University of Southern Queensland

School of Engineering

Creativity improvement in engineering design of undergraduate students through 3-D part design modelling.

A dissertation submitted by

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towards the degree of

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ENP4111 Dissertation Project

(This is a 2-unit research project in Bachelor of Engineering Honours Program)

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ABSTRACT

Engineering Drawing is a vital skill in engineering design by forming the foundation for effective communication among engineers and professionals. However, in early introductory drafting course focuses in 2D computer-aided design (CAD) tools often limits students' ability to fully understand and visualize complex 3D structures. This research explores the integration of enhance creativity and practical skills among the undergraduate students. The study centres around reverse-engineering an alternator, creating detailed sectional, top, and front views and presenting them in a clear acrylic display box to illustrate the complexities of mechanical assemblies.

The methodology involves providing students in a drafting mechanical class with opportunities to model parts from images, collaborate in groups to assemble these parts, and individually 3D prints a component. This is a hands-on approach is designed to mirror real-world engineering practices and foster essential skill such ass collaboration, problem solving, and adaptability. Also, feedback from engineering students is collected to assess the effectiveness of these activities in enhancing their understanding and skills.

The findings suggest that incorporating 3D modelling and printing into engineering education can significantly improve students' creativity and practical abilities, better preparing them for professional roles that demand teamwork and innovation. This study proposes a more interactive and practical method for teaching engineering drawing, bridging the gap between theoretical knowledge and real-world application.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

δ   =   Deflection

E   =   Young's modulus

σ   =   Normal Stress

τ   =   Angle of internal friction

r   =   Radius of Shaft

J   =   Polar Moment of Inertia

T   =   Applied Torque

GLOSSARY

2D   =   2 Dimensional

3D   =   3 Dimensional

AM   =   Additive Manufacturing

AR   =   Augmented Reality

BMD   =   Bending Moment Diagram

CAD   =   Computer Aided Design

CLIP   =   Continuous Liquid Interface Production

EBM   =   Electron beam melting

FDM   =   Fused Deposition Modelling

GD&T   =   Geometric Dimensioning and Tolerancing

SFD   =   Shear Force Diagram

SLA   =   Stereolithography

STL   =   Stereolithography

VR   =   Virtual Reality

CHAPTER 1 INTRODUCTION

Engineering education must continually adapt to prepare students for the complex challenges of modern industry. A key aspect of this preparation to bridge the gap between theoretical knowledge and practical application especially in engineering design and drawing. In early engineering curricula often rely on 2D CAD like Autodesk AutoCAD while these tools provide a solid foundation for understanding the basic principles of GD&T it limits student ability to fully grasp the intricacies of complex geometries and assemblies. As engineering becomes increasingly reliant on digital and continued increase of use of additive manufacturing techniques. There is growing need to incorporate more dynamic practical teaching methods that encourage creativity that improves problem-solving abilities and provide students real-world experience is expanding as engineering relies more and more on digital manufacturing procedures.

Additive manufacturing or 3D printing represents one such transformative approach in comparison to traditional subtractive manufacturing methods the 3D printing adds material layer by layer to build objects that enables the creation of intricate geometries and highly customized products. This flexibility has revolutionized fields ranging from automotive and aerospace to biomedical and fashion. In an educational context the 3D printing offers unique opportunities for developing students' spatial visualization skills to understanding material properties and applying theoretical knowledge to practical scenarios. By allowing students to design a prototype then fabricate mechanical components and use 3D printing can make theoretical concepts more tangible and accessible.

This thesis explores the integration of 3D part design modelling and 3D printing into the mechanical engineering curriculum to enhance creativity and practical skills among

undergraduate students. Building upon methods discussed in recent educational literature, this study involves the reverse engineering of an alternator an essential component in automotive and industrial applications. The model will include sectional views, top views, and front views, all displayed in a clear acrylic box to highlight the complexities involved in mechanical assemblies. This visual aid aims to help students understand the complete reverse engineering and 3D modelling process, improving their comprehension of mechanical design principles.

The educational approach proposed in this thesis provides each student in a drafting mechanical class with an opportunity to model parts based on provided images and collaborate in groups to assemble these parts and then individually 3D print a component. This method mirrors real-world engineering practices to promoting both individual creativity and teamwork. In professional industry normally rough measurements and hand-drawn sketches turned into precise CAD models. As the iterative process of refining these designs to ensure that all parts fit together correctly is a challenging yet essential skill for aspiring engineers.

The practical application of these skills is crucial as it fosters for a deeper understanding of both the theoretical and real-world aspects of engineering. Also, the dissertation will also engage with current engineering students to gather feedback on their experiences with this hands-on approach, assessing its impact on their learning and creativity. The insights gained from these discussions will be used to refine the proposed methodology and further align it with the evolving needs of engineering education.

This dissertation is structured as follows: Chapter 2 reviews existing literature on 3D modelling and printing in engineering education. Additionally, Chapter 3 outlines the proposed methodology, including reverse engineering, CAD modelling, manual calculations, finite element analysis, and 3D printing. Chapter 4 details the application of this methodology, providing insights into each step and documenting the learning outcomes and challenges encountered. Chapter 5 presents the results and analysis, highlighting the effectiveness of the proposed approach in meeting educational objectives. Finally, Chapter 6 offers conclusions and recommendations, emphasizing the potential of this hands-on approach to enhance engineering education and suggesting future directions for research.

CHAPTER 2 BACKGROUND AND LITERATURE REVIEW

Engineering education has traditionally focused on theoretical knowledge with an emphasis on 2D drawing to convey design concepts. However, this approach has limitations in providing students with the hands-on experience needed to apply these concepts effectively. The integration of 3D printing technology is a promising way to allow new engineering students to better understand practical applications in engineering design projects. As this literature review examines the current methodologies and software tools used for 2D and 3D modelling in engineering education and their advantages on the role of 3D printing that enhancing learning outcomes(Cantero et al. 2015).

2.1 BACKGROUND ON 2D AND 3D DRAWING IN ENGINEERING EDUCATION

The evolution of engineering drawing in education has progressed significantly from manual drafting to the use of sophisticated computer-aided design (CAD) tools. The traditional manual drafting which normally relies on drawing boards, T-squares, and compasses, was gradually replaced by 2D CAD software like AutoCAD, which became the standard in educational institutions from the 1980s onwards(Bertol 2013).

Figure 1: A drafting class in the early 1970s.

These tools allowed engineering students to transition from labour-intensive manual methods to faster more precise digital drafting techniques. The shift to 2D CAD transformed engineering education by enabling students to efficiently

learn technical drawing fundamentals, including orthographic projections, dimensioning, and technical documentation.

However, engineering problems a complex and multidisciplinary so need for 3D representations grew 3D CAD software tools like SolidWorks, Autodesk Inventor, and PTC Creo began to replace or complement 2D CAD software in curricula, providing more realistic models that better represented real-world applications. These tools not only allowed for visualization of complex geometries but also supported functionalities like simulations, parametric modelling, and digital prototyping as more innovation come in making them essential for modern engineering education(Afiqah Hamzah et al. 2021).
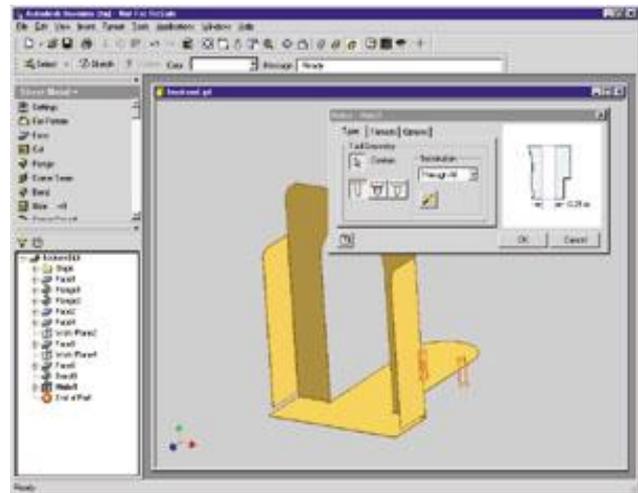
Figure 2: Autodesk Inventor 2 from year 2000

The integration of 3D CAD tools into the curriculum aligns with a common academic principle of "learning by doing," which emphasizes practical hands-on experience over theoretical instruction as this stimulated student's brain. This approach is especially beneficial in engineering where the ability to visualize, manipulate, and understand 3D objects is crucial for success of product that being manufactures(Alghazzawi 2016). Despite the rise of 3D CAD, the 2D drawings remain fundamental in teaching technical drawing laying the groundwork for students to understand the core principles before transitioning to more advanced 3D modelling.

2.2 ADVANTAGES OF 2D DRAWING SOFTWARE

While 3D CAD tools offer advanced capabilities the 2D CAD software still plays a critical role in engineering education and industry for several reasons:

- For beginners the ease use 2D CAD software like AutoCAD is more accessible due to its straightforward interface and functionality in which focuses on the basics of technical drawing without overwhelming students with advanced features of the 3D modelling. As a result, this simplicity allows students to build a strong foundation in drafting, which is crucial before moving on to more complex 3D modelling.

- 2D drawings still remain essential for creating a detailed technical documentation including blueprints, electrical schematics, and Piping and Instrumentation Diagrams (P&IDs). These documents are critical for manufacturing, construction, and maintenance activities of components as they provide precise measurements, annotations, and instructions needed for assembling or fabricating components. Also, the 2D do not require 3D representations, such as floor plans, wiring diagrams, and flowcharts in certain engineering field like civil and electrical.

- Compared to 3D CAD software the 2D CAD software tools generally require less computing power and are more affordable. Thus, making them accessible for educational institutions with limited budgets this affordability ensures that all students, regardless of their institution's resources, can access quality drafting education.

Despite these advantages the limitations of 2D CAD tools in terms of visualizing complex assemblies and simulating real-world scenarios have prompted educators and institutions to integrate 3D modelling tools into their courses.

2.3 3D CAD SOFTWARE AND THEIR EDUCATIONAL BENEFITS

3D CAD software has become a keystone of modern engineering education due to its ability to provide students with a more interactive and engaging learning experience. A sample of this like SolidWorks, Autodesk Inventor, and PTC Creo allows for the creation of detailed 3D models that can be viewed, manipulated, and analyzed from different angles offering several educational benefits and it takes advantages of parametric modelling where revision of model it takes second that redrawing it again.

3D CAD tools enable students to visualize models from multiple perspectives, helping them understand spatial relationships and assembly structures. This capability is particularly valuable in mechanical, aerospace, and civil engineering, where the ability to visualize complex systems is critical (Brière-Côté et al. 2012). Also, 3d Parametric design features allow students to make dynamic adjustments to models by changing parameters like dimensions, constraints, and features. As a result, this flexibility enables to play with different design variations and understand the implications of their changes on the overall model that is assembled. Additionally, many 3D CAD packages, such as SolidWorks and Inventor, integrate with simulation tools that allow students to perform structural, thermal, and fluid flow analyses on their models. This integration helps bridge the gap between theoretical learning and practical application by giving students the opportunity to validate their designs against real-world scenarios.

3D CAD software facilitates digital rapid prototyping this allowing student to create and test virtual models before physical production. This process reduces material waste and promotes rapid iteration, enabling students to refine their designs efficiently. However, the benefits of 3D CAD software are not without challenges. There is required steep learning curve and the need for more powerful computing resources can pose issue for some students

and institutions. Educators need to balance the introduction of 3D CAD tools with foundational training in 2D drawing to ensure that students are well-rounded in their technical skills.
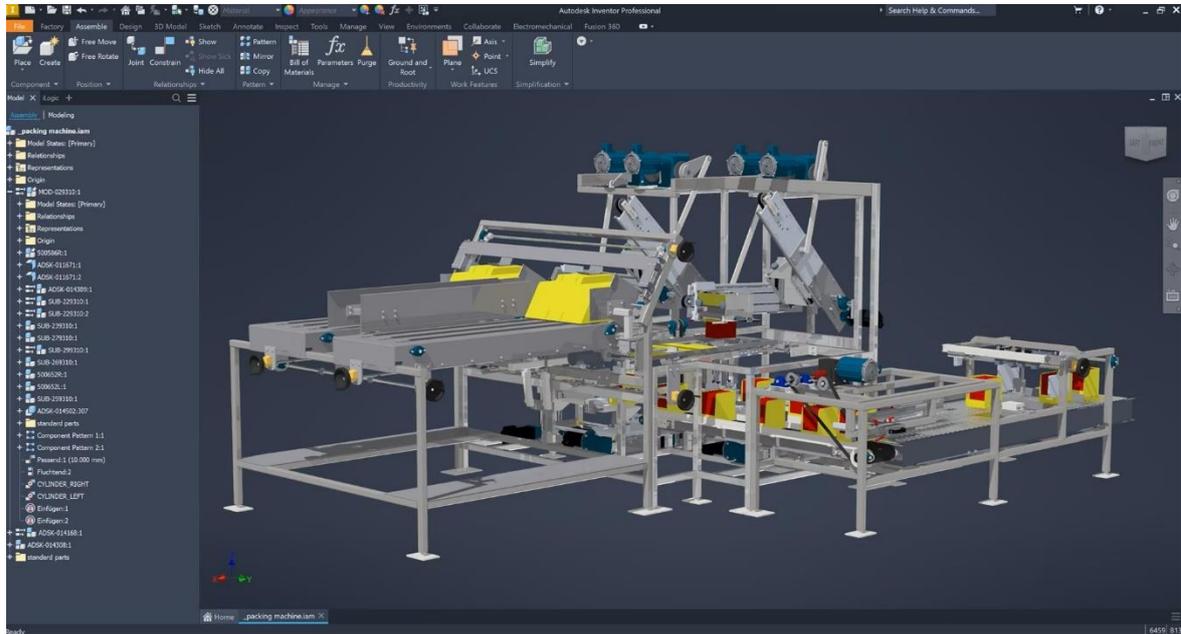
Figure 3: Autodesk Inventor 3D modelling

2.4 INTEGRATION OF 3D PRINTING IN ENGINEERING COURSES

The integration of 3d printing into engineering education offers transformational approaches to teaching design and manufacturing principles. 3d printing, also known as additive manufacturing, takes advantage of creation of complex geometries and highly customizable component they would been challenging to produce using traditional methods like subtractive manufacturing methods. A Study shown the incorporation of 3D printing technologies into high school curricula provides students with hands-on experience related to gaining a technical knowledge (Chien & Chu 2018).
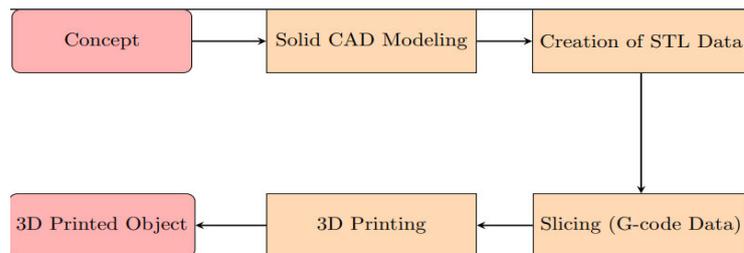
Figure 4: A Common Workflow of 3D Printing

As show in figure 4 a typical work flow of 3D printing into involves several stages in each providing distinct learning opportunities and challenges that enhance students understanding of both design principles and manufacturing processes.

1. **Conceptual Design**: This initial stage involves developing a clear idea of the component or assembly to be created normally purpose is this it brainstorms ideas that have functionality, and aesthetics of the design. This stage fosters creativity and innovation, allowing to explore various design options, materials, and mechanisms. Also, it allows to emphasize problem-solving and decision-making skills as considering factors such as feasibility, cost, and functionality.

2. **CAD Modelling**: the next step is to translate ideas into a digital format using CAD software where develops the conceptual ideas to a precise 3D model. This normally have details like dimensions, geometry, and the relationship between different parts. It reinforces their understanding of engineering drawing principles and geometrical constraints while also enhancing their proficiency in using CAD tools. The process must include how to consider factors such as part interconnectivity, assembly, and design for manufacturability.

3. **Conversion to STL Files**: Once the CAD model is finalized it must be converted into a format suitable for 3D printing like typically format of a STL file. This step involves understanding the mesh resolution and fidelity as the quality of the STL file directly impacts the accuracy of the printed model.
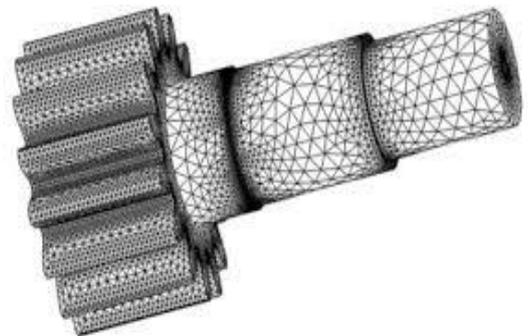
Figure 5: STL File

4. **Slicing to Generate G-Code**: Slicing is the process of converting the STL file into G-code in which is the language that 3D printers understand and what is commonly used in subtractive manufacturing. This stage involves using slicing software to set various parameters such as layer height, infill density, print speed, and support structures. Students must understand how these parameters affect the print quality, structural integrity, and print time. For instance, slicing allows to minimize material waste while ensuring strength and precision, and how to adjust for different material properties and printer capabilities.
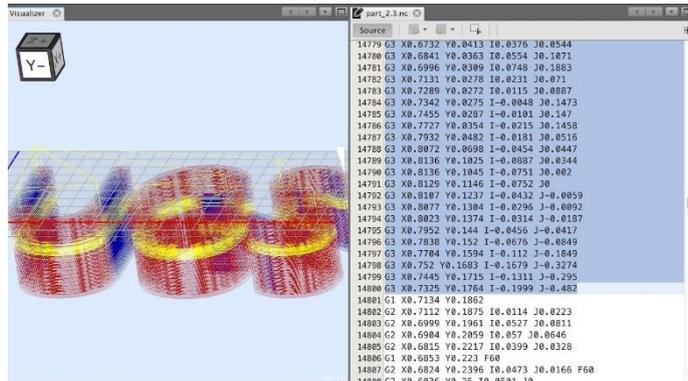
Figure 6 G Code Sample

5. **3D Printing**: The actual printing process allows users to see their digital models come to life. It provides practical exposure to the operation and troubleshooting of 3D printers. They experience firsthand the challenges that can arise during printing, such as warping, stringing, or layer adhesion issues, and learn how to adjust printer settings and techniques to address these problems. This stage also provides insight into the material science aspect, as it requires observation on how different materials behave under different printing conditions.
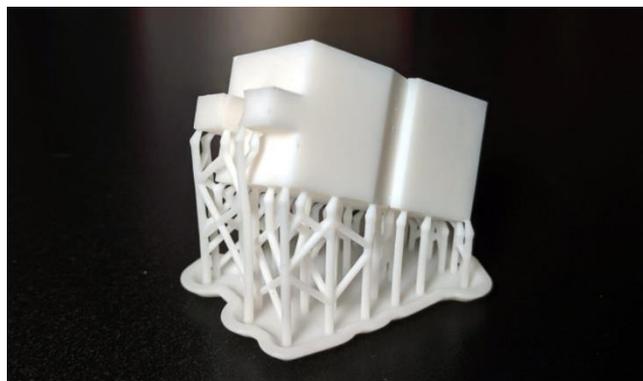
Figure 7: 3d Print with Support

10

6. **Post-Processing**: Once the print is complete the post-processing is required to improve the appearance and functionality of the part. This involves removing support structures, sanding, painting, or adding additional features that could not be printed directly. Also, this stage requires about the importance of finishing techniques and their impact on the final product. It also highlights the limitations of additive manufacturing and the need for complementary processes.
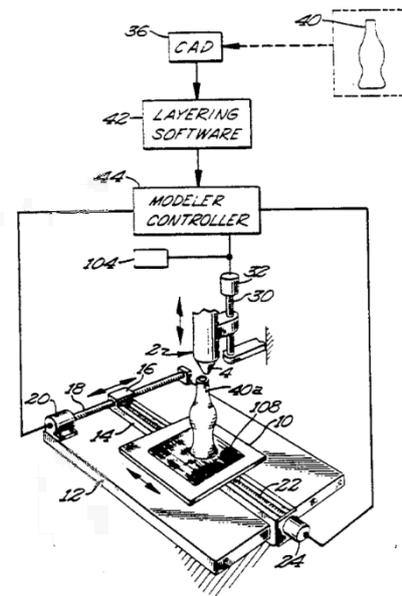
Figure 8: Charles Hull Apparatus (Hull,1984)

Each of these stages bridges the gap between theoretical knowledge and practical application by allowing students to understand the full scope of the design and manufacturing process. As a result, they gain valuable insights into tolerances, material properties, support structure requirements, and the iterative nature of engineering design. By navigating these stages, students develop a general understanding of engineering challenges, enhancing their problem-solving skills and preparing them for real-world engineering tasks.
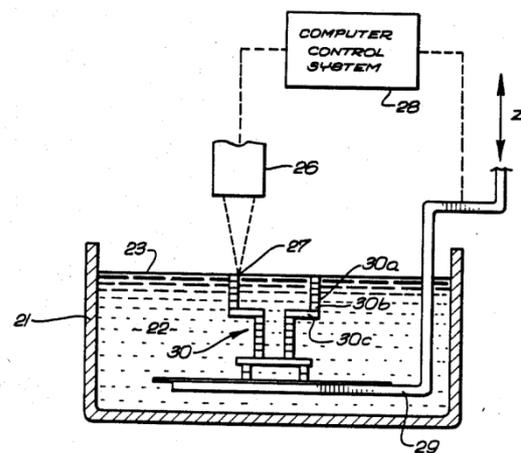
Figure 9: Scott Crump Apparatus (Crump, 1991)

2.5 BRIEF HISTORY OF 3D PRINTING TECHNOLOGY

The history of 3D printing or commonly known as additive manufacturing is originated in the 1980s as new approach to rapid prototyping. Charles Hulls founder of SLA in 1984 was a groundbreaking moment that allow groundbreaking production of three dimensional objects by solidifying photopolymer resin by using ultraviolet lasers(Hull 1984). Also, later in 1988 Scott Crump introduced FDM in which involves pushing a filament through a nozzle to layer it and create objects, from the ground up. This technique made prototyping more accessible by utilizing cost materials and streamlining the printing procedure. The easy access, to FDM technology enabled design and engineering improvements that appealed to industries looking for cost effective prototyping options. The pioneering work by Crump played a role in expanding the use of 3d printing from industrial settings to a wider audience in smaller businesses and schools. This shift has led to the integration of 3d printing as an asset, in product development and engineering processes(Crump 1991). This does not stop in innovation in 3D printing current manufacturers focuses on strong emphasis on the ongoing development of materials and sustainability practices within the industry. Cutting edge 3D printers now offer the capability for material printing which enables the integration of diverse properties like rigidity and flexibility into a single 3D print build plate. This breakthrough has significantly broadened the scope of applications for 3D printing across many sectors of engineering. Furthermore, there has been a shift towards sustainability in this field with a focus on creating eco-friendly resources such, as biodegradable polymers and recycled plastics. These advancements aim to reduce the environmental impact of 3D printing, promoting a more sustainable approach to manufacturing. This shift helps balance innovation with environmental responsibility, aligning with global sustainability goals(Lipson & Kurman 2013).

2.6 ADVANTAGES OF 3D PRINTING IN ENGINEERING EDUCATION

3D Printing has becoming integral part of engineering education with the range of benefits that can enhance learning outcomes and bridge the gap between theoretical knowledge and practical application. The use of 3D printing can enable students to engage more deeply with complex concepts develop hands on skills, and foster innovation. This section reviews the various advantages of integrating 3D printing into engineering education and its impact on the students' learning experiences based on existing sources can be found on the internet. Also, one of the primary advantages of 3D printing in engineering education is the ability to provide a tangible representation of complex theoretical concepts. In general, engineering education often involves the study of intricate systems and components often involve the study of intricate systems and components that can be difficult to visualize. By incorporating 3d printing models into coursework's students can create physical models of mechanical parts, structural design, or circuit prototypes, thereby improving their

Figure 10: Bambu Lab Printer (Bambu Lab, 2023)

comprehension and retention of many complex topics(Ford & Despeisse 2016). This approach supports deeper understanding of engineering principles and encourages active problem solving. Another significant benefit is the enhancement of students' design and prototyping skills. 3D printing allows students to transform their digital CAD models into real-world objects, bridging the gap between virtual simulations and physical testing. This experience is particularly valuable in design-focused courses where students can iteratively test and refine their projects. The hands-on experience with prototyping fosters critical

thinking, as students must consider material properties, design constraints, and manufacturing limitations(Fletcher 2024). The iterative nature of 3D printing supports experiential learning, where students learn from both successes and failures, an essential skill for engineering problem-solving. Overall, in engineering education at the university level 3D printing presents advantages such as comprehension of intricate ideas that develops advanced skills in design and prototyping as it fosters creativity and innovation and interdisciplinary teamwork. These benefits help shape engineering students who're ready to tackle the challenges of today's industry.

2.7 INTEGRATION OF 3D CAD WITH VIRTUAL REALITY AND AUGMENTED REALITY

The integration of 3D CAD with VR and AR is increasingly recognized as a transformative tool in engineering education, particularly for online and external learning modes this would be beneficial for USQ as most of students is enrolled online. These technologies offer immersive and interactive experiences that can enhance students' understanding and provide practical learning opportunities that go beyond traditional 2D CAD software.

Key Benefits

- The enhanced spatial understanding VR and AR enable students to engage with complex 3D models as examining them from multiple perspectives and interacting with their components. As a result, this engagement significantly boosts spatial visualization skills which is a critical competency in mechanical and structural engineering (Afiqah Hamzah et al. 2021). For students in online or remote learning environments, VR and AR help simulate hands-on experiences that might otherwise be limited by the lack of physical interaction.

- remote collaboration and engagement the AR technologies facilitate collaborative learning by allowing students and instructors to interact with the same virtual model in real-time, even from different locations. This feature fosters teamwork and collective problem-solving, essential skills in engineering design (Chien & Chu 2018). The ability to collaborate on complex models enhances the online learning experience, making it more interactive and engaging.

Challenges

- Technological and Financial Barriers: While the benefits of VR and AR are compelling, their implementation can be stalled by high costs and technical requirements. VR headsets, AR glasses, and the necessary required high-performance computing resources pose financial challenges especially for educational institutions with limited budgets. For students participating in external learning accessing these tools might be restricted due to personal resource constraints.

- Learning Curve and Training Needs: Effectively using VR and AR in engineering courses requires training for both students and educators. Adapting to these technologies can be time-consuming and may initially slow down the learning process. Ensuring continuous support for students in online programs is crucial to maximize the potential of these tools without compromising the quality of instruction as the current engineering program shifted from semester to trimester which has shorted by 3 weeks.

Current Implementations and Impact

Universities offering online engineering degrees are starting to incorporate VR and AR to simulate real-world scenarios and bridge the experiential gap between remote and in-person education. For example, some engineering programs use AR to overlay virtual models on physical components, allowing students to visualize internal mechanisms and assembly processes. This dual-layered approach helps deepen the understanding of engineering concepts and improves engagement in online settings.

The integration of CAD-based simulations with VR/AR also allows students to experiment with design modifications, test virtual models, and identify potential issues before moving to physical prototyping. This iterative process helps students refine their problem-solving and design skills while providing feedback that enhances the learning experience (Afiqah Hamzah et al. 2021).

Potential for Future Research

While significant strides have been made in using VR and AR in engineering education, research gaps remain. Future studies could explore the long-term impact of these technologies on student learning outcomes in online programs, as well as the effectiveness of different implementation strategies to ensure accessibility and inclusivity.

2.8 SOFTWARE-BASED SIMULATIONS IN ENGINEERING EDUCATION

The use of software-based simulations in engineering education has greatly improved how students learn by connecting gaps between theoretical concepts and practical applications. Ansys Mechanical is renowned for its advanced capabilities in in structural analysis and

FEA. These features enable students to validate manual calculations and understand theoretical concepts in depth and makes design improvements before moving into physical prototyping. In this project, students use ANSYS Mechanical to evaluate CAD model ensuring it structuring strength before 3D printing. This phase teaches students to uses manual calculations with real world simulations reinforcing analytical skills in which crucial for engineering practice.
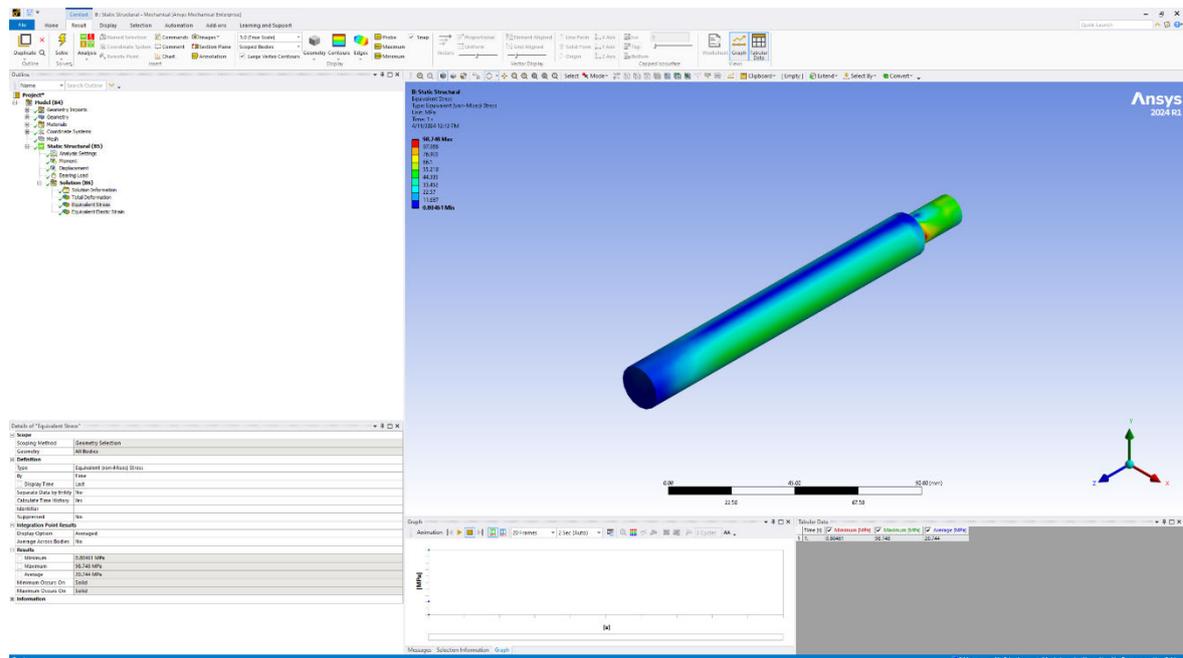
Figure 11: ANSYS Mechanical Software

2.9 CHALLENGES IN IMPLEMENTING 3D PRINTING IN EDUCATIONAL CURRICULA

The implementation of 3D printing in educational offers numerous potential benefits but is not without its challenges. The primary issue for some institutions is the financial burden associated with high quality 3d printers, maintenance, materials, and online students, this expense often limits the access to 3d printing technologies particularly in intuition with constrained budget(To et al. 2024). Also, technical expertise among educators is another significant barries. Choi and Jung 2014 successful implementation requires instructor to understand 3d printing and its application in teaching. Without sufficient training the

17

educators may not fully leverage the technology's potential leading to superficial use in courses that fails to engage students meaningfully. Additionally, access to resources remains an ongoing issue as Kurman and Lipson 2013 pointed out that limited availability of 3D printers can lead to unequal learning experiences among students particularly in large classes and the external students. To ensuring all students have adequate time to engage with 3D printing processes is essential for maximizing the educational benefits. Finally, addressing these challenges requires strategic investment, targeted training, and thoughtful curriculum design. While the potential for 3D printing to enhance engineering education is significant overcoming these barriers is crucial for its successful implementation in engineering education.

2.10 ADVANCES IN 3D PRINTING TECHNOLOGIES AND THEIR IMPACT ON EDUCATION

The implementation of 3d printing into engineering education has enhances the learning by bridging the gap between theoretical knowledge and practical applications. Also, the use of 3d printer have enabled students to prototype complex components that foster creativity and improving design thinking (Chua & Leong 2016; Ford & Minshall 2019). The rapid prototyping process encourages iterative learning this allows students to refine their design and learn from failures (Marks & Chase 2019). The 3d printing supports a hands-on approach that deepen the understanding of material properties, load distribution and assembly (Fernández 2023). Sustainability considerations have been integrated into engineering curriculum as United Nation have been pushing the approach on sustainable development goals as this help the future engineers to align with industry expectations and promotes sustainable practices (Tseng et al. 2021).

CHAPTER 3 PROJECT METHODOLOGY

3.1 CHAPTER OVERVIEW

The following chapter provides a comprehensive understanding of the proposed methodology implemented to ensure achievement of successful project outcomes. This dissertation seeks to explore the integration of 3D printing technology into the engineering curriculum at the University of Southern Queensland (UniSQ). The primary objective is to enhance students' creativity, practical skills, and understanding of fundamental engineering concepts by utilizing tools such as reverse engineering, CAD modelling, FEA, and 3D printing.

The chosen model for this study is an alternator which is a mechanical component known for its variety of geometric features and complex assembly structure. The chosen model is alternator selected because it incorporates key many geometrical shapes such as cubes, parallelepipeds, cylinders, and spheres as it provides an ideal case for demonstrating both fundamental and advanced engineering design principles.

 Also, this research follows a structured methodology where students begin with the **reverse engineering** of the alternator shaft, documenting its dimensions and characteristics. This stage fosters a foundational understanding of physical components and prepares students for digital modelling. Next, students create a **CAD model** using modelling software, applying best practices in design representation to ensure accuracy.

To validate their designs, students conduct **FEA** using ANSYS Mechanical assessing structural integrity under defined loading conditions. This step bridges manual calculations and simulation, reinforcing students' analytical skills and their ability to interpret results critically.

Finally, students proceed with **3D printing** their validated models to test fitment and evaluate real-world application. This hands-on phase allows students to experience the iterative process of design refinement based on physical feedback, enhancing their problem-solving abilities. The incorporation of 3D printing encourages students to troubleshoot, adapt, and improve their designs, fostering creativity and practical expertise.

This comprehensive methodology aims to balance theoretical knowledge with practical application the structured activity fosters creativity while enhancing both technical knowledge and hands-on expertise.

3.2 DESIGN METHODOLOGY

This design methodology outlines a structured approach aimed at achieving specific learning outcomes through the integration of reverse engineering, CAD modelling, manual calculations, FEA, and 3D printing. The proposed activities are designed to:

1. **Encourage creativity** in the design process through hands-on modelling and problem-solving.
2. **Develop students' ability** to reverse-engineer and understand the mechanical operation of components.
3. **Provide practical** experience in CAD software and 3D modelling to reinforce technical skills
4. **Validate theoretical knowledge** by comparing manual calculations with FEA results.
5. **Introduce 3D printing** and its role in modern manufacturing, emphasizing how design decisions affect the final product.

These objectives guide the methodology as this ensuring that students gain comprehensive hands-on experience that balances theoretical learning with practical application. Each stage in the methodology has been crafted to contribute to these educational outcomes as detailed in the following subsections:

3.2.1 Reverse Engineering

Reverse engineering is the first step of this methodology, this aims to developing students' deconstructing and analysing mechanical components to understand its design and function. This process requires the disassembly of the shaft to meticulously measure critical dimensions and analyse how each individual part integrates within the broader mechanical system. During this stage, students are tasked with documenting their observations through detailed technical sketches and comprehensive written descriptions, ensuring a precise and thorough understanding of the component's functionality.

While the alternator shaft serves as the model for this study, the methodology is designed to be adaptable. Instructors have the flexibility to substitute this component with other mechanical parts such as gears, brackets, or pump components depending on the desired learning outcomes of future iterations of the activity.

The reverse engineering process is intended to cultivate critical thinking and analytical skills in students, prompting them to reflect deeply on the mechanical design process and the interactions between individual components. This foundational step is essential, as it informs and guides subsequent stages of the project, including CAD modelling, finite element analysis, and eventual 3D printing, by providing a clear understanding of the component's structural

3.2.2 Technical Sketches and Written Descriptions

In this phase, the focus is on understanding how each part within the alternator shaft interacts with others to contribute to the overall functionality of the assembly. This involves examining the roles of different components, such as the shaft, pulleys, and bearings, to determine how mechanical power is transferred and converted within the system. By

mapping out these interactions, students develop a deeper understanding for design considerations such as load paths, stress distribution, and the importance of specific features that enhance performance or durability.
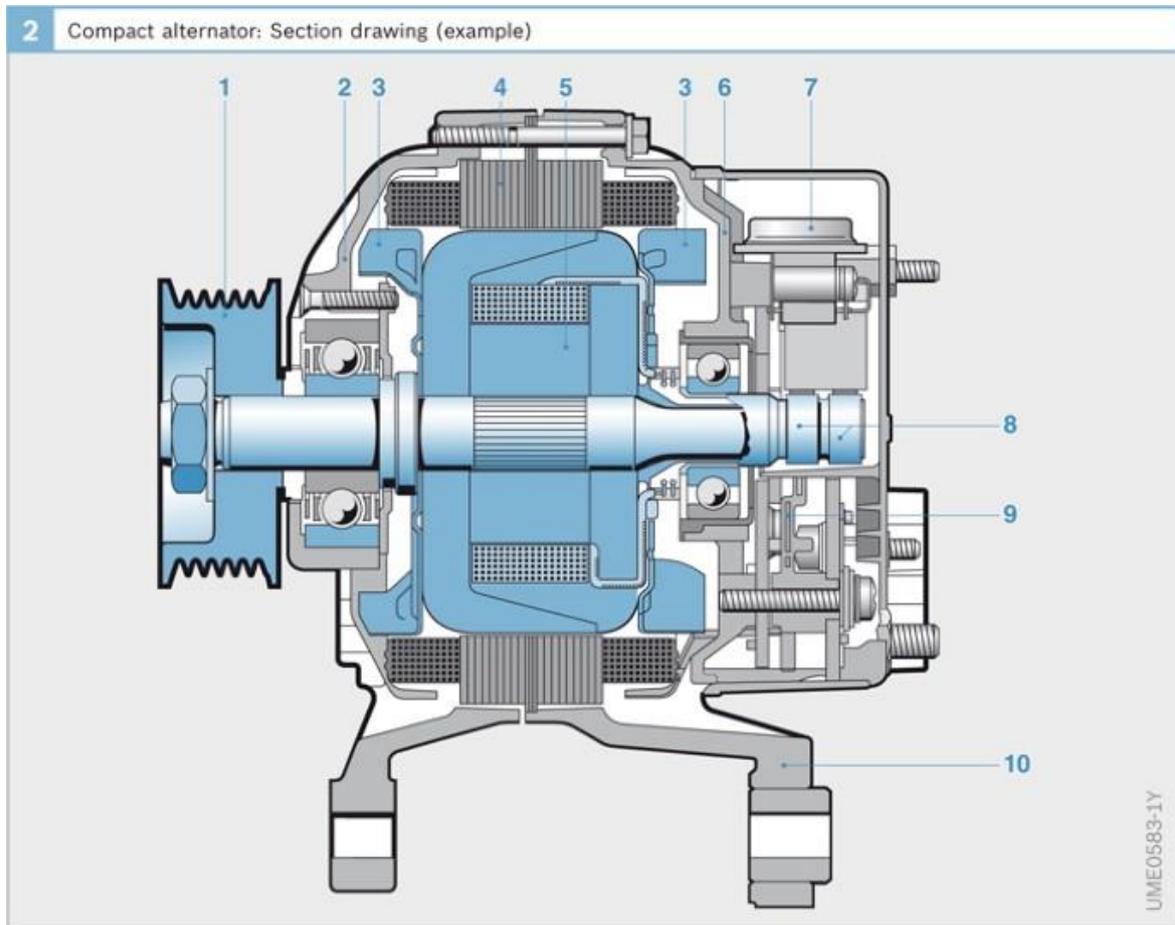
Figure 12: Alternator Sectional Drawing ('Alternators' 2014)

This analysis helps students bridge the gap between disassembly observations and digital modelling by linking each physical feature to its function. It also provides a foundation for validating the CAD model and simulations in later stages, ensuring that every modelled component reflects its real-world application accurately.

3.2.3 Analysis of Functional Integration

In this section, students analyse how the parts of the alternator shaft work together to achieve mechanical functionality. This involves identifying how the power is transferred through the shaft, understanding the roles of pulleys, and recognizing how mechanical efficiency and durability are achieved through specific design choices.
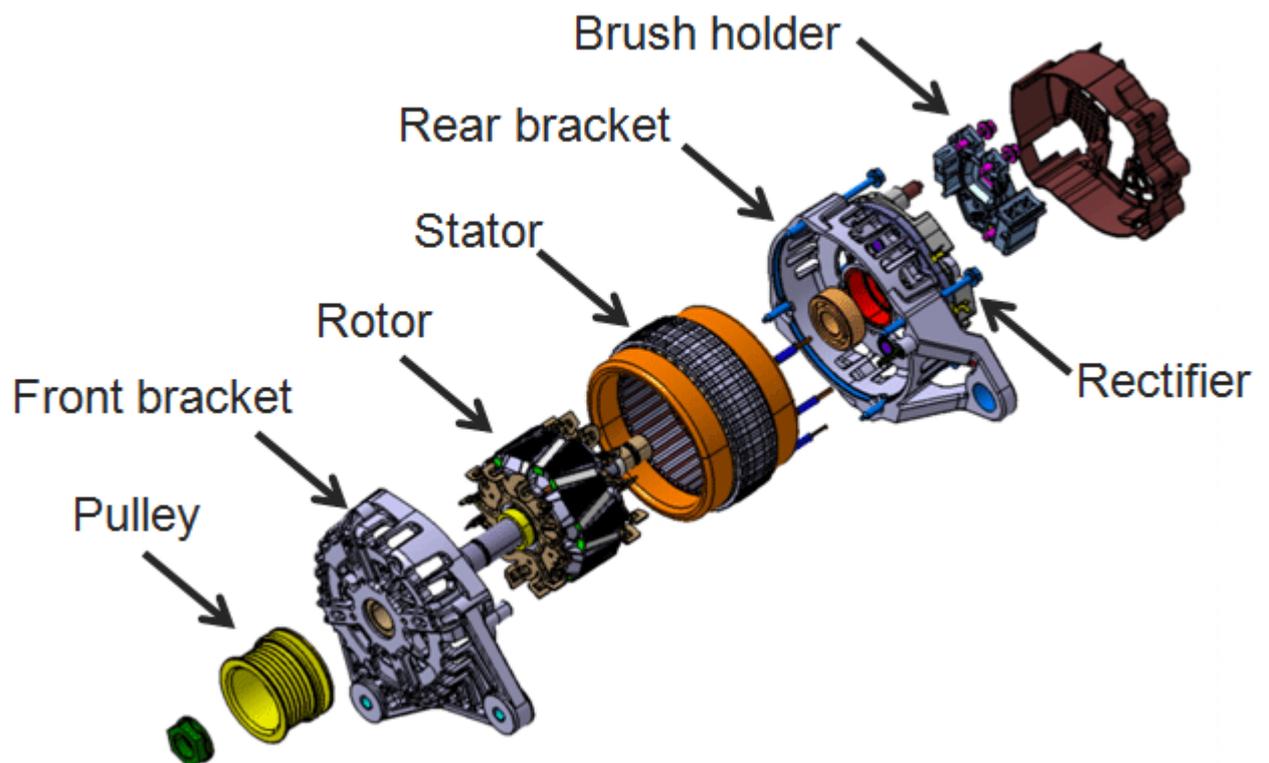
Figure 13: Exploded View of Alternator (Tan-Kim et al. 2017)

By mapping out these interactions, students gain insights into the importance of design elements and their impact on performance. This analysis sets a foundation for accurate CAD modelling and later when they are doing simulation.

3.2.4 Adaptability of the Methodology

The proposed methodology is flexible that it can be adapted other mechanical components such as gear, brackets, pump assemblies. This adaptability ensures that the learning approach

remains relevant for various educational objectives tailored to the process to fit different course goals. Also, this flexibility reinforces the reverse engineering skills across different types of components and prepares students for real-world engineering challenges that requires adaptability and innovative thinking.

3.2.5 Educational Objectives and Skill Development and functional relationships.

The reverse engineering phase supports key educational objectives by providing students with hands-on experience that enhances critical skills. Through this method, students gain:

1. **Attention to Detail:** Cultivated through precise measurement and documentation.
2. **Analytical Thinking:** Developed by understanding the role of each component within the assembly.
3. **Practical Application of Theory:** Achieved by connecting physical observations with engineering principles.

These skills lay the groundwork for further phases of the methodology, ensuring that students are well-prepared for CAD modelling, manual calculations, and FEA. This approach aligns with the overarching goal of equipping students with both theoretical knowledge and practical engineering skills.

3.3 CAD MODELLING

Once Student have completed the necessary steps of measurement and have gathered insights from the reverse engineering phase, they will employ cad software to create a detailed 3D digital model of the alternator shaft. This digital modelling process will involve generating sectional views, exploded views, and comprehensive technical drawings to accurately capture the internal structure of the shaft. These views will aid in both

visualization and further analysis. During this phase, students will gain proficiency in both basic and advanced CAD techniques, including:

- **Creating and manipulating 3D shapes and features**: This includes generating geometric forms and integrating them into a cohesive model.

- **Parametric design exploration**: Students will use parametric design to investigate how changing specific parameters affects the overall geometry of the model, providing insight into design optimization.

- **Generating sectional and exploded views**: These views will allow students to visualize how different components fit together, which is essential for understanding assembly processes.

The completed CAD model will serve as a crucial resource for subsequent manual calculations and Finite Element Analysis (FEA). It bridges the gap between physical measurements and digital analysis, helping students translate their hands-on work into a format suitable for computational simulations and further structural evaluations.

3.3.1 Creating the 3D Model

Students will focus on constructing 3d models by generating and manipulating geometric forms. This process involves integrating various design features such as extrusions, revolutions, and fillets into cohesive model that represent the alternator shaft with accuracy. This practice enhances students' understanding of how individual shaped and elements contribute to the overall assembly.
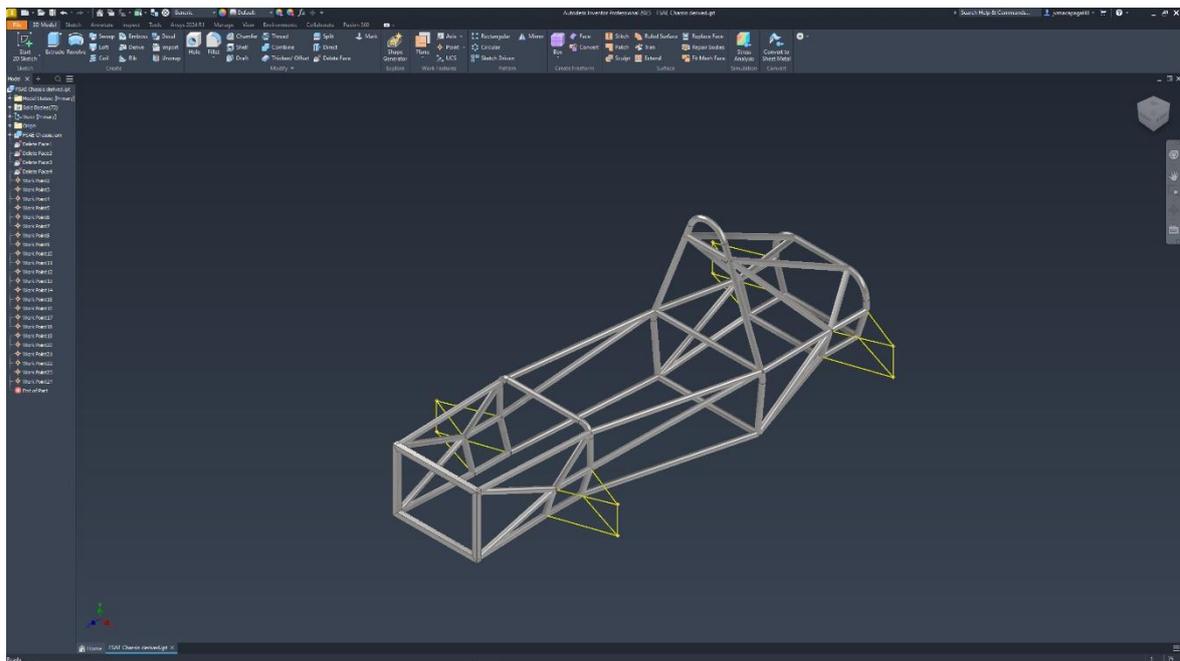
Figure 14: Cad Model

3.3.2 Parametric Design Exploration

To deepen their understanding of design optimization, students will employ parametric modelling. This involves setting parameters that can be easily adjusted to observe how changes affect the overall geometry of the model. Through this exploration, students gain insight into how design modifications can improve performance, manufacturability, and functionality.

Figure 15: Parametric Modelling Tab

3.3.3 Generating Sectional and Exploded Views

Creating sectional and exploded views is essential for understanding the internal structure of complex components and visualizing how individual parts fit together. Students will generate these views to display cross-sections that reveal hidden features and exploded diagrams that illustrate the assembly's relationships between parts. These visual tools are crucial for preparing technical documentation and understanding assembly processes.

3.3.4 Preparing the CAD Model for Further Analysis

The completed CAD model will serve as a footing for later manual calculations and FEA. It bridges the gap between physical measurements and digital analysis helping students translate their hands-on work into a format suitable for computational simulations and structural evaluations. This transition from physical to digital allows students to verify the structural integrity of their designs and refine them based on insights gained from both manual and computational assessments.

3.4 MANUAL CALCULATIONS AND FEA

Once the completion of the CAD model the students will perform manual calculations to assess the mechanical performance of the alternator shaft. This phase of the residential school includes the following activities:

- **Creation Free Body Diagram:** The creation FBD diagrams will test students if they understand how forces are distributed along the length of the shaft.

- **Calculating stresses and deflections**: Using beam theory and classical mechanics, students will compute the stresses and deflections experienced by the shaft under various loading conditions.

- **Comparing calculations with industry standards**: The calculated values will be compared to established safety margins and mechanical performance criteria used in industry, ensuring that the designs meet relevant mechanical standards.

Once manual calculations are completed the students will utilize FEA software such as ANSYS to simulate the alternator shaft's behaviour under real-world loading conditions. FEA will provide an in-depth analysis of stress distribution, deflection, and overall mechanical behaviour, offering valuable insights into how the design will perform in practice.

The outcomes of both the manual calculations and the FEA simulations will be compared to assess the accuracy of the students' designs. This comparison will serve as a key step in validating the computational model and identifying any discrepancies between theoretical predictions and computational analysis, facilitating an iterative design improvement process.

3.4.1 Free Body Diagrams Creation

The creation of Free Body Diagrams (FBDs) allows students to visualize and understand how forces are distributed along the length of the alternator shaft. This practice is essential for identifying the points of maximum stress and determining the reactions at supports or connections.
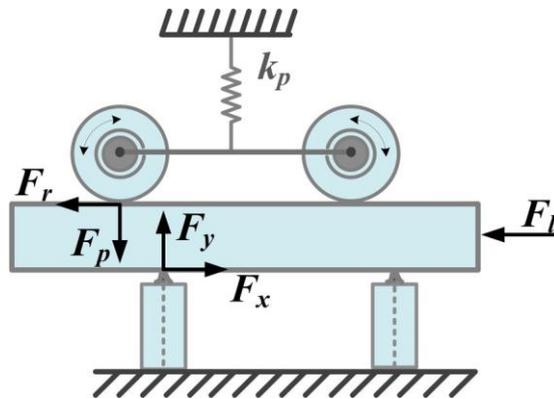
Figure 16: FBD of a Motor (Uzunovic et al. 2016)

3.4.2 Stress and Deflection Calculations

The creation of FBD allows students to visualize and understand how forces are distributed along length of the alternator shaft. This practice is essential for identifying the points of maximum stress and determining the reaction at supports or connection.
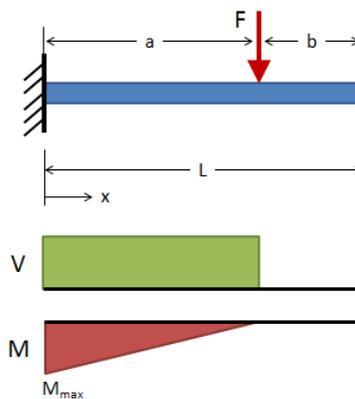
Figure 17: Cantilever Beam with Point Load Showing SF and BMD

29

3.4.3 Verification Against Industry Standards

Once the theoretical manual calculations are completed, they are evaluated against industry standards for solid shafts to ensure design robustness and safety compliance. In particular, we focus on verifying the stress and deflection values using standardized formulas applicable to a solid shaft the formulas are extracted from AS1403-2004.

Torsional Shear Stress for a Circular Solid Shaft:

$$\tau = \frac{Tr}{J}$$

τ = Torsional shear stress, (Pa)
T = Torque applied to the shaft, (Nm)
r = Radius of the shaft, (m)
J = Polar moment of inertia.
Maximum Bending Stress Formula:

$$\sigma_{max} = \frac{Mc}{I}$$

σ_{max} = *Maximum Bending Stress*
M = Bending Moment (Nm)
C = Distance from the neutral axis to the outermost fibre (m)
I = Moment of inertia
Beam Deflection Formula

$$\delta = \frac{P\,L^3}{3\,E\,I}$$

δ = Maximum deflection (m)
P = Load applied (N)
L = Length of the shaft (m)
E = Modulus of elasticity (Pa)
I = Moment of inertia

These calculated values are then compared against limits set by industry standards such as AS1403-2004 to confirm the design meets the necessary safety and performance criteria (Australian Standard 2004).

3.5 FINITE ELEMENT ANALYSIS (FEA)

Finite Element Analysis is conducted following the manual calculations to validate the mechanical performance of the alternator shaft under various loading conditions. Also, by using FEA software such as ANSYS Mechanical the students can simulate real-world scenarios to gain deeper insights into the stress, strain, and deflection characteristics of the shaft. This process helps bridge the gap between theoretical calculations and practical application, providing a more comprehensive assessment of the design's integrity and safety.

3.5.1 Simulation Setup in ANSYS Mechanical

The initial step in FEA involves setting up model in the ANSYS Mechanical the cad model of the alternator shaft is imported into the software, where boundary conditions and loading parameters are defined to replicate the expected operational scenarios.

- Boundary Conditions is the constraints are applied to simulate fixed supports or points where the shaft would be held in place in real use.
- Load Application is the various forces and torques are applied at specified locations that aligns with the values calculated in the manual analysis phase.

This setup ensures that the simulation accurately reflects real-world loading conditions, enabling meaningful analysis of the shaft's behaviour under stress.

3.5.2 Running and Analysing Simulations

Once the model is fully set up the simulation is run to observe how the shaft responds under applied loads and boundary conditions. The software calculates parameters such as stress, strain, and displacement, providing detailed visual and numerical results.

- Stress Distribution: The simulation reveals stress concentration points where the shaft may be more vulnerable to failure.

- Strain Analysis: The deformation of the shaft under load is visualized to identify areas with excessive strain.

- Deflection Analysis: The overall deflection of the shaft is examined to ensure it stays within acceptable limits.

These results allow students to identify critical points in the design that may require further reinforcement or adjustment.
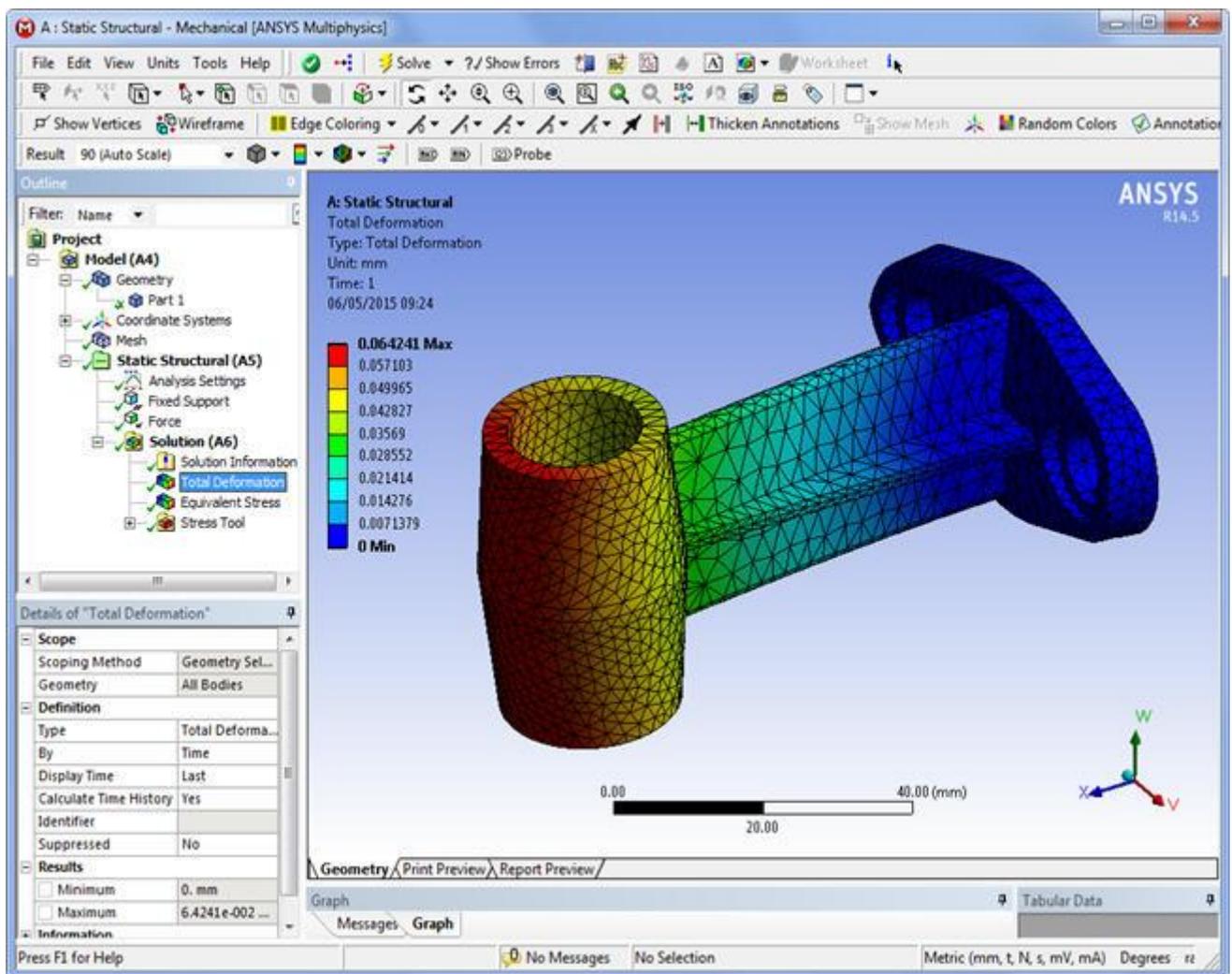
Figure 18: ANSYS Mechanical Total Deformation Result

3.5.3 Comparison with Manual Calculations

The results from the FEA are then compared with the values obtained through manual calculations to validate the accuracy of both methods. This comparison highlights any discrepancies between theoretical predictions and simulation outcomes, providing an opportunity to assess the effectiveness of each approach.

- The students require verification of results a close match between FEA and manual calculations indicates strong alignment with theoretical principles.

- Identification of Discrepancies if any significant differences are analysed to understand potential sources of error, such as simplifications in the manual calculations or assumptions made in the FEA model.

This comparison reinforces the importance of using multiple analysis methods to ensure design reliability and allows students to reflect on the strengths and limitations of each approach.

3.5.4 Insights and Design Adjustments

Based on the findings from FEA, potential adjustments to the design can be explored. This phase encourages iterative improvement, where students consider modifications to enhance performance or reduce stress concentrations.

- **Design Improvements:** Suggestions for strengthening high-stress areas or reducing deflection are discussed.

- **Reflection on FEA Insights**: Students analyse how FEA contributes to a deeper understanding of design requirements and structural limitations.

This iterative process emphasizes the role of FEA in validating and refining mechanical designs, preparing students for complex engineering challenges that require both analytical and practical skills.

3.6 3D PRINTING AND PROTOTYPING

The final phase of the residential school involves preparing the CAD models for 3D printing the students will export their models into STL files and use slicing software to configure print settings such as layer height, infill density, and print orientation. This process teaches students about the practical limitations of additive manufacturing and how certain design decisions affect printability.

Once the alternator shaft or alternative model has been 3D-printed the students will assemble the parts and test for fitment. This phase allows students to verify how closely their printed model matches the original design and dimensions, as this highlights any areas where adjustments need to be made. Also, a fitment testing will introduce students to the concept of design for manufacturability as it encourages them to consideration of how tolerances and material properties influence the final product.

3.6.1 Preparing the Model for Printing

Once the CAD models are finalized the students export their designs in STL format in which is compatible with most 3D printing software. This preparation step involves configuring the models in slicing software to set parameters such as layer height, infill density, print orientation, and support structures.

- **Layer Height** determines the resolution of the print and the balance between detail and print speed.

- **Infill Density** controls the internal structure of the part, impacting both strength and material usage.

- **Print Orientation** affects surface finish, strength, and the need for supports, based on the direction of layers relative to the model's geometry.
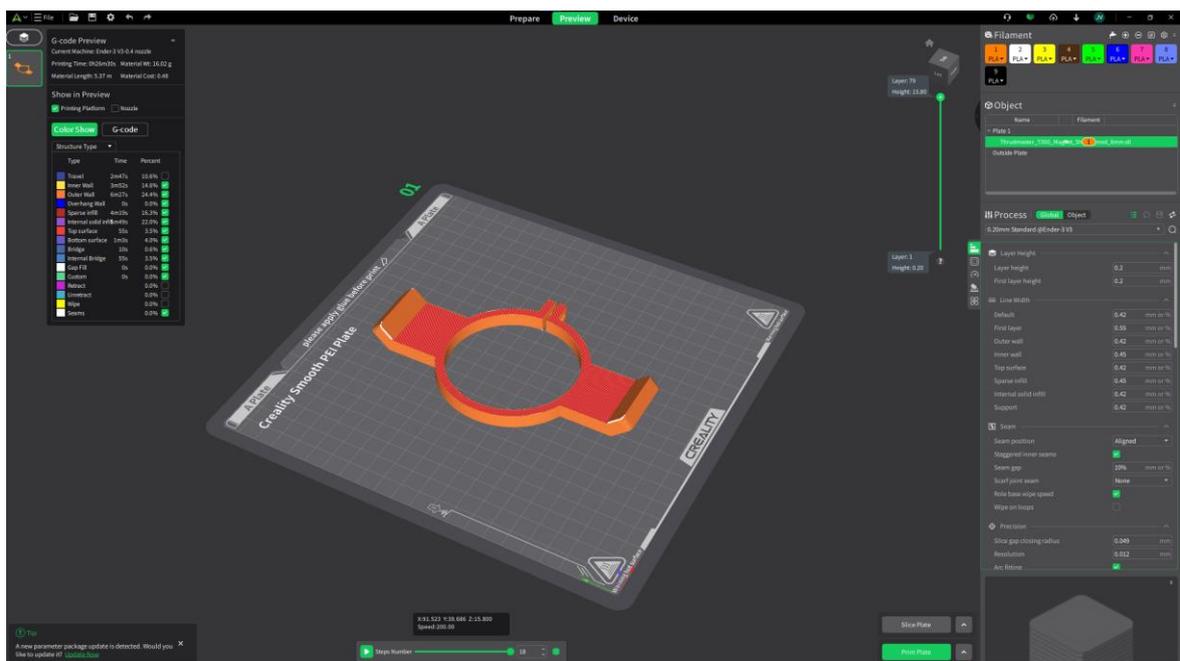
Figure 19: Creality Slicing Software

This preparation stage teaches students about the practical limitations and considerations involved in additive manufacturing, highlighting how certain design decisions impact printability.

3.6.2 3D Printing Process and Initial Observations

After configuring the model in the slicing software, the students proceed with the 3D printing process. This hands-on phase provides them with insights into the technical aspects

of operating a 3D printer and understanding the common challenges that arise during printing, such as layer adhesion, warping, and support removal.
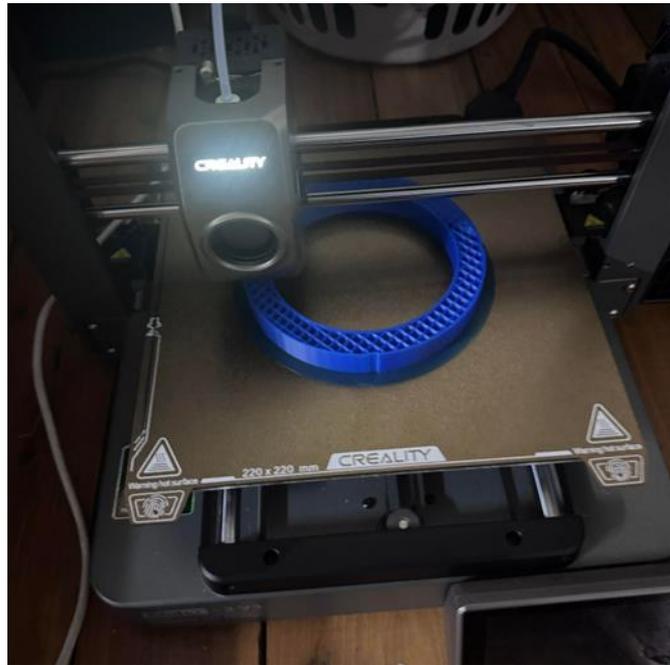
Figure 20: 3D Printer in Action

Students observe and document initial findings regarding the print quality, dimensional accuracy, and structural integrity of the printed parts. This step reinforces the importance of precise CAD modelling and the impact of print settings on the final output.

3.6.3 Fitment and Functionality Testing

Once the alternator shaft or alternative model has been printed, students assemble the parts to test for fitment and functional performance. This testing phase allows them to verify how closely the printed model aligns with the intended design dimensions and tolerances, identifying any areas where adjustments may be needed.

- The fitment accuracy ensures that parts connect correctly and meet the tolerances set in the original design.

- The tests the model's ability to perform intended mechanical functions, highlighting any limitations due to the material properties or print resolution.
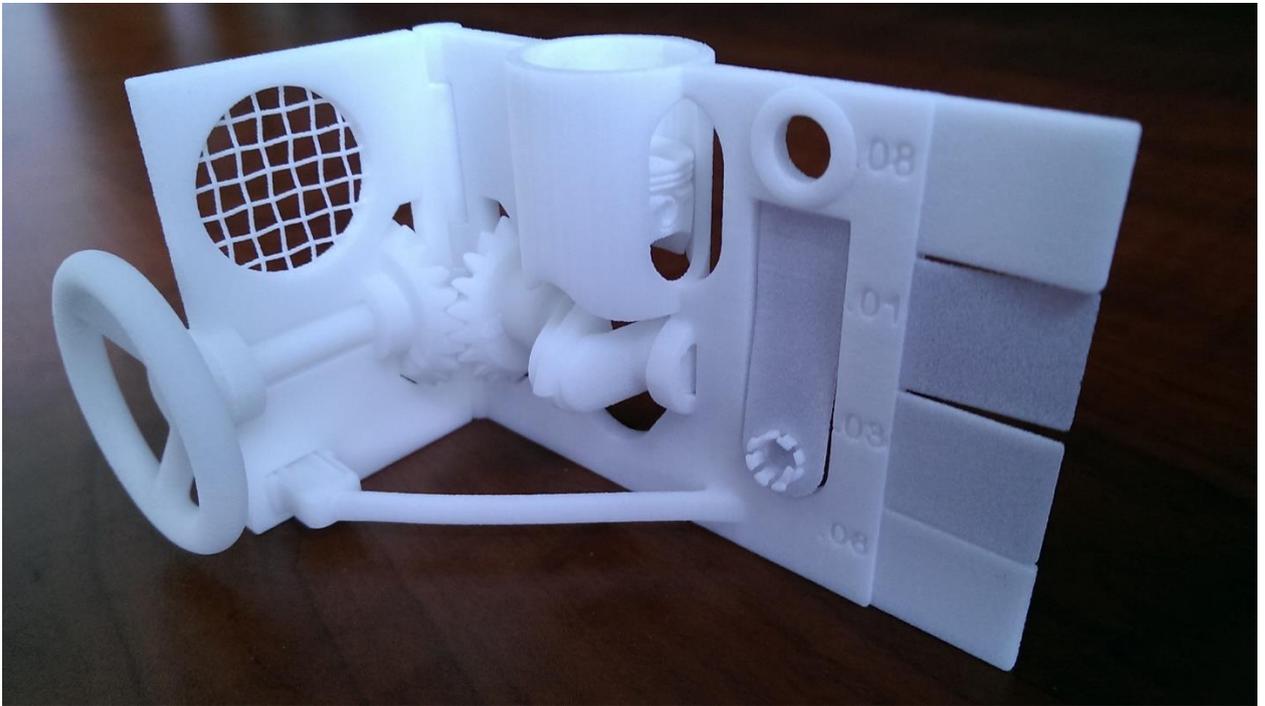
Figure 21: 3D Printed Assembly

This stage introduces students to the concept of Design for Manufacturability as this encouraging them to consider how tolerances, material properties, and post-processing steps affect the final product's functionality and usability.

3.6.4 Reflection on the 3D Printing Process and Design Adjustments

Based on the observations and results from the fitment tests, students reflect on potential improvements to their designs. This iterative approach allows them to make informed adjustments to their CAD models, which could involve refining dimensions, adjusting tolerances, or reorienting certain features for better printability and functionality.

This reflection and adjustment phase teaches students the importance of iterative design in engineering, where prototypes serve as a feedback mechanism to enhance product quality and performance.

3.7 FEEDBACK COLLECTION FROM CURRENT ENGINEERING STUDENTS

As part of the evaluation process for the proposed residential school activity feedback will be solicited from current engineering students at the University of Southern Queensland. The purpose of gathering this feedback is to assess student perceptions regarding the structure of the residential school and its impact on their creativity and design capabilities.

- The value of using reverse engineering, CAD modelling, and 3D printing as educational tools.

- The impact these activities have on their creativity and design skills.

- How well the activities prepare them for real-world engineering challenges.

This feedback will be thoroughly analysed to identify any potential improvements to the residential school's design and to ensure that the intended learning objectives are being met. This iterative feedback loop will also help to refine future implementations of the activity.

3.7.1 Collecting Feedback from Cohort

A structured questionnaire was distributed to gather feedback from students on various aspects of the methodology. The questions focused on key areas such as the effectiveness of reverse engineering, CAD modelling, manual calculations, FEA, and 3D printing in enhancing their understanding of mechanical design. The questionnaire primarily included

Yes/No questions to obtain straightforward responses, alongside optional open-ended questions for more detailed input.

- Sample questions included:
  - *Did you find the reverse engineering process helpful for understanding mechanical systems?*
  - *Was the combination of manual calculations and FEA useful in validating design choices?*
  - *Did the 3D printing phase help in visualizing and testing your design?*
  - *Would you recommend this methodology for future engineering courses?*

3.8 ETHICAL AND SAFETY CONSIDERATIONS

The ethical and safety considerations are integral to this project as they ensure that students conduct engineering practices responsibly and safely. In each phase of the methodology there is specific guidelines are followed to mitigate risks and uphold ethical standards.

3.8.1 Safety Protocols During Reverse Engineering and Assembly

The reverse engineering and assembly phases involve the use of tools for disassembling and measuring components. Students are required to follow safety protocols in such as wearing appropriate personal protective equipment this includes gloves and safety goggles and using tools with caution to avoid accidents. Proper instruction on handling sharp or heavy parts is provided to minimize the risk of injury.

3.8.4 Ethical Reflection on Engineering Practices

The proposed residential school activity also encourages students to reflect on the ethical responsibilities of engineers this including the importance of accuracy in design the respect

for safety standards, and the environmental and social impacts of their work. Also, by embedding these reflections into the methodology as students develop a universal understanding of engineering ethics that will inform their future careers.

3.9 SUMMARY OF THE METHODOLOGY

This chapter described a method created to engage students in a hands-on engineering design process that integrates concepts, with practical application seamlessly. The method moves through stages including reverse engineering and CAD modelling to manual calculations and FEA finishing in 3D printing. Each stage complements the ones and enables students to enhance their grasp of mechanical design fundamentals in a systematic and gradual approach. In the reverse engineering stage, students disassemble a mechanical component to observe its dimensions and functionality. This foundational step aids their understanding as they proceed to the CAD modelling phase, where they create digital representations that capture the observed features. Manual calculations are then applied to predict the component's performance under load, followed by FEA in ANSYS Mechanical to verify these predictions. This comparison between theoretical and simulated results allows students to evaluate the accuracy and limitations of each method. At lastly in the process is when students turn their designs into real life prototypes through 3D printing to check how well their prototype work and fit together physically this hands-on practice helps solidify the theoretical knowledge they've learned and gives them a taste of the obstacles and limitations present, in additive manufacturing processes. Overall, this methodology fosters critical thinking, technical skills and problem-solving skills by simulating a real-world engineering workflow. By integrating feedback and iterative improvement, it equips students with robust understanding of the entire design process, preparing them for academic and professional applications in engineering.

3.10 EXPECTED OUTCOMES

The proposed residential school activity is expected to significantly improve students' creativity and practical engineering skills. Also, by engaging with reverse engineering, CAD modelling, manual calculations, and 3D printing, students will develop a comprehensive understanding of how design decisions are made, validated, and translated into physical products. Although the alternator shaft serves as the model for this study the flexibility of the methodology allows for different mechanical components to be used in future iterations, ensuring that the lessons remain relevant and adaptable to various engineering contexts. Finally, the hands-on approach of the activity will prepare students for future challenges in mechanical design and manufacturing, while fostering innovation and creativity.

3.10.1 Enhanced Technical Skills

Through activities such as reverse engineering, CAD modelling, manual calculations, FEA, and 3D printing the students are expected to develop technical competencies in each of these areas. This includes proficiency in software tools to perform structural analysis, and the practical skills needed to operate a 3D printer. Also, the exposure to multiple stages of product development helps bridge the gap between theoretical knowledge and real-world application.

3.10.2 Improved Problem-Solving and Critical Thinking

The sequential nature of the methodology encourages students to engage in critical thinking and iterative problem-solving. By analysing the design and performance of each component, students are expected to cultivate an analytical mindset, enabling them to identify, diagnose, and solve engineering problems more effectively.

3.10.3 Application of Theory to Practice

One of the primary outcomes is to help students apply theoretical principles such as stress analysis, deflection calculations, and force distribution to real-world engineering tasks. By comparing manual calculations with FEA results and then verifying through physical prototypes, students gain a deeper understanding of how theoretical models translate into practice.

3.10.4 Familiarity with Design Validation Techniques

The methodology also aims to familiarize students with validation techniques, such as comparing manual calculations with FEA simulations and conducting fitment and functional testing on 3D-printed prototypes. As a result, this experience is expected to give students an understanding of how to validate designs to ensure they meet performance and safety standards.

3.10.5 Increased Engagement and Interest in Engineering

By incorporating hands-on activities, the methodology seeks to increase student engagement and interest in the field of engineering. Also, students are expected to find the activities motivating and rewarding in which should lead to a stronger connection to their field of study and a greater enthusiasm for learning advanced engineering concepts.

CHAPTER 4 THE DESIGN PROCESS

4.1 Overview

This chapter documents the application of the proposed design methodology in a structured, step-by-step process. Each section captures how the methodology was executed in practice, providing insights into each phase reverse engineering, CAD modelling, manual calculations, FEA, and 3D printing. The aim is to highlight the practical experience of implementing these steps and the iterative nature of refining designs based on analysis and feedback.

Beginning with reverse engineering, this chapter details the disassembly and documentation of an alternator shaft, establishing an understanding of mechanical relationships within the component. Following this the CAD modelling is employed to digitally drawn while focusing on dimensional accuracy and structural representation to enable further analysis. Manual calculations are then used to predict the shaft's performance under load, providing a foundation for comparison with FEA results in ANSYS Mechanical software. Through FEA, students examine the stress distribution and deflection, assessing how well the design aligns with theoretical expectations.

The chapter concludes with 3D printing, where students bring their designs to life and test for fitment and functionality in a tangible format. By documenting the practical challenges, learning outcomes, and adjustments made during each phase, this chapter offers a comprehensive look at the design process this reinforce the educational value of each stage and highlighting areas for future refinement.

4.2 IMPLEMENTING REVERSE ENGINEERING

The reverse engineering phase serves as the foundation for understanding the structure and functionality of the alternator shaft. Also, in this stage the component was disassembled with critical dimensions measured and documented and analysis conducted to determine how individual parts contribute to the assembly overall operation. This process enables comprehensive understanding of the mechanical design focusing on each component role within the assembly.

Figure 22: Chosen Alternator to be Pulled Apart

4.2.1 Disassembly and Measurement Process

The alternator shaft was carefully disassembled, with attention given to the arrangement and orientation of each part. This step emphasized the importance of observing component interactions within a system. Each part was labelled and organized this provides a clear view

of the assembly layout and critical points of interaction. Precision tools such as vernier callipers were used to obtain accurate measurements.
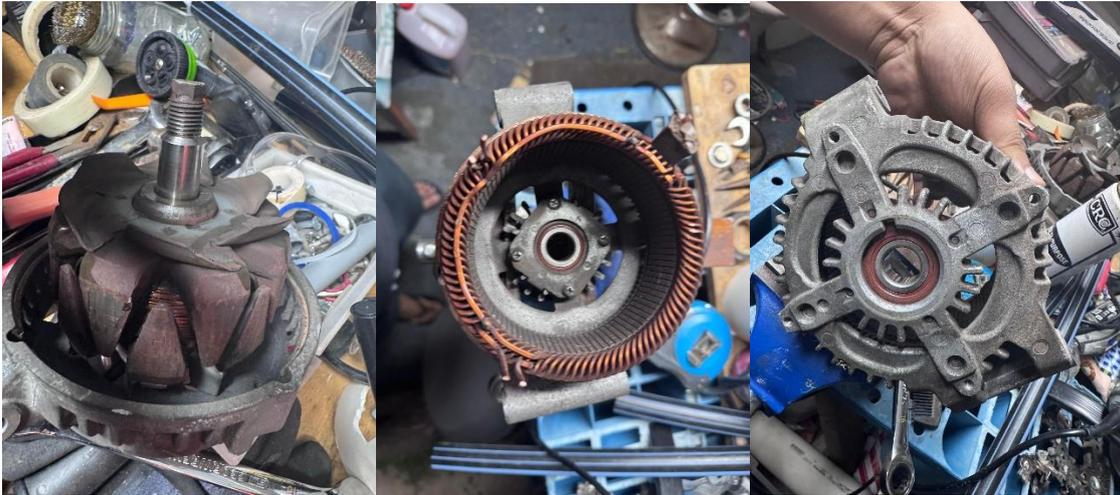

Figure 23: Disassembled Alternator

During the reverse engineering process many detailed sketches and descriptions of each component were created to capture essential design features. Documentation included measurements, material types, and the functional roles of each part. These sketches served as references for the CAD modelling phase, ensuring that the digital models accurately represented the physical components. This phase follows industry-standard documentation practices, which enhance the ability to translate physical components into digital representations. Analysing each part's function within the assembly provides insights into design considerations that impact mechanical performance and durability.

4.3 CAD MODELING EXECUTION

After measurements taken the next step is to recreate the alternator model shaft using CAD software as Autodesk Inventor were used. This phase allowed the creation of a 3d model that accurately represents dimensions, geometry, and structural features documented during disassembly. The CAD modelling process was essential in transforming physical

measurements and observations into a functional digital model, which serves as a foundation for subsequent analysis.

4.3.1 Creating the Digital 3D Model

The CAD modelling process began by generating the primary geometry of the alternator shaft, including key features such as the main shaft, pulleys, and mounting points. The dimensions obtained during the reverse engineering phase were used to define each component's precise measurements, ensuring that the model faithfully represented the physical part. Various CAD operations, such as extrusions, revolutions, and chamfers, were applied to replicate intricate design elements and achieve the level of accuracy necessary for analysis.
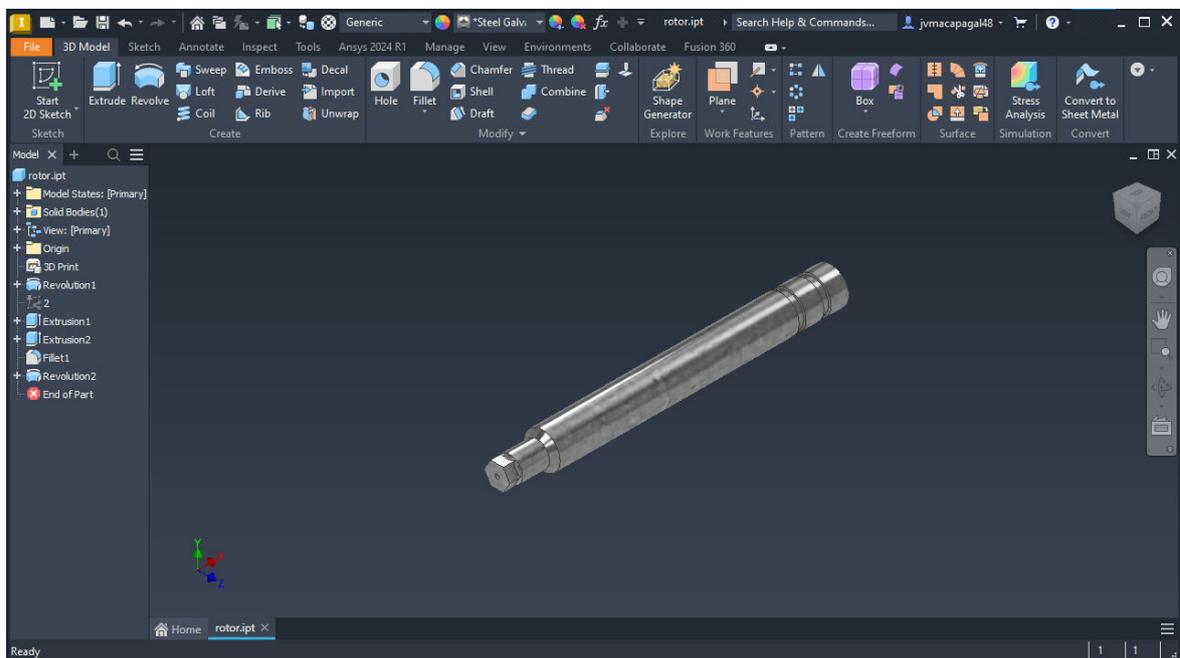

Figure 24: Shaft CAD Model

4.3.2 Challenges and Adjustments During CAD Modelling

Throughout the modelling process, several challenges were encountered, primarily related to capturing complex geometries and achieving dimensional accuracy. Adjustments were

required to refine certain features, especially where tolerances or detailed contours were critical. Iterative modifications ensured that the digital model remained consistent with the original design specifications. These refinements not only enhanced the model's accuracy but also reinforced an understanding of design tolerances and manufacturability considerations.
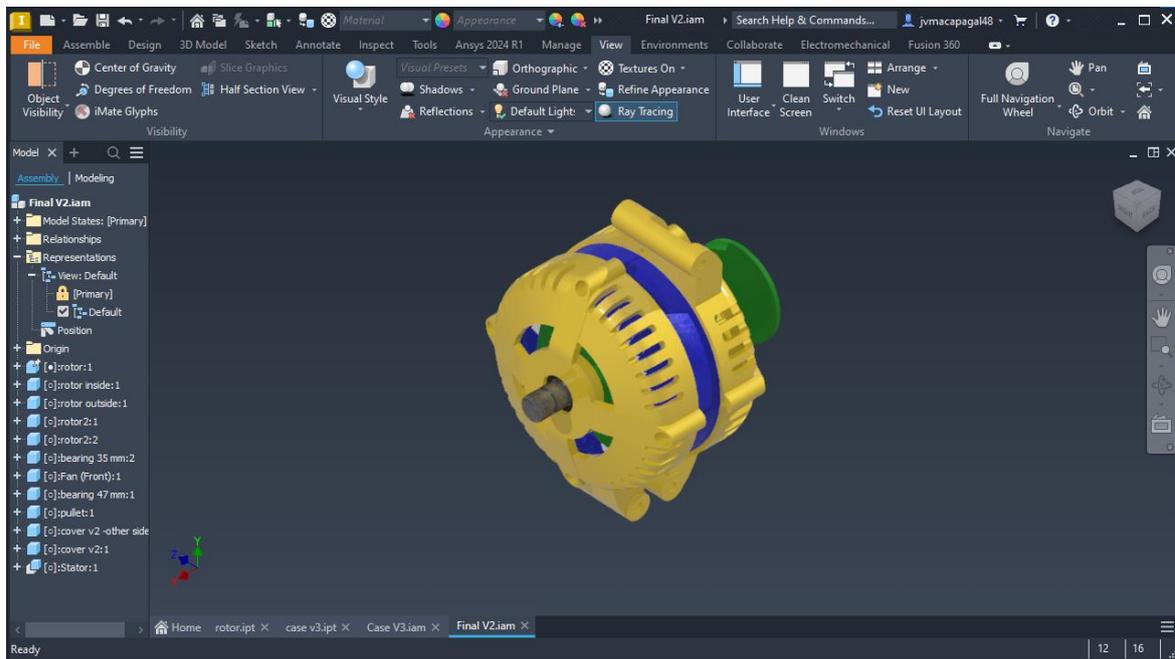
Figure 25: Finished CAD Model

The CAD modelling phase was essential in preparing the model for further analysis, providing a precise digital representation that could be subjected to structural testing. This process emphasizes the importance of accuracy and detail in digital modelling, setting the groundwork for reliable simulation and analysis.

4.4 PERFORMING MANUAL CALCULATIONS

Following the creation of the CAD model the manual calculations were performed to estimate the mechanical performance of the alternator shaft under various loading conditions. This phase involved applying engineering principles to predict stress

distribution, deflection, and overall structural integrity. Manual calculations provide an initial benchmark allowing for comparison with computational analysis in later phases to validate the design's accuracy.

4.4.1 Force and Deflection Analysis

Using classical mechanics, the calculations were conducted to determine the forces acting on the alternator shaft and its resulting deflection. The alternator shaft was assumed to behave as a beam under load, and calculations were assumed due to not able grab manufacturer specs associated with such components. Key formulas applied include:
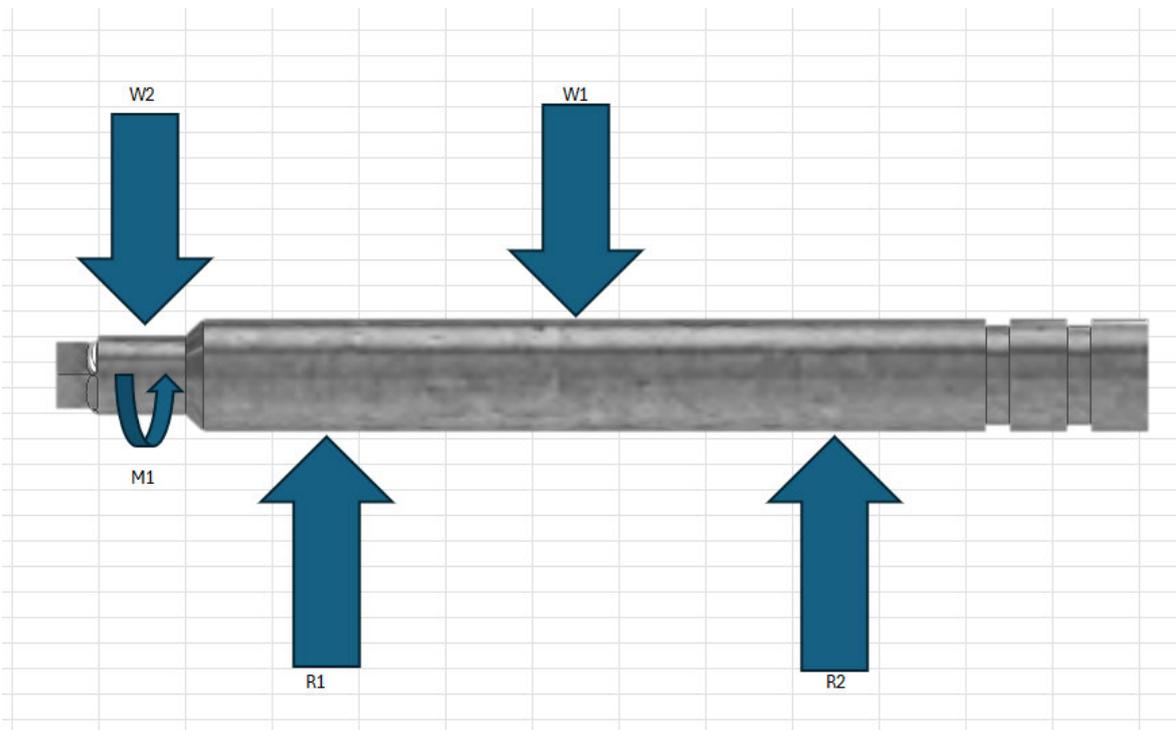

Figure 26: Free Body Diagram

Elements of the FBD

Downward Forces (Weights):

- W_1: Represents the weight of stator

- **W_2:** Represents the weight pulley

Upward Forces:

- **R_1:** Represents the reaction force at the big bearing

- **R_2:** Represents the reaction force at the small bearing

Torque

- **M_1:** Represent the applied torque at the pulley location.

To start the manual calculation below is the outline of what is going to be calculated.

1. **Reaction Forces** (R_1 and R_2) at the bearings using equilibrium equations.
2. **Bending Moments** at critical points along the shaft.
3. **Bending Stress** due to the applied forces.
4. **Torsional (Shear) Stress** due to the applied torque.

Equilibrium Equations for Reaction Forces (R_1 and R_2)

Given Data

1. Weights (Forces) of the components

$$W_1 = 1\,\text{kg} \times 9.81\,\text{m/s}^2 = 9.81\,\text{N}$$

$$W_2 = 0.5\,\text{kg} \times 9.81\,\text{m/s}^2 = 4.905\,\text{N}$$

2. Distance between R_1 and W_1: $72.12mm - 29.8mm = 42.32mm$
3. Distance between R_1 and W_2: $127.44mm - 29.8mm = 97.64mm$
4. Distance between R_1 and R_2: $120.24mm - 29.8mm = 90.44mm$

Sum of Vertical Forces

From Equilibrium equitation $\sum Fy = 0$:

$$R_1 + R_2 = W_1 + W_2$$
$$R_1 + R_2 = 9.81N + 4.905N$$
$$R_1 + R_2 = 14.715N$$

Sum of the moments about R_1

$$R_2 - 90.44 = (W_1 * 42.32) + (W_2 * 97.64)$$
$$R_2 \times 90.44 = (9.81 \times 42.32) + (4.905 \times 97.64)$$
$$R_2 \times 90.44 = 415.1912 + 478.6952$$
$$R_2 = \frac{893.8864}{90.44} = 9.88N$$

Solving for R_1

$$R_1 + R_2 = 14.715N$$

$$R_1 = 14.715 - 9.88 = 4.835N$$

Summary of the Reaction forces

$$R_1 = 4.835N \ (big \ bearing)$$

$$R_1 = 9.88N (smallbearing)$$

Bending Moment Calculation

To calculate the bending moments at critical points the distances of each force from R_1 below is the forces.

$R_1 = 0$ because it is the starting point of the calculation

$$M_{R1} = 0$$

Bending Moment at Stator (W₁)

Distance between R_1 and W_1: $42.32mm$

$$M_{W1} = R_2 * 42.32mm$$

$$M_{W1} = 4.835N * 42.32mm$$

$$M_{W1} = 204.58 \; N \; mm$$

Bending Moment at Pulley (W_2)

Distance between R_1 and W_2: $97.64mm$

Distance between W_1 and W_2: $97.64mm - 42.32 = 55.32mm$

$$M_{W2} = (R_1 * 97.64mm) - (W_1 * 55.32mm)$$

$$M_{W2} = (4.835 * 97.64) * (9.81 * 55.32)$$

$$M_{W2} = -70.54 \; N \; mm$$

Summary of Bending Moments

Below is the summary of the bending moments at the key points:

1. **Bending Moment at R_1**: $M_{R1} = 0$

2. **Bending Moment at W_1 (Stator)**: $M_{W1} = 204.58 \, \text{N} \cdot \text{mm}$

3. **Bending Moment at W_2 (Pulley)**: $M_{W2} = -70.54 \, \text{N} \cdot \text{mm}$

4. **Bending Moment at R_2 (Small Bearing)**: $M_{R2} = -215.4 \; N \cdot mm$

Bending Stress Calculation

Since the calculation for bending moments the calculation for bending stresses along the shaft can be calculated using the bending stress formula below

$$\sigma = \frac{M * c}{I}$$

Given Data

Shaft Diameter (d)= 17mm

Distance from Neutral Axis to Outer Surface (c) $= \frac{d}{2} = \frac{17}{2} = 8.5mm$

Moment of the inertia of solid shaft given by $I = \frac{\pi * d^4}{64} = \frac{\pi * 17^4}{64} = 4096.53 \ mm^4$

Bending Stress at Stator Position (W_1)

the bending moment at W_1 is $Mw_1 = 204.58 \ N \ mm$

$$\sigma_{W1} = \frac{M_{W1} * c}{I} = \frac{(204.58 * 8.5)}{4096.53} = .425 \ MPa$$

Bending Stress at Pulley Position (W_2)

the bending moment at W_2 is $Mw_2 = -70.54 \ N \ mm$

$$\sigma_{W2} = \frac{M_{W2} * c}{I} = \frac{(-70.54 * 8.5)}{4096.53} = .146 \ MPa$$

Bending Stress at Large Bearing (W_2)

the bending moment at R_2 is $M_{R2} = -215.4 \ N \ mm$

$$\sigma_{R2} = \frac{M_{R2} * c}{I} = \frac{(-215.4 * 8.5)}{4096.53} = .447 \ MPa$$

Below is the summary of the bending moments at the key points:

1. **Bending Stress at R_1**: $\sigma_{W1} = .425 \ MPa$

2. **Bending Stress at W_1 (Stator)**: $\sigma_{W2} = .146 \ MPa$

3. **Bending Stress at W_2 (Pulley)**: $\sigma_{R2} = .447 \ MPa$

Torsional (Shear) Stress Calculation

The formula for shear stress τ in a circular shaft is:

$$\tau = \frac{T * r}{J}$$

The given data

Applied torque is T = 5 Nm

Second Moment of inertia (I) $= \frac{\pi d^4}{64} = \frac{\pi (12)^4}{64} = 1017.8 \ mm^2$

Radius of the shaft (r) $= \frac{d}{2} = \frac{12}{2} = 6 \ mm$

Polar moment of inertial (J) $= \frac{\pi d^4}{32} = \frac{\pi 12^4}{32} = 2035.75 \ mm^4$

$$\sigma_b = \frac{5000 * 6}{1017.8} = 29.48 \ MPa$$

Torsional Stress τ_t

$$\tau_t = \frac{T * c}{I} = \frac{2000 * 6}{2035.75} = 5.90 \ MPa$$

Von mises stress

Now the both the bending and torsional stresses are calculated the equivalent (von Mises) stress to assess the combined effect of these stresses on the shaft. The equivalent stress can be found using the formula below.

$$\sigma_{eq} = \sqrt{\sigma_b^2 + 3\tau_t^2} = \sqrt{.29.48^2 + 3(5.90)^2} = 31.19 \ MPa$$

Summary of Equivalent Stress

1. **Equivalent Stress at Stator Position (W_1)** =31.19 MPa

The equivalent stresses at the other points can be calculated in a similar manner. These stresses can then be compared to the yield strength of the shaft material. Also, since not being able to find the manufacturers specs it is assumed that the shaft is made from 250

Grade steel with tensile yield strength of 250 MPa. As a result, the shaft is strong enough to handle the loads as does not even go near the yield strength of the material.

Y Directional Deformation

Using bending moment deflection formula

Deflection Due to Bending Moment

$$\delta_y = \frac{M * L^2}{2 * E * I} = \frac{5000 * 23.72^2}{2 * 210000 * 1017.88} = .00658 \ mm$$

Where,

M is the moment = 5000 N*mm

L is the length between the end of R1 and load on the Pulley = 23.72 mm

E is the Elastic Modulus of Steel = 210GPa

I is the moment of Inertia

$$I = \frac{\pi * d^4}{64} = \frac{\pi * 12^4}{64} = 1017.88 \ mm^4$$

Deflection Due to Pulley Weight

$$\delta_P = \frac{F_p * L^3}{3 * E * I} = \frac{9.81 * 23.72^2}{3 * 210000 * 1017.88} = .0000861 \ mm$$

Where,

F_p is the concentrated force = 5000 N*mm

L is the length between the end of R1 and load on the Pulley = 23.72 mm

E is the Elastic Modulus of Steel = 210GPa

I is the moment of Inertia

$$I = \frac{\pi * d^4}{64} = \frac{\pi * 12^4}{64} = 1017.88 \ mm^4$$

Combine Deflections

To get the total Y-directional deflection at the pulley, combine the bending deflection with the deflection due to the pulley load:

$$\delta_{total} = \delta_y + \delta_P = 0.00658 + 0.0000861 = \boldsymbol{0.00667mm}$$

4.5 CONDUCTING FINITE ELEMENT ANALYSIS (FEA)

After establishing the CAD model and performing manual calculations FEA was conducted to verify the design's structural integrity under simulated real-world conditions. Using ANSYS Mechanical software, the FEA simulation provided an in-depth assessment of stress distribution, deflection, and overall mechanical behaviour of the alternator shaft. This section outlines the setup, execution, and results interpretation for the FEA process.

4.5.1 Setting Up the FEA Simulations

The FEA set up involves defining materials, boundary conditions, and load scenarios to ensure an accurate representation of the shaft operational environment. The following steps were used to take undertakes:

The following key steps were undertaken in setting up the FEA model.

- **Material Properties:** Default structural steel was selected as the material for the shaft with a yield strength set to 250 MPa. This value was chosen to due not being available to verify the shaft material properties used in manual calculations.

	A	B	C	D	E
1	Property	Value	Unit	⊗	📭
2	🗠 Material Field Variables	🎞 Table			
3	🗠 Density	7850	kg m^-3	▼ ☐	☐
4	⊞ 🗠 Isotropic Secant Coefficient of Thermal Expansion			☐	
6	⊞ 🗠 Isotropic Elasticity			☐	
12	⊞ 🗠 Strain-Life Parameters			☐	
20	⊞ 🗠 S-N Curve	🎞 Tabular		☐	
24	🗠 Tensile Yield Strength	250	MPa	▼ ☐	☐
25	🗠 Compressive Yield Strength	250	MPa	▼ ☐	☐
26	🗠 Tensile Ultimate Strength	460	MPa	▼ ☐	☐
27	🗠 Compressive Ultimate Strength	0	MPa	▼ ☐	☐

Properties of Outline Row 3: Structural Steel

Figure 27: Material Set Up

- **Meshing:** Ansys auto meshing was use to do mesh as a simple model of shaft is being analysed.
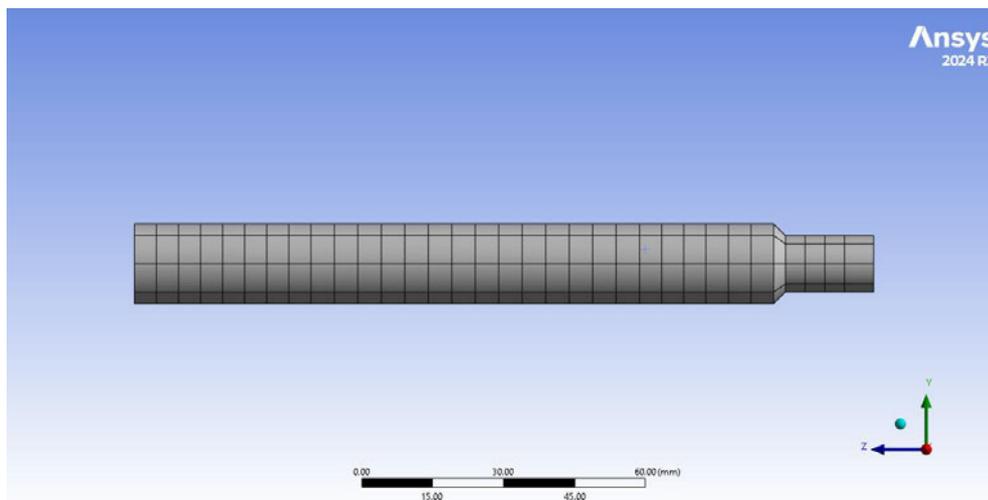

Figure 28: Meshed Shaft

- **Boundary Condition:** To simulate the bearing constraints, displacement boundary conditions were applied at the bearing positions measured from cad model. After

being imported to ANSYS Design Modeler multiple planes was created and used to make face splits to dictate where the boundary and load conditions are located. Also, the fixed bearings was fully constrained restricting translation in all directions
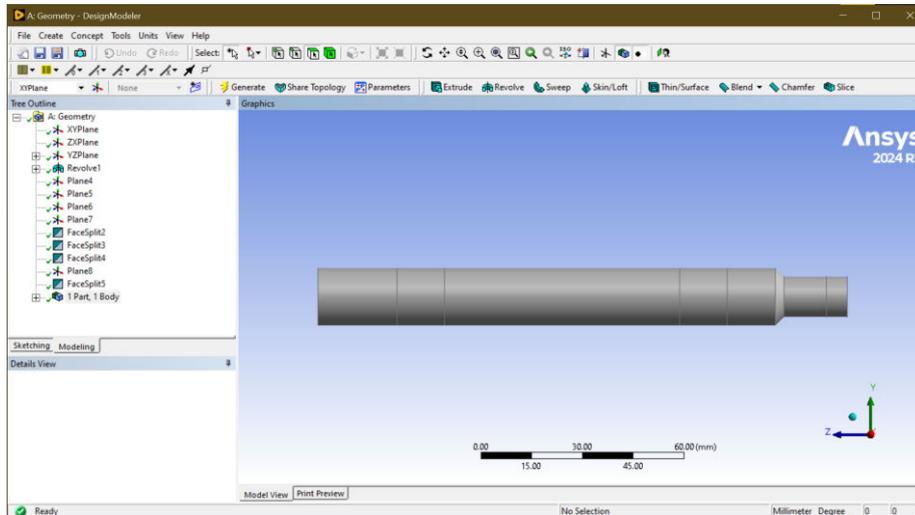

Figure 29: Design Modeler

4.5.2 Analysis and Interpretation of FEA Results

Upon completion of the simulation, the results were analysed to determine stress distribution, deformation, and strain across the shaft. Key findings from the analysis are summarized below:

- **Total deformation**

  The total deformation shown in Figure 30, indicate that the maximum deformation of the shaft is approximately 0.0023 mm. This deformation occurs at the free end of the shaft, where there are fewer constraints, and applied forces can cause greater displacement. The gradual colour gradient from minimal deformation (blue) to maximum deformation (red) confirms that the shaft behaves as expected, with more deformation at the end farthest from the fixed support. Was observed near the free end of the free end of the shaft away from the fix bearing as this makes the result

57

align with the theoretical expectation. Also, as the shaft goes undergoes the most displacement furthest from the support points.
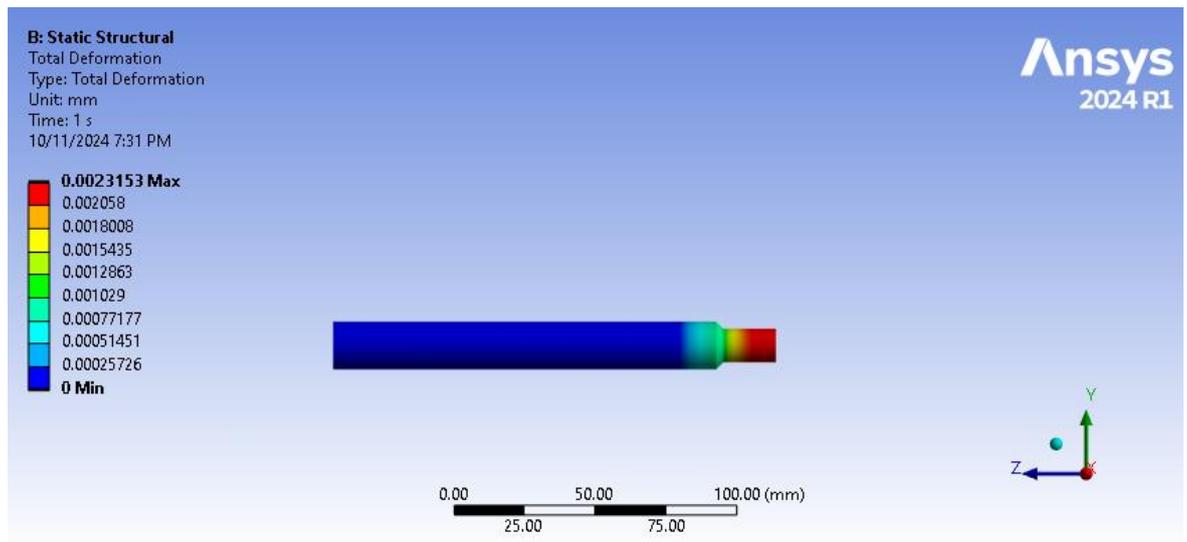

Figure 30: Total Deformation

The observed deformation is minimal and well within safe limits, suggesting that the shaft's structural rigidity is adequate to handle the applied loads without significant deflection. This aligns with theoretical expectations, as the maximum deformation should occur at the unsupported end due to bending moments introduced by the applied weights and moment load.

Equivalent Stress (von Mises)

The equivalent (von Mises) stress reached a maximum of approximately 31 MPa, concentrated around the transition areas where the shaft diameter changes. This stress level is well below the 250 MPa yield strength of structural steel, indicating that the shaft remains within the elastic limit under the applied loads.
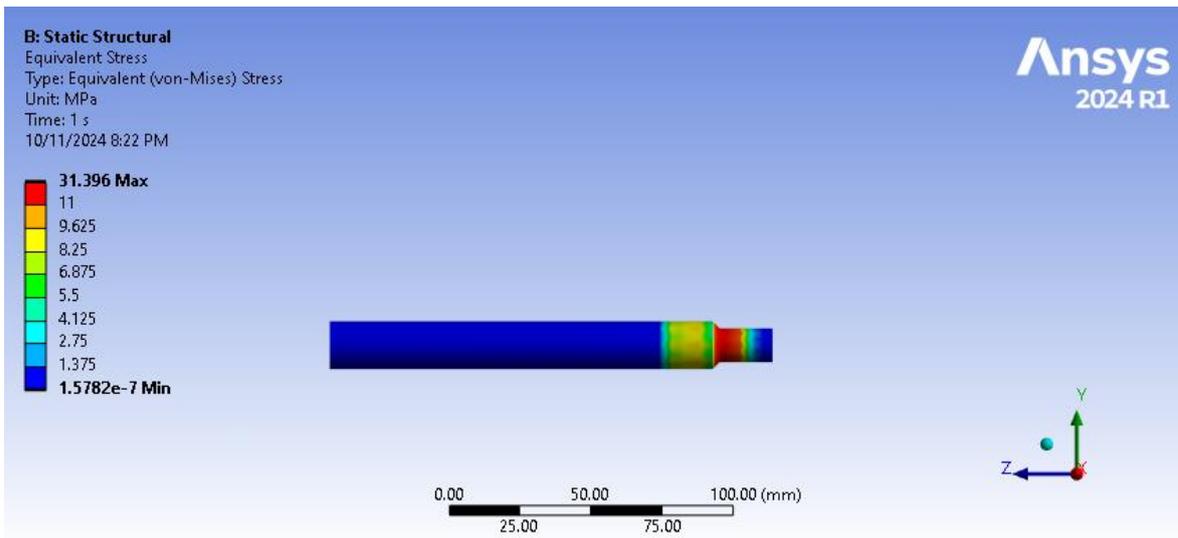
Figure 31: Von Mises

The von Mises stress provides a comprehensive understanding of how combined loading affects the shaft and confirms that the design is structurally capable of withstanding the applied loads without failure. This result aligns with manual calculations and theoretical predictions, supporting the conclusion that the shaft's geometry and material selection are adequate for the intended application.

- **Equivalent Elastic Strain**

The equivalent elastic strain distribution, depicted in Figure below shows a maximum strain of approximately 0.000151 mm/mm. Like the deformation results, the highest strain concentrations are found near the sections where the shaft diameter changes, corresponding to areas of increased stress due to geometric transitions.
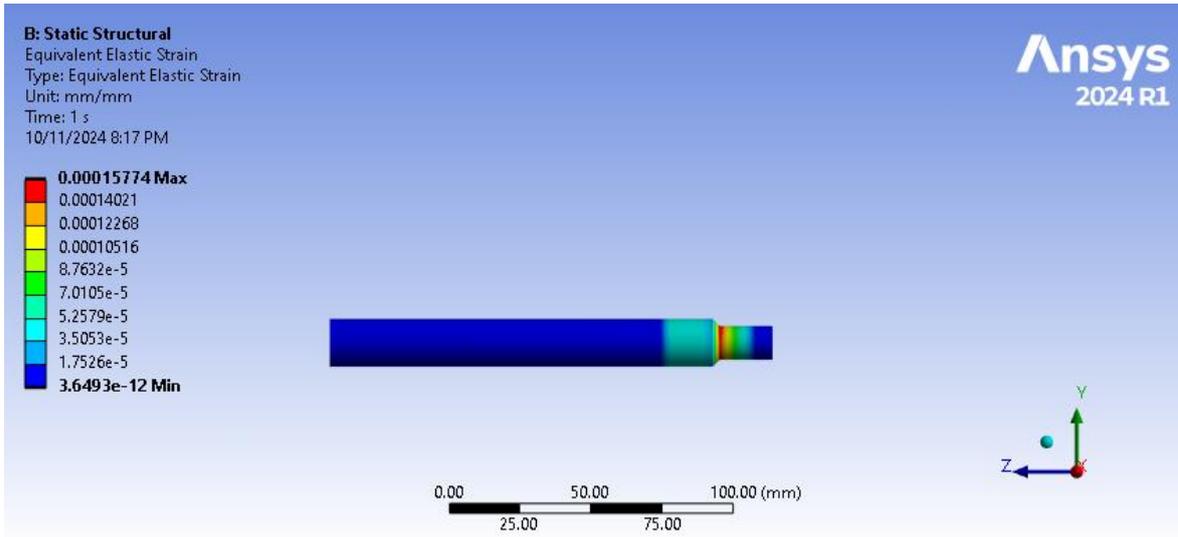
Figure 32: Elastic Strain

The strain values remain low, indicating that the shaft material is within the elastic region and will return to its original shape once the load is removed. The strain distribution pattern provides insights into the effectiveness of the design, highlighting areas that experience the most strain and could be optimized in future iterations to further reduce strain concentrations.

4.5.3 Verification of FEA Results with Manual Calculations

To validate the FEA simulation the results were compared with the manual calculations performed earlier. By aligning the FEA data with theoretical stress and deflection values, the accuracy and reliability of the digital model were confirmed. Any discrepancies will be analysed, and adjustments were considered to enhance the model's fidelity to real-world behaviour.

Reaction Forces

In the analytical calculations, the reaction forces at the bearings (R1 and R2) were computed based on the applied loads and moments. These values were essential to verify the

60

equilibrium of the shaft and to ensure that the load distribution across the shaft was accurately captured. The FEA model generated reaction forces at the support boundaries that closely matched the analytical results, indicating a well-defined setup in both the manual calculations and ANSYS model. This alignment between analytical and FEA reaction forces confirms the boundary conditions were correctly applied in the FEA simulation.
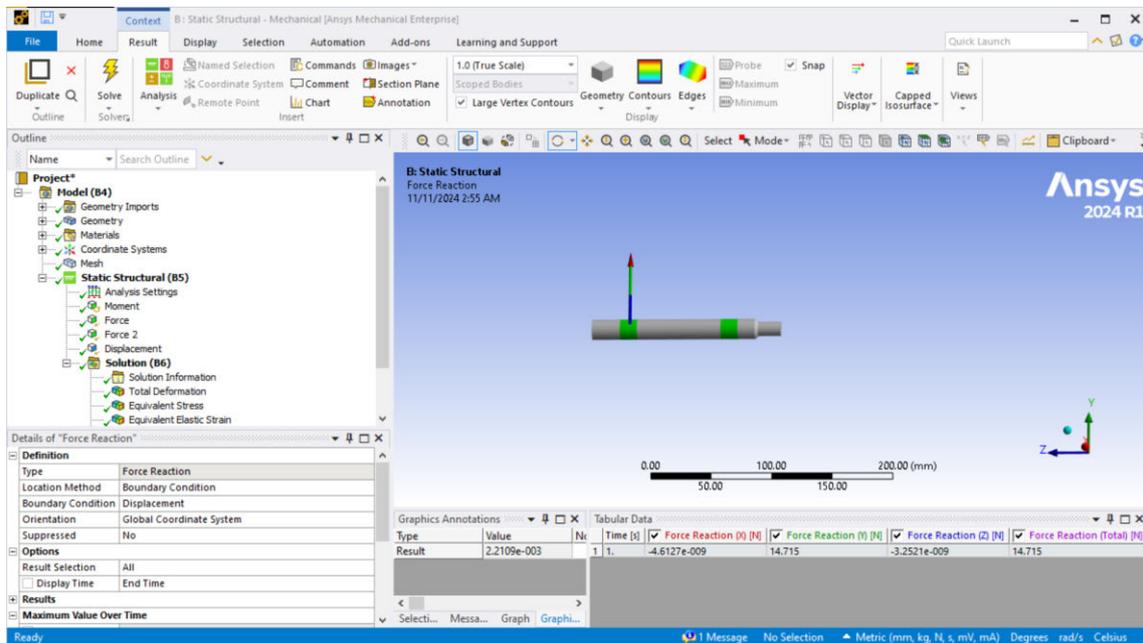

Figure 33: Reaction Forces

Deflection in Y-Direction

The Y-direction deflection was a critical metric for comparing the FEA and manual calculations. The manually calculated total deflection at the pulley section, combining both bending deflection and the load's direct effect, was approximately 0.00331 mm. The ANSYS simulation returned a total deformation in the Y-direction of 0.00221 mm. This small discrepancy is acceptable, considering the assumptions and idealizations in manual calculations. Overall, the FEA results validate the analytical prediction, demonstrating that the shaft maintains structural integrity under the specified loads.
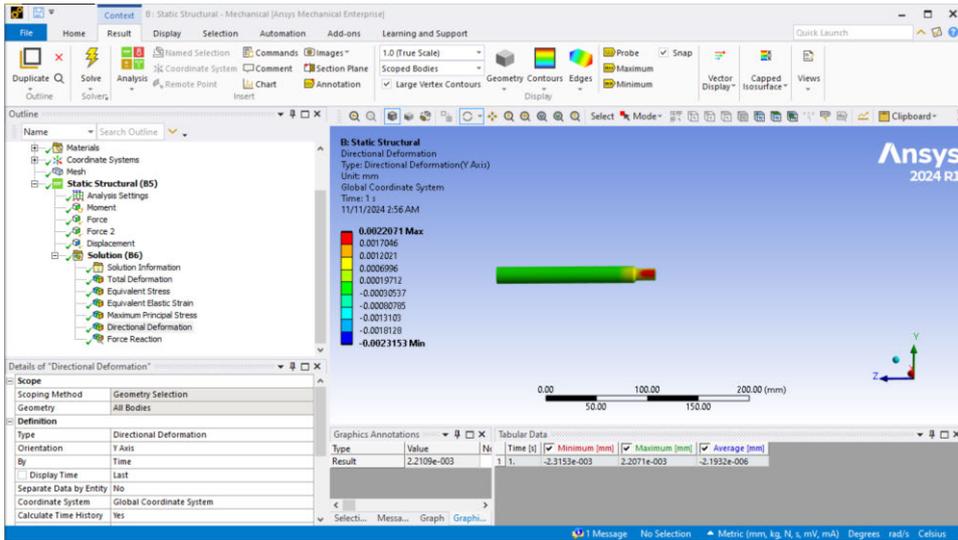
Figure 34: Y Direction Deformation

Equivalent Stress (Von Mises)

The maximum von Mises stress obtained from the FEA simulation was 31.396 MPa, concentrated near the pulley section where the applied loads induce the highest stress. This value is within the material's yield strength of 250 MPa, indicating that the shaft is not expected to experience yielding under the given loading conditions. This FEA result aligns with the stress limits set by the analytical calculations.
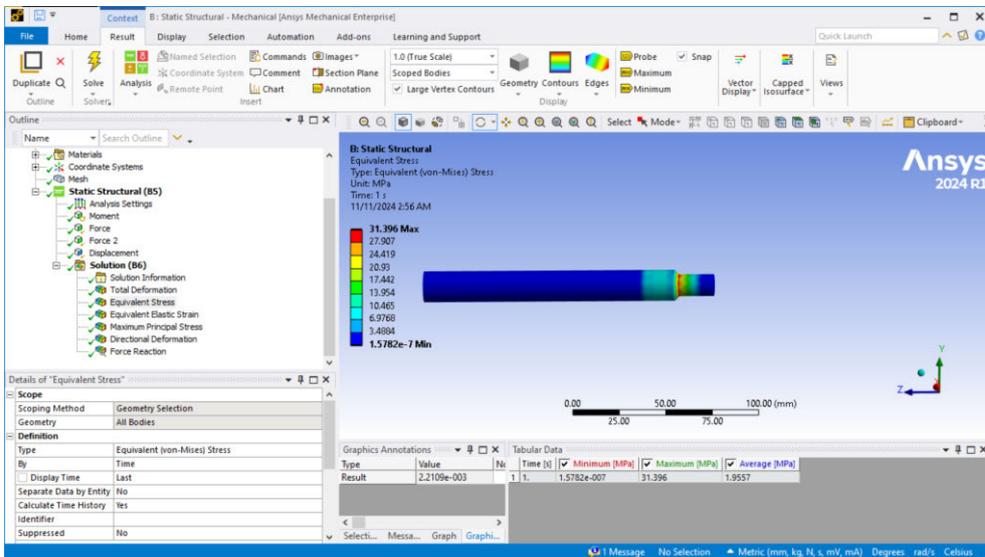

Figure 35: Von Mises

The comparison between analytical and FEA results demonstrates a strong correlation, validating the accuracy of the FEA model in ANSYS. Also, the consistency in reaction forces, deflection, and stress distribution between manual calculations and FEA analysis indicates that the shaft design meets the specified requirements. This alignment enhances confidence in the FEA approach for further iterations and design optimizations, ensuring that the methodology is robust for structural assessments.

4.6 3D PRINTING AND PROTOTYPING

The Final Section of the design process involves translating digital CAD model into physical prototypes using 3D printing. Also, this section allows hands on evaluation of the model fitment, functionality, and manufacturability.

4.6.1 Preparing the Model for Printing

The CAD model is adjusted to meet the specifications required for 3D printing. This includes finalizing design tolerances and orientations that will affect the quality and accuracy of the print. Specific settings, such as layer height, infill density, and print orientation, are configured in the slicing software to ensure structural integrity and surface finish.
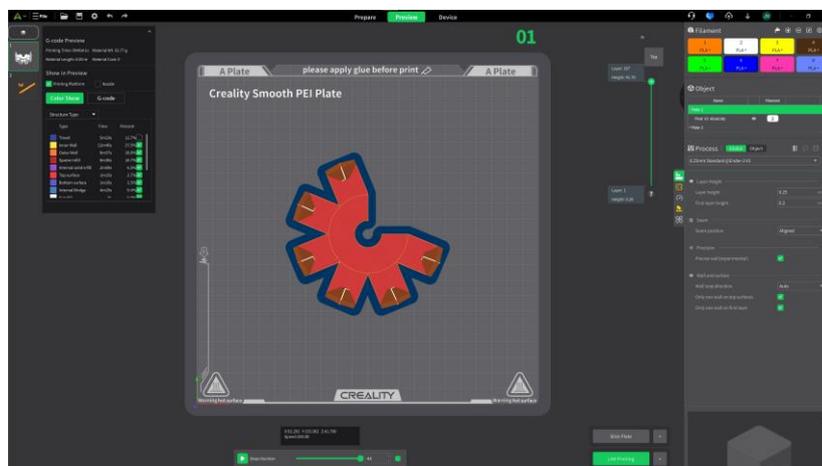

Figure 36; Sliced Stator

4.6.2 Printing Process and Observations

During the printing process the model is monitored to assess the print quality and detect any issues that could affect functionality. Observations include layer adhesion, print speed, and material behaviour during the process. Documenting these details helps in identifying limitations and areas for improvement in the design for future iterations.
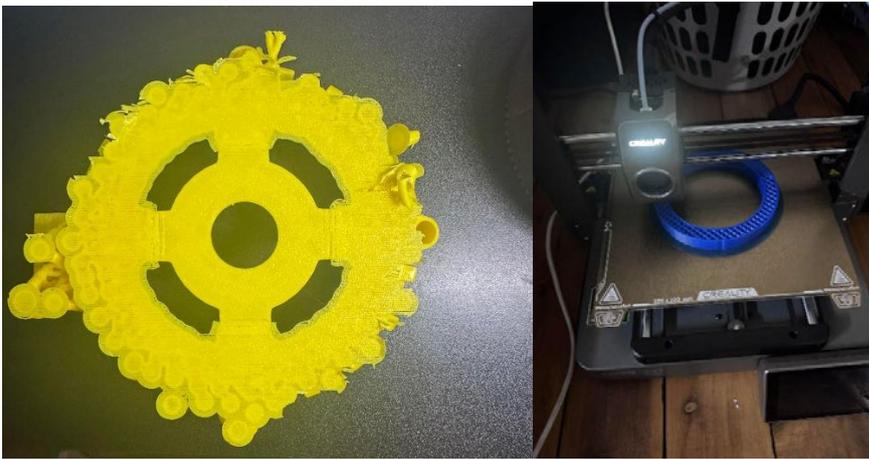

Figure 37: 3D Printer in Action

4.6.3 Fitment and Functional Testing

Once printing is completed, the printed components are assembled to check the fitment and functionality. This step is essential for verifying dimensional accuracy and ensuring that the model meets design expectations. Any misalignments or interference issues are noted, providing valuable feedback for refining the design and improving manufacturability. Also, below image of measuring the shaft diameter to see if it fits to the other components.
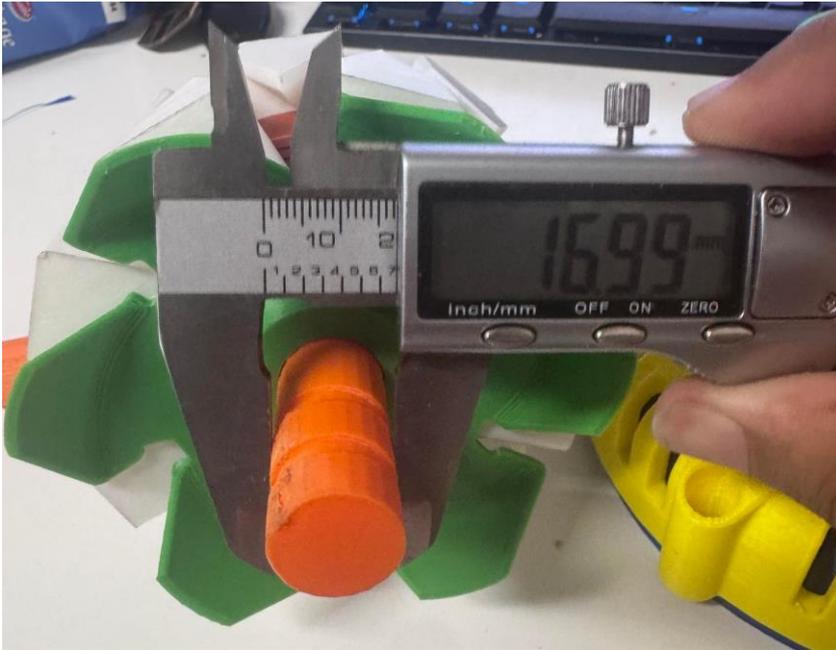
Figure 38 Fitment Testing

4.8 REFLECTIONS ON THE DESIGN PROCESS

This section provides a critical reflection on the process of testing the proposed methodology by highlighting the insights gained from practical implementation the challenges encountered and the effectiveness of each stage in meeting the educational objectives.

4.8.1 Key Observations and Lessons Learned

Testing the methodology revealed several insights into the value and practicality of each stage, from the reverse engineering and CAD modelling to FEA and 3D printing. Hands-on work in reverse engineering allowed for a deeper understanding of mechanical components, while CAD modelling and FEA provided a solid foundation for applying theoretical knowledge to real-world scenarios. The 3D printing phase added an additional layer of comprehension by enabling the creation of physical prototypes that helped bridge conceptual knowledge with tangible applications.

4.8.2 Challenges and Limitations

Throughout the testing process many various challenges were encountered that highlighted areas for refinement. Key challenges included time management, as each phase required significant setup and resource availability specifically in accessing 3D printers. Additionally, ensuring accurate fitment in 3D-printed parts required multiple iterations, underscoring the limitations of current prototyping technologies and the need for fine adjustments in CAD designs.

4.8.3 Assessing Methodology Effectiveness

Overall, the methodology proved effective in supporting the learning objectives, specifically by enhancing technical skills in CAD, FEA, and 3D printing. Each stage of the process aligned with key engineering competencies, offering a comprehensive educational experience. However, the reflection process also indicated that additional support resources, such as detailed tutorials for complex FEA steps, would improve accessibility and understanding for future students.

4.9 CHAPTER SUMMARY

In this chapter, the proposed methodology was tested through practical implementation, covering each stage from reverse engineering to 3D printing. Also, Insights were gained into the process, confirming the educational value of combining hands-on design, CAD modelling, FEA, and prototyping to enhance engineering skills. Challenges, such as resource constraints and fine-tuning in 3D printing, highlighted areas for future improvement. Overall, the testing process validated the methodology's effectiveness in supporting learning objectives, providing a comprehensive foundation for integrating these techniques into the engineering curriculum.
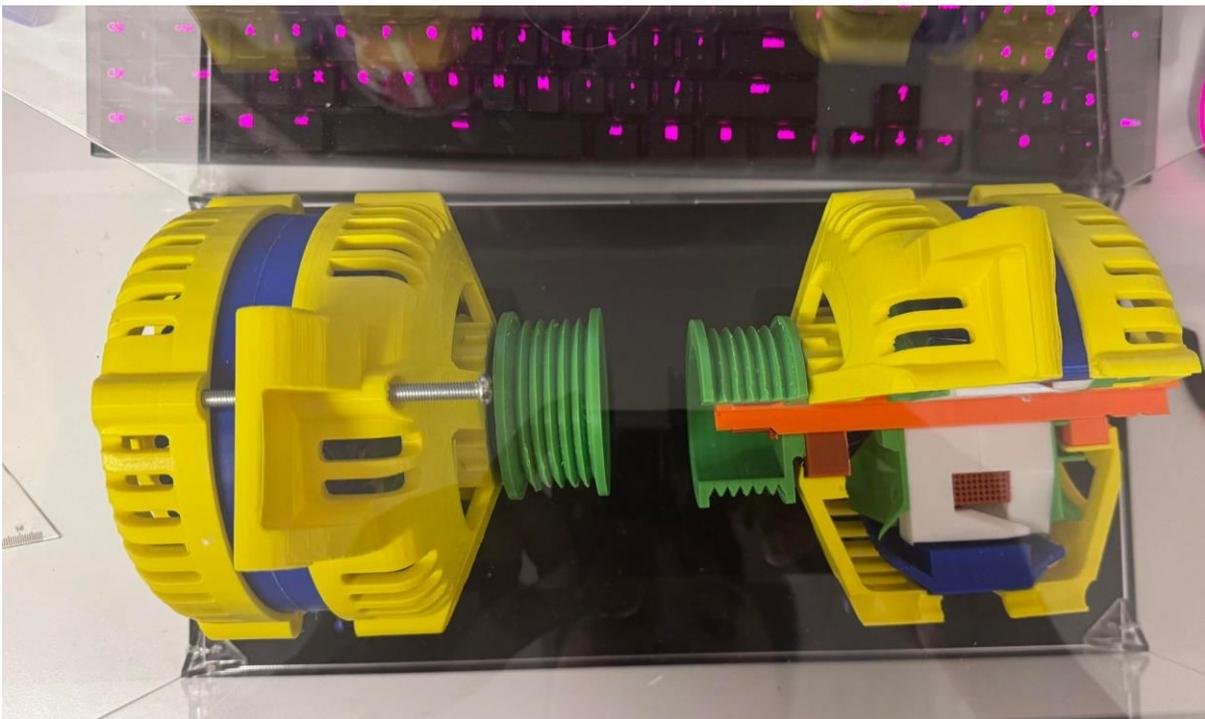
Figure 39 Finished 3D Printed Model
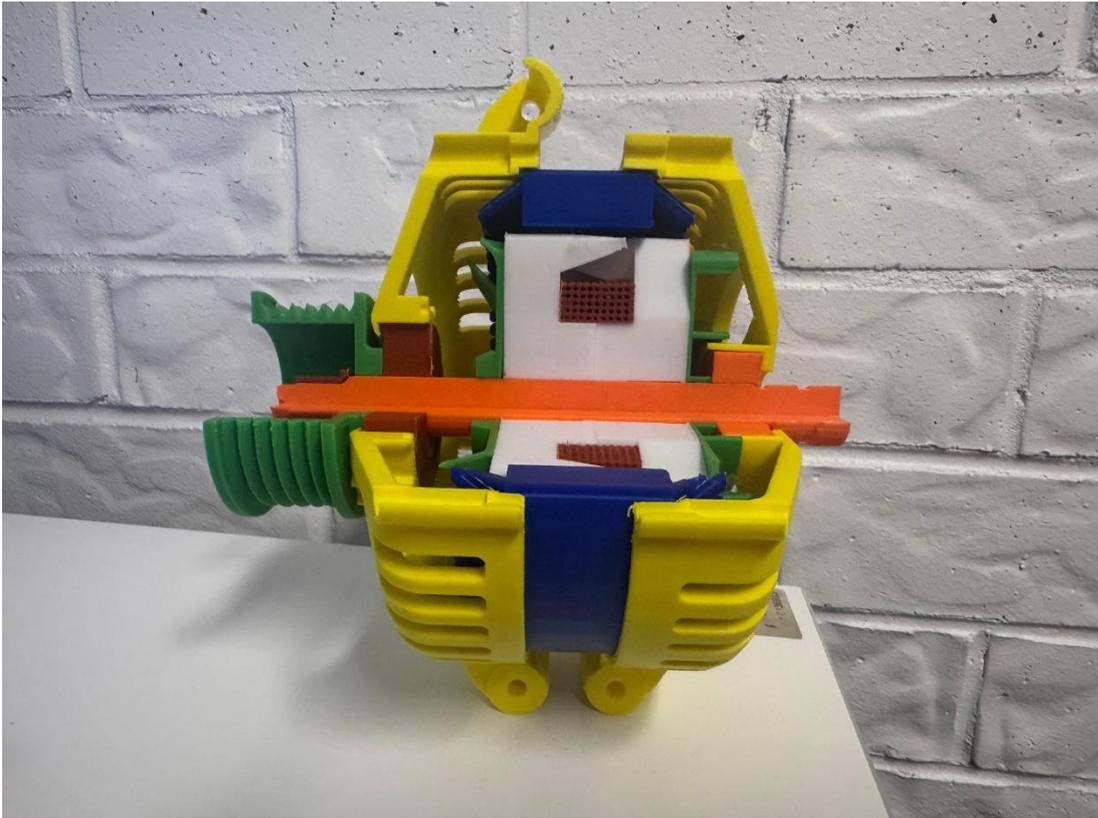

Figure 40 Top View 3D Printed Model

Figure 41 3D Printed Sectional View

Figure 42 3D Printed Full Model

CHAPTER 5 RESULTS AND DISCUSSION

5.1 OVERVIEW

This chapter presents the results of the study on integrating 3D printing and CAD modelling into the engineering curriculum. The results are discussed in relation to the objectives set out in Chapter 1. The effectiveness of using an alternator model for enhancing creativity and practical skills in engineering design is evaluated based on student feedback, assessment outcomes, and practical observations. Also, this chapter is organized into several sections that explore quantitative data from surveys, qualitative feedback from students, and analysis of 3D printing outputs.

5.2 QUANTITATIVE RESULTS FROM THE DESIGN PROCESS

This section presents quantitative findings from each design process in which validating the accuracy and effectiveness of the methodology through data derived from manual calculations, FEA simulations, and 3D printing. Also, by comparing quantitative results the reliability of the design methodology is assessed, and key performance metrics are established.

5.2.1 CAD Model and FEA Simulation Results

The CAD model of the alternator shaft was created based on precise measurements obtained during the disassembly phase. Also, the model was then imported into ANSYS for FEA simulations to analyse reaction forces, stress distribution, and deflection.

- **Reaction forces** as shown in chapter 4, the obtained from FEA aligned closely with the manual calculations, confirming that the applied boundary conditions accurately reflected the support conditions of the shaft.

- **Von Mises Stress** as shown in chapter 4 the obtained value closely aligned with the manual calculation as this confirm the design's safety under applied loads.

- **Total and Directional Deflection** The simulated deflection values closely matched those derived manually, validating the model's accuracy in representing load-bearing capacity

Below is the summarized table of comparison between analytical and FEA results

Table 1 Analytical Result vs ANSYS Result

Parameter	Analytical Result	ANSYS Result	Difference %
Total Reaction Force	$14.715N$	14.715 N	0%
Direction Deformation	0.00667 mm	.002071 mm	68.94%
Von Mises Stress	31.19 MPa	31.396 MPa	0.66%

The results show that the ANSYS simulations are closely aligned with the analytical calculations especially for the reaction force and Von Mises stress with differences of 0.00% and 0.66% respectively. As a result, this indicates that the simulated boundary conditions and applied loads are consistent with the theoretical expectations. However, there is a notable discrepancy in the directional deformation, with a 68.94% difference. This variance could be attributed to differences in modelling assumptions or simplifications in the analytical calculations, particularly for displacement predictions, where factors such as boundary conditions and material properties may affect precision. Overall, the results validate the model, while highlighting areas for potential refinement in predicting deformations

5.3 OBSERVATIONS FROM 3D PRINTING AND PHYSICAL TESTING

This section presents the outcome of the 3D printing process, fitment testing, and the subsequent adjustments made based on the physical testing results. Also, the purpose of this phase was to validate the design by producing a tangible prototype and examining against the design expectations.

5.3.1 3D Printing Outcomes

The 3d printing process involves translating the cad model of the alternator components into physical prototypes. Using FDM printer, the model was printed with PLA material as chosen for its ease of use and dimensions stability.

Figure 43: 3D Printed Parts

Key outcomes and observations from the 3D printing process are as follows:

1. **Dimensional Accuracy:** the printed parts exhibit minor deviation from the original cad dimensions due primarily to material shrinkage and FDM limitations. dimensional discrepancies were found to be within ±0.5mm, which, while small, impacted the overall fitment slightly in high-tolerance areas. These deviations highlighted the importance of adjusting CAD tolerances for 3D printing applications.

Figure 44: 3D Printed Shaft Discrepancies

2. **Surface Finish**: The prototype had a generally smooth surface finish, with noticeable layer lines typical of FDM printing. Certain areas required minimal sanding and finishing to improve surface quality, especially for contact surfaces where fitment was critical. The layer height was set to 0.2mm, which provided a balance between resolution and print time, but future prints may benefit from a finer layer height if smoother finishes are required.

Figure 45: Surface Finish

5.3.2 Fitment and Functional Test Results

After completing the 3D printing phase, the prototype was subjected to fitment and functional tests to assess its accuracy, assembly compatibility, and overall functionality. These tests were crucial in evaluating how closely the printed model matched the original design specifications and determining any adjustments needed for future iterations.

Key observations from the fitment and functional testing are as follows:

1. **Tolerance Evaluation:** The 3d printed prototype revealed areas where tolerance adjustments would be beneficial, particularly in regions with tight clearances. Certain connections, such as the shaft and bearing interfaces, demonstrated a snug fit that, while functional, could be improved by expanding tolerances slightly in the CAD model. This would allow for smoother assembly and reduce the need for post-processing adjustments.
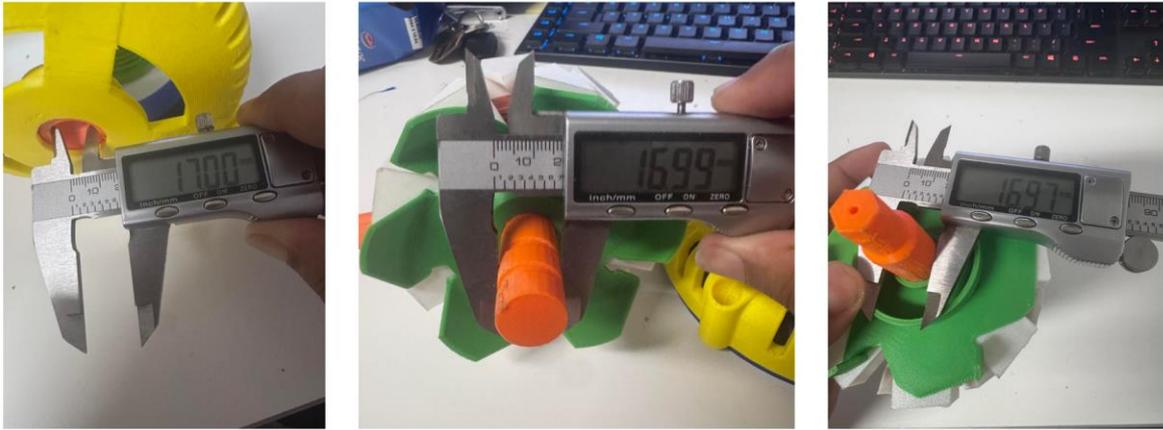
Figure 46 Tolerance Evaluation

2. **Structural Stability:** Although the prototype demonstrated sufficient stability for fitment purposes, certain sections showed minor flexing, particularly in thinner regions. This feedback is useful for refining the model in future prints, where specific parts might be reinforced or adjusted for greater structural integrity.
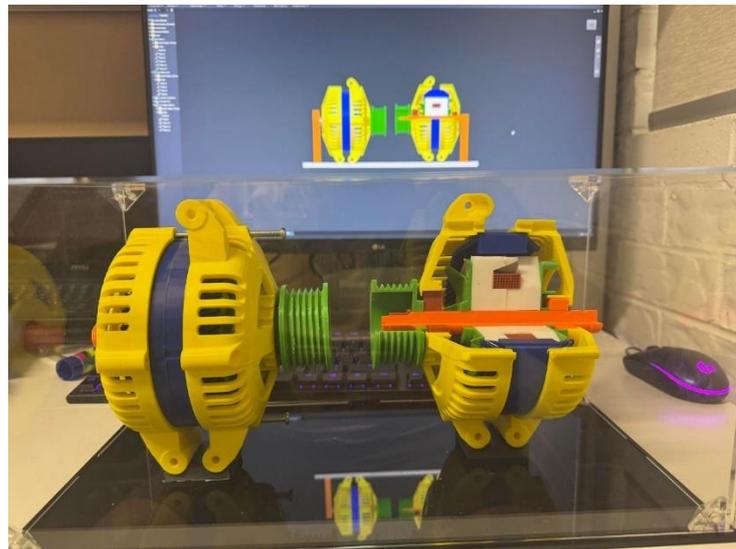

Figure 47 Structural Stability

5.3.3 Iterations and Adjustments Post-Testing

Following the initial fitment and functional tests, it became evident that certain refinements were necessary to enhance the performance and assembly accuracy of the 3D printed

prototype. The iterative process is crucial in engineering design, as it allows for continuous improvement based on observed results and practical testing feedback. Also, based on the fitment issues observed during assembly some of the tolerances in specific areas such as the shaft bearings interface and pulley mount need to be modified. Increasing the tolerance in these areas allowed for easier assembly, reducing the need for post-processing adjustments like sanding or filing. This adjustment improved the overall alignment and ensured that each part could be assembled with minimal friction, Additionally, to achieve smoother movement in rotational parts, the design of the shaft and pulley components was slightly adjusted. The fit between these components needs to be refined to reduce friction while maintaining stability. This adjustment allowed for smoother operation during rotation, which was one of the primary goals for improving functionality in subsequent iterations.

5.4 FEEDBACK FROM ENGINEERING COHORT

On this section will present the finding of the feedback collected from current engineering student regarding on the proposed methodology. Also, this feedback aims to assess students' perceptions of reverse engineering, CAD modelling, FEA, and 3D printing as educational tools, evaluating the methodology's effectiveness and identifying potential areas for improvement.

5.4.1 Value of Reverse Engineering and Hands-On Prototyping

The result of questionnaire is revealed that many students rated reverse engineering as highly valuable tool for understanding mechanical, with responses split between "Very valuable" and "Extremely valuable." As a result, this response suggests that hands-on disassembly and inspection of components help bridge the gap between theoretical knowledge and practical application. Also, this suggests students' interest to develop a deeper understanding of

mechanical systems' inner workings. Also, students also expressed that the combination of theory with hands-on prototyping provided a unique learning experience that enhances the engagement and reinforcing conceptual knowledge.

5.4.2 Integration of CAD Modelling, FEA, and 3D Printing

The result of survey revealed that students overwhelmingly indicated the combination of CAD modelling and FEA with 3D printing would be beneficial in future UniSQ courses with 66.7% responding "Very likely" and 33.3% "Extremely likely." As a result, this feedback highlights the perceived value of integrating digital design and simulation with physical prototyping, providing a holistic approach to engineering education. Also, many students felt that these tools allowed them to visualize and test designs more effectively that contributes more to their problem-solving and creativity skills.

5.4.3 Benefits and Challenges of 3D Printing as a Learning Tool

The questionnaire revealed that 83.3% of students viewed 3D printing as "Very helpful" or "Extremely helpful" in connecting theory with real-world application. Also, this feedback reinforces the importance of prototyping in understanding design limitations and fitment. However, students also identified challenges associated with 3D printing, such as limited access to equipment, particularly for online students, and the potential time required for complex designs. Suggestions included ensuring ample 3D printing resources and considering simpler components for early projects to accommodate time constraints.

5.4.4 Summary of Student Recommendations

The feedback gathered provided several valuable recommendations for enhancing the methodology:

1. **Access to 3D Printing**: Addressing the shortage of 3D printers at the university and exploring alternatives for online/external students to access prototyping facilities.

2. **Simplification of Project Components:** Simplifying the components used in early projects to allow for manageable timelines, especially for complex assemblies like an alternator.

3. **Enhanced Support for Digital Tools**: Offering additional tutorials or resources for CAD and FEA tools to help students feel more confident in using these technologies effectively.

Overall, the feedback from the cohort highlights the strengths of the proposed methodology in fostering practical and technical skills while also providing constructive insights into logistical challenges. These findings underscore the potential of hands-on, integrative methodologies in advancing engineering education, with adjustments to improve accessibility and efficiency.

5.5 ANALYSIS OF METHODOLOGY OUTCOMES

5.5.1 Successes and Strengths Identified

The integration of 3D printing and CAD modelling into the engineering design process proved highly beneficial in this initial trial in chapter 4. Also, this approach allowed for hands-on engagement helping clarify complex design concepts by transforming them into tangible models. Also, applying CAD and FEA to produce a functioning prototype gave valuable insights into the practical and theoretical aspects of engineering. Also, the methodology fostered creative problem-solving as every step required adapting designs to meet 3D printing constraints and assembly requirements. Moreover, by simulating real engineering work, the methodology demonstrated potential for enhancing engineering

students' understanding of core design and manufacturing principles that encourages a deeper appreciation of the interconnectedness of design, analysis, and physical realization.

5.5.2 Challenges and Limitations Encountered

Implementing the methodology presented some challenges this is primarily related to logistical constraints and resource availability. Also, time constraints were particularly challenging, as integrating 3D printing within an already packed curriculum proved to be difficult. Additionally, varying levels of CAD experience highlighted the need for potential pre-session tutorials to ensure all participants could fully engage with the design software. Despite these limitations, the outcomes underscored the feasibility and educational value of the approach, suggesting areas for improvement in future implementations.

5.6 LESSONS LEARNED AND INSIGHTS GAINED

integrating 3D printing and CAD modelling into the curriculum revealed valuable insights into enhancing engineering education. Also, this approach can bridge the gap between theory and practical application allowing students to experience hands-on learning and gain a deeper understanding of mechanical design. Additionally, the freedom to make creative decisions in design encouraged engagement, innovation, and a sense of ownership. Also, the project highlighted the need for adequate resources and support that emphasize that reliable equipment, software, and time are crucial for successful implementation. Overall, by blending theory with hands-on practice, coupled with creativity and flexibility, can transform engineering education, providing a more comprehensive learning experience for students.

5.7 OVERALL EFFECTIVENESS OF THE METHODOLOGY

The methodology outlined in this project focused on reverse engineering and hands on 3D modelling that demonstrates a comprehensive approach to teaching mechanical design. Also, through disassembling and analysing an alternator this methodology provides students with a realistic and detailed understanding of component interaction, functionality, and engineering principles. Also, the effectiveness of this approach lies in its blend of practical skills, theoretical application, and the iterative design process. By engaging in detailed measurements, the use of CAD modelling, and 3D printing. As a result, the students can gain a holistic view of the design cycle from conceptualization to physical realization. This hands-on experience solidifies theoretical knowledge, encouraging a problem-solving mindset while building confidence in using engineering tools and techniques.

Incorporating 3D scanning as a future addition could enhance accuracy and streamline the reverse engineering process, allowing for even more precise CAD models. This iterative improvement suggests that the methodology is adaptable, paving the way for further enhancements in educational settings. Overall, this methodology serves as a valuable educational tool, fostering critical thinking, technical skills, and creativity in engineering students.

5.8 CHAPTER SUMMARY

This chapter presented an in-depth analysis of the testing and outcomes of the proposed methodology. Key findings from analytical and simulation comparisons highlighted the strengths and limitations of the design approach. Insights gained from 3D printing and functional testing underscored the practical applicability of the methodology, while feedback from the engineering cohort provided valuable perspectives on its educational

potential. Overall, the methodology demonstrated its effectiveness in enhancing students' understanding of engineering design, fostering hands-on skills, and encouraging iterative improvement.

CHAPTER 6 CONCLUSIONS

6.1 CHAPTER OVERVIEW

This is the final section of the dissertation as it synthesizes the research outcomes to provide evaluation of the proposed methodology and possible educational impact observed through the integration of 3D printing, CAD modelling, and reverse engineering into engineering coursework. Also, this chapter begins by summarizing the main finding and insight gained from implementing and testing the proposed methodology. After, then it critically examines the methodology's strengths and limitations, discussing its potential for broader educational application and ways to address the challenges encountered. Furthermore, the possible contribution of this project to the field of engineering education is highlighted. Also, this emphasizes how hands-on approaches can enhance theoretical understanding and foster creativity and problem-solving skills among students. Finally, recommendations for future iterations and improvements to the methodology are proposed, paving the way for continued innovation in engineering curricula. The chapter concludes with reflective observations on the overall impact of the project, underscoring its role in bridging the gap between theoretical knowledge and practical skills essential for engineering professionals.

6.2 SUMMARY OF KEY FINDINGS

The summary of key findings of the project has demonstrated the effectiveness of incorporating hands on activity that has 3D printing, CAD modelling, and reverse engineering that can enhance engineering education. Also, the key findings from this study are the value of the techniques can deepen the student's understanding of a complex mechanical components and process. Additionally, through the use of practical applications of the proposed methodology the students will be better equipped to connect theoretical

concepts with real world engineering applications that foster a more profonde comprehension of component design, structural analysis, and assembly principles. Also, the study revealed that the students can benefit from visualizing and physically interacting with the components leading to improved spatial awareness, attention to detail, and problem-solving skills. Additionally, the feedback from the current engineering cohort indicates a increased engagement and enthusiasm toward learning when actively involved in a real design and prototyping process. However, the study also identified certain limitations, such as resource constraints in terms of 3D printing availability and time restrictions within the academic schedule, which may impact the methodology's full integration into the curriculum. Overall, the findings validate the potential of this hands-on methodology to bridge the gap between theoretical learning and practical application in engineering education. These insights contribute to the broader discussion on innovative teaching approaches that better prepare students for the demands of professional engineering practice.

6.3 RECOMMENDATIONS FOR FUTURE WORK

Several recommendations are proposed to further develop and refine the integration of 3D printing and CAD modelling in engineering education. As this thesis presents a proposed methodology a valuable next step would be to conduct a trial run involving a diverse group of engineering students with varied backgrounds. Also, this trial could include students with strengths in different areas, such as those with strong CAD skills but limited experience in FEA, as well as students with minimal prior exposure to either. As a result, having a many diverse backgrounds would allow for a more comprehensive evaluation of the methodology's effectiveness in addressing different learning needs and skill levels. Furthermore, the methodology to cover a wider range of mechanical components and design challenges could deepen students' exposure to real-world applications. Additionally,

considerations for future work include implementing advanced simulations, such as dynamic analyses and multi-material 3D printing. As a result, this would further enhance students' understanding of complex engineering concepts. Also, by incorporating systematic feedback from both instructors and students during these trials would enable iterative improvements that ultimately leads to a methodology that is adaptable, inclusive, and better aligned with diverse engineering curricula.

6.4 FINAL THOUGHTS

The final thoughts on this project represents a significant step forward in enhancing creativity and practical skills within engineering education by taking advantage of booming 3D printing technology. Also, through the use of hands-on approach of reverse engineering and prototype creation the students can gain a deeper understanding of the design process that translate theoretical knowledge into real outcomes. Also, the methodology proposed that been tested shows promise for developing a more engaging and effective learning experience that bridge the gap between conceptual design and real-world application. Furthermore, since the engineering education continues to develop, the introduction of emerging technologies such as 3D printing will be of great significance in preparing students for any future industry needs. Finally, the insights and results obtained within this thesis serve as a base for future improvements and allow highlighting the necessity of flexibility within the engineering curriculum.
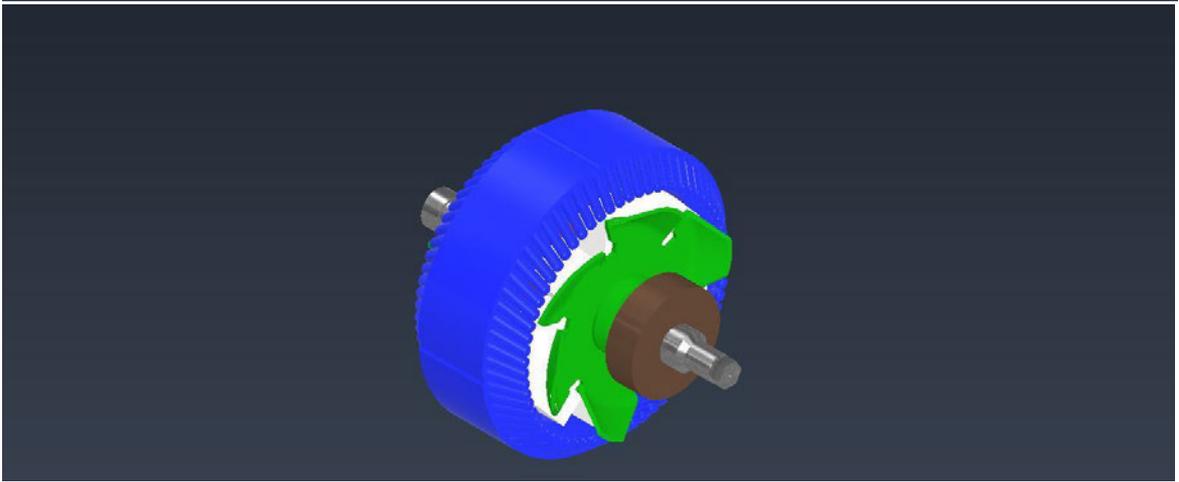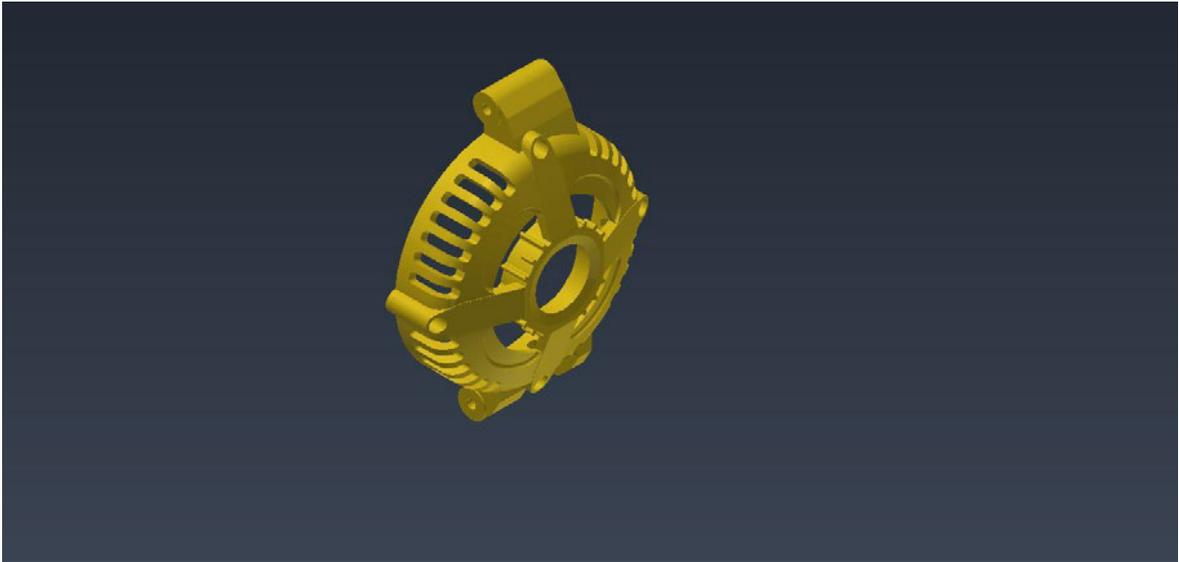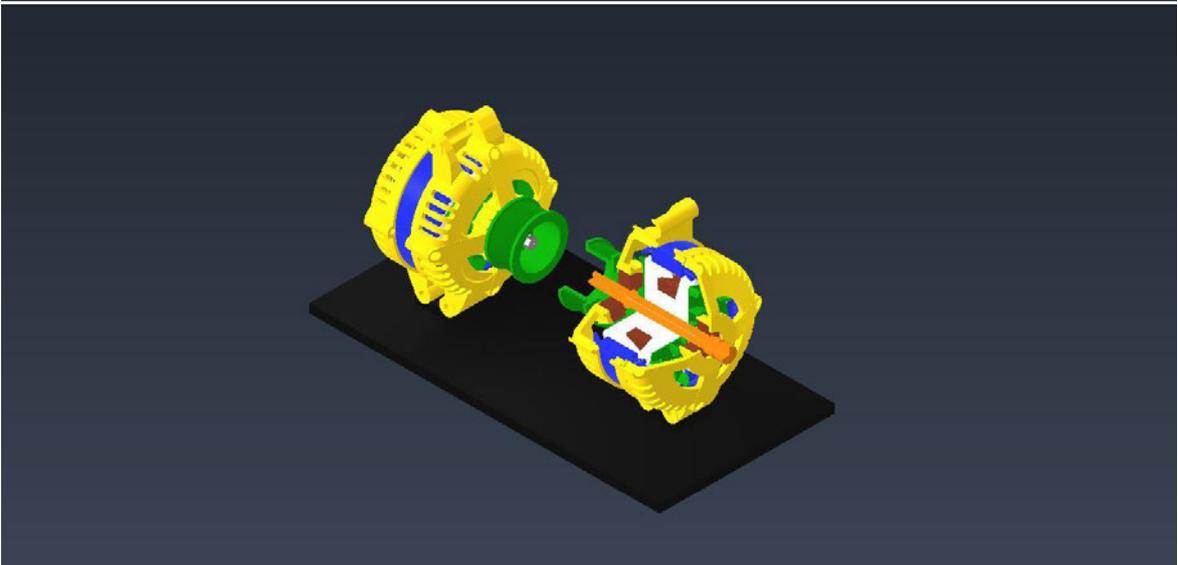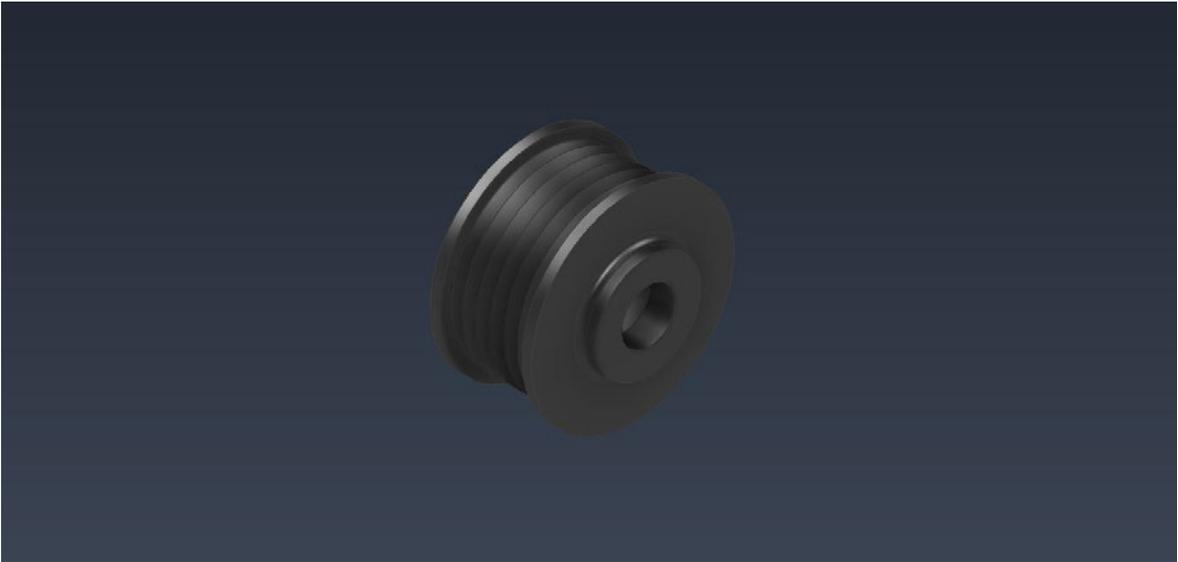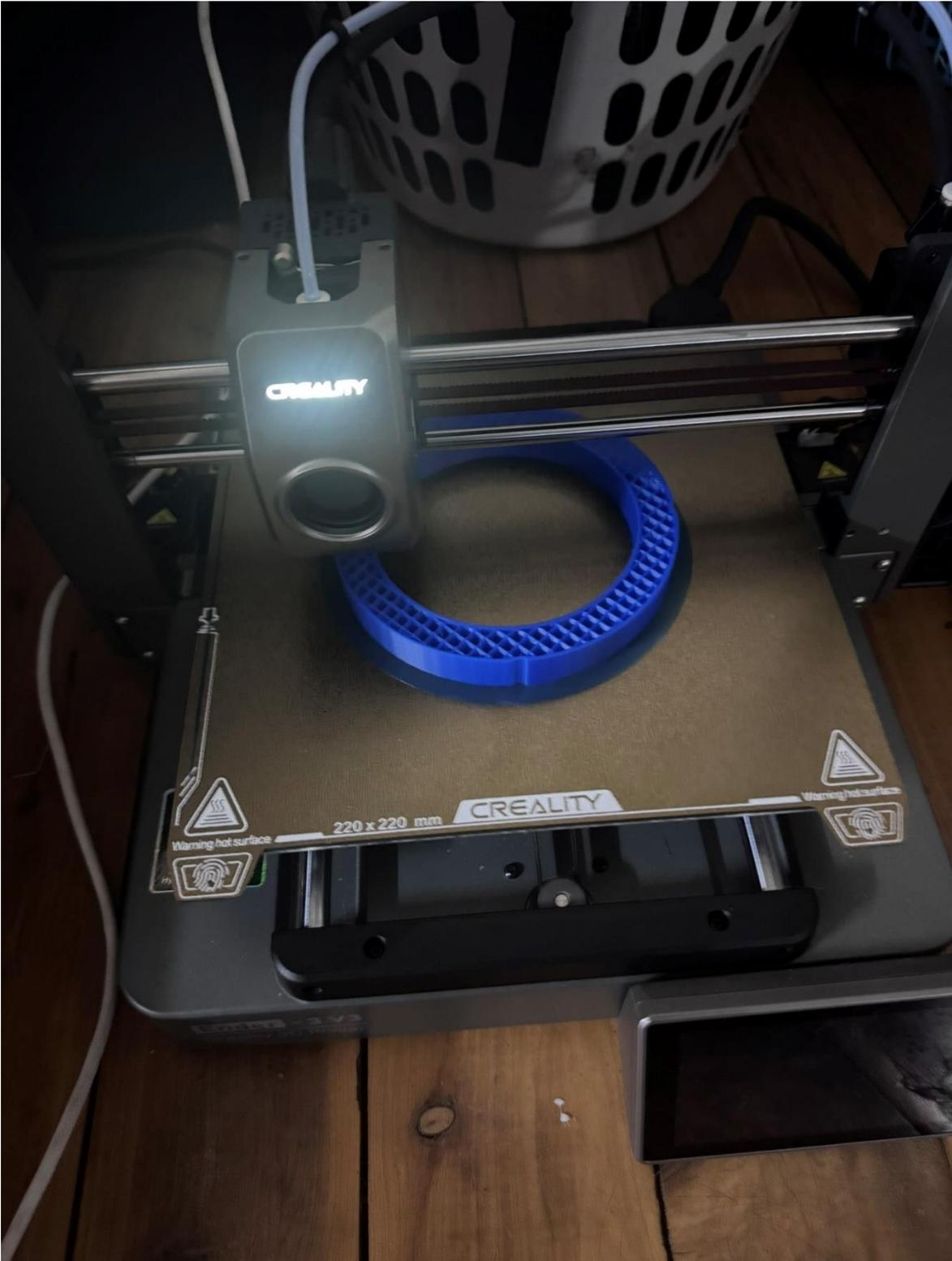
APPENDIX A REVERSE ENGINEERING PROCESS
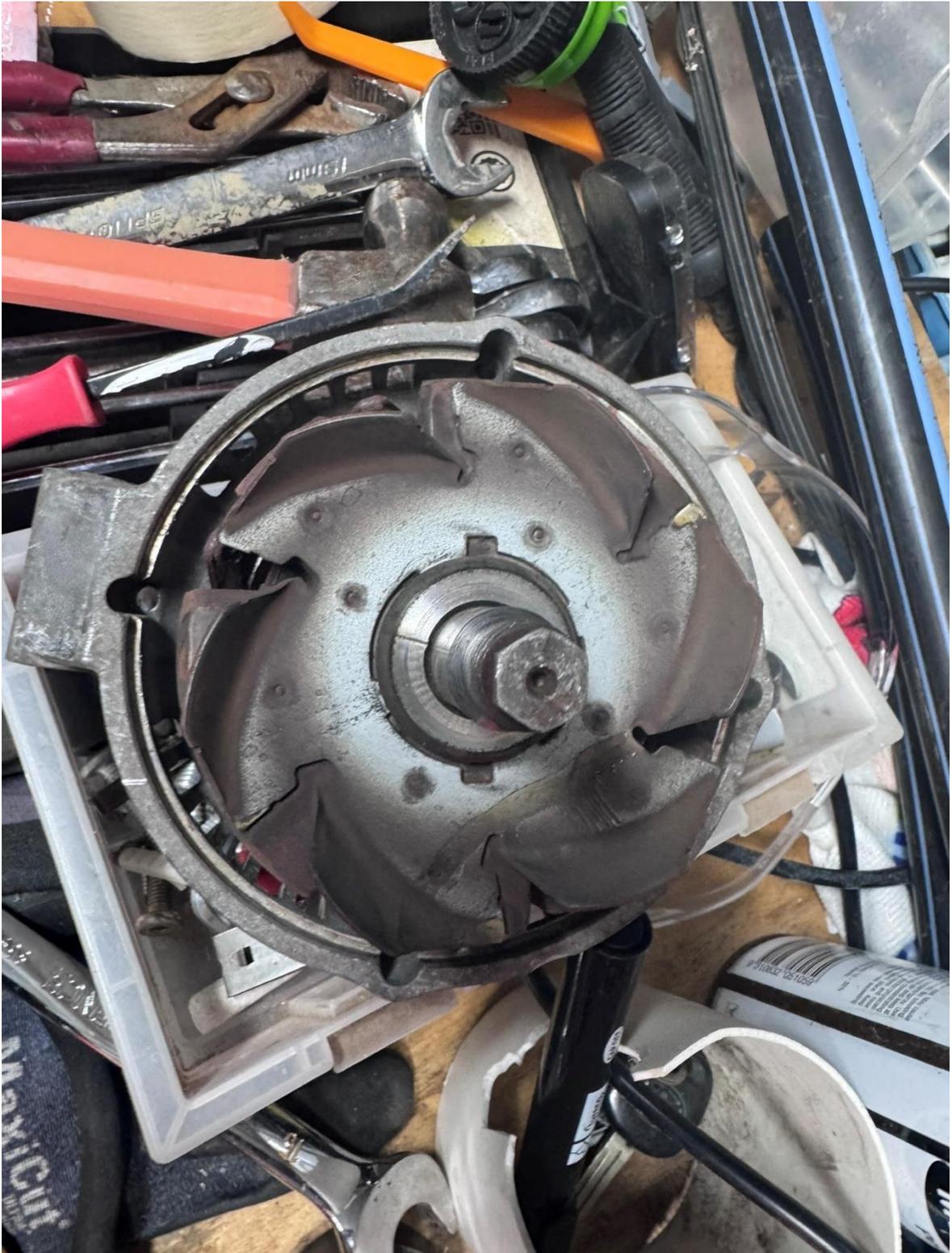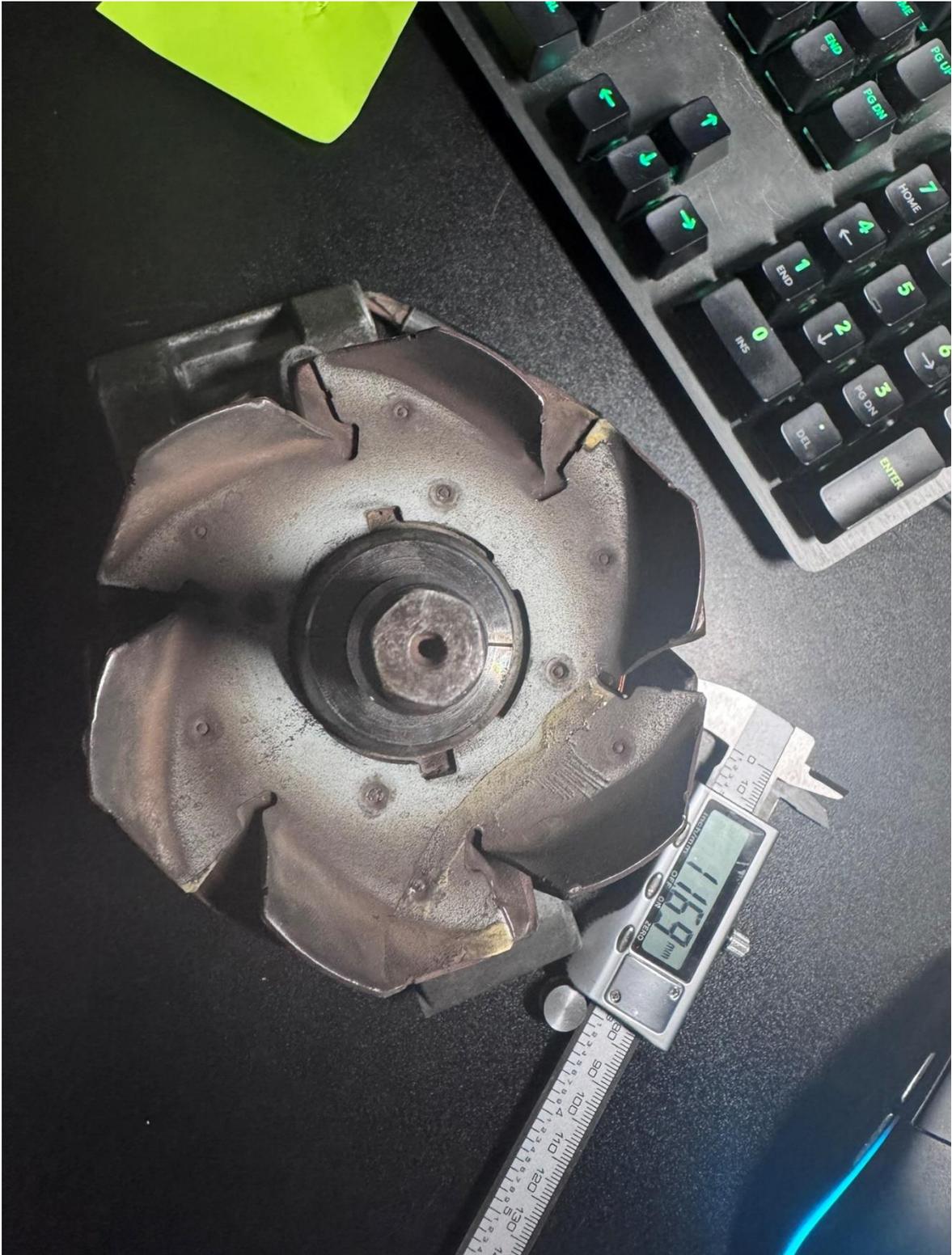
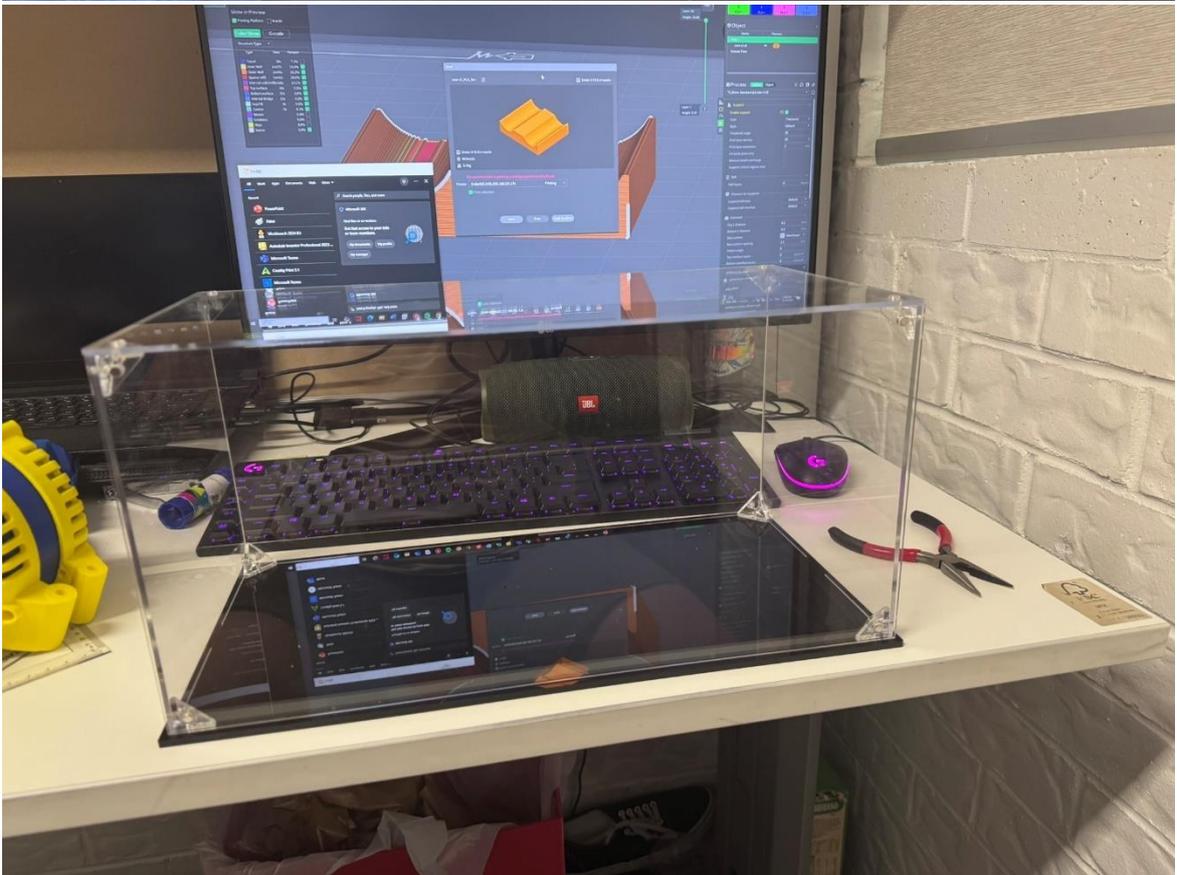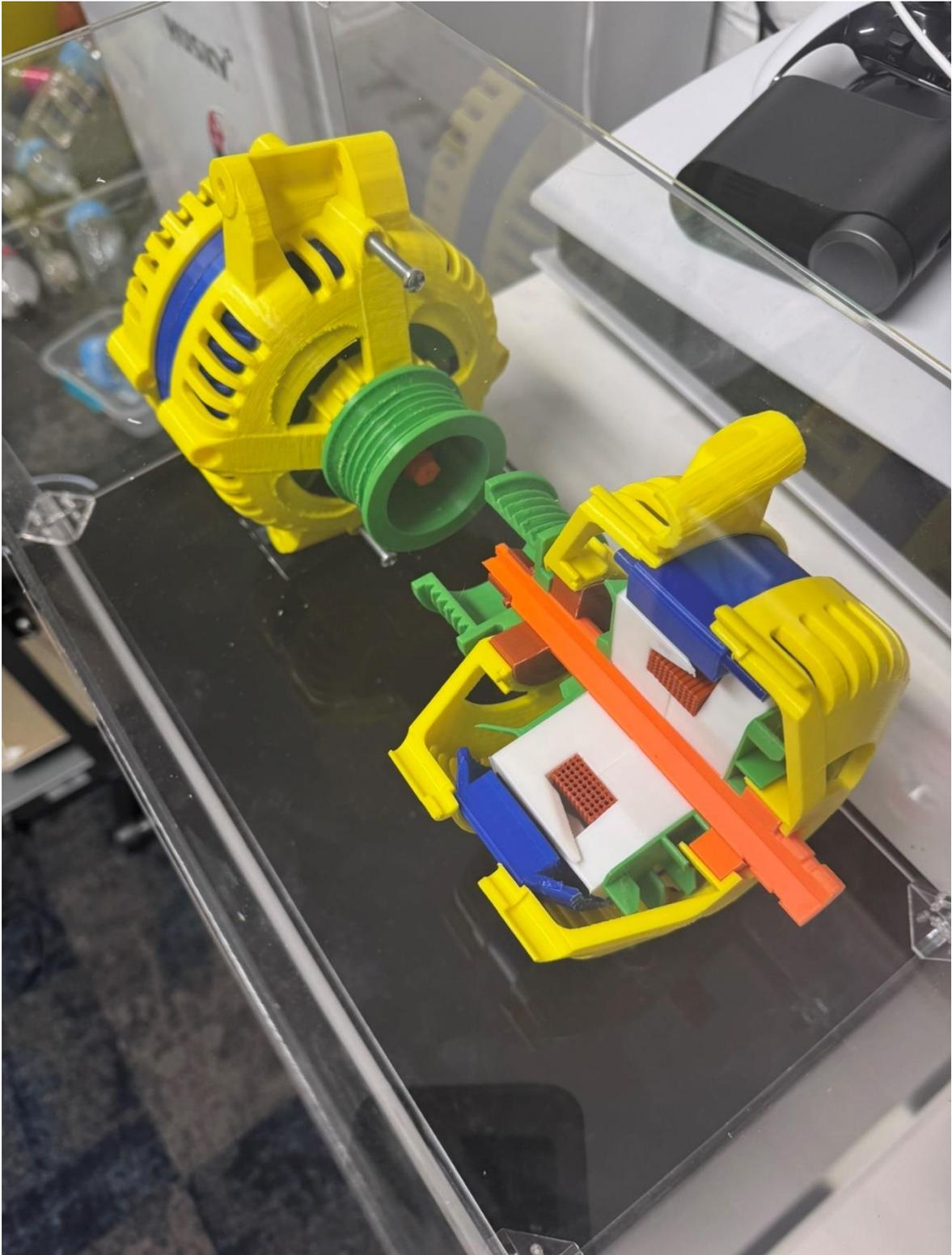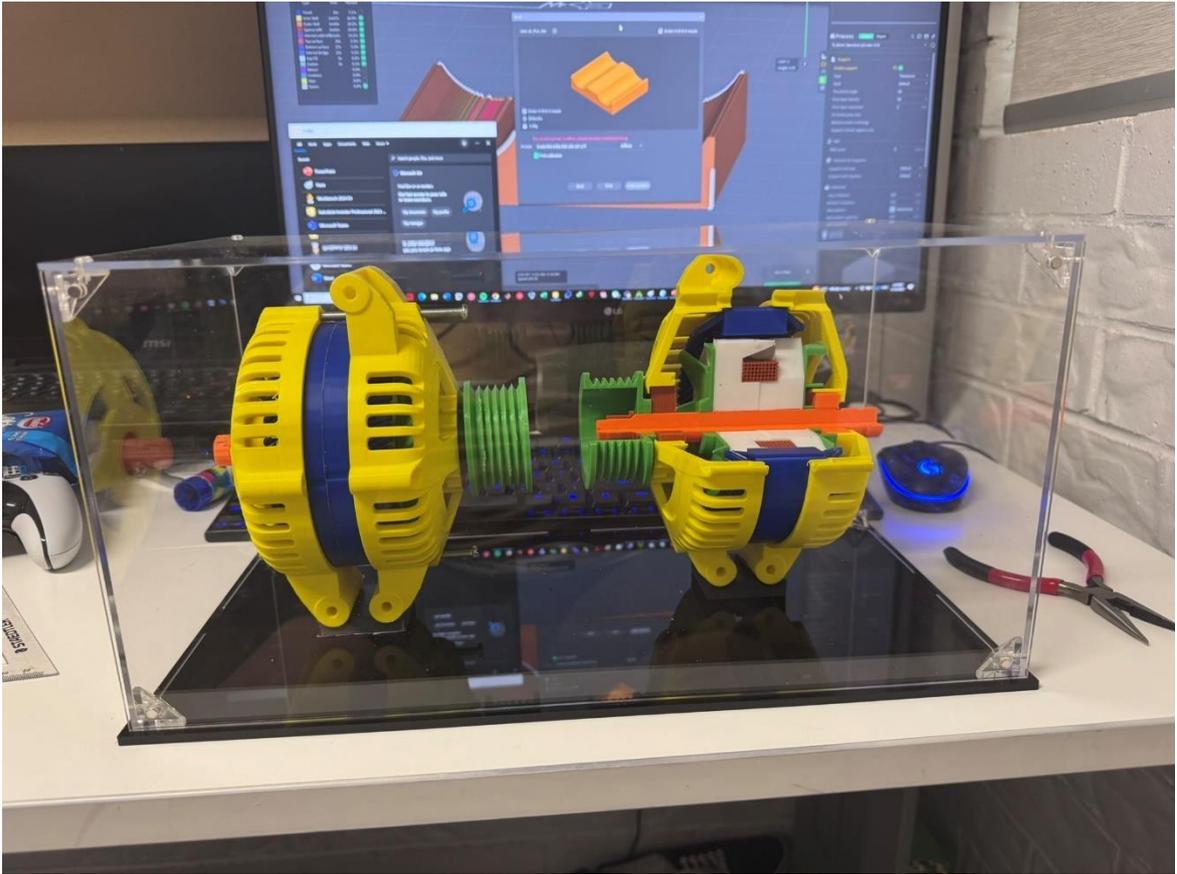# APPENDIX B: CAD MODEL DEVELOPMENT

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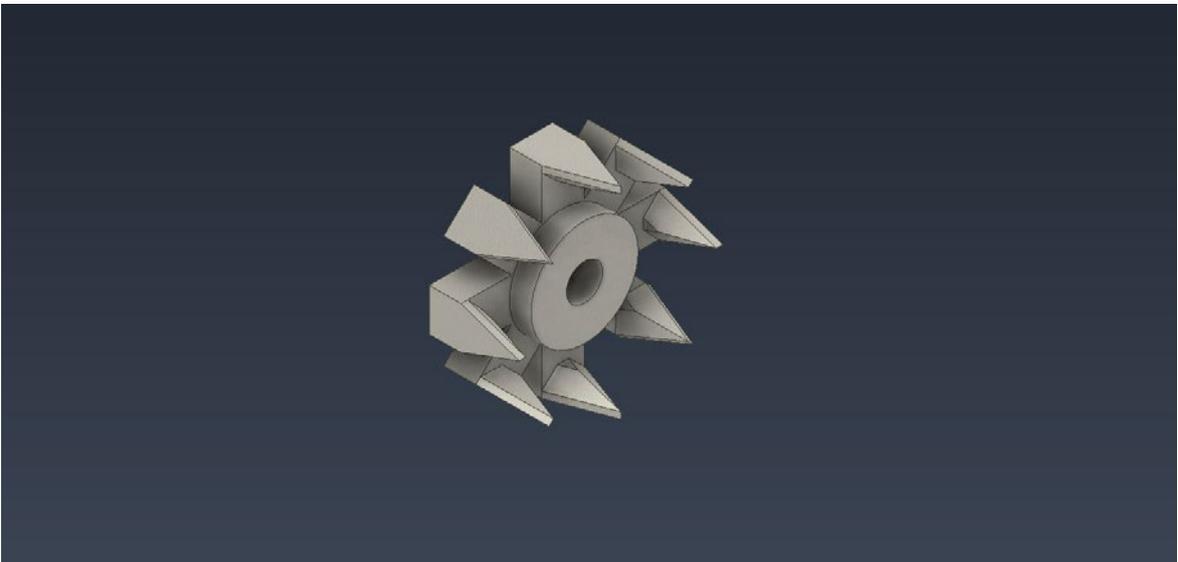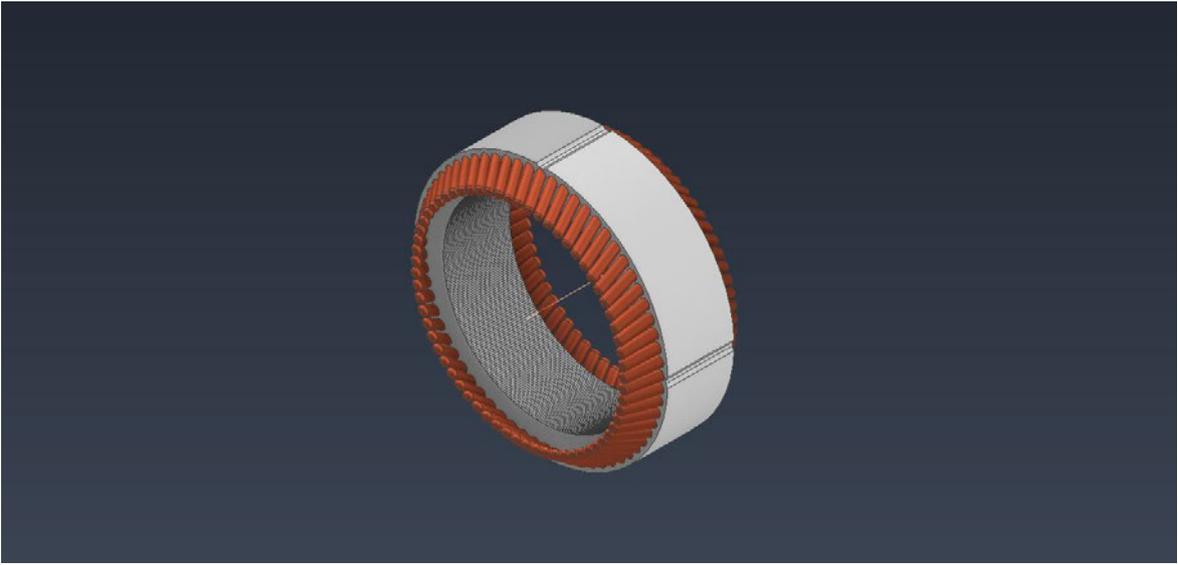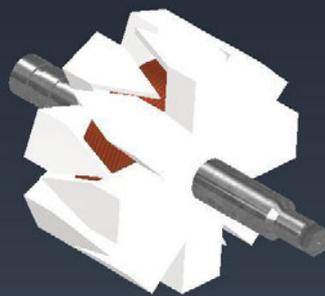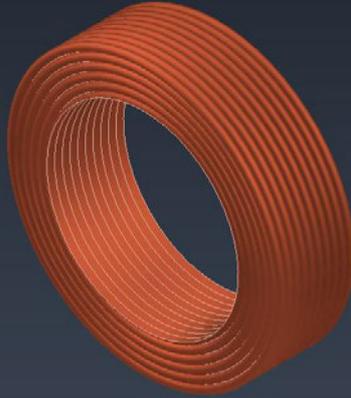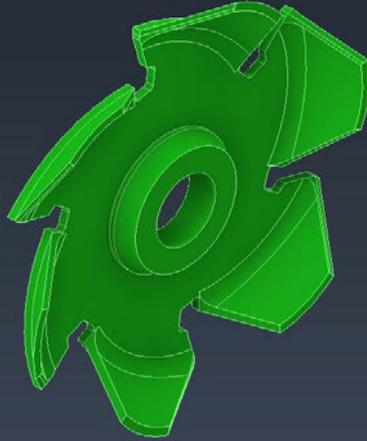
APPENDIX C: 3D PRINTED PROTOTYPE AND FITMENT TESTING

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