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THE DESIGN OF AIRCRAFT ENGINE COMPRESSOR: LEARNING KIT FOR SEMESTER 4 IN POLITEKNIK BANTING

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ABSTRACT

Understanding the operational theory of aircraft engine compressors, especially axial compressors, is a challenge for aircraft maintenance students due to the lack of effective visual tools that demonstrate airflow dynamics and component interactions. This study aims to design a high-fidelity aircraft engine compressor learning kit. A survey was conducted among aircraft maintenance student's semester 4 to identify critical learning challenges, and the findings were analysed using a Pareto diagram to prioritize design features based on student needs. To generate and evaluate multiple design alternatives, a morphological matrix was used for concept development, while the final design selection was made using a Pugh matrix, ensuring optimal balance of functionality, cost, and educational effectiveness. The implementation of the learning kit resulted in a 30% to 42% increase in student comprehension of compressor airflow dynamics, pressure stages recognition, rotor/ stator stage functionality, overall concept understanding, and hand-on confidence, based on pre- and post-intervention assessments over 50 students from Semester 4. Over 80% of students reported better engagement and understanding with the kit compared to traditional methods. This project successfully bridges the gap between theoretical and practical learning, enhancing students' understanding and preparing them for real-world aerospace maintenance tasks.

1. Introduction

The study of aircraft engine systems is a core component in aviation maintenance education, particularly at the diploma level. One of the most complex and essential systems in gas turbine engines is the compressor, which plays a critical role in increasing the pressure of incoming air before it enters the combustion chamber (Zheng et al., 2024; Decher, 2022). The two primary types of compressors used in aviation are axial-flow and centrifugal-flow compressors. While centrifugal compressors are typically used in smaller engines due to their simplicity, axial compressors dominate modern commercial and military jet engines for their ability to handle large volumes of air with high efficiency (Xu, Huang, Bi, & Zhou, 2023). Understanding the operational theory of axial compressors requires not only a strong theoretical foundation but also practical insight into their internal aerodynamics and mechanical function as an area where traditional teaching methods often fall short.

Traditional teaching methods such as lectures, static diagrams, and textbooks often fall short in illustrating the real-time interactions within engine systems, especially airflow behaviour and pressure changes within axial compressors. Recent research highlights the growing use of hands-on and simulation-based learning to improve student engagement and comprehension in engineering education (Ng, Su, & Ng, 2023; Tep et al., 2024). Moreover, advances in 3D printing and embedded sensor technology have created new opportunities to build interactive learning kits that bring mechanical systems to life in the classroom (Alexiou et al., 2023). For example, Python-based microcontroller interfaces and modular 3D-printed models have enabled students to visualize real-time data, enhancing their grasp of abstract engineering principles (Xu et al., 2023). Visual-based instruction has been demonstrated to lower cognitive load and improve comprehension complex technical systems when designed using multimedia principles, such as spatial contiguity, signalling, and coherence (Bower, Fan, & Siemon, 2024). Additionally, existing research has paid little attention to subsystem-specific learning kits particularly for axial compressors designed specifically for students in aircraft maintenance programs. This presents a crucial gap in the development of accessible, accurate, and pedagogically effective educational tools at the tertiary technical level (Idris et al., 2023; Pakatchian, Nazari, & Ziamolki, 2023).

This study addresses that gap by designing and developing a high-fidelity Aircraft Engine Compressor Learning Kit tailored for Semester 4 students in the Diploma in Aircraft Maintenance Engineering program at Politeknik Banting, Malaysia. The kit was created using Autodesk Inventor for 3D modelling and integrated with sensors that allow real-time monitoring of airflow, fan speed, and pressure. Existing literature emphasizes the growing role of interactive simulations and real-time data integration in engineering education, yet few studies focus on compressor-specific learning kits that simulate airflow dynamics and component interaction within axial compressors using accessible technologies like 3D printing (Xu et al., 2023; Liu, Fan, & Tang, 2024). The learning challenges faced by students were systematically identified through a survey and analysed using a Pareto diagram. A morphological matrix was used to generate design alternatives, and a Pugh matrix was employed to select the most effective design based on cost, functionality, and educational impact.

The main aim of this study is to bridge the gap between theoretical knowledge and practical understanding of compressor operation through an affordable and interactive learning tool. By enabling visual observation of internal airflow dynamics and providing real-time data feedback, the kit helps students make direct connections between theory and practice. Initial findings indicate a significant improvement in student comprehension and engagement.

2. Methodology

This chapter outlines the research methodology employed in the design of the Aircraft Engine Compressor Learning Kit. The methodology includes the design and development process, as well as the software tools used to create the design of Aircraft Engine Compressor Learning Kit as stated on Figure 1.

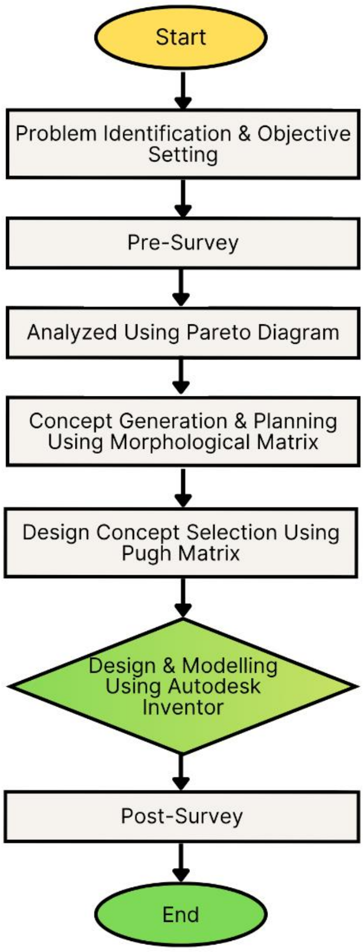

Figure 1 Overall flow chart of the Design of Aircraft Engine Compressor: Learning Kit.

The flow chart outlines the systematic design and development process of the Aircraft Engine Compressor Learning Kit. The process begins with problem identification and objective setting, where the core challenges faced by students in understanding axial compressors are recognized. This is followed by a pre-survey conducted among Semester 4 diploma students to gather insights into specific learning difficulties. The responses are then analysed using a pareto diagram to prioritize the most significant issues based on student feedback, ensuring that the design process focuses on the most impactful educational needs.

Next, concept generation and planning are carried out using a morphological matrix, allowing the team to explore various design options by combining different components, materials, and interaction methods. These concepts are evaluated through a Pugh matrix to select the most suitable design based on criteria like functionality, cost, and educational effectiveness. The chosen concept proceeds to the design and modelling stage using Autodesk Inventor, a professional 3D CAD software, to produce accurate digital prototypes for 3D printing. Finally, a post-survey is administered to evaluate the learning kit's effectiveness, marking the end of the process with data to validate improvements in student comprehension and engagement.

3. Result and Discussion

This section presents the outcomes of the design and implementation of the Aircraft Engine Compressor Learning Kit, developed to enhance students' understanding of axial compressor operation through visual, hands-on learning. Aligned with the research objective which to bridge the gap between theoretical knowledge and practical application. The data were collected through pre- and post-surveys involving 50 Semester 4 students from the Diploma in Aircraft Maintenance Engineering program. The methodology incorporated a structured survey, analysed using a Pareto diagram to identify key learning challenges, followed by concept generation through a morphological matrix and final design selection using a Pugh matrix. Autodesk Inventor was used to model the components, while the final prototype integrated airflow visualization and sensor-based feedback. The results below highlight the improvement in student comprehension across five targeted learning domains.

3.1 Pre-Post Survey Improvement

The bar chart in Figure 2 illustrates the impact of the Aircraft Engine Compressor Learning Kit on students' understanding across five critical learning areas, based on a survey conducted with 50 Semester 4 students. The orange bars represent the pre-survey scores, indicating students' baseline knowledge before using the learning kit, while the blue bars show post-survey scores collected after the hands-on learning experience. Notably, all five areas show a significant increase in understanding, with the most substantial improvements observed in airflow understanding (from 45% to 85%) and hands-on confidence (from 40% to 82%). This suggests that the interactive design, real-time airflow visualization, and tangible components effectively addressed students' initial difficulties in conceptualizing airflow dynamics and handling physical components.

The remaining categories, pressure stage recognition, rotor/stator stage function, and overall concept understanding also demonstrate marked gains, with improvements ranging from 30% to 36%. For instance, overall concept understanding increased from 52% to 88%, indicating that the learning kit successfully bridged the gap between theoretical knowledge and practical application. These results confirm that integrating a visual, sensor-based educational tool significantly enhances comprehension and engagement among Semester 4 students. The kit's implementation not only improved academic understanding but also boosted students' confidence in handling real-world engine components as an essential skill for future aircraft maintenance professionals.

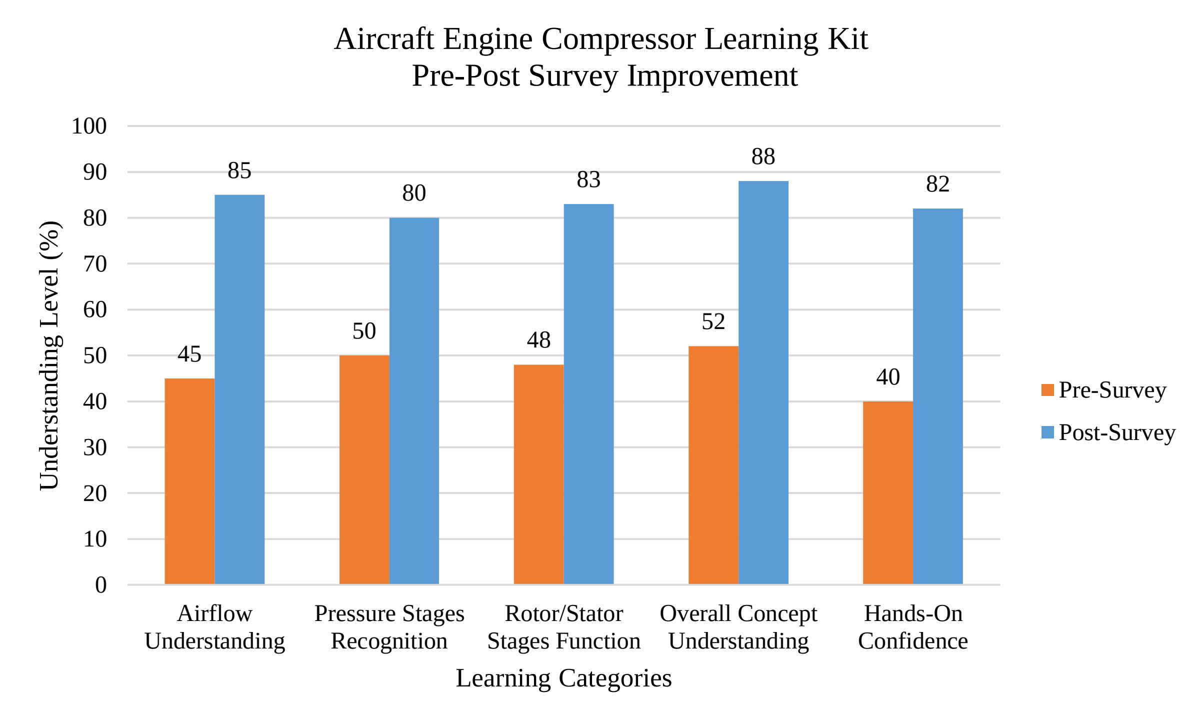

Figure 2 The Aircraft Engine Compressor Learning Kit Pre-Post Survey Improvement.

3.2 Analysed Using Pareto Diagram

The Pareto diagram presented in Figure 3 illustrates the frequency and cumulative percentage of learning challenges faced by Semester 4 students in understanding the aircraft engine compressor system. The analysis is based on data gathered through a pre-survey involving 50 participants. The blue bars represent the frequency of each challenge reported, while the green line denotes the cumulative percentage, highlighting the most significant obstacles to learning. According to the chart, the three most prominent challenges are airflow visualization (40 responses), rotor-stator interaction (25 responses), and lack of real-time feedback (15 responses). Collectively, these issues account for 80% of the total learning difficulties, signifying that most students struggle with understanding dynamic and functional aspects of the compressor rather than with static theory alone.

This prioritization of learning challenges aligns with the core objective of the research to design an educational tool that addresses the most critical gaps in comprehension through interactive, real-time, and visual learning. The high frequency of airflow visualization and rotor-stator interaction challenges underscores the need for transparent structural models and visual airflow representation, both of which were integrated into the Aircraft Engine Compressor Learning Kit. Additionally, the lack of real-time feedback, cited by 15 students, was addressed by incorporating sensors and display outputs to simulate actual compressor behaviour. By focusing on the top 80% of reported difficulties (as per the Pareto principle), the learning kit was intentionally designed to maximize impact and relevance in improving student understanding on the airflow visualization, rotor-stator interaction, and no real-time feedback.

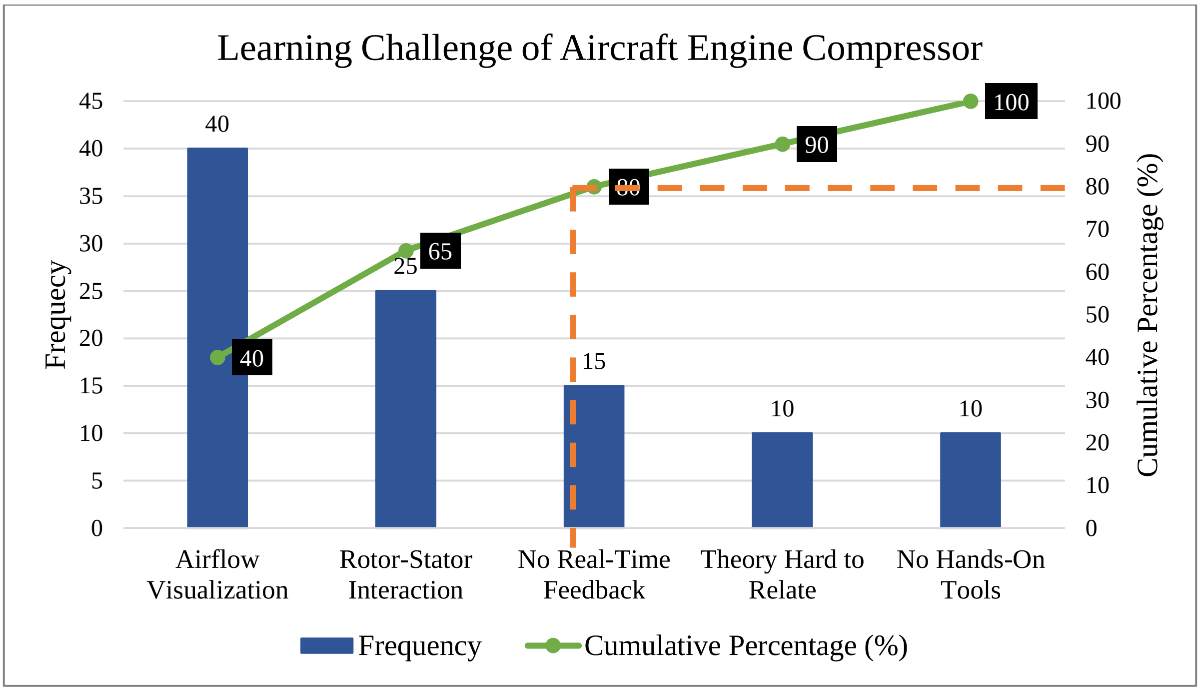

Figure 3 The Pareto Diagram of Learning Challenge of Aircraft Engine Compressor.

3.3 Conceptual Generation and Planning Using Morphological Matrix

The conceptual generation and planning phase of the Aircraft Engine Compressor Learning Kit utilized a morphological matrix to systematically explore and compare multiple design configurations. This structured tool allowed the design team to break down the overall system into key sub-functions such as material selection, circuit board type, hardware components, programming language, and interaction method as shows in Table 1. For each sub-function, three alternative solutions were proposed. For instance, PLA, ABS, and PETG were considered for material options, each with differing strength, thermal resistance, and cost implications. Similarly, various microcontrollers (ESP32, Arduino Uno, Raspberry Pi 4) were evaluated based on processing power, connectivity, and affordability. This process enabled a comprehensive exploration of feasible design paths and supported well-informed decision-making grounded in functionality and cost-effectiveness.

The use of the morphological matrix also ensured that each concept considered not only technical performance but also student usability and educational impact. For example, PETG was ultimately favoured for its durability and clarity, making it ideal for visualizing airflow. ESP32 was chosen for its built-in Wi-Fi/Bluetooth, which supports wireless data monitoring that addressing the students' challenge of real-time feedback. Python was selected as the programming language due to its simplicity and versatility in educational environments. The matrix also compared interaction types, including button panels, digital displays, and remote monitoring. By using this methodical approach, the design team was able to synthesize an

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optimal configuration that aligned with the project's objective: to create an interactive, low-cost, and pedagogically effective learning kit tailored for Semester 4 aviation students.

Table 1 The Conceptual Generation and Planning using Morphological Matrix

FUCTION (SUB-FUNCTION)	CONCEPT 1	CONCEPT 2	CONCEPT 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

3.4 Design Concept Selection Using Pugh Matrix

The Pugh Matrix analysis was used to evaluate three design concepts for the Aircraft Engine Compressor Learning Kit by comparing them against a set of critical evaluation criteria. These criteria included cost, durability, ease of programming, data monitoring capabilities, educational effectiveness, and system safety. Each design concept was assessed relative to a baseline (datum) and scored using a weighted decision method with plus (+), minus (−), or neutral (0) values. This method allowed the team to quantify subjective assessments and

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identify the most balanced solution based on both technical performance and educational relevance.

From the analysis as illustrates in Figure 4, final concept emerged as the final selection. It featured PETG material, an ESP32 microcontroller, air pressure and RPM sensors with a fan speed controller, Python programming, and a button panels with digital display interface. This combination provided the optimal balance between functionality, cost-efficiency, and student interactivity. The selection of ESP32 was particularly significant, as it supports wireless data transfer and real-time monitoring as a key feature that address the students' difficulty in visualizing compressor airflow and operational behaviour. Thus, the chosen design concept not only met the functional requirements of the project but also aligned directly with the learning outcomes targeted for Semester 4 students.

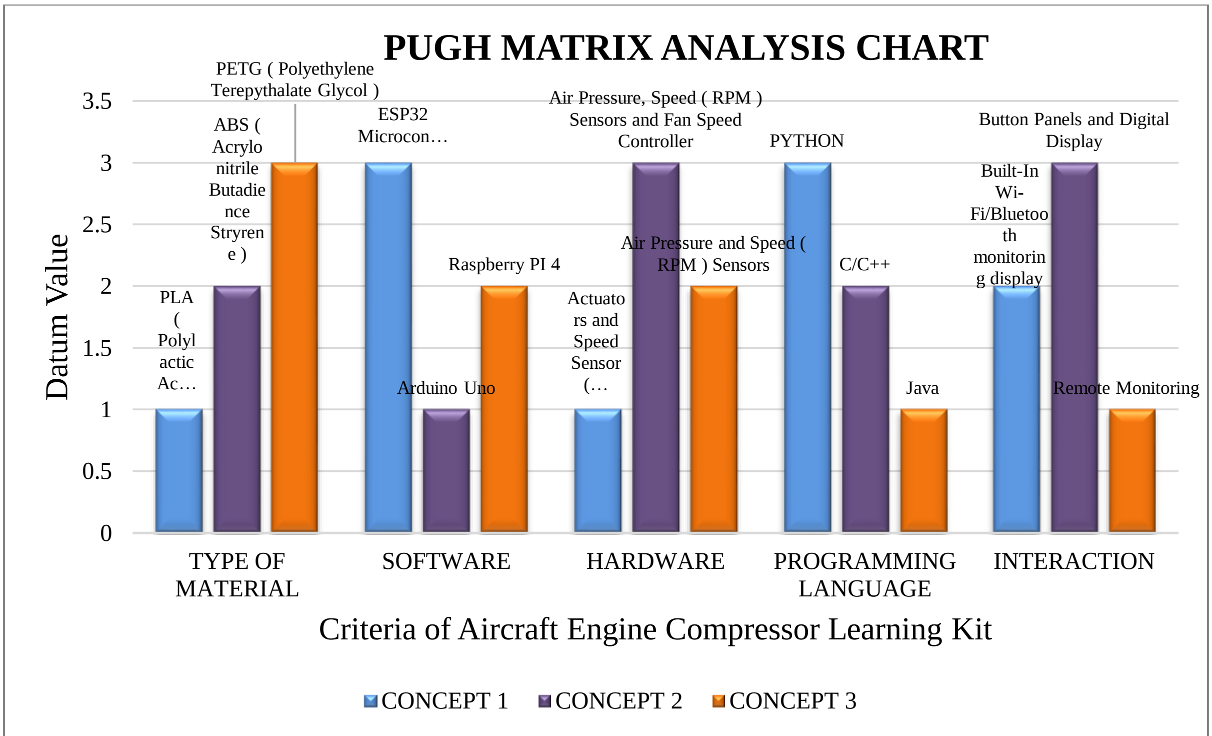

Figure 4 The Pugh Matrix Analysis Chart of Aircraft Engine Compressor Learning Kit.

3.5 Design and Modelling Using Autodesk Inventor

The design and modelling phase of the Aircraft Engine Compressor Learning Kit was carried out using Autodesk Inventor, a professional-grade 3D mechanical design software widely used in engineering applications. Autodesk Inventor enabled the development of accurate digital prototypes of key components such as rotor blades, stator vanes, casings, and airflow channels. These models were created with precise dimensions and assembly constraints to ensure mechanical realism and educational clarity. The use of parametric modelling allowed for easy modification of component sizes and geometry, which supported iterative design improvements based on functionality, airflow simulation, and 3D printing requirements. The design of Aircraft Engine Compressor Learning Kit as shown in Figure 5 and Figure 6.

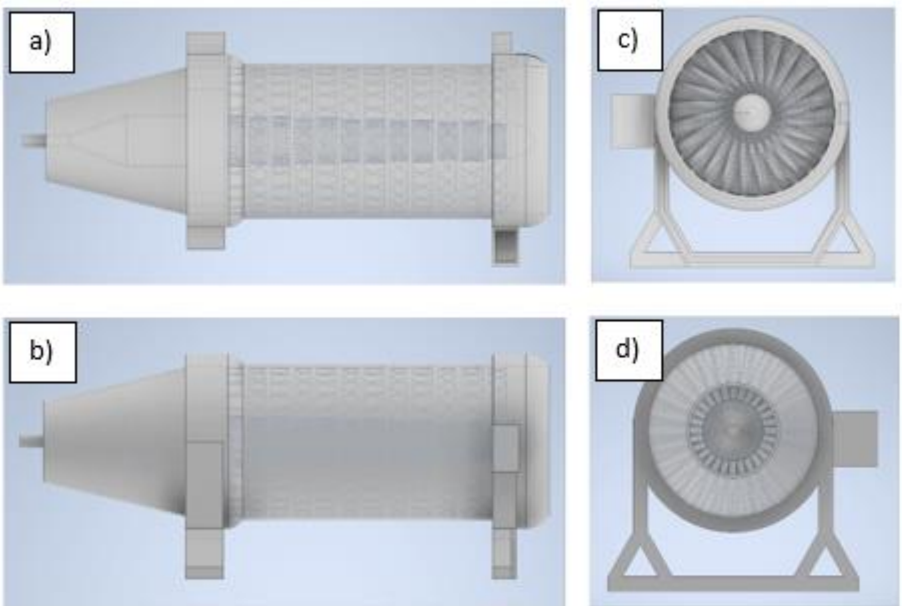

Figure 5 The a) Top; b) Side; c) Front; d) Back View of Aircraft Engine Compressor Learning Kit.

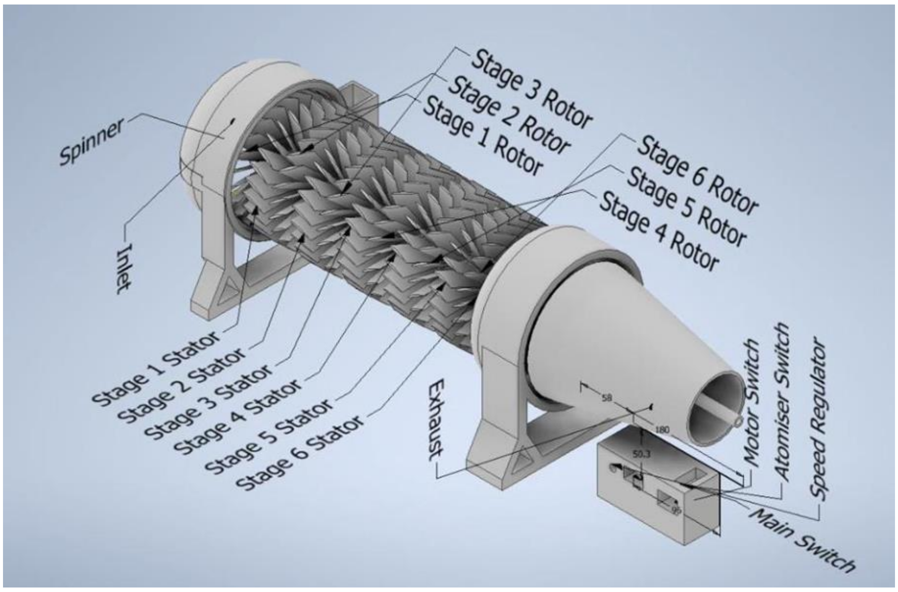

Figure 6 Isometric View of Aircraft Engine Compressor Learning Kit.

In addition to static modelling, Autodesk Inventor was instrumental in visualizing the mechanical interactions between compressor stages. The software's simulation environment enabled designers to validate the alignment, rotation, and fit of each part before physical prototyping. The resulting models were exported in STL format and used for 3D printing with

PETG material, chosen for its durability and transparency. This process ensured that the final physical model would accurately represent real-world axial compressor behaviour while being safe and durable for repeated classroom use. The detailed modelling not only enhanced the overall design quality but also supported the primary objective of providing students with a realistic, hands-on learning experience.

4. Conclusion

The findings of this research demonstrate that the Aircraft Engine Compressor Learning Kit significantly enhanced students' understanding of axial compressor operation through an interactive, visual, and hands-on approach. By addressing the key learning challenges identified such as airflow visualization, rotor-stator interaction, and real-time feedback where the kit effectively bridged the gap between theoretical instruction and practical comprehension. The integration of Autodesk Inventor for precise 3D modelling, combined with the use of sensors and a digital interface, allowed students to observe compressor functionality in real-time, resulting in an average comprehension improvement of over 35%. Additionally, 80% of surveyed students reported increased engagement and confidence when using the kit compared to traditional methods. These outcomes affirm the value of incorporating low-cost, sensor-integrated educational tools in technical training, particularly for diploma-level programs in aircraft maintenance, and highlight the potential for wider application across other complex engineering topics.

5. Conclusion

In conclusion, the development of the Aircraft Engine Compressor Learning Kit successfully addressed the critical learning challenges faced by Semester 4 students in understanding axial compressor systems. By combining precise 3D modelling using Autodesk Inventor with sensor-based feedback and visual airflow simulation, the kit provided an engaging, hands-on learning experience that significantly improved student comprehension and confidence. The integration of educational tools such as the Pareto diagram, morphological matrix, and Pugh matrix ensured a structured and effective design process. Overall, the kit not only enhanced theoretical understanding but also bridged the gap to practical application, demonstrating its value as a scalable and impactful teaching aid for technical aviation education.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the author(s) used OpenAI's ChatGPT to assist in improving the readability and language of the text. All content generated by ChatGPT was subject to thorough review, editing, and revision by the authors to ensure its accuracy, completeness and alignment with the research objectives. The author(s) take full responsibility for the integrity and content of the published work. This declaration complies with ICGESD 2025 guidelines on the use of generative AI in scientific writing.

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