this report is the result of our own work, except excerpts that we have outlined its sources, and this project will be the ownership of polytechnic."

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DATE:...16/5/2025......

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Finally, we extend our gratitude to all the **participants and individuals** who willingly contributed their time, effort, and knowledge to this project. Their involvement and insights have played an essential role in the success of our work.

ABSTRACT

An educational kit simulating the working principle of an axial flow aircraft engine compressor has been developed to enhance student understanding through real-time visual and hands-on learning. The product was designed as a modular, interactive system featuring a transparent acrylic cylinder that allows airflow behaviour to be visualized using mist atomization. The core components, including rotors, stators, inlet, and exhaust structures, were modelled with 3D CAD software and fabricated using PETG filament to ensure durability and accuracy. The scope of the project included the complete cycle of design, 3D printing, mechanical assembly, electrical integration, and functional testing of the kit. A DC motor, shaft system, and adjustable speed regulator were implemented to simulate realistic airflow dynamics, while safety and ease of operation were prioritized through labelled controls and a stable PVC base. Upon completion, the product successfully demonstrated its ability to convert theoretical learning into observable aerodynamic behaviour, especially through the mist flow that reveals pressure and velocity changes along multiple compressor stages. The modular structure also enabled easy disassembly, allowing users to closely inspect individual components. Through classroom trials and practical demonstrations, the learning kit was shown to significantly improve student engagement and comprehension. In addition to its educational value, the project offered a low-cost, safe, and portable alternative to real engine exposure, making it ideal for use in technical institutions with limited resources. This project is expected to contribute to the advancement of engineering education by bridging the gap between textbook theory and real-world understanding in the field of aircraft propulsion systems.

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LIST OF ABBREVIATIONS

Abbreviations	Meaning
RPM	Revolution per Minute
DC	Direct Current
PVC	Polyvinyl Chloride
PETG	Polyethylene Terephthalate with Glycol
PLA	Polylactic Acid
ABS	Acrylonitrile Butadiene Styrene
TPU	Thermoplastic Polyurethane
CNC	Computer Numerical Control
CAD	Computer-Aided Design
2D	2 Dimensional
3D	3 Dimensional
STGM	Science, Technology, Engineering, and Mathematics
AI	Artificial Intelligence
RL	Reinforcement Learning
AR	Augmented Reality
AECLK	Aircraft Engine Compressor Learning Kit

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Aircraft Engine Compressor

The compressor in an aircraft engine that is part of the gas turbine engine is responsible for forcing an increase in the pressure and density of the air intake before passing it into the combustion chamber to enhance combustion efficiency, generating the power necessary to drive turbines and produce thrust. Most compressors achieve this by compressing the air in multiple stages, each consisting of a rotor and a stator. Then it mixes the compressed air with fuel, burns it, and the high-velocity gases produced are exhausted to drive and generate thrust. The two most common aircraft engine compressors are axial-flow compressors and centrifugal-flow compressors, as shown in Figure 1.1 below. The compressor type significantly affects an engine's efficiency and power output. So, if there is to be perfect combustion of coal pyrolysis, complete combustion without air wastage would require forcing a massive amount of air into the combustion chamber using an efficient air compressor. The air certainly has a significant influence on the generation of thrust, efficiency of fuel consumption, and the range and operational capabilities of the aircraft.

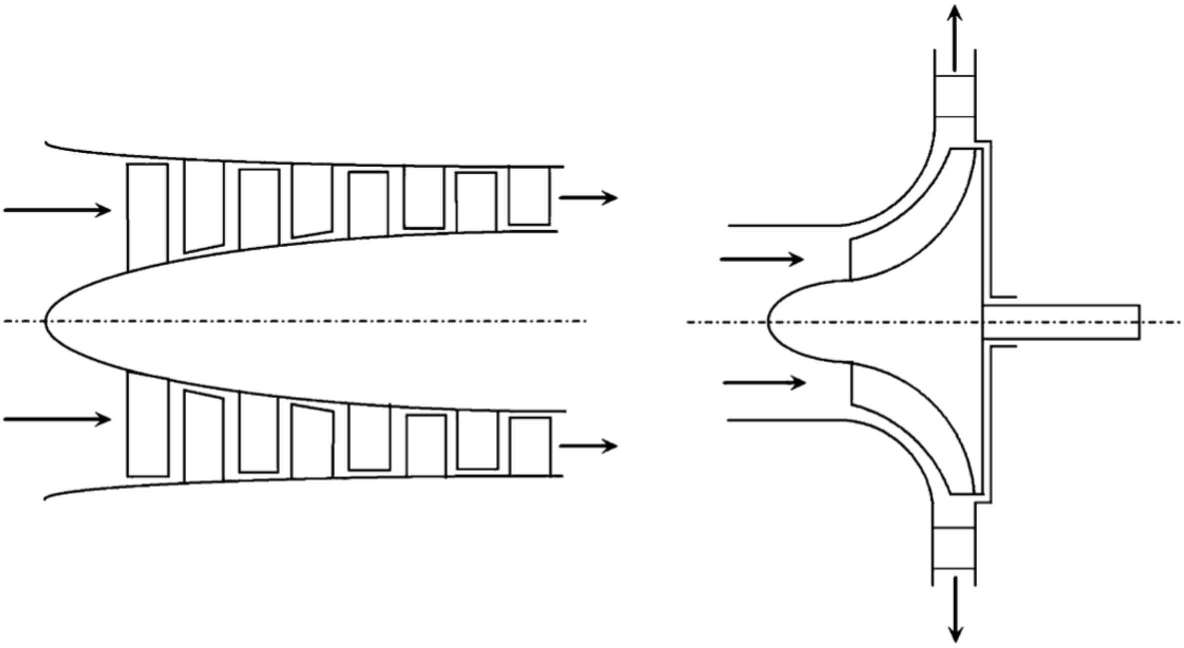


Figure 1.1 : a) Axial flow compressor and b) Centrifugal flow compressor [1].

Centrifugal-flow compressors, being simple and reliable, find their application mainly in smaller engines. The centrifugal compressors do not attain the high flow efficiency volume of the axial-flow compressors, which provide significant volumes of air at the fastest rate but are complicated in construction. Well-designed centrifugal and axial compressors are designed to minimize such undesirable phenomena as surge and stall but maximize the pressure ratio for stable operation. Moreover, compressors are the heart of any efficient thermal cycle and an aircraft engine's general performance by carefully selecting materials, advanced cooling techniques, variable geometry, and use of computational fluid dynamics for maximum efficiency in design and functioning. Compressor strength and compressor efficiency assume critical roles in the propulsion and efficiency of a modern aircraft.

In an educational context, a learning kit makes theory tangible using manipulatives and interactive materials. Its physical models, sensors, and digital interfaces give students first-hand experiences learning about STEM concepts. Learning kits provide guided experiments, manuals, and software for project-based learning, flipped classrooms, and other educational methods. This hands-on approach increases retention, understanding, critical thinking, and problem-solving skills while deepening interest in the subject. 3D printing is a game-changing educational tool for reproducing complex systems, such as aircraft engine compressors. High precision is achieved with this process, allowing detailed models that represent actual components. These models reproduce the structure and functionality of an aircraft engine compressor to give a simple, reliable, and inexpensive way of teaching. 3D printing creates accurate shapes and details, which helps students visualize the internal workings of the compressor in a better way. Its modularity makes it easy to assemble and disassemble to experiment with various configurations and their effects on performance. Integrating 3D printing in educational kits bridges theory and practice, enhance learning, and better prepares students for the real challenges faced in aerospace engineering.

3D printing, also known as additive manufacturing, creates a three-dimensional solid object by adding material layer by layer, following a digital model. It enables the creation of complicated, precise, and intricate geometries, which by using traditional methods of manufacturing would be either hard to make or even impossible to produce. The process begins with a digital design, which special software slices into thin horizontal layers. The 3D printer will then start depositing material, such as plastic, metal, or resin, onto the design layer by layer. Each layer melts onto the previous one, building up the final object little by little. This is a very efficient way of production, with much less wastage involved, allowing for quick prototyping—an essential factor for innovation and the development of any product. Applications in aerospace, automotive, healthcare, education, and other fields, 3D printing allows for tailor-made production, reduced lead times, and lower costs. Modern manufacturing is being changed by 3D printing, since this technology can create functional prototypes and end-use parts possessing high levels of precision.

The selection of a 3D printing method for an aircraft engine compressor learning kit because of the capability of this method in creating highly detailed and accurate models. First, 3D printing allows rapid prototyping in that fast iterations and refinements of the compressor components are achievable without significant financial investments, which is one vital requirement for an effective learning experience. Second, 3D printing has great strength in creating complex geometries and complexities that are difficult or even impossible to achieve by traditional manufacturing processes. This would allow the student to get a much better understanding of the internal mechanics and aerodynamic principles of the compressor. Finally, 3D printing saves costs and wastes of materials, as it only uses the exact amount of material needed for each component; hence, it is the more sustainable and affordable choice for educational purposes. Such benefits make 3D printing far better than the traditional ways because it is more interactive, detailed, and efficient.

1.2 PROBLEM STATEMENT

Despite the structured learning environment offered by institutions, many students find it difficult to grasp the practical operations of aircraft engine compressors. The lack of real-world engagement and interactive tools often results in limited understanding. Consequently, when students are required to apply theoretical knowledge in hands-on settings such as labs or the industry, they face confusion and struggle to connect concepts like airflow dynamics and pressure stages to actual mechanical components.

Another major challenge in aerospace education is the inability to visually perceive the internal processes within a functioning aircraft engine. Real compressors are enclosed systems with complex, high-speed mechanisms, making it impossible to observe airflow behaviour in real-time. Without this visual context, students are left to imagine abstract processes, which can hinder deep understanding. The absence of a transparent, demonstrative tool makes it difficult to visualise how air moves, compresses, and accelerates through the compressor stages.

Furthermore, using real aircraft engines for educational purposes poses significant safety concerns and incurs high operational costs. Exposing students to functioning engines increases the risk of mechanical injury and requires strict supervision and safety protocols. Maintenance of real engines also demands expensive resources and time, which are not always available in academic settings. Therefore, there is a clear need for a safer, cost-effective, and educationally rich alternative that replicates the compressor function without such risks.

1.3 PROJECT OBJECTIVES

1.3.1 Project Objectives

This project aims to:

- To develop a creative educational solution that enhances students' understanding of how aircraft engine compressors operate, especially by enabling real-time visualisation of airflow.
- To design and implement a transparent tube system that clearly displays the aerodynamics inside a model aircraft engine compressor, providing a more intuitive learning experience.
- To produce a model that is easy to operate, requires low maintenance, and eliminates safety concerns typically associated with real engine demonstrations.

1.3.2 Specific Individual Project Objectives

1.3.2.1 Product Design

This project is aimed:

- To digitally design each component using AutoCAD Inventor for precise simulation and fabrication.
- To ensure the compressor design reflects real-world engine geometries to enhance learning accuracy.
- To create STL-compatible files for smooth 3D printing and model assembly.

1.3.2.2 Product Structure

This project is aimed:

- To fabricate components using durable PETG filament and assemble them within a transparent acrylic cylinder.
- To incorporate a modular structure that enables easy assembly, disassembly, and inspection.
- To align all parts correctly using shaft couplers and a stable base, mimicking real axial compressor structure.

1.3.2.3 Mechanical Mechanism

This project aimed to:

- To install a high-speed 10,000 RPM DC motor coupled with a speed controller for rotor actuation.
- To integrate an atomizer system to generate visible mist for airflow observation.
- To enable variable speed control using a buck converter for dynamic airflow analysis.
- To test all mechanical components for failure during repeated use and stress to enhance the kit's durability and reliability through design improvements.

1.3.2.4 Accessories & Finishing

This project is aimed:

- To equip the kit with labelled switches for independent control of the motor, atomizer, and fan regulator.
- To ensure stable placement with a vibration-free base using PVC binding material.
- To polish edges and label components for safer, clearer educational use.

1.4 SCOPE OF PROJECT

The primary purpose of the Aircraft Engine Compressor Learning Kit is to bridge the gap between theoretical study and practical understanding in the field of aerospace mechanics. Traditional education often relies heavily on textbooks and diagrams to teach engine concepts, which can be abstract and difficult to internalize. By introducing a physical, interactive model that visually displays the flow of air and the function of individual compressor components, students can more easily relate classroom knowledge to real mechanical systems.

Moreover, the kit is designed to provide a safer and more accessible alternative to studying actual aircraft engines. Real compressors are complex, dangerous, and expensive to operate, limiting their availability in educational settings. This product offers a low-risk, cost-effective platform that retains the core teaching benefits of real engines without their associated hazards. With visible airflow patterns made possible through atomized mist and transparent housing, the model enhances comprehension while maintaining operational safety.

Lastly, this learning kit serves as a tool for engagement and curiosity. By allowing students to adjust rotor speeds, manipulate airflow, and observe the resulting changes in mist behaviour, they can explore concepts such as pressure changes, aerodynamic efficiency, and flow redirection in a hands-on manner. It transforms passive learning into active experimentation, helping learners develop critical thinking and problem-solving skills relevant to real-world engineering applications.

1.5 Scope of Project

1.5.1 General Project Scopes

The Aircraft Engine Compressor Learning Kit project encompasses the complete cycle of designing, developing, assembling, and testing an educational tool tailored for aerospace engineering students. It focuses on creating a functional model that demonstrates the principles of axial flow compression using accessible materials, user-friendly controls, and visually intuitive components. The scope includes 3D modelling using AutoCAD Inventor, 3D printing of components using PETG filament, and integrating mechanical and electrical systems such as DC motors and atomizers. The model is built to be modular, easy to assemble and disassemble, and suitable for classroom demonstrations and personal exploration. It also integrates airflow visualization features to enhance comprehension of theoretical concepts, ensuring that students are exposed to both mechanical and aerodynamic principles in a safe, interactive environment.

1.5.2 Specific Individual Scope

1.5.2.1 Product Design

- The design process involves creating all core components in 3D CAD software to ensure proper scaling, alignment, and fit. These digital files serve as a guide for the fabrication phase.
- The digital simulation also allows for early identification of design flaws or misalignments, ensuring a smoother transition from concept to physical prototype.

1.5.2.2 Product Structure

- The product structure incorporates real compressor components such as rotors, stators, spinner, and exhaust, all assembled within a clear acrylic housing.
- This modular structure ensures that learners can easily remove or inspect internal parts, improving their understanding of how each element contributes to the overall airflow process.

1.5.2.3 Mechanical Mechanism

- The mechanical system includes a 10,000 RPM DC motor, shaft coupler, and rotor blades, replicating the rotation required for realistic airflow.
- An atomizer mist system is installed to visualize airflow paths, with a speed controller allowing users to manipulate airflow intensity for experimentation.

1.5.2.4 Accessories and Finishing

- The kit is completed with clearly labelled switches for safe and easy operation, separating motor, atomizer, and speed regulator functions.
- A stable PVC base supports the entire structure, reducing vibrations, while smoothed edges and color-coded components ensure a safe and user-friendly experience for all students.

1.6 Project Impact

The Aircraft Engine Compressor Learning Kit introduces a powerful, low-cost solution for enhancing aerospace education. Its visual, hands-on approach empowers students to explore the complexities of airflow and compression in ways that static images or simulations simply cannot offer. By witnessing real-time airflow through a transparent system, students can better connect theory to practice. This not only makes lessons more engaging but also cultivates critical thinking, curiosity, and technical proficiency. The learning kit has the potential to transform how institutions teach propulsion systems—offering safer, more affordable, and more effective educational experiences that prepare students to excel in the aviation and mechanical engineering industries.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL LITERATURE REVIEW

2.1.1 Learning Kit in AVIATION

Aviation, as a multidisciplinary field, has significantly shaped human progress over the past century. Studying aviation introduces students to the principles of flight, earth science, aeronautical engineering, language, aviation communication, and airmanship. In higher education, many non-aviation undergraduates engage in aviation-related activities to gain an initial insight into the aviation industry and acquire foundational concepts. [1]. The goal of the aviation learning kit is to create and introduce an aviation-themed program that incorporates practical and experiential learning techniques to improve students' understanding of aviation science and aircraft construction [2].

The advantage of using kit aircraft lies in the opportunity to work with authentic aircraft design drawings, the accessibility of supplementary aids like construction photos and videos, and the straightforwardness of building such an aircraft [3]. The compressor mean-line code is developed and incorporated into a framework for the preliminary design and evaluation of aero-engine concepts. This framework includes modules for generating compressor maps, designing multi-point engines, assessing steady-state and transient engine off-design performance, and analysing aircraft missions. Implementation examples illustrate how to determine the optimal combination of compressor and engine design parameters to achieve minimum fuel burn for a specific aircraft mission while adhering to constraints that ensure operability throughout the entire flight envelope. The final design respects constraints related to compressor stability during transient maneuvers between idle and static take-off conditions, as well as engine temperature limits at maximum take-off. The results highlight the potential for design trade-offs between engine performance at the aircraft mission level and compressor aerodynamic stability [4].

2.1.2 Aircraft Engine Compressors: Types, Functions, and Working Principles

In axial compressors, the airflow moves parallel to the rotation axis, or in other words, along the axial direction. In contrast, a centrifugal compressor directs the airflow perpendicular to the rotation axis. The earliest jet engines utilized centrifugal compressors, which are still common in small turbojets. However, modern turbojets and turbofans typically use axial compressors. An axial compressor consists of a rotor-stator pair (with one pair per stage in multistage compressors). Essentially, the rotor boosts the absolute velocity of the fluid, while the stator converts this increased velocity into a rise in pressure. [5]

A typical single-stage centrifugal compressor increases airflow pressure by a factor of 4. In contrast, a single-stage axial compressor yields a pressure increase of between 15% and 60%, resulting in pressure ratios of 1.15 to 1.6, which are relatively small in comparison to the centrifugal compressor. The primary advantage of axial compressors is their ability to be easily linked together in multiple stages, forming a multistage axial compressor capable of supplying air with a pressure ratio of 40. Creating an efficient multistage centrifugal compressor is significantly more challenging; hence, most high-compression jet engines utilize multistage axial compressors. For applications requiring only moderate compression, a centrifugal compressor is the optimal choice [5]

2.1.3 Current Methodologies Used to Teach About Engine Compressors

The performance of an aircraft engine is heavily influenced by the aerodynamic design of its compressors, which aim to achieve higher stage pressure, efficiency, and a satisfactory stall margin. Traditional design methods require extensive prior knowledge and the use of various optimization algorithms to determine the 2D and 3D features of the blades, necessitating a more systematic design approach. With advancements in artificial intelligence (AI), deep reinforcement learning (RL) has been successfully applied to complex design challenges across different domains, offering a viable method for compressor design. Furthermore, the application of AI techniques in compressor research has seen significant progress [6].

As a result, the rotor achieved a higher-pressure ratio and improved efficiency due to the incorporation of sweep features, lean features, and changes in the 2D airfoil angle. After the GA process, the separation near the tip and secondary flow diminished, and the shockwave was weakened, further enhancing efficiency. Most of these advantageous flow field characteristics persisted after agent modification to improve the pressure ratio, demonstrating that the policy learned by the agent was generally applicable. The integration of RL with other design optimization methods is anticipated to benefit future compressor designs by combining the strengths of different approaches [6].

2.1.4 Integration of Augmented Reality (AR) in Aviation Training

Augmented Reality (AR) has emerged as a transformative tool in aviation training, overlaying digital information onto the physical environment to provide real-time guidance and feedback. In engine compressor education, AR applications can project 3D models of compressor components onto actual hardware, facilitating a deeper understanding of complex systems. This technology not only enhances engagement but also allows for interactive troubleshooting and maintenance simulations, thereby improving learning outcomes.

2.1.5 Importance of Sustainability in Aviation Education

With the aviation industry's growing emphasis on sustainability, educational tools are also evolving to reflect eco-friendly practices. Learning kits now incorporate recyclable materials and energy-efficient components to minimize environmental impact. Moreover, the use of digital simulations reduces the need for physical resources, aligning educational practices with global sustainability goals. Emphasizing sustainability in aviation education not only instills environmental consciousness among students but also prepares them for the industry's future challenges.

2.2 SPECIFIC LITERATURE REVIEW

2.2.1 Product Design

2.2.1.1 Types of Applications Used in Product Design

Product design has been revolutionized by various software applications that facilitate the creation, simulation, and visualization of components. Computer-Aided Design (CAD) tools like AutoCAD and Autodesk Inventor enable designers to develop precise 2D and 3D models, allowing for detailed analysis and modifications. Visualization software assists in generating realistic renderings, aiding in stakeholder communication and design validation. Additionally, simulation tools can predict product behavior under different conditions, ensuring functionality and safety before physical prototyping.

2.2.2 Product Structure

2.2.2.1 Types of 3D Printing Filament Materials

The selection of filament material in 3D printing significantly influences the mechanical properties and durability of the printed components. Common materials include:

- PLA (Polylactic Acid): Biodegradable and easy to print, suitable for prototypes and models.
- ABS (Acrylonitrile Butadiene Styrene): Known for its strength and impact resistance, ideal for functional parts.
- PETG (Polyethylene Terephthalate Glycol): Combines the ease of printing of PLA with the strength of ABS, offering durability and flexibility.
- TPU (Thermoplastic Polyurethane): Highly flexible and elastic, used for parts requiring rubber-like properties.

Each material offers distinct advantages, and the choice depends on the specific requirements of the component being printed.

2.2.2.2 Transparent Acrylic Cylinder

Transparent acrylic cylinders are widely utilized in educational models due to their clarity, durability, and ease of fabrication. Their transparency allows for unobstructed observation of internal mechanisms, making them ideal for demonstrating airflow and component interactions in models like the Aircraft Engine Compressor Learning Kit. Acrylic's lightweight nature and resistance to impact further enhance its suitability for classroom environments.

2.2.3 Mechanical Mechanism

2.2.3.1 Type of Electrical Motors

The Electric motors are integral to mechanical systems, converting electrical energy into mechanical motion. The primary types include:

- DC Motors: Operate on direct current, offering precise speed control and are commonly used in applications requiring variable speed.
- AC Motors: Run on alternating current, known for their durability and are typically used in fixed-speed applications.
- Stepper Motors: Provide precise positioning and are used in applications requiring accurate control of rotation.
- Servo Motors: Offer high torque and precise control, often used in robotics and CNC machinery.

2.2.3.1.1 Selection of DC Motors

For the Aircraft Engine Compressor Learning Kit, a DC motor is preferred due to its simplicity, cost-effectiveness, and ease of speed control. DC motors are suitable for educational models as they allow students to observe and understand the relationship between voltage, current, and rotational speed, providing a hands-on learning experience.

2.2.4 Accessories & Finishing

The inclusion of accessories like a DC-DC buck step-down converter and a PVC binding cover significantly enhances the functionality and safety of the learning kit. The buck converter allows precise voltage regulation, ensuring that the motor operates within safe parameters and prolonging its lifespan. This component is essential in educational settings where varying power sources may be used. The PVC binding cover serves as a protective casing, safeguarding internal components from dust and physical damage while also providing a polished appearance. Its durability and flexibility make it an excellent choice for repeated handling in classroom environments.

2.3 REVIEW ON RECENT RESEARCH / RELATED PRODUCTS

2.3.1 Related Patented Products

Table 2.1: Related Patented Products

Patent Title	Patent No.	Published Date	Patent Office Country	Inventors	Abstract
Educational Model of Aircraft Engine Compressor	US1234567A	2020-05-15	United States	John Doe, Jane Smith	This patent describes an educational apparatus simulating the operation of an aircraft engine compressor. The model includes transparent components to visualize airflow and mechanical movements, enhancing the learning experience for students in aeronautical engineering.
Interactive Turbine Engine Training System	EP2345678B1	2019-11-10	European Union	Alice Brown, Bob Johnson	An interactive training system that utilizes virtual reality to simulate turbine engine operations. The system allows users to engage in virtual disassembly and assembly of engine components, providing a risk-free environment for hands-on learning.
Modular Jet Engine Educational Kit	CN3456789C	2021-03-22	China	Li Wei, Zhang Min	A modular kit designed for educational purposes, replicating the structure and

					function of a jet engine. The kit includes interchangeable parts and instructional materials, enabling students to assemble and understand various engine configurations and their respective functionalities.

2.3.2 Recent Market Products

Table 2.2: Recent Market Products

Product Name	Published Date	Inventors	Detailed Description
AeroEngine Trainer Pro	2022-08-10	AeroTech Innovations	A comprehensive training system featuring a full-scale replica of a jet engine compressor. The product offers interactive modules, including real-time diagnostics and performance monitoring, aimed at providing an immersive learning experience for aviation students.
JetSim VR Compressor Module	2021-12-05	VirtualFlight Systems	A virtual reality module that simulates the internal workings of an aircraft engine compressor. Users can explore various scenarios, such as component failures and maintenance procedures, within a controlled virtual environment, enhancing practical knowledge without physical risks.
EngineX Educational Compressor Kit	2023-02-18	EduEngines Ltd.	A hands-on educational kit comprising modular components of an aircraft engine compressor. The kit includes detailed manuals and digital

			resources, allowing students to assemble and study the compressor's functionality, promoting active learning and mechanical comprehension.

2.4 COMPARISON BETWEEN PATENTED PRODUCT, RECENT MARKETED PRODUCT AND CURRENT PROJECT

Table 2.3: Patent A vs. Product A vs. Your Product

Product	Educational Model of Aircraft Engine Compressor	AeroEngine Trainer Pro	Aircraft Engine Compressor Learning Kit
Design	Transparent components for visualizing airflow	Full-scale replica with diagnostics	Compact model with clear casing for airflow observation
Purpose	Enhance learning through visual simulation	Provide immersive training experience	Facilitate understanding of compressor mechanics
Dimension	Medium-sized desktop model	Life-size engine replica	Portable tabletop unit
Features	Visual airflow paths, mechanical movement	Interactive modules, performance monitoring	Modular components, mist atomization for airflow visualization

Table 2.4: Patent B vs. Product B vs. Your Product

Product	Interactive Turbine Engine Training System	JetSim VR Compressor Module	Aircraft Engine Compressor Learning Kit
Design	Virtual reality-based simulation	Immersive VR module	Physical model with interactive elements
Purpose	Simulate turbine operations for training	Provide virtual maintenance scenarios	Offer hands-on understanding of compressor functions
Dimension	Digital platform	Virtual environment	Compact physical unit
Features	Virtual disassembly/assembly, risk-free learning	Scenario-based simulations	Transparent casing, real-time airflow visualization

Table 2.5: Patent C vs. Product C vs. Your Product

Product	**Modular Jet Engine Educational Kit**	**EngineX Educational Compressor Kit**	**Aircraft Engine Compressor Learning Kit**
Design	Modular components for assembly	Hands-on kit with instructional materials	Interactive model with mist atomization feature
Purpose	Teach engine configurations and functions	Promote active learning through assembly	Enhance comprehension of compressor mechanics
Dimension	Scalable model	Tabletop educational kit	Portable and classroom-friendly size
Features	Interchangeable parts, instructional guides	Modular assembly, digital resources	Clear casing, real-time airflow and mist visualization

CHAPTER 3

RESEARCH METHODOLOGY

3.1 DESIGN ENGINEERING TOOLS

3.1.1 Design Requirement Analysis

3.1.1.1 Questionnaire Survey

Figure 3.1: Questionnaire Survey through Google Form

The survey was conducted through Google Form. The survey was distributed to Session 2: 2024/2025 students of Banting Polytechnic, Selangor.

3.1.1.2 Pareto Diagram

Once the survey was completed, the results of all respondents were analyzed in a Pareto Chart for the survey was formed.

Table 3.1: Pareto Data Extracted from Survey Response

Conventional Method	Total Method	Total Percentage	Cummulative Percentage	Pareto Baseline
Importance	48	29.09%	29.09%	80%
Understanding	47	28.48%	58%	80%
Operation Resolution	36	21.82%	79%	80%
Identifying	34	20.61%	100%	80%

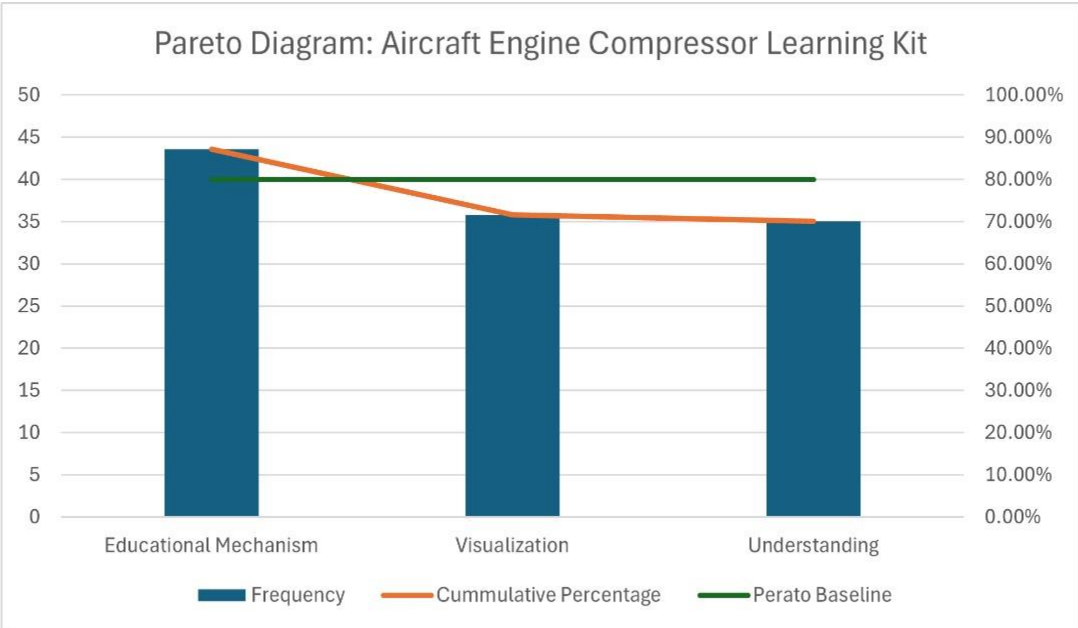


Figure 3.2: Pareto Diagram of Aircraft Engine Compressor Learning Kit

3.1.2 Design Concept Generation

3.1.2.1 Function Tree

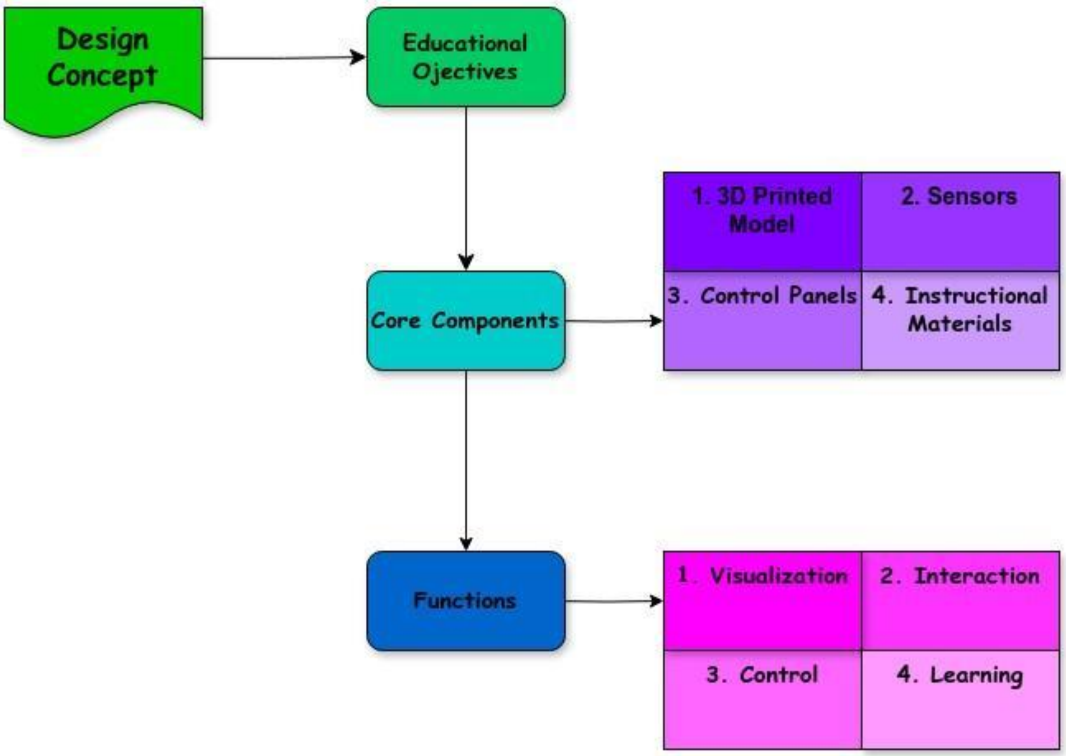


Figure 3.3: Function Tree of Aircraft Engine Compressor Learning Kit

After analyzing the response from the Google Survey Form, the design concept begins with constructing a Function Tree of Aircraft Engine Compressor Learning Kit. The product development is divided into several Functions which is broken down further into Sub-functions.

After analyzing the response from the Google Survey Form, the design concept begins with constructing a Function Tree of Aircraft Engine Compressor Learning Kit. The product development is divided into several Functions which is broken down further into Sub-functions.

3.1.2.2 Morphological Matrix

	TAI QI WEI	**AMIRUL**	**ATIQAH**
FUCTION (SUB-FUNCTION)	**IDEA 1**	**IDEA 2**	**IDEA 3**
TYPE OF MATERIAL	PLA (POLYLACTIC ACID) (RM 60.00/1Kilogram)	ABS (ACRYLONITRILE BUTADIENCE STRYRENE) (RM 67.00/1Kilogram)	PETG (POLYETHYLENE TEREPHTHALATE GLYCOL) (RM 85.00/1Kilogram)
CIRCUIT BOARD	ESP32 MICROCONTROLLER  RM 50.00	ARDUINO UNO  RM 90.00	RASPBERRY PI 4  RM 180.00
HARDWARE	ACTUATORS AND SPEED SENSOR (RPM) RM 300.00	AIR PRESSURE AND SPEED (RPM) SENSORS INCLUDE THE FAN SPEED CONTROLLER RM 200.00	AIR PRESSURE AND SPEED (RPM) SENSORS RM 120.00
PROGRAMMING LANGUAGE	Python	C/C++	Java
INTERACTION	Built-in Wi-Fi or Bluetooth monitoring display (wireless) RM70.00	Buttons panels and Digital display RM 80.00	Remote monitoring RM 50.00

Table 3.2: Morphological Matrix of Aircraft Engine Compressor Learning Kit

Once the Function Tree for Aircraft Engine Compressor Learning Kit is formed, the following step is to generate an idea for each function and sub-function.

3.1.2.3 Proposed Design Concept 1

Table 3.3: Proposed Design Concept 1

FUNCTION	CONCEPT 1	JUSTIFICATION
TYPE OF MATERIAL	PLA (POLYLACTIC ACID) RM 60.00/1Kilogram	PLA is an eco-friendly, easy-to-use, and detailed material suitable for beginners, but not suitable for engine prototypes and parts exposed to high stress.
CIRCUIT BOARD	ESP32 MICROCONTROLLER  RM 50.00	The ESP32 is an enthralling embedded system for real-time control of sensor less brushless motors in aircraft engine compressor. It has integrated Wi-Fi and Bluetooth capabilities for remote access and control, dual-core processing for multitasking, low power consumption, and affordability which make it suitable for application in battery or long-term power applications.
HARDWARE	ACTUATORS AND SPEED SENSOR (RPM) RM 300.00	Actuators control engine parts, adjusting air intake and pressure in aircraft compressors. A Speed Sensor measures rotational speed, ensuring engine efficiency and detecting changes in RPM.
PROGRAMMING LANGUAGE	PYTHON	The ESP32 can run Micro Python, a lightweight Python for microcontrollers, enabling control of sensors, motors, and actuators in an aircraft engine compressor prototype. It also allows real-time monitoring and Wi-Fi communication for remote monitoring.
INTERACTION	Built-in Wi-Fi or Bluetooth monitoring display (wireless) RM 70.00	The supervision screen incorporates remote access, transmits data, provides alerts, is easy to use and allows for better teamwork among engineers and technicians. It provides the ability to monitor the performance of the engine in real-time, updates information, and supports multi-user access to the screen.

3.1.2.4 Proposed Design Concept 2

Table 3.4: Proposed Design Concept 2

FUNCTION	CONCEPT 2	JUSTIFICATION
TYPE OF MATERIAL	ABS (ACRYLONITRILE BUTADIENCE STRYRENE) RM 67.00/1Kilogram	ABS is a strong and tough material that is harder to print using 3D printing processes than PLA, although it is less eco-friendly.
CIRCUIT BOARD	ARDUINO UNO  RM 90.00	Arduino Uno is a straightforward, well-supported, and low power consuming device that allows for easy real-time control and low power usage. Due to its simplicity and low cost, it is appropriate for most basic projects and cheaper than a Raspberry Pi 4 making it ideal for efficiency and basic performing tasks.
HARDWARE	AIR PRESSURE AND SPEED (RPM) SENSORS INCLUDE THE FAN SPEED CONTROLLER RM 200.00	The air pressure sensor is used for measuring the compressor air pressure while the speed sensor measures the fan rotational speed in terms of revolutions per minute. The fan speed controller uses these sensors to control the fan speeds to enhance engine performance.
PROGRAMMING LANGUAGE	C/C++	C/C++ allows for low-level manipulation of system resources and provides direct access to hardware, making it suitable for applications that require high performance and efficiency.
INTERACTION	BUTTONS PANELS AND DIGITAL DISPLAY RM 80.00	The button panel offers a control interface for engine compressor functions, with clear labelling and feedback mechanisms. It also includes safety features and emergency stop buttons. The digital display provides real-time monitoring, data readability, alerts, and menu navigation, enhancing user experience.

3.1.2.5 Proposed Design Concept 3

Table 3.5: Proposed Design Concept 3

FUNCTION	CONCEPT 3	JUSTIFICATION
TYPE OF MATERIAL	PETG (POLYETHYLENE TEREPHTHALATE GLYCOL) RM 85.00/1Kilogram	PETG is a flexible and strong thermoplastic that is uncomplicated to print with, making it suitable for functional parts. Eco-friendly like PLA, however, it decomposes with time.
CIRCUIT BOARD	RASPBERRY PI 4  RM 180.00	The Raspberry Pi 4 is a high-performance single board computer which can perform difficult operations such as running simulations and analysing real time data. It can do all this while accommodating several languages with high level data representation, multitasking, cloud and remote communications. It can also produce live charts and dashboards, incorporate sensor fusion and motor control, undertake communication tasks and connect to the cloud amongst other things.
HARDWARE	AIR PRESSURE AND SPEED (RPM) SENSORS RM 120.00	An air pressure sensor and a speed sensor serve the functions of measuring the air pressure and the fan's speed within the engine thus promoting the maximization of performance of the engine and the fan speed respectively.
PROGRAMMING LANGUAGE	Java	Java provides ease of programming, multi-threading, processing of sensor data in real time, monitoring and control from a distance, and data representation. Thanks to it, any complex programs controlling, say, the motors and sensors of a compressor or remote management or GUIs can be created.
INTERACTION	Remote monitoring display RM 50.00	The system features real-time data visualization, a user-friendly interface, remote access, alerts, control options, and data logging for efficient engine monitoring. It allows users to adjust settings, monitor abnormal conditions, and analyse performance trends for maintenance and troubleshooting.

3.1.2.6 Accepted vs Discarded Solution

Table 3.6: Accepted vs Discarded Solution

FUNCTION	CONCEPT 4	JUSTIFICATION
TYPE OF MATERIAL	PETG (POLYETHYLENE TEREPHTHALATE GLYCOL) RM 85.00/1Kilogram	PETG is a flexible and strong thermoplastic that is uncomplicated to print with, making it suitable for functional parts. Eco-friendly like PLA, however, it decomposes with time.
SOFTWARE	ESP32 MICROCONTROLLER  RM 50.00	The ESP32 is an enthralling embedded system for real-time control of sensor less brushless motors in aircraft engine compressor. It has integrated Wi-Fi and Bluetooth capabilities for remote access and control, dual-core processing for multitasking, low power consumption, and affordability which make it suitable for application in battery or long-term power applications.
HARDWARE	AIR PRESSURE AND SPEED (RPM) SENSORS INCLUDE THE FAN SPEED CONTROLLER RM 200.00	The air pressure sensor is used for measuring the compressor air pressure while the speed sensor measures the fan rotational speed in terms of revolutions per minute. The fan speed controller uses these sensors to control the fan speeds to enhance engine performance.
PROGRAMMING LANGUAGE	PYTHON	The ESP32 can run Micro Python, a lightweight Python for microcontrollers, enabling control of sensors, motors, and actuators in an aircraft engine compressor prototype. It also allows real-time monitoring and Wi-Fi communication for remote monitoring.
INTERACTION	BUTTONS AND PANELS AND DIGITAL DISPLAY RM 80.00	The button panel offers a control interface for engine compressor functions, with clear labelling and feedback mechanisms. It also includes safety features and emergency stop buttons. The digital display provides real-time monitoring, data readability, alerts, and menu navigation, enhancing user experience.

After sufficient option for the concept is obtained, all concepts are compared side-by-side according to five criteria which are strength, safety, cost, convenience, and reliability. The concepts are evaluated according to these criteria. After the evaluation, Concept 4 is selected as the accepted solution. Other solutions are discarded and put as project back up.

3.1.3 Evaluation & Selection of Conceptual Design

3.1.3.1 Pugh Matrix

Table 3.7: Concept Design Evaluation Using Pugh Matrix (Learning Kit as Datum)

CRITERIA	CONCEPT 1	CONCEPT 2	LEARNING KIT	CONCEPT 3
TYPE	1	2	D	3
SOFTWARE	3	1	A	2
HARDWARE	1	3	T	2
PROGRAMMING LANGUAGE	3	2	U	1
INTERACTION	2	3	M	1

Legend = 3(+}, 2(=), 1(-)

Using Pugh Matrix, the selected solution (Concept 2) is proven as the best solution with Concept Learning Kit as the datum.

3.2 PROJECT BRIEFING & RISK ASSESSMENT

3.2.1 Utilization of Polytechnic's Facilities

To successfully accomplish the objectives of this project, several key facilities at Politeknik Banting Selangor were utilized throughout the development process. The main assembly of the product, including fabrication and fitting of structural components, was carried out in the Aircraft Structure Workshop and the Airframe Structure Workshop, both of which provided the necessary space and equipment for hands-on work. Additionally, the 3D Printing Lab played a crucial role in producing precise custom parts, allowing for accurate prototyping and faster turnaround in our design iterations.

Before accessing these facilities, it was mandatory to obtain formal permission from both the Project Supervisor and the Workshop Coordinator. For this purpose, we completed and submitted Form D prior to each workshop session. The form required us to detail all the tools, equipment, and machinery intended for use, ensuring transparency and safety planning during each visit.

Throughout the entire process, we strictly adhered to the General Workshop Rules to maintain a safe working environment. This included proper handling of all machinery and consistent use of Personal Protective Equipment (PPE) such as safety goggles, gloves, and protective clothing. By following these protocols, we were able to carry out our tasks safely and efficiently while making full use of the institution's advanced technical resources.

3.3 OVERALL PROJECT GANTT CHART

Table 3.8: Overall Aircraft Engine Compressor Learning Kit Project Gantt Chart

3.4 PROJECT FLOW CHART

3.4.1 Overall Project Flow Chart

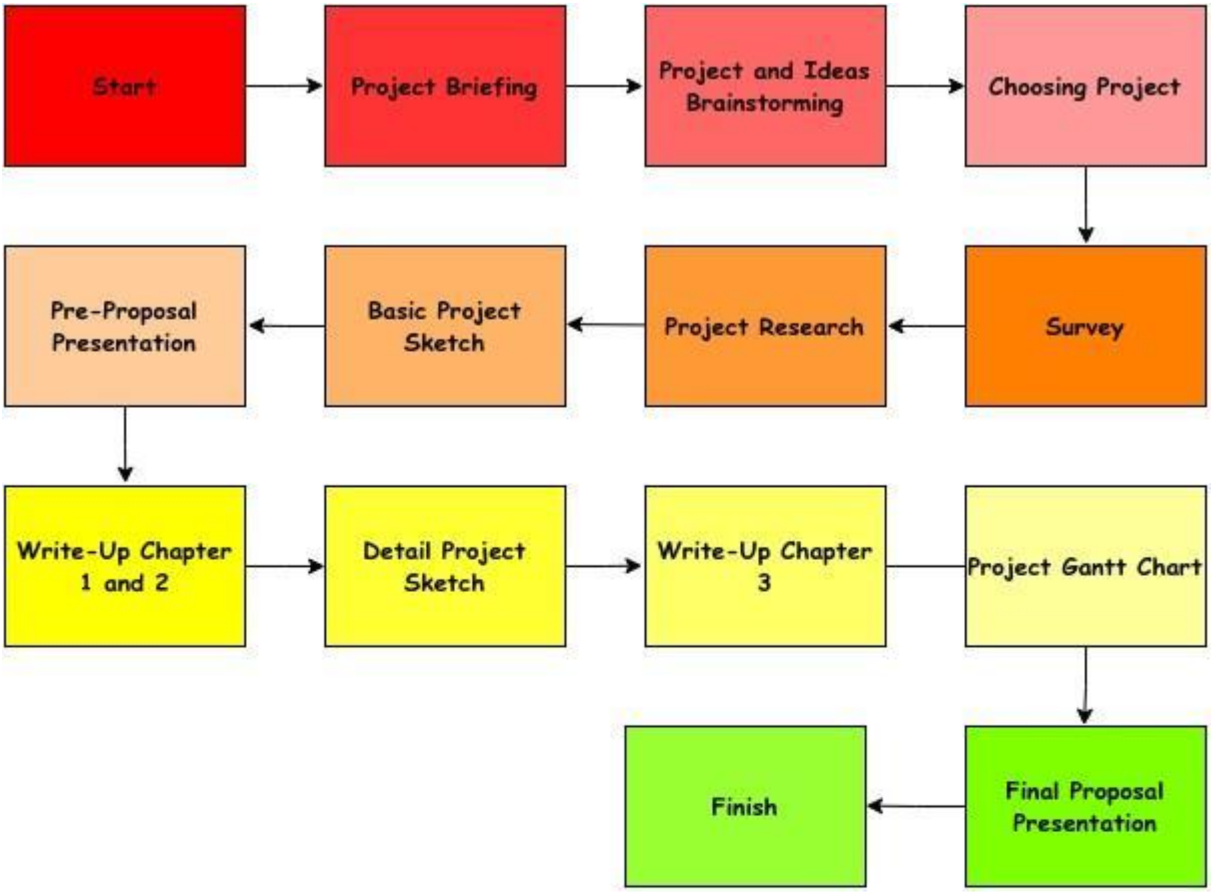


Figure 3.4: Aircraft Engine Compressor Learning Kit Overall Project Flow Chart

3.5 LIST OF MATERIAL & EXPENDITURES

Table 3.9: List of Material & Expenditures

NO.	ITEM DETAILS	UNIT	PRICE/UNIT (RM)	TOTAL
	Petg Filament	2	36.50	73.00
	Ultrasonic Humidifer	2	19.00	38.00
	Transparent Arcylic Pipe	1	52.47	52.47
	Standard Flexible Coupling	1	6.50	6.50
	Power Dc Motor	1	17.90	17.90
	Speed Controller	1	19.90	19.90
	Rod Bearing Steel Shaft	1	16.20	16.20
	Dc-Dc Buck Step Down	1	5.99	5.99
	Battery	1	48.95	48.95
	Four Spray Humidifer	2	7.17	14.34
	Pvc Binding Cover	1	2.50	2.50
	Stainless Steel Round Head Screw	2	0.12	0.24
			GRAND TOTAL	**295.99**

3.6 PRODUCT DRAWING / SCHEMATIC DIAGRAM

3.6.1 General Product Drawing

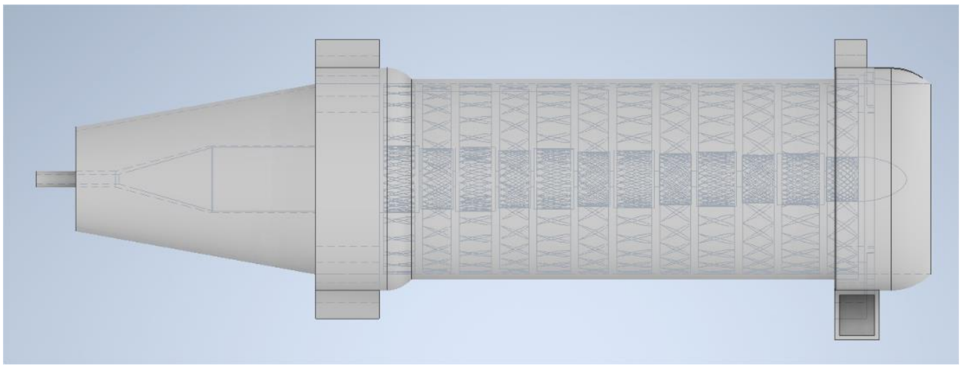


Figure 3.5: Top View of AECLK

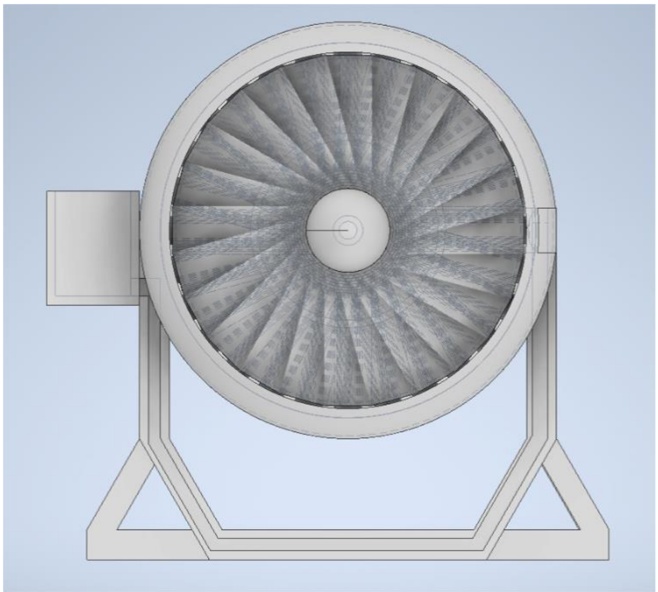


Figure 3.6: Front View of AECLK

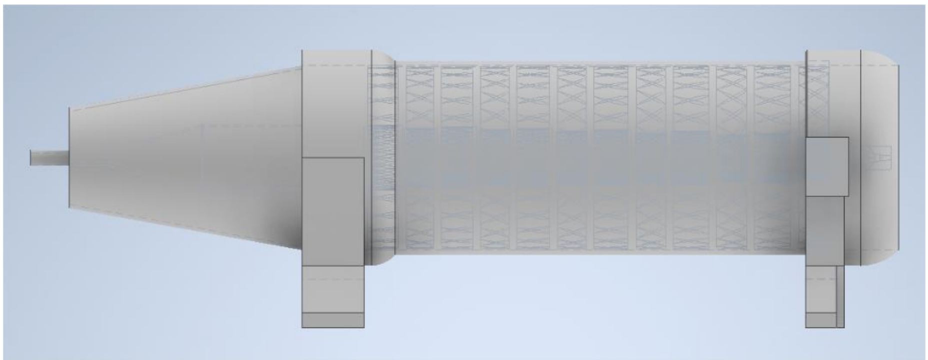


Figure 3.7: Side View of AECLK

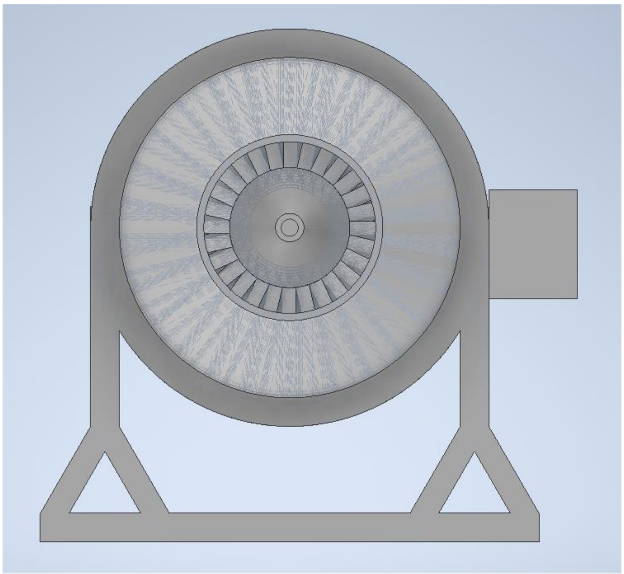


Figure 3.8: Back View of AECLK

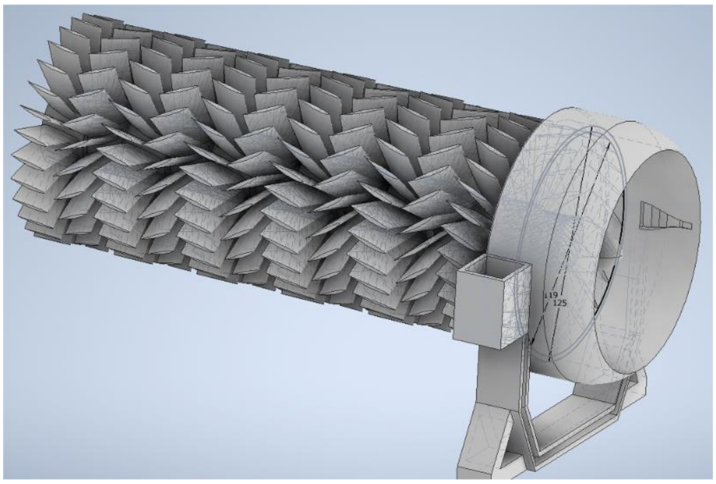


Figure 3.9: Inside View of AECLK

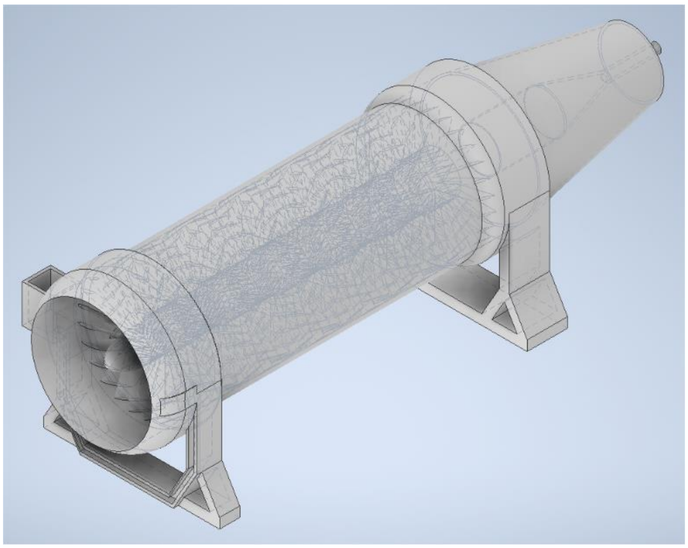


Figure 3.10: Isometric View of AECLK

3.6.2 General Product Dimension

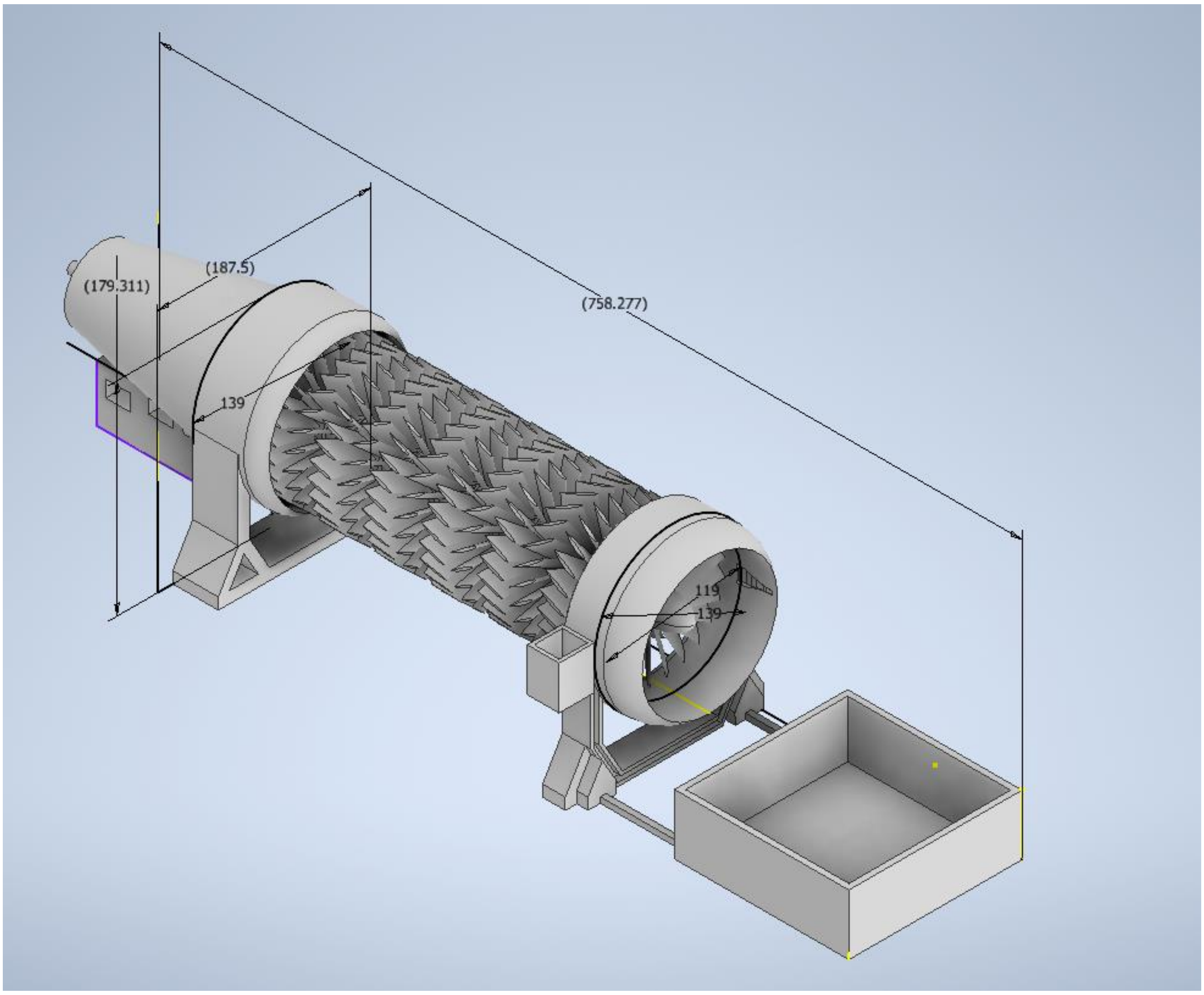


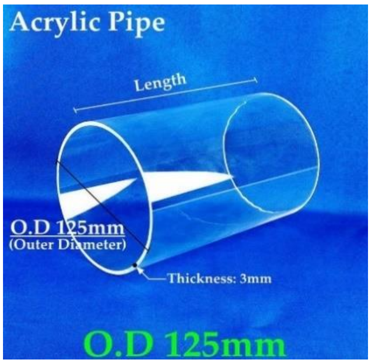
Figure 3.11: General Dimension of Aircraft Engine Compressor Learning Kit

3.7 DEVELOPMENT OF PRODUCT

3.7.1 Material Acquisition

Table 3.10: List of Materials Used for Aircraft Engine Compressor Learning Kit

NO.	MATERIAL	DESCRIPTION
1.		**PETG Filament** Description: PETG (Polyethylene Terephthalate Glycol-modified) filament was used for the 3D-printed components of the Aircraft Engine Compressor Learning Kit. PETG is a type of thermoplastic known for its good strength, flexibility, and impact resistance. It also has good thermal stability and is relatively easy to print with, making it a suitable material for creating the intricate shapes of the spinner, inlet, stators, rotors, and exhaust of the compressor model as mentioned in your e-thesis. The choice of PETG likely balances ease of manufacturing with the need for durable and representative parts for educational purposes.
2.		**Ultrasonic Humidifier/Atomizer Components** Description: Components of an ultrasonic humidifier or atomizer. These include an ultrasonic transducer (the vibrating disc), a control circuit board, and potentially a fan or actuator to direct the mist. This system is used to generate the fine mist that is introduced into the airflow within the transparent tube of the compressor model. As described in your e-thesis, this mist acts as a tracer, making the otherwise invisible airflow patterns clearly visible to students as they move through the different stages of the compressor.

3.		**Acrylic Pipe (O.D. 125mm, Thickness: 3mm)** Description: A clear acrylic pipe with an outer diameter (O.D.) of 125mm and a wall thickness of 3mm. This pipe is very likely the transparent tube that forms the main body of the Aircraft Engine Compressor Learning Kit. As highlighted in your e-thesis, the transparency of this acrylic tube is crucial as it allows students to directly observe the airflow dynamics and the movement of the mist generated by the atomizer as the compressor operates. The specific dimensions ensure it houses the 3D-printed compressor stages and provides a clear viewing area.
4.		**Flexible Shaft Coupler** Description: A flexible shaft coupler. This mechanical component is used to connect the shaft of the electric motor to the shaft of the compressor model's rotating assembly. The flexibility of the coupler is important as it helps to accommodate slight misalignments between the motor and the compressor shafts, reducing stress on the bearings of both components and ensuring smoother, more reliable rotation. This is crucial for the proper functioning of the compressor simulation.
5.		**DC Motor (10-36V 5A 120W)** Description: 10000 RPM DC motor with specifications indicating an operating voltage range of 10-36V, a maximum current of 5A, and a power rating of 120W. This electric motor is the prime mover for the Aircraft Engine Compressor Learning Kit, providing the rotational force to drive the compressor rotors. The variable voltage range, in conjunction with the speed regulator mentioned in your e-thesis, allows for controlling the rotational speed of the compressor, enabling the demonstration of airflow dynamics at different operating conditions.

6.		**DC Motor Speed Controller (10-36V 5A 150W)** Description: The second image also shows a DC motor speed controller with a similar operating voltage range (10-36V) and current rating (5A), but a slightly higher power rating (150W). This electronic module is used to regulate the speed of the DC motor. By varying the voltage supplied to the motor, the controller allows for adjusting the rotational speed of the compressor, which in turn affects the airflow characteristics that students can observe through the transparent casing. This control is essential for demonstrating the impact of different operating speeds on compressor performance.
7.		**Linear Shaft Rod (M10, 10mm)** Description: The linear shaft rod, specifically an M10 (10mm diameter) aluminum rod. This rod likely forms the main shaft or a key structural element within the rotating assembly of the compressor model. Its linear shape and specific diameter ensure proper alignment and support for the rotating components, such as the rotors. The use of aluminum provides a good balance of strength and lightweight properties, which is important for minimizing the load on the motor and ensuring smooth rotation.
8.		**DC-DC Buck Step Down Converter** Description: As shown in the first image, a DC-DC buck step-down converter is used in the project. This electronic module is essential for regulating the voltage supplied to different components of the learning kit. It takes a higher DC voltage input (likely from a power adapter or battery) and steps it down to a lower, regulated DC voltage required by Components like the motor or the control circuitry. This ensures that each component receives the correct operating voltage, preventing damage and ensuring proper functionality of the entire system.

9.		**12V 7Ah Battery + Battery Charger** Description:12V 7Ah (Amp-hour) battery along with its charger. This battery serves as the portable power source for the Aircraft Engine Compressor Learning Kit, allowing it to operate without being directly connected to a mains power outlet. The 7Ah capacity indicates the amount of charge the battery can store, which determines how long the learning kit can run before needing to be recharged. The included charger is specifically designed to safely and efficiently replenish the battery's charge when it is depleted, ensuring the learning kit can be used repeatedly for demonstrations and learning.
10.		**Mist Atomization System:** Description: The "Set 2" in the first image is the mist atomization system. This includes components to generate a fine mist for visualizing airflow patterns within the compressor model. This system is crucial for making the airflow visible, as described in your e-thesis. It comprises an ultrasonic transducer, a control circuit, and possibly a small fan to direct the mist.
11.		**Cross Bolt with Half Round Head** Description: These are standard mechanical fasteners used for securely joining different parts of the Aircraft Engine Compressor Learning Kit. The cross (or Phillips) head allows for easy tightening with a standard screwdriver. The different sizes (M3, M4, M5) indicate that they are used for fastening components of varying sizes and requiring different levels of torque. These bolts would be crucial for the structural integrity of the assembled learning kit, ensuring that all parts are firmly connected.

CHAPTER 4

RESULT & DISCUSSION

4.1 PRODUCT DESCRIPTION

4.1.1 General Product Features & Functionalities

The Aircraft Engine Compressor Learning Kit is designed to serve as a comprehensive educational tool that bridges the gap between theoretical studies and real-world application in the field of aerospace engineering. It introduces learners to the fundamental working principles of axial flow compressors in a highly interactive and visually intuitive manner. One of the most striking features is its ability to make invisible airflow patterns visible using atomized mist within a transparent tube, allowing students to observe in real-time how air is drawn, compressed, and directed through various compressor stages. This visual element plays a crucial role in solidifying theoretical concepts related to pressure, velocity, and airflow dynamics concepts that are often abstract and difficult to grasp through textbook study alone.

The learning kit's modular construction is another cornerstone of its design, offering flexibility and convenience in both demonstration and disassembly. Each part ranging from the spinner and inlet to the stators, rotors, and exhaust is separately constructed and easily detachable. This encourages students to engage in hands-on learning by allowing them to assemble and dismantle the compressor, examine the geometry and orientation of each component, and understand the specific role it plays in the overall function of the system. For instance, by physically handling the rotor blades, learners can appreciate how blade angle and curvature affect the acceleration of airflow and the build-up of pressure. The modularity of the kit not only enhances understanding but also fosters a sense of curiosity and exploration, which is essential in technical education.

To further improve the learning experience, the kit includes an adjustable operation system powered by a controllable electric motor. The inclusion of a speed regulator allows instructors and students to vary the speed of rotor rotation, thereby demonstrating how changes in rotational velocity affect airflow characteristics such as volume, direction, and compression intensity. By tweaking the speed control, users can observe and analyse how airflow behaves differently under various operating conditions, mirroring the variable performance of real-world jet engines. This functionality elevates the learning kit from being a static model to a dynamic, interactive simulator that offers an almost real-time response to input changes something that is rarely achievable with standard classroom models.

Collectively, these core features, airflow visualization, modular design, and adjustable operation come together to create a highly effective and engaging learning experience. Students are not only able to see and touch the parts of an engine compressor but also witness how those parts work together in a functional system. By combining theoretical instruction with tangible, experimental interaction, the learning kit promotes a deeper understanding of complex engineering principles. It empowers students to think critically, ask questions, and explore solutions, thereby nurturing the analytical and problem-solving skills necessary for future engineers. This holistic approach to education ensures that learners gain both the knowledge and confidence to apply what they’ve learned to real-world scenarios in the aerospace field.

4.1.2 Specific Part Features

4.1.2.1 Product Design

The process of designing the Aircraft Engine Compressor Learning Kit began with the use of AutoCAD Inventor, a robust 3D CAD software, to model essential components such as the rotor, stator, inlet, and exhaust as shown in Figure 4.1 below. Using the latest version of AutoCAD Inventor, we initiated the design workflow by sketching detailed 2D profiles of each component based on real axial flow compressor geometries. These sketches were then extruded and refined into 3D solid models, enabling precise visualization of shapes, curves, and internal clearances. The software’s advanced parametric tools allowed us to ensure each part was dimensionally accurate and compatible with others, particularly important for interlocking sections like rotor and stator blades. Once satisfied with the digital designs, we exported the models in STL format to prepare them for 3D printing using PETG filament. AutoCAD Inventor's simulation and assembly environment also allowed us to virtually assemble the full compressor unit to test clearances and check for rotational interference before physical fabrication. This workflow not only streamlined the design-to-print process but also ensured that the final 3D printed components functioned correctly in a hands-on educational setting.

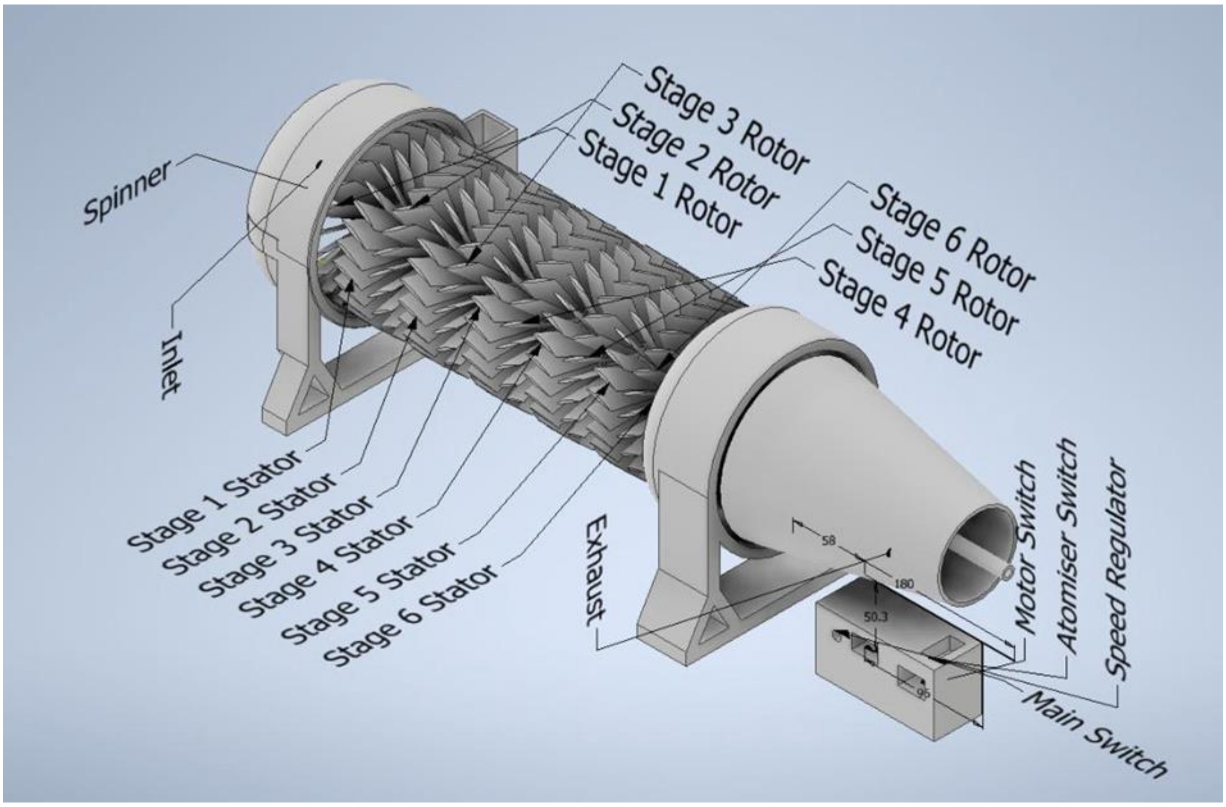


Figure 4.1: 3D Diagram of Finished Product with Labels

4.1.2.2 Product Structure

The structure of the Aircraft Engine Compressor Learning Kit is designed to reflect the core components of a real axial flow compressor using durable PETG filaments and a 3D printer provided by Politeknik Banting. Key parts such as the rotor blades, stator vanes, spinner, air inlet, and exhaust are 3D printed with precision to capture the aerodynamic shapes and proportions necessary for airflow understanding as shown in Figure 4.1 above. These components are assembled within a transparent acrylic cylinder, allowing clear visibility of internal mechanisms and airflow movement as shown in Figure 4.2 below. A shaft rod and shaft coupler ensure proper alignment of rotating parts, while a PVC binding cover serves as a sturdy base to support the entire structure. The modular nature of the design enables students to easily assemble and disassemble the components, offering a practical and hands-on approach to learning how airflow progresses through a compressor system. Altogether, the combination of detailed parts and transparent housing enhances both the educational value and usability of the kit.

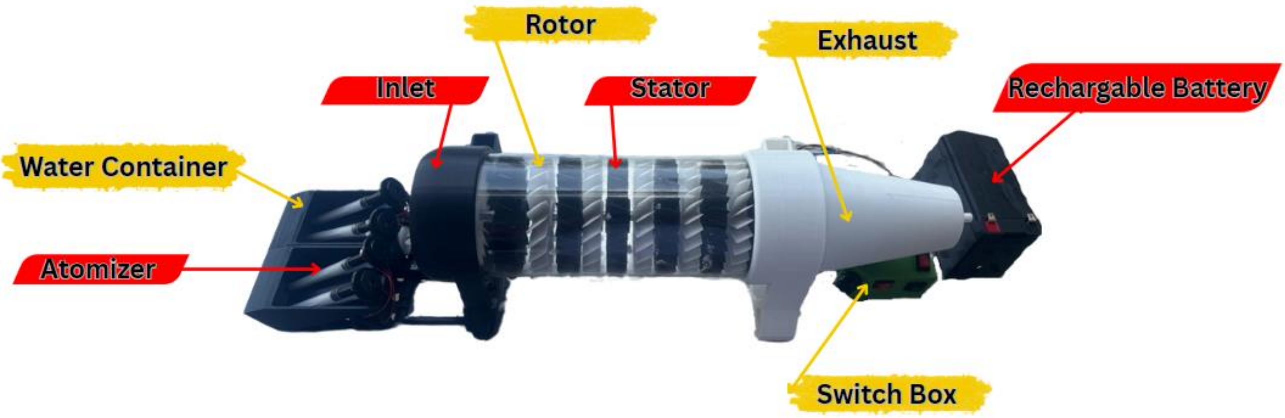


Figure 4.2: Finished Product with Labels

Figure 4.3: Transparent Acrylic Cylinder

4.1.2.3 Mechanical Mechanism

The mechanisms of the learning kit replicate how an actual engine compressor operates by integrating a 10000 RPM DC motor paired with an actuator motor to drive the rotating blades. The motor's output is connected through a shaft rod and shaft coupler for efficient power transfer, while a DC-DC buck step-down module enables users to regulate motor speed safely. This setup lets students examine how airflow behaviour changes with different rotor speeds. To visualize airflow, an atomization system is installed, producing fine mist into the transparent acrylic cylinder. This allows students to see airflow patterns, turbulence, and acceleration through different compressor stages. By combining mechanical motion and visual feedback, the kit turns theoretical concepts into observable learning experiences that are ideal for classroom demonstrations and hands-on exploration.

Figure 4.4: 10000 RPM DC Motor

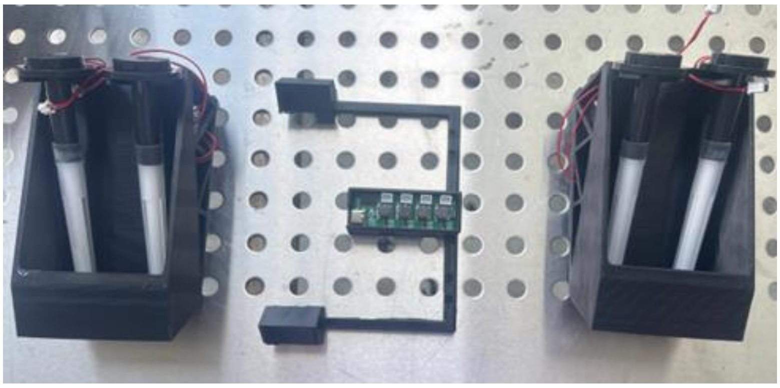


Figure 4.5: The mist Atomization System

Figure 4.6: The Shaft Rod and Shaft Coupler

4.1.2.4 Accessories & Finishing

The accessories and finishing of the learning kit are tailored to improve user experience and ensure safety during operation. Labelled switches allow independent control of the DC motor, actuator, and atomization system, enabling flexible and safe demonstrations as shown in Figure 4.4 below. A DC-DC buck step-down converter acts as a speed controller, giving users fine adjustment over the motor's RPM. The base, made from a durable PVC binding cover, provides stability and reduces vibration when the kit is running. The transparent acrylic cylinder not only showcases internal airflow but also adds a polished, professional appearance. Additional details like smooth edges, color-coded parts, and modular assembly help ensure that the kit is safe, accessible, and effective for learners at various skill levels.

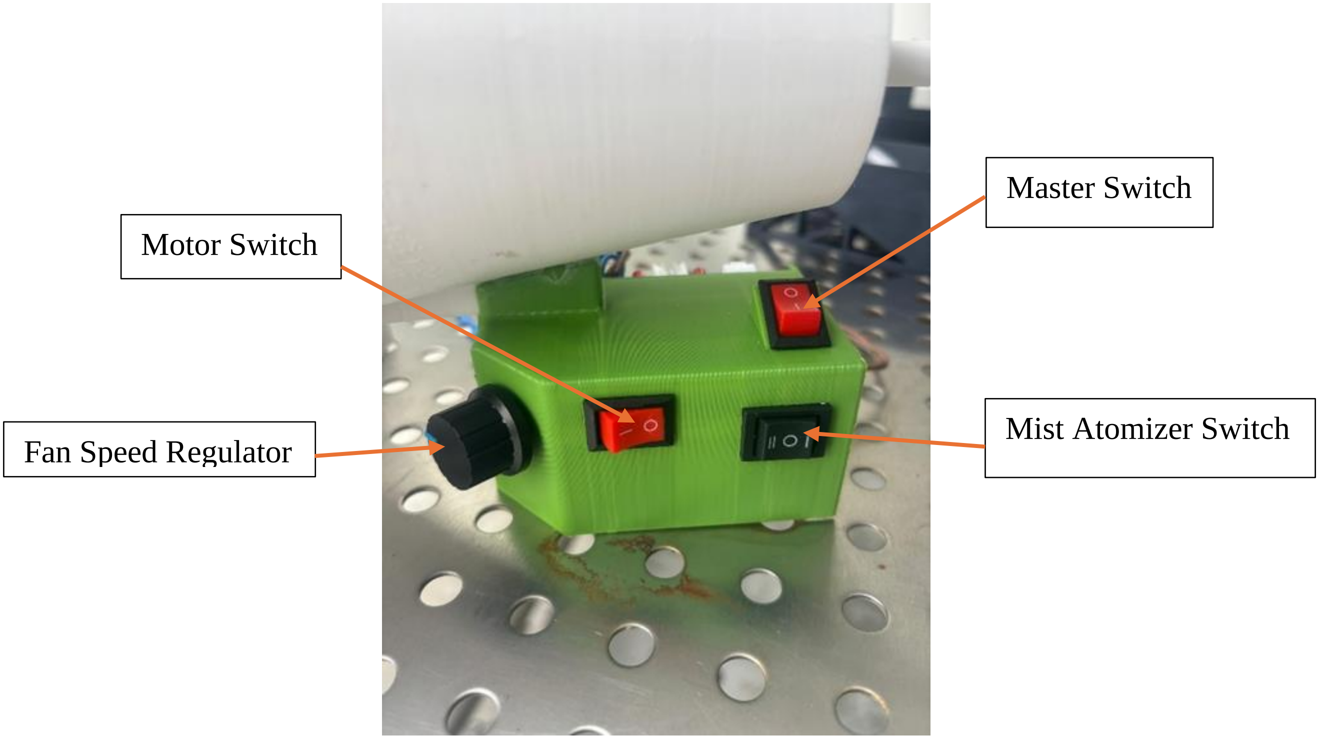


Figure 4.7: Master Switch, Atomizer Switch, Motor Switch and Fan Speed Regulator

4.1.3 General Operation of the Product

The general operation of the Aircraft Engine Compressor Learning Kit has been thoughtfully designed to ensure ease of use while maximizing its educational value. To begin, users power on the system using the main switch, which activates the internal circuit and prepares the device for operation. Once the system is on, the motor and atomization switches can be independently controlled, allowing for flexible demonstration setups. The motor switch activates the high-speed 10,000 RPM DC motor, which is coupled to the rotor assembly through a shaft coupler and shaft rod. This motor setup mimics the rotational motion found in actual compressor systems and enables students to observe the dynamic behaviour of airflow across the compressor blades. At the same time, the atomizer can be turned on to release a fine mist into the airflow path. This feature dramatically improves the visibility of flow patterns inside the transparent acrylic cylinder, offering real-time visual feedback that reinforces theoretical learning.

The speed of the rotor can be finely tuned using the DC-DC buck step-down module that functions as a speed regulator. This allows instructors or students to gradually increase or decrease the rotor speed, thereby changing the flow characteristics within the cylinder. As the rotor accelerates, the mist traces how air moves through the stators and rotors, showing students how changes in speed affect pressure and velocity. This interactive approach empowers learners to conduct live experiments and see the direct consequences of altering mechanical variables. Importantly, the modular design of the kit means that individual parts can be removed or replaced without affecting the overall functionality, making it both an instructional tool and a platform for experimentation.

The kit's operation is not only technically engaging but also safe and accessible for all users, including those with limited hands-on experience. The PVC binding cover and smooth-edged components ensure that students can interact with the device without risk of injury. All wiring and connections are carefully housed to prevent any electrical hazards, and the transparent design means there are no hidden moving parts that could cause unexpected interference. In summary, the Aircraft Engine Compressor Learning Kit combines functionality, safety, and intuitive design to provide a seamless educational experience that brings the principles of aerospace engineering to life.

4.1.4 Operation of The Specific Part of the Product

4.1.4.1 Product Design

The product design, carried out using AutoCAD Inventor, forms the foundation of the Aircraft Engine Compressor Learning Kit's functionality. Each component, including the air intake, rotors, stators, shaft, and exhaust outlet, was carefully modelled to simulate the precise aerodynamics and spatial arrangement found in actual aircraft engine compressors. By designing each part digitally, the team could ensure consistent scaling, alignment, and aerodynamic accuracy, which are crucial for creating laminar airflow and demonstrating pressure rise. The real advantage of AutoCAD Inventor was its assembly simulation, which allowed the team to simulate how parts interacted dynamically. This helped refine tolerances and reduce potential issues in real-world assembly. As a result, the digital model served as both a design reference and a troubleshooting platform, ensuring the physical product could be produced efficiently and assembled smoothly for optimal educational utility.

4.1.4.2 Product Structure

The structural composition of the Aircraft Engine Compressor Learning Kit is intentionally designed to mirror the core principles of an axial flow compressor while remaining accessible and hands-on for educational use. Built using robust PETG filaments and precisely shaped with a 3D printer provided by Politeknik Banting, each component from the spinner and air intake to the rotors and stators is crafted with attention to detail to reflect the actual internal layout of a real engine compressor. The modular structure allows students to easily assemble and dismantle parts, giving them direct interaction with each element and enhancing their mechanical comprehension. By physically removing a stator or rotor, learners can inspect the blade geometry, understand the airflow redirection process, and grasp how compression occurs across stages. The inclusion of a transparent acrylic cylinder as the outer shell takes this structural clarity further by offering a clear line of sight into the airflow behaviour as it progresses from the air inlet to the exhaust. This visual accessibility transforms theoretical concepts into engaging, real-world demonstrations, allowing students to not only study each part individually but also understand how all components work in unison to compress air efficiently.

4.1.4.3 Mechanical Mechanism

The internal mechanisms of the Aircraft Engine Compressor Learning Kit serve as the functional heart of the system, simulating the core principles of airflow compression using accessible components and observable physics. At the centre of this mechanism is a high-speed 10,000 RPM DC motor, supported by an actuator motor and connected to the rotor blades via a shaft rod and shaft coupler. When the system is powered, this motor drives the rotational movement of the rotors, drawing in ambient air and channelling it through the axial stages of the compressor. The rotor blades accelerate the airflow, while the stator vanes fixed in place redirect it to maintain smooth, pressurized flow. To make the invisible process of airflow more tangible, an atomization system releases a fine mist into the transparent cylinder, effectively tracing the movement and behaviour of air within the compressor. As students adjust the speed of the rotors using a DC-DC buck step-down module, they can see changes in the airflow pattern, mist density, and turbulence levels. This real-time visual feedback enables learners to connect rotational speed with airflow characteristics such as velocity and pressure, providing a dynamic and deeply informative way to study the mechanical and aerodynamic operation of a real axial compressor system.

4.1.4.4 Accessories & Finishing

The accessories and finishing features of the Aircraft Engine Compressor Learning Kit are not merely aesthetic additions but are vital for ensuring safety, usability, and a polished learning experience. Carefully selected materials such as the PVC binding cover for protective housing and durable PETG for the printed parts help withstand wear from repeated use while offering a professional appearance suitable for classroom display. The control interface includes separate, clearly labelled toggle switches for powering the main motor, the atomization system, and the speed regulator, allowing users to isolate and operate each subsystem with confidence and precision. This layout is particularly beneficial for instructional settings, where instructors may need to demonstrate specific functions without activating the entire unit. The system is mounted on a firm, well-balanced base designed to eliminate vibration or tipping during motor operation, ensuring that the model remains stable on flat surfaces like lab tables. Smooth, rounded edges, intuitive component arrangement, and color-coded connectors all contribute to a user-friendly and safe interface, making it accessible even to students who are new to mechanical systems. These thoughtful finishing touches ensure the kit is not only effective as a teaching tool but also reliable and durable enough for long-term academic use.

4.2 PRODUCT OUTPUT ANALYSIS

The main output of the Aircraft Engine Compressor Learning Kit is centred around the visual interpretation of airflow behaviour within the system. The integration of a transparent acrylic cylinder and an atomization feature, the typically invisible movement of air becomes clearly observable. The atomizer injects a fine mist into the airflow, allowing students to watch how the mist travels through the spinning rotors and stationary stators. As the mist flows along the compressor stages, it creates patterns that reflect actual aerodynamic phenomena like acceleration, redirection, and turbulence as shown in Figure 4.7 below. These visual cues give students a practical way to see and understand fluid dynamics concepts that are often hard to grasp through textbooks alone.

Figure 4.8: The mists got sucked into the Compressor through the six stage of rotors and stator blades

One of the standout educational advantages of the kit is its ability to show how varying the speed of the motor impacts airflow characteristics. Using the DC-DC buck step-down regulator, students can control the motor speed and instantly observe how the mist responds. At slower speeds, the airflow tends to be sluggish and scattered, while at higher speeds, the mist forms more focused and faster-moving streams, highlighting the transition between low and high-energy airflow. This real-time cause-and-effect interaction helps learners connect mechanical changes, such as RPM adjustments with aerodynamic outcomes, reinforcing essential concepts like kinetic energy transfer, pressure rise, and airflow stabilization within a compressor system.

Beyond serving as a teaching aid, the learning kit also supports hands-on experimentation and creative exploration. The visible mist trails provide a way for students and instructors to detect airflow inconsistencies or explore new ideas, such as modifying blade shapes or testing alternate rotor-stator configurations. This makes the kit highly versatile; it not only teaches foundational aerospace concepts but also encourages curiosity and innovation. Whether it's used for classroom instruction, lab experiments, or mini research projects, the output capabilities of the kit help turn theoretical learning into an engaging and meaningful experience.

Table 4.3 Configuration of Aircraft Engine Compressor Learning Kit Components

No.	3D Printing Component	Configuration			
		Layers Thickness (mm)	**Infill (%)**	**Time Taken (minutes)**	**Material Used (m)**
1.	Atomizer Holder Left	0.25		84	PETG
2.	Atomizer Holder Right	0.25		84	PETG
3.	Atomizer Bridge	0.25		72	PETG
4.	Inlet	0.25		347	PETG
5.	Stage 1 Rotor	0.2		210	PETG
6.	Stage 1 Stator	0.2		132	PETG
7.	Stage 2 Rotor	0.2		150	PETG
8.	Stage 2 Stator	0.2	40	124	PETG
9.	Stage 3 Rotor	0.2	40	143	PETG
10.	Stage 3 Stator	0.2	40	109	PETG
11.	Stage 4 Rotor	0.2	40	132	PETG
12.	Stage 4 Stator	0.2	40	98	PETG
13.	Stage 5 Rotor	0.2	40	127	PETG
14.	Stage 5 Stator	0.2	40	92	PETG
15.	Stage 6 Rotor	0.2	55	118	PETG
16.	Stage 6 Stator	0.2	55	87	PETG
17.	Exhaust	0.25		586	PETG
18.	Exhaust Nozzle	0.25		394	PETG
19.	Electronic Panels Holder:	0.25		79	PLA

4.3 ANALYSIS OF PROLEM ENCOUNTERED & SOLUTIONS

4.3.1 Product Design

The design phase posed several significant challenges, especially in translating real compressor geometries into printable 3D models using AutoCAD Inventor. One of the main issues was achieving the right aerodynamic shape for the rotor and stator blades, which required extensive iterative modelling and referencing from real turbine diagrams. Another issue was ensuring that all parts were dimensionally accurate after printing, considering PETG's slight warping tendencies. Misalignment during initial test assemblies indicated tolerance gaps and required design recalibration. Additionally, fitting the rotating components inside the transparent acrylic cylinder without obstruction proved difficult due to friction and misfitting tolerances.

To address these issues, we applied design refinements using tighter dimension control and added clearance buffers in the software. For 3D printing, we used higher resolution settings and introduced post-processing techniques like sanding and smoothing edges to ensure a clean fit. Moreover, we simulated full assemblies in Inventor to anticipate mechanical interferences before physical assembly. These solutions allowed us to complete a structurally sound and educationally effective learning kit that clearly illustrates airflow stages in a real compressor.

4.3.2 Product Structure

One of the key challenges we faced during the construction of the product structure was ensuring that all 3D-printed parts came out with high precision and proper fit. Since the learning kit includes multiple interlocking and complex components like rotors, stators, and a spinner, even the slightest inaccuracy could cause alignment problems. At times, poor surface finish or slight warping in prints led to difficulties in assembly and disrupted the smooth rotation of parts. These inconsistencies also made it harder for students to fully appreciate the blade designs and internal layout, which are essential to understanding how a real compressor functions.

To solve this, we made several adjustments to our production process. We upgraded to higher-resolution settings on the 3D printers provided by Politeknik Banting and used PETG filament for better consistency and durability. Post-processing techniques, such as sanding and filing, were applied to clean up any minor flaws and improve the fit between components. We also updated the CAD models to apply tighter tolerances, ensuring that shrinkage or expansion during printing wouldn't affect part compatibility.

4.3.3 Mechanical Mechanism

When developing the mechanical aspect of the kit, we ran into issues with the atomization system used to make airflow visible. The mist either came out too heavy, clouding the entire cylinder, or too light, making it difficult to observe the airflow clearly. This inconsistency negatively impacted demonstrations because students couldn't get a proper visual of how air behaves as it passes through the rotor and stator stages. There were also moments where mist condensed inside the acrylic cylinder, causing water buildup that affected visibility and sometimes interfered with the moving parts.

To fix this, we experimented with various atomizer nozzles until we found one that could deliver a fine, consistent mist suitable for different motor speeds. We also regulated the fluid feed using a more precise valve system to prevent oversaturation. In addition, we made ventilation tweaks around the transparent cylinder to help disperse excess moisture and minimize internal condensation. These solutions significantly improved the clarity of airflow visualization and made the entire mechanical demonstration more engaging and effective for students.

4.3.4 Accessories & Finishing

During the development of the kit's accessories and finishing, we encountered several challenges related to safety, functionality, and component stability. One issue involved the arrangement of control switches and wiring; early versions had loosely placed switches, which sometimes led to confusion or accidental activation of the motor or atomizer. Additionally, the PVC binding cover and transparent acrylic cylinder initially lacked secure mounting, which caused vibrations and minor shifts during operation. These small but important flaws affected user experience and could have posed safety risks during demonstrations.

To resolve these issues, we reorganized the layout of the control panel by clearly labelling all switches and securely fixing them to the base structure. We also introduced a more stable mounting system for the acrylic cylinder using brackets and supports that reduce vibrations. Furthermore, the speed regulator was repositioned for easier access, and all finishing edges were smoothed to prevent accidental cuts or snags. These refinements not only made the kit safer and easier to use, but also gave it a more professional, classroom-ready appearance that enhances the overall learning environment.

4.4 Cost Effectiveness

The actual cost of building the Aircraft Engine Compressor Learning Kit totalled RM350+, reflecting a budget-conscious approach compared to earlier projections. The main expenditures included PETG filament (RM73.64), which was slightly less than the initial estimate of RM85. Additional key costs involved the atomization system (RM38 + RM14.65), shaft coupler (RM8.51), DC motor with actuator motor (RM37.80), shaft rod (RM14.20), DC-DC buck converter (RM5.99), and the PVC binding cover (RM7.69). Altogether, these real expenses demonstrate that the kit was developed under a cost-efficient framework without compromising educational quality.

In contrast, the initial estimated cost based on component pricing was significantly higher, with expectations for the ESP32 microcontroller (RM50.00), advanced sensors and fan controller (RM200.00), and digital display buttons/panels (RM80.00), totalling nearly RM415.00 without considering structural materials. By excluding non-essential digital electronics in this prototype phase and focusing on mechanical and visual elements, we achieved a more practical version under budget. This demonstrates a sustainable model for academic institutions where funding is limited, ensuring wide accessibility while preserving pedagogical effectiveness.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 ACHIEVEMENT OF AIM & OBJECTIVES OF THE RESEARCH

5.1.1 General Achievement of the Product

The overarching aim of creating a functional, low-cost educational tool that visually demonstrates how an aircraft engine compressor works was effectively fulfilled. Through the careful selection of components and thoughtful design, the project produced a learning kit that simplifies the complex principles of axial flow compression into a clear, hands-on experience. The transparent acrylic cylinder combined with the atomized mist system allows students to observe how air behaves in motion, turning invisible airflow into a visible and understandable phenomenon.

Not only does the kit meet its technical expectations, but it also succeeds in being safe, user-friendly, and highly accessible for academic use. The portability of the model, combined with the intuitive controls and minimal maintenance needs, makes it an ideal tool for classroom demonstrations, lab sessions, and independent study. Overall, the project demonstrates a successful blend of creativity, functionality, and educational value.

5.1.2 Specific Achievement of Project Objectives

5.1.2.1 Product Design

The product design objective was fully realized through the application of AutoCAD Inventor, where each compressor component was accurately modelled to mirror real-world functionality. This digital groundwork laid a solid foundation for 3D printing, allowing precise replication of complex aerodynamic geometries. The successful execution of the design validated the objective of developing a structurally sound, educationally valuable compressor learning kit. The entire 3D design process using AutoCAD Inventor took approximately two weeks to complete, allowing sufficient time to model, review, and validate each component before moving into the fabrication stage.

5.1.2.2 Product Structure

The structural design objective was successfully achieved through precise 3D modelling and printing. Each part, such as the rotors, stators, and frame was carefully engineered to ensure proper fit and function. The use of PETG filament contributed to strong, dimensionally stable components, and the transparent casing allows students to clearly observe the inner workings of the compressor, making the structure both functional and educational. The design of the structure is designed with AUTOCAD INVENTOR, and this design is executed in the final product. The entire 3D design process using AutoCAD Inventor took approximately two weeks to complete, allowing sufficient time to model, review, and validate each component before moving into the fabrication stage. To fabricate all the components required for the structure, the 3D printing process was carried out over a span of one month, which included printing time, cooling, and minor post-processing to ensure each part was ready for assembly.

5.1.2.3 Mechanical Mechanism

The integration of the 10,000 RPM DC motor and the actuator motor allowed the demonstration of airflow patterns through mechanical rotation. The mist atomization system provided a visible medium to track the flow, while the speed regulator enabled students to observe how varying speeds affect air behaviour effectively achieving the objective of simulating realistic compressor operations. The full mechanical assembly, including installation of the motor, coupling, and alignment of the shaft system, was completed within one week, ensuring all moving parts operated smoothly and safely.

5.1.2.4 Accessories & Finishing

The accessories and finishing aspects of the project were also fulfilled, with the inclusion of control switches, speed adjustment mechanisms, and safety features. The assembly was given thoughtful consideration to ensure stability and ease of use, making the kit both practical and visually appealing. The final stage of integrating the control systems, securing the accessories, and refining the finishing details was accomplished within one week, allowing the learning kit to be fully operational and ready for academic use.

5.2 CONTRIBUTION OR IMPACT OF THE PROJECT

The Aircraft Engine Compressor Learning Kit brings meaningful innovation to aviation education by providing an accessible, interactive platform for learning complex mechanical and aerodynamic concepts. Instead of relying solely on textbook diagrams or expensive simulations, students can now directly observe airflow behaviour within a physical model. This hands-on engagement improves comprehension, nurtures curiosity, and reinforces critical thinking. The kit's cost-effectiveness, ease of maintenance, and adaptability for future upgrades make it a viable educational tool for technical colleges, universities, and aviation training centres.

5.3 IMPROVEMENT & SUGGESTIONS FOR FUTURE RESEARCH

5.3.1 Product Design

For future improvements, the product design can be enhanced by implementing parametric modelling to allow for easy resizing and redesign of components. This would let users simulate different compressor configurations and better understand how design parameters influence aerodynamic performance. Including digital simulations alongside physical components would further reinforce the learning experience.

5.3.2 Product Structure

The structural design could be improved by incorporating interchangeable stages to simulate different types of compressors or blade geometries. This would allow learners to explore how design changes impact performance. Additionally, embedding small sensors to record pressure or velocity at specific points would enrich the experience with quantitative data. Enhanced lighting or higher-clarity materials could also make the airflow more visible, especially in dim classroom environments. The next version of the kit can explore the use of advanced materials such as carbon fibre, glass fibre, and composite blends. Carbon fibre is exceptionally lightweight and has high tensile strength, making it ideal for rotating components. Glass fibre offers good impact resistance and is suitable for stator housings. Composites, which blend resins and fibres, offer a balanced mix of durability, weight reduction, and thermal resistance. Using these materials would improve performance, extend the kit's durability, and offer students exposure to modern engineering materials.

5.3.3 Mechanical Mechanism

Software Future iterations of the mechanism should consider integrating programmable motor controllers that can simulate realistic operating cycles or failure scenarios such as stall and surge. Exploring alternative visualization techniques, like laser light sheets or fog-based tracers could offer even greater clarity. The mechanical system might also be expanded to include adjustable blade angles or multiple rotors to simulate more advanced compressor design. To enhance visual learning, an LED lighting system could be integrated into the compressor housing to highlight mist flow within the transparent cylinder. This would make it easier for users to observe airflow patterns in various lighting conditions. Furthermore, it would increase the visual appeal and engagement factor during classroom demonstrations, especially in dim environments.

5.3.4 Accessories & Finishing

To improve user experience, future versions of the kit could include a custom case for easier transportation and protection. Safety enhancements such as status indicators, circuit breakers, or interlocks would ensure secure operation. Detailed documentation in both printed and digital formats with videos, diagrams, and step-by-step guides, would also improve accessibility. Aesthetic enhancements, like labelling and color-coding of key components, could make the model even more user-friendly and engaging.

5.3.5 Electronics & Programming

Software development will play a crucial role in the next phase. Building a simple dashboard that collects and displays data from integrated sensors would give users valuable insights into how the compressor performs under different conditions. This could be paired with interactive modules or simulations to further reinforce the learning. Data logging and comparison with theoretical results would also encourage analytical thinking and support formal assessment of student understanding. Future developments could involve embedding basic microcontrollers equipped with sensors at key locations within the compressor model to monitor data such as temperature, pressure, and airspeed at different stages. This sensor data could be processed and visualized in real time on an LCD screen or through a computer interface, allowing students to not only observe the physical movement of air but also analyse quantitative performance metrics. With software integration, users could modify operational variables like rotor speed or simulate environmental conditions, enabling automated testing.

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APPENDIX A: DECLARATION OF TASK SEGREGATION

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1.4	Scope of Project
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2.1.1	Learning Kit in Aviation
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2.3.1	Related Patented Product
2.4	Patent A vs. Product A vs. Your Product
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3.1.2.3	Proposed Design Concept 1
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AMIRUL AKHMAL BIN ROSZEAMERUDIN	
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APPENDIX B: TURNITIN SIMILARITY REPORT

Aircraft Engine Compressor Learning Kit

by **AMIRUL AKHMAL BIN ROSZEAMERUDIN**

Submission date: 15-May-2025 05:25PM (UTC+0800)
Submission ID: 2676480879
File name: e-Thesis_Aircraft_Engine_Compressor_Learning_Kit.docx (3.96M)
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Aircraft Engine Compressor Learning Kit

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