



DESIGN FOR X PROJECT

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ACMA5002 – MANUFACTURING DESIGN & TECHNOLOGY

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Abstract

This paper explores the importance of design optimisation and efficient manufacturing processes in the development of an aircraft bracket and portable wind turbines. The objective is to enhance the manufacturability, assembly, and performance of these turbines, making them more accessible and cost-effective for widespread adoption. Various techniques and methodologies are examined, including Design for Assembly (DFA), SCAMPER (Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse), and Failure Modes and Effects Analysis (FMEA), along with considerations for sustainability and the product life cycle.

The implementation of DFA in the assembly process of portable wind turbines is discussed, highlighting its benefits in streamlining manufacturing, reducing production time, and minimising costs. The SCAMPER technique is explored as a creative approach to generate innovative design solutions by questioning existing elements and considering alternative materials, geometries, and manufacturing processes. The application of FMEA enables manufacturers to identify potential failure modes and develop mitigation strategies to ensure reliable and safe operation.

Sustainability considerations are emphasised throughout the design and development process. This includes the selection of recyclable materials, minimising energy consumption during manufacturing, and exploring responsible end-of-life disposal options. By designing for sustainability and optimising the product life cycle, manufacturers can improve the environmental performance of portable wind turbines.

The paper concludes that by implementing these techniques and methodologies, manufacturers can optimise the design and manufacturing processes of portable wind turbines, leading to improved performance, reliability, and cost-effectiveness. This not only makes these turbines more accessible to a wider range of users but also contributes to the global transition towards renewable energy sources.

Overall, this paper provides valuable insights into the significance of design optimisation and efficient manufacturing processes in the development of aircraft brackets and portable wind turbines. The findings and methodologies discussed serve as a guide for manufacturers to enhance the manufacturability, assembly, and performance of these turbines, ultimately accelerating the adoption of clean and renewable energy sources in our society.

Introduction

A Design for Additive Manufacturing (DfAM) study is initiated to optimise an aircraft bracket with the use of a topology study. The aim of the study is to increase the strength of the unit while making it lighter. The urgent need for sustainable energy solutions has propelled the development of portable wind turbines as a promising technology for harnessing wind power in diverse environments. To ensure efficient and cost-effective mass production of these turbines, optimising their design and manufacturing processes is of utmost importance. This paper delves into the techniques and methodologies that can be employed to enhance the design optimisation and manufacturing of portable wind turbines, facilitating their widespread adoption, and furthering the advancement of renewable energy systems.

Design optimisation lies at the core of creating high-performing and reliable portable wind turbines. By incorporating concepts such as Design for Assembly (DFA), manufacturers can streamline the assembly process and reduce production time and costs. DFA involves analysing the interaction of components, identifying potential assembly issues, and redesigning components for ease of assembly. This approach enhances manufacturability and simplifies the assembly process, leading to more efficient production and higher-quality turbines.

To stimulate creativity and generate innovative design solutions, the SCAMPER (Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse) technique can be employed. By questioning existing design elements and considering alternative materials, geometries, and manufacturing processes, designers can explore possibilities that improve performance or reduce costs. SCAMPER encourages a comprehensive exploration of design alternatives, empowering manufacturers to optimise portable wind turbine designs.

Risk management is a crucial aspect of the design and manufacturing process. Failure Modes and Effects Analysis (FMEA) is a systematic approach that helps identify potential failure modes, their causes, and their effects on the product. By conducting an FMEA, manufacturers can proactively assess the impact of design and manufacturing decisions on product reliability, safety, and performance. Mitigation measures can then be implemented to address identified risks, ensuring the production of reliable and durable portable wind turbines.

Furthermore, environmental and product life cycle factors play an essential role in sustainable design and development. Considering the recyclability of materials, minimising energy consumption during manufacturing, and exploring end-of-life disposal options are vital considerations. By designing for sustainability and optimising the product's life cycle, manufacturers can minimise the environmental footprint of portable wind turbines, aligning with global efforts towards a greener future.

This paper aims to provide an in-depth analysis of these techniques and methodologies, showcasing their application and potential benefits in the context of portable wind turbine production. Through a comprehensive exploration of design optimisation and manufacturing processes, manufacturers can create more efficient, reliable, and sustainable wind turbines. Ultimately, these advancements will contribute to the wider adoption of renewable energy systems, paving the way for a cleaner and more sustainable future.

1. Aircraft Bracket

1.1. Product Selection

The chosen product for this case study is an airplane bracket. This critical component is utilised to provide support for various systems and structures within an aircraft. It necessitates both high strength and reliability, while also being lightweight to optimise fuel efficiency.

Throughout the years, significant transformations have taken place in the field of airplane brackets. The utilisation of computer-aided design and finite element analysis has enabled design optimisation, resulting in enhanced strength and reduced weight. Material selection has also expanded, now encompassing high-strength materials such as titanium alloys and composites. These materials offer improved strength-to-weight ratios and fatigue resistance. The introduction of additive manufacturing has revolutionised bracket production, facilitating the creation of intricate geometries, internal lattice structures, and consolidated components. Additionally, advancements in manufacturing techniques, such as CNC machining, have contributed to the production of multi-material designs and improved bracket manufacturing (Dziubińska & Gontarz, 2015).

To further enhance the performance of the airplane bracket, various surface treatments and coatings have been implemented to improve corrosion resistance. Moreover, stringent quality assurance and certification processes have been established to ensure safety and performance standards are met. These advancements collectively result in the development of lighter, stronger, and more durable airplane brackets, thereby contributing to improved efficiency and safety within the aviation industry.

For the design of the aircraft bracket in this case study, the Selective Laser Melting (SLM) process has been chosen. SLM is a powder bed fusion technique that offers exceptional design flexibility and the ability to fabricate complex geometries with high accuracy. The material selected for this specific case study is titanium alloy (Ti6Al4V), a commonly utilised material in aerospace applications due to its notable strength-to-weight ratio and corrosion resistance properties (Gan, et al., 2020).

1.2. Design for Additive Manufacturing (DfAM) Principle and Design Tools

In the design stage, a failure mode effects analysis (FMEA) should be undertaken to ensure that all risks are considered and ranked accordingly with the defined matrix. The key failure modes are considered and evaluates its effects on the system, considering factors such as safety, functionality, reliability, customer satisfaction, and regulatory compliance. Severity ratings are assigned to each failure mode to prioritise critical issues, summarised in table 1.

Degree	Severity Description	Rating
Minor	It is unlikely that this minor failure will result in any significant impact on the material, system process, or subsequent processes. It is improbable that the customer will be able to detect this failure.	1
Low	The inconvenience experienced by the customer is minimal. They might notice a slight decrease in item or system performance or encounter a minor inconvenience during a subsequent process or assembly operation, such as requiring minor rework.	2-3
Moderate	Failure can result in customer dissatisfaction, causing discomfort and annoyance. The customer will observe a decline in the performance of the item or system, potentially leading to unscheduled rework or repair, as well as possible equipment damage.	4-6
High	The inoperability of an item or system due to failure can result in a considerable level of customer dissatisfaction. While not directly related to safety or government regulations, such failures can cause significant disruptions in subsequent processing or assembly operations, potentially requiring substantial rework.	7-8
Very High	Failure gives rise to a safety hazard or noncompliance with government regulations, which could jeopardize the safety of the machine or assembly operator. The risk level is assigned a rating of 9 with warning and 10 without warning.	9-10

Table 1 - Severity for FMEA

The causes of failures are determined, along with the likelihood of detection before reaching the end-user. Occurrence and detection ratings are assigned to assess the likelihood of failures occurring and being detected, as shown in tables 2 & 3 respectively.

Degree	Occurrence Description	Rating
Remote	The occurrence of a failure is highly improbable since there have been no reported failures linked to this process or similar processes (1 in 1.5 million).	1
Very Low	This process or closely related processes are associated with only isolated failures (2 in 1.5 hundred thousand).	2
Low	Failures are observed in separate processes that exhibit similarities (3 in 30,000; 4 in 4,500; 5 in 800).	3
Moderate	The process experiences intermittent failures, but they are not significant in magnitude (6 in 150; 7 in 50).	4-6
High	This process or comparable processes have frequently encountered failures (8 in 9; 9 in 6).	7-8
Very High	Failure is nearly unavoidable (10 in 3).	9-10

Table 2 - Occurrence for FMEA

Degree	Detection Description	Rating
Very High	The current controls in place are highly effective in detecting the failure mode. There are dependable detection controls accessible for similar processes. Furthermore, the process is designed to automatically cease further processing as a precautionary measure.	1-2
High	The likelihood of controls identifying the failure mode is high, and the process itself possesses the capability to automatically detect the failure mode.	3-4
Moderate	There is a possibility that controls will identify the presence of a failure mode.	5-6
Low	The probability of controls detecting the presence of a failure mode is low.	7-8
Very Low	The detection of the failure mode by controls is improbable. Currently, there are no known controls capable of identifying this specific type of failure.	9-10

Table 3 - Detection for FMEA

Risk Level	Range
Low	0 - 96
Medium	97 – 196
High	197 - 1000

Table 4 - RPN Classification Matrix

By multiplying severity, occurrence, and detection ratings, a Risk Priority Number (RPN) is calculated to prioritize high-risk failure modes. Actions and recommendations are developed based on the RPN, aiming to reduce identified risks through design modifications, process improvements, or additional controls. These actions are implemented, monitored, and evaluated for effectiveness. This has been conducted for the bracket and is shown in table 5.

		Alex Greenslade	DESIGN FAILURE MODE and EFFECTS ANALYSIS on an Airplane Bracket						Rev 1.	
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Seq	Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes Failure	Occurrence	Preventative Measures	Detection	R.P.N.	Recommended Actions
1	Load-bearing	Insufficient strength resulting in deformation or	Structural failure, compromising the overall integrity and safety of the aircraft.	8	Inaccurate calculation or estimation of anticipated loads and	5	Load testing and strain measurement to verify the structural integrity and	5	200	Regular inspection and maintenance to detect and repair

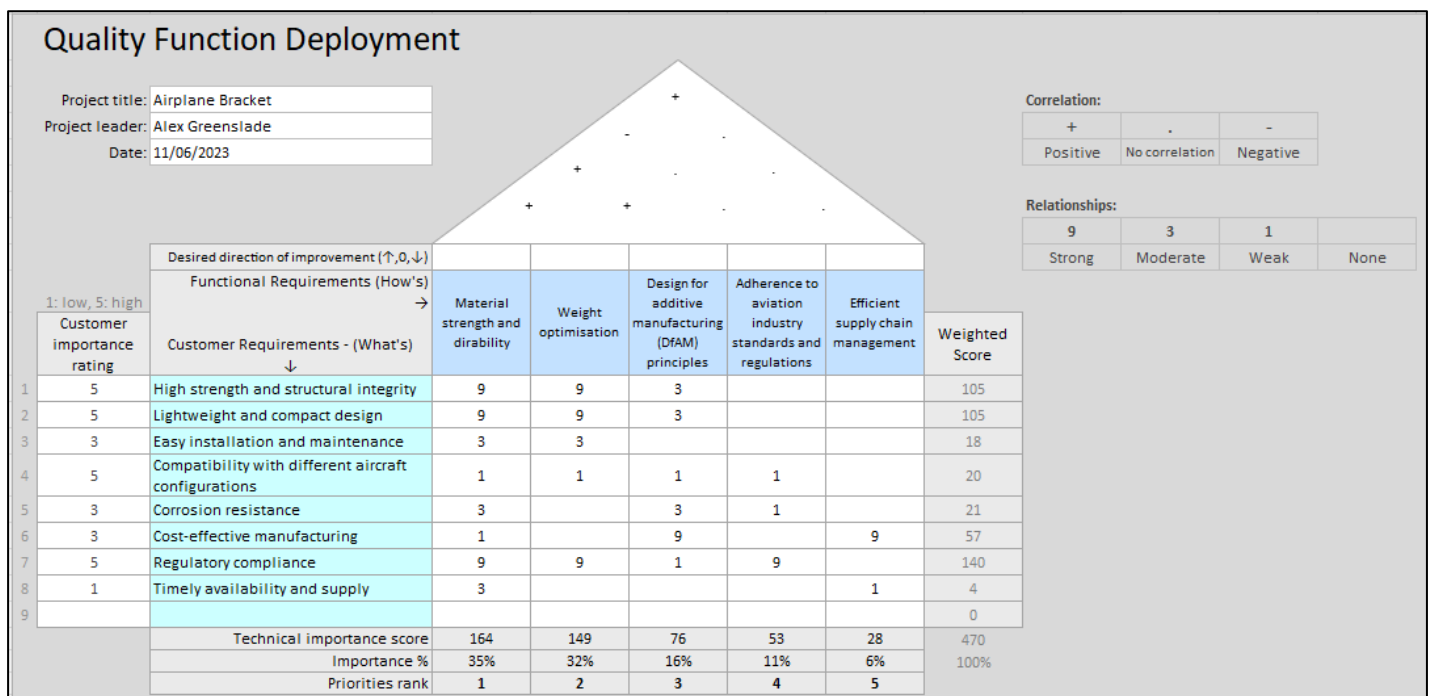
		failure under applied loads.			stresses.		performance of the bracket.			any cracks or damage.
2	Structural integrity	Warping or distortion due to residual stresses, compromising the bracket's structural integrity.	Structural deformation, leading to misalignment or interference with other components.	7	Inadequate consideration of material properties, resulting in suboptimal structural design.	5	Non-destructive testing methods such as X-ray or computed tomography (CT) scanning to detect internal defects or voids.	4	140	Implement strict process control during SLM manufacturing to minimise the risk of defects and voids.
3	Dimensional accuracy	Inaccurate hole placement or sizing affecting assembly or attachment of other parts.	Difficulties in assembly, hindering the integration of other components.	6	Thermal distortion during the SLM process, causing dimensional deviations from the intended design.	5	Dimensional inspection using coordinate measuring machines (CMM) or optical measurement systems to verify the bracket's dimensional conformity to the design specifications.	5	150	Calibrate and maintain measurement equipment to ensure accurate dimensional inspections.
4	Material properties	Inconsistent material quality or composition causing variations in strength, stiffness, or other properties.	Increased risk of fatigue or stress-related failures.	7	Inadequate powder quality or contamination leading to compromised material properties.	5	Material testing and analysis, including tensile testing, hardness testing, and microstructural analysis, to verify material properties and conformity to specifications.	3	105	Establish stringent material quality control measures to ensure consistent and reliable material properties.
5	Heat dissipation	Inadequate thermal conductivity resulting in	Thermal stress or damage to nearby systems, affecting their	7	Inadequate thermal design, leading to inefficient heat transfer	6	Thermal analysis, such as computational fluid dynamics (CFD), to	3	126	Conduct thermal analysis to validate and optimize the

		excessive heat accumulation, leading to degradation or failure.	functionality.		and localized hot spots.		simulate and validate the heat dissipation performance of the bracket design.			bracket's heat dissipation performance.
6	Weight optimization	Insufficient lattice or cellular structures resulting in excessive weight or reduced weight-saving benefits.	Excessive weight, leading to increased fuel consumption and reduced overall aircraft performance.	7	Incomplete or inaccurate design optimization process, resulting in suboptimal weight reduction.	6	Finite element analysis (FEA) and topology optimization studies to validate the weight reduction achieved and ensure the bracket's structural integrity.	3	1 2 6	Validate the weight reduction achieved through physical weight measurements and compare with target values.
7	Corrosive resistance	Inadequate material selection or surface treatment resulting in susceptibility to corrosion or oxidation.	Corrosion or oxidation of the bracket, reducing its lifespan and compromising its structural integrity.	7	Poor choice of material or surface finish, resulting in inadequate corrosion protection.	4	Salt spray or humidity testing to assess the corrosion resistance of the bracket's surface finish.	4	1 1 2	Implement regular inspections and maintenance to identify and address any signs of corrosion.
8	Vibration damping	Inadequate vibration absorption or damping leading to resonance, fatigue, or failure under dynamic loads.	Accelerated wear and fatigue of other components due to excessive vibration transmission.	6	Insufficient analysis or understanding of vibration characteristics and frequencies.	5	Modal analysis to determine the bracket's natural frequencies and vibration behaviour.	4	1 2 0	Conduct comprehensive vibration analysis to identify potential vibration issues and design solutions.

9	Surface finish	Rough or uneven surface finish causing wear, abrasion, or frictional issues with adjacent components.	Difficulties in maintaining or lubricating the bracket, affecting its functionality and lifespan.	6	Insufficient control over surface roughness or texture during the SLM process.	7	Surface roughness measurement using profilometers or optical instruments to ensure compliance with specified surface finish requirements.	4	168	Implement proper post-processing techniques to achieve the desired surface finish.
10	Assembly	Incompatible or misaligned features hindering proper assembly or integration with other components.	Delays or difficulties in assembly, leading to increased production time and costs.	6	Insufficient consideration of assembly sequence or joining methods.	3	Use of assembly fixtures, jigs, or alignment aids to ensure accurate and repeatable assembly.	3	54	Establish clear assembly guidelines and procedures to ensure proper fit and alignment.
11	Compatibility	Inadequate mounting provisions or attachment points resulting in improper installation or insecure attachment.	Inability to integrate the bracket with other components, requiring redesign or replacement.	5	Inadequate consideration of interface requirements or compatibility with other components.	4	Design reviews and collaboration between different design teams or suppliers to address potential compatibility issues.	3	60	Collaborate closely with component suppliers and conduct thorough compatibility testing.
12	Maintenance and repair	Inaccessible or hard-to-reach areas preventing effective inspection, maintenance, or repair procedures.	Difficulties in inspecting, maintaining, or repairing the bracket, leading to increased downtime and maintenance costs.	5	Inadequate accessibility or serviceability considerations during the design phase.	4	Periodic inspections and condition monitoring to detect any signs of wear, fatigue, or damage that may require maintenance or repair.	3	60	Develop comprehensive maintenance and repair procedures specific to the bracket.

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To ensure the products purpose and is designed and manufactured to a high quality, a quality function deployment matrix can be constructed which compares the customer requirements against the functional requirements to produce a prioritised rank of importance. This has been completed for the airplane bracket and shown in figure 1.



1.2.1. Component Consolidation

The design freedom offered by Additive Manufacturing (AM) allows for the consolidation of multiple separate components into a single optimised bracket. By integrating various functionalities into a unified design, the number of individual parts is reduced. This consolidation simplifies assembly processes, reduces the need for fasteners or joining techniques, and eliminates potential points of failure associated with multiple interfaces. The resulting single-piece bracket promotes overall structural integrity and improves the reliability and maintenance of the aircraft system (Schmelzle, et al., 2015).

employed to determine the optimal distribution of material within the bracket based on specific load requirements. This ensures that material is concentrated where it is most needed, further reducing weight while maintaining the necessary structural integrity (Leary, 2020).

1.2.3. Multi-Material Design

While the primary material for the bracket may be titanium alloy, AM facilitates the integration of multi-material elements within the design. For instance, areas of the bracket that require enhanced wear resistance can be reinforced with a wear-resistant material. This can be achieved through a combination of AM processes, such as utilising a different material in specific regions, or through post-processing techniques like surface cladding or coating. By selectively introducing different materials, the bracket's performance can be optimised for specific operational demands, improving durability, and extending the component's lifespan (Leicher, et al., 2020).

1.2.4. Tessellation

Tessellation involves the division of the bracket's surface into smaller geometric patterns, such as infill patterns or reinforcing ribs. By introducing strategically placed infill patterns or ribs, the load-bearing capabilities of the bracket can be enhanced. These patterns distribute and redirect stresses within the structure, improving strength and stiffness. Tessellation also allows for improved material usage efficiency, as it reduces the need for solid sections throughout the bracket. The overall result is a lightweight design with optimised mechanical properties (Leicher, et al., 2020).

1.2.5. Mass Customisation

One of the significant advantages of AM is its ability to enable mass customisation. Each bracket can be tailored to specific aircraft configurations or requirements. Design parameters can be easily modified to accommodate variations in size, shape, or mounting interfaces. By leveraging digital design tools, such as parametric modelling, customisation becomes more accessible and cost-effective. This capability allows for the production of brackets that are precisely adapted to individual aircraft systems, optimising performance, and functionality (Reeves, et al., 2011).

1.2.6. Build Volume Optimisation

When designing brackets for AM, it is essential to consider the build volume of the AM machine. Optimisation techniques, such as iterative design and simulation tools, can be employed to ensure that the bracket design efficiently utilises the available space within the AM machine. By carefully positioning and arranging the brackets within the build volume, manufacturing time and costs can be minimised. Efficient material usage is also achieved by optimising the orientation and placement of brackets, reducing waste and optimising printing processes (Reeves, et al., 2011).

1.3. Finite Element Analysis & Topology Expectations

1.3.1. Structural Analysis

A detailed structural analysis of the bracket can be conducted using Finite Element Analysis (FEA), allowing for an evaluation of its performance under different loading conditions and the identification of potential areas of high stress or deformation. This analysis ensures that the bracket can withstand the expected loads and meets the necessary safety and performance requirements (Luo, et al., 2022). From the figures shown in 2 & 3 from the topology analysis, the displacement has been reduced where the concepts maximum displacement was 4.2mm which has been reduced to 1.2mm through optimisation with a 57% improvement. In figure 2 the maximum displacement seen in 4.283mm and the minimum is 0.8164mm. Whereas in figure 3, the maximum displacement is 1.163mm and the minimum is 0.03832mm.

1.3.2. Weight Reduction

The application of topology optimisation techniques in conjunction with FEA enables the identification of the optimal distribution of materials within the bracket. Through iterative iterations that remove material from non-critical areas while maintaining structural integrity, the weight of the bracket can be significantly reduced. This weight reduction offers benefits such as improved fuel efficiency, increased payload capacity, and an overall reduction in aircraft weight (Gopsill, et al., 2018). A topology study was constructed which reduced the weight of the bracket from 1.062kg to 0.323kg which is a 70% reduction in mass.

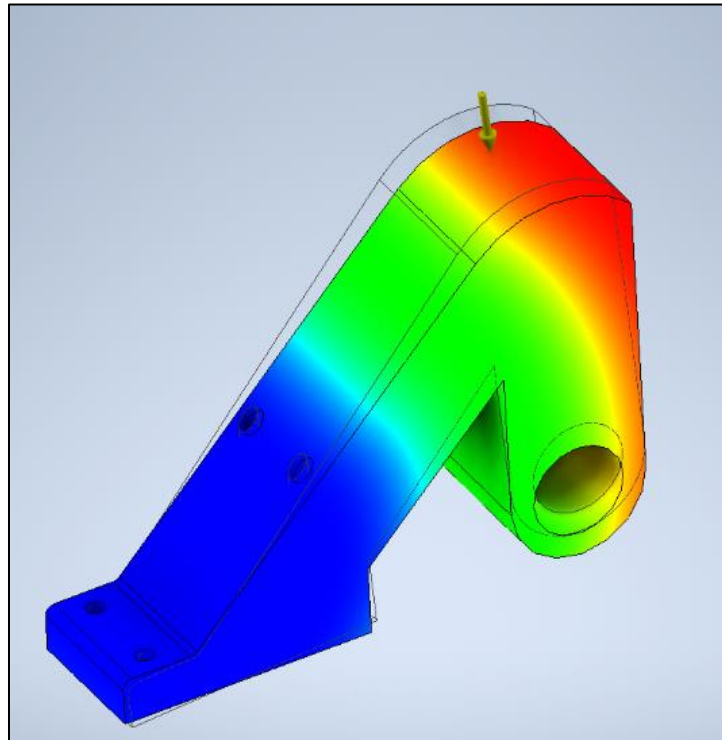


Figure 2 - Topology Simulation of Concept Bracket

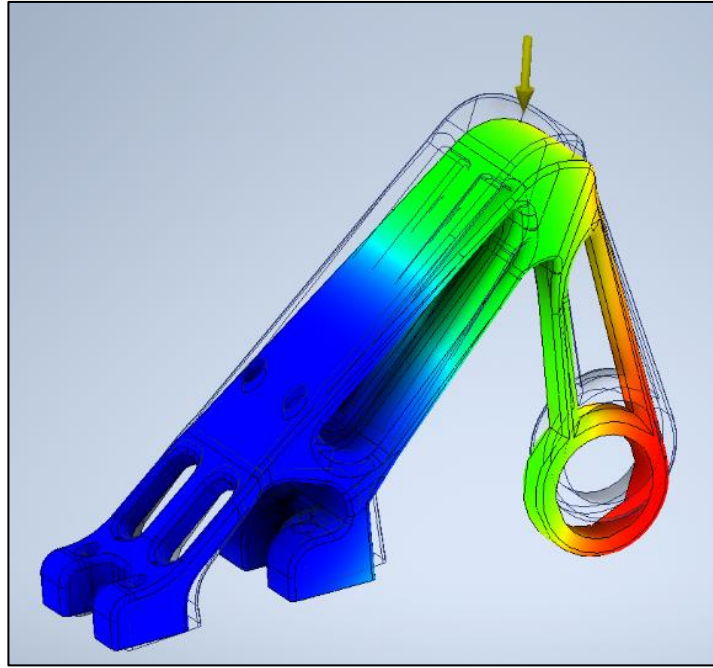


Figure 3 - Topology Analysis of Optimised Bracket

1.3.3. Material Efficiency

FEA, in conjunction with topology optimisation, helps identify regions within the bracket that experience low stress or load concentration, where material can be minimised or even eliminated. This results in efficient material usage during the manufacturing process, leading to cost savings (Gopsill, et al., 2018).

1.3.4. Enhanced Structural Performance

By optimising the bracket's topology, FEA can unveil new design configurations that enhance the bracket's stiffness, strength, and fatigue resistance. The study can identify load paths, stress redistribution, and areas where additional reinforcement may be beneficial, resulting in an optimised bracket design with superior performance characteristics (Luo, et al., 2022).

1.3.5. Design Validation and Verification

FEA enables virtual testing of the bracket design, simulating various operating conditions, such as vibrations, thermal loads, and dynamic forces. This validation process ensures that the bracket will perform as intended in real-world scenarios, reducing the risk of failures or structural issues (Szabo & Babuska, 2011).

1.3.6. Optimisation of Manufacturing Process

FEA and topology optimisation studies provide insights into the manufacturability of the bracket design. By considering manufacturing constraints and process limitations, such as support structure requirements, material deposition angles, or overhangs, the design can be optimised for easier and more efficient production using additive manufacturing techniques (Szabo & Babuska, 2011).

1.3.7. Cost Reduction

Through weight reduction, material efficiency, and improved structural performance, FEA and topology optimisation studies contribute to cost reduction in terms of material usage,

manufacturing, and operational expenses. This can lead to significant savings in overall aircraft production and maintenance costs (Szabo & Babuska, 2011).

1.4. SLM Considerations

1.4.1. Shrinkage Distortion

During the SLM process, the material undergoes thermal expansion and contraction as it is melted and solidified. This can lead to shrinkage distortion, causing deviations from the intended design. To minimise shrinkage distortion, appropriate orientation, support structures, and process parameters must be implemented (Didier, et al., 2021).

1.4.2. Porosity

Porosity refers to the presence of voids or gas pockets within the printed part, which can result from trapped gas or inadequate fusion during the melting process. Controlling process parameters, such as laser power, scan speed, and gas atmosphere, is necessary to minimise porosity and ensure high-quality parts (Didier, et al., 2021).

1.4.3. Residual Stresses/Concentrations

The rapid heating and cooling involved in SLM can create residual stresses within the printed part, which can cause warping, cracking, or reduced mechanical properties. Proper heat treatment and post-processing techniques, such as stress relieving or hot isostatic pressing (HIP), can help mitigate residual stresses and improve part performance (Didier, et al., 2021).

1.4.4. Material Considerations

SLM is compatible with various materials, including metals, alloys, and some ceramics. However, material selection is crucial as process parameters and performance can vary based on material properties. Laser energy absorption, thermal conductivity, and melting behaviour of each material need to be considered during design and process planning (Didier, et al., 2021).

1.4.5. Anisotropy and Inhomogeneity

SLM parts can exhibit anisotropic behaviour, where mechanical properties vary based on the build direction due to the layered printing process. Additionally, material distribution and microstructure can be inhomogeneous, particularly in regions with rapid solidification. Understanding and accounting for these variations are essential for consistent and predictable part performance (Holoch, et al., 2022).

1.4.6. Surface/Tribological Considerations

SLM parts may have rougher surface finishes compared to conventionally manufactured components. Additional post-processing steps like machining or surface finishing may be necessary to achieve the desired surface quality or meet specific tribological requirements, such as reducing friction or wear (Holoch, et al., 2022).

1.4.7. Support Structure Requirements

SLM often requires the use of support structures to prevent deformations and ensure structural integrity during printing. These supports need to be designed and optimised to minimise post-processing requirements and enable their efficient removal without causing damage to the printed part (Holoch, et al., 2022).

1.4.8. Post-Processing

Post-processing operations, including heat treatment, machining, polishing, or coating, may be necessary to achieve the final part specifications and performance. Planning and accounting for these steps in the overall manufacturing process are crucial to ensure the desired part quality and functionality (Holoch, et al., 2022).

1.4.9. Cost Calculations and Comparisons

While SLM can be cost-effective for low-volume or complex parts, it may not always be the most economical choice for high-volume production due to equipment, material, and post-processing costs. Conducting a thorough cost analysis that considers factors such as equipment utilisation, material waste, labour, and post-processing requirements is necessary to evaluate the economic feasibility of SLM for a specific component (Holoch, et al., 2022).

2. Portable Wind Turbine

2.1. Concept Design Appraisal

2.1.1. Overview

It is assumed that the portable wind turbine is designed to be lightweight and compact, allowing for easy transportation and setup. The turbine should be small enough to fit in a backpack or a small carrying case. It is also assumed that the wind turbine is designed to generate a modest amount of power suitable for portable applications, with a power output range of 50 to 200 watts. The wind turbine is expected to incorporate an aerodynamic design, to maximise its efficiency in capturing wind energy. Durability is also assumed, with the wind turbine designed to withstand outdoor conditions and made of durable materials such as lightweight metals or composites. It should be able to withstand moderate wind speeds and occasional rough handling during transportation. Ease of use is also considered, assuming that the portable wind turbine is designed to be user-friendly, with a simple setup process and intuitive controls that require minimal technical knowledge.

2.1.2. Design Appraisal

The strengths of the turbine include its portability, allowing for easy transportation and setup in various locations, making it suitable for camping, outdoor activities, and emergency power needs. Additionally, the wind turbine provides a renewable and environmentally friendly source of energy. It offers versatility, providing power for various small-scale applications such as charging electronic devices, powering LED lights, or running small appliances. However, there are weaknesses to consider, such as power output limitations due to its portable nature and smaller size, making it less suitable for high-demand applications or powering larger devices. The effectiveness of the wind turbine also relies heavily on the availability and strength of wind, which may lead to inconsistent or insufficient power generation in areas with low wind speeds. Maintenance and repairs may pose challenges due to the compact design, and periodic maintenance may be required to ensure optimal performance.

There are opportunities for the portable wind turbine, such as using it as an educational tool to raise awareness about renewable energy and promote its benefits. It can also serve as a reliable power source during emergencies, providing electricity for essential devices and communication equipment. The portable wind turbine can find applications in remote locations or off-grid setups where access to traditional power sources is limited or unavailable. However, there are threats to consider, such as competing technologies like solar panels or fuel-based generators, which may offer alternative options for portable power generation and reduce the demand for portable wind turbines. Regulatory and safety considerations may also arise, especially in urban or densely populated areas where specific regulations and safety requirements related to deploying wind turbines may apply.

In terms of design and engineering, thorough research and development should be conducted to design a compact and efficient wind turbine suitable for portability. Computer-aided design (CAD) software can be utilised to create detailed 3D models of the turbine components, allowing for simulations and analysis to optimise the design for aerodynamic efficiency, structural integrity, and power output (Jamieson, 2018).

After-sales service is important, which includes providing customer support such as technical assistance and troubleshooting guides to address any issues or queries related to the portable wind turbine. Establishing a system for warranty claims and repairs ensures prompt and reliable service to maintain customer satisfaction (Jamieson, 2018).

2.2. Manufacturing Process Proposal

To propose an appropriate manufacturing process for mass production, various factors need to be considered, including business/company needs, cost drivers, and scalability. Injection moulding could be a suitable manufacturing process for the portable wind turbine components, as it allows for the production of complex geometries with high repeatability and efficiency. This process is particularly suitable for high-volume production and offers cost advantages compared to 3D printing. However, certain components that require higher precision or have lower production volumes may be manufactured using CNC machining. Justification for the chosen manufacturing processes should consider factors such as initial investment costs, production cycle times, material selection, quality control, and scalability (Billinton, et al., 2003).

Component procurement involves identifying reliable suppliers for necessary components, such as lightweight metals or composite materials for the turbine blades, generator, and support structure. Electrical components like cables, connectors, controllers, and necessary bearings or gears should also be procured. Quality standards and specifications should be ensured when selecting materials and components. To ensure the turbine is designed and manufactured to a high-quality standard, quality function deployment (QFD) analysis can be conducted, as shown in figure 4. QFD follows a matrix which compares the customer requirements vs the function requirements to prioritise the importance.

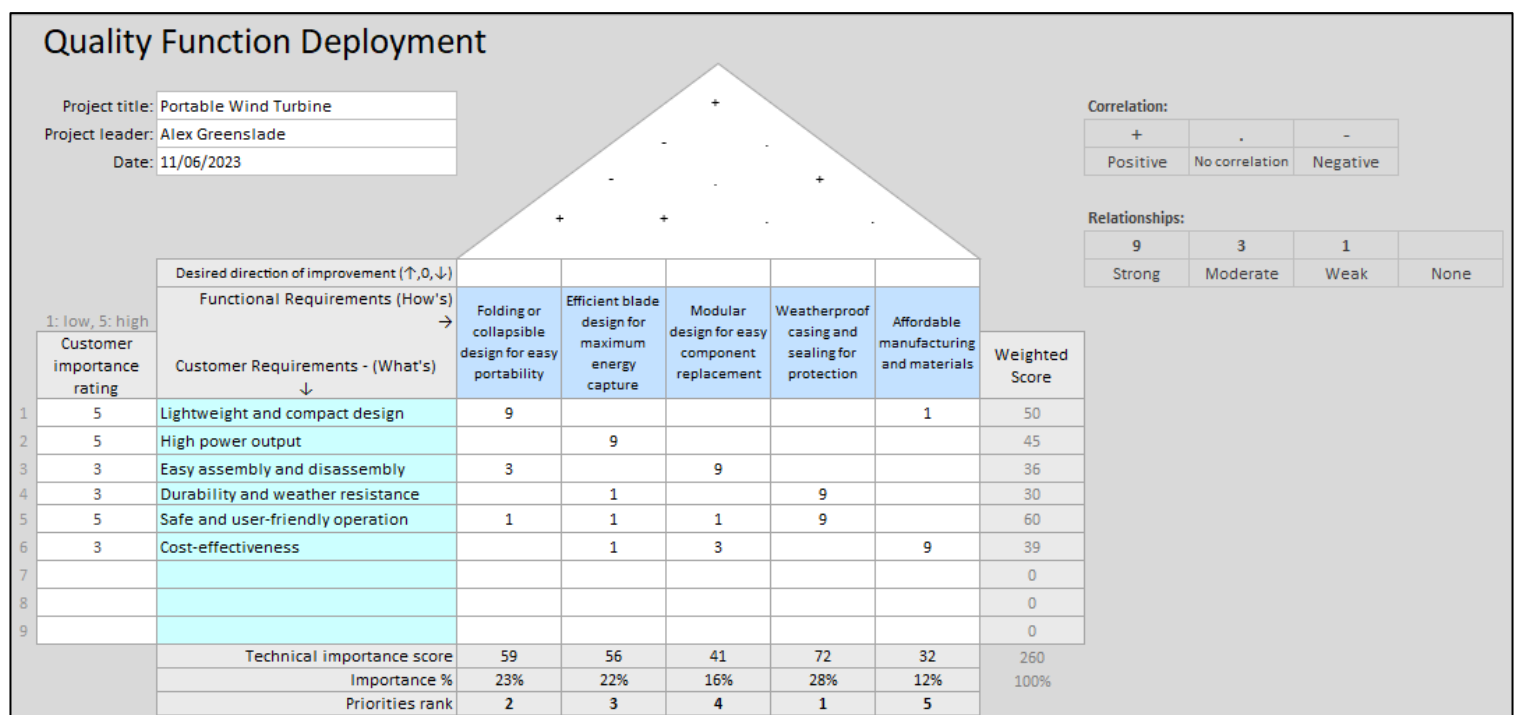


Figure 4 - QFD of Portable Wind Turbine

The blade manufacturing process would involve fabricating turbine blades using precision cutting techniques such as laser or water jet cutting, shaping, and profiling them according to the optimised design using specialised moulds or CNC machining. Quality control checks should be performed during the blade manufacturing process to ensure accuracy, balance, and structural integrity.

The hub, which connects the blades to the main shaft, can be fabricated using machining or casting techniques, depending on the material and design requirements. The support structure, which includes the tower or pole, should be manufactured using lightweight yet sturdy materials to ensure ease of assembly and disassembly. Quality control measures should be implemented to ensure proper fit, alignment, and structural strength of the hub and support structure.

For electrical system integration, the generator, controller, and other electrical components should be assembled into a compact and protective housing. The electrical system should be integrated with the turbine components, ensuring proper wiring, connection, and grounding. Thorough testing and quality assurance checks should be conducted to verify the functionality and safety of the electrical system.

Final assembly and testing involve assembling the turbine components, including the blades, hub, support structure, and electrical system, according to the design specifications. Comprehensive testing should be conducted to ensure proper functioning, stability, and power output of the wind turbine. Testing in various wind conditions is necessary to assess performance and make any necessary design or component adjustments.

Packaging and distribution require securely packaging the portable wind turbines to ensure safe transportation and protection from damage. Detailed user manuals and assembly instructions should be included to guide users through the setup and operation of the turbine. Distribution channels and logistics should be established to deliver the portable wind turbines to customers efficiently and cost-effectively.

2.3. Design and Development Work Undertaken

2.3.1. Design for Assembly (DFA)

Assembly analysis techniques, such as Design for Assembly (DFA), can be utilised to optimise the assembly process. DFA involves analysing the interaction of components, identifying potential assembly issues, and redesigning components for ease of assembly. This approach streamlines the manufacturing process and reduces production time and costs (Boothroyd & Knight, 1993). During this concept, this can be included in the manufacture of the blade and its housing. By making this one part instead of two, it allows for a smoother installation. For enhanced optimisation, a poke yoke design can be implemented to ensure the assembly is fitted correctly.

2.3.2. SCAMPER Technique

The SCAMPER (Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse) technique can be employed to stimulate creativity and generate innovative design solutions. SCAMPER encourages the exploration of different design possibilities, considering materials, geometries, and manufacturing processes that may improve performance or reduce costs (Serrat, 2017). It can be applied to optimise the design for X:

- **Substitute:** Consider substituting materials, components, or processes with more efficient or cost-effective alternatives. Instead of using conventional metals, composites can be used to be as strong while being lighter in weight.
- **Combine:** Explore opportunities to combine different features or functions to enhance overall performance or reduce complexity. Although creating bespoke parts can improve the performance of the turbine, it is important to consider costs. It is worth considering first principles to combine with new manufacturing techniques to find a happy medium to have a cost effect, while highly efficient product.
- **Adapt:** Think about how the design can be adapted or modified to work in different environments or meet specific user needs. As the turbine can be subjected to low wind environments, the utilisation of a small solar panel on the motor can help create wind energy, along with solar energy.
- **Modify:** Identify aspects of the design that can be modified or improved to enhance performance, efficiency, or user experience. The more parts within the systems, enhance the failure rate of the design. For example, by redesigning the blade to have an integrated housing as one part, reduces the failure rate by half as the number of components has reduced from two to one. This also allows for quicker servicing and maintenance. Secondly, although socket head cap screws offer multiple benefits, they can be tricky to remove, especially at a small size. Quick release pins would be preferred as they can still hold the components in place but be removed in a fraction of the time.
- **Put to another use:** Explore alternative applications or markets where the design can be repurposed or used in a different context. Not only can this concept be used for personal use, but it could also be used in emergency scenarios or in research and development practices.
- **Eliminate:** Identify unnecessary or redundant elements in the design that can be eliminated to simplify the product or reduce costs. Where possible, merge the design of components to reduce the bill of materials.
- **Reverse:** Consider reversing or flipping certain design elements to explore new possibilities or overcome existing limitations. Instead of using this traditional design, could a similar design to the cup anemometer be adopted.

2.3.3. Failure Modes and Effects Analysis (FMEA)

Risk management techniques, such as Failure Modes and Effects Analysis (FMEA), should be applied to identify and mitigate potential failure modes in the redesigned components. FMEA helps in assessing the impact of design and manufacturing decisions on product reliability, safety, and performance (Mikulak, et al., 2017).

FMEA is a systematic approach to identifying potential failure modes, their causes, and the effects they can have on the product. The following are steps on how to conduct an FMEA with an example shown in table 6. Here's how an FMEA can be constructed for the portable wind turbine:

- Identify potential failure modes: Consider all possible failure modes that can occur in the wind turbine design, such as blade damage, electrical system malfunction, or structural failure.
- Determine the causes: Analyse the root causes of each failure mode, considering factors such as material fatigue, inadequate maintenance, environmental conditions, or manufacturing defects.
- Assess the effects: Evaluate the impact and consequences of each failure mode on the overall performance, safety, and reliability of the wind turbine.
- Assign severity, occurrence, and detection rankings: Rate the severity of the effects, the likelihood of occurrence, and the ability to detect the failure mode during inspections or testing.
- Calculate the Risk Priority Number (RPN): Multiply the severity, occurrence, and detection rankings to determine the RPN for each failure mode.
- Mitigate risks: Prioritise the failure modes with the highest RPN values and develop appropriate mitigation measures, such as design changes, quality control processes, or maintenance procedures, to reduce the risk.

By conducting an FMEA, potential risks can be proactively identified, and design changes or processes can be implemented to mitigate those risks, improving the overall reliability and safety of the portable wind turbine. The ranking systems can be seen through tables 1 to 4.

		Alex Greenslade	DESIGN FAILURE MODE and EFFECTS ANALYSIS							Rev 1.
			Portable Wind Turbine							08.06.23
Seq	Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes Failure	Occurrence	Preventative Measures	Detection	R.P.N.	Recommended Actions
1	Generate Electricity	Failure of electrical generator	Power outage or inability to supply electricity to connected devices or systems	7	Generator malfunction or failure due to manufacturing defects, inadequate maintenance, or electrical component failure.	5	Voltage and current sensors to monitor the electrical output and detect abnormal fluctuations or deviations.	3	105	Conduct regular maintenance and inspections of the electrical generator to ensure proper functioning and identify any signs of wear or damage.
2	Rotational movement	Blade imbalance causing excessive vibration	Reduced or halted energy generation due to the turbine's inability to capture wind energy efficiently	6	Blade imbalance caused by manufacturing defects, damage, or improper installation.	4	Vibration sensors or accelerometers to measure and detect excessive vibrations indicating blade imbalance or bearing failure.	3	72	Perform regular balancing of turbine blades during manufacturing or maintenance to prevent blade imbalance.
3	Blade aerodynamics	Blade damage or deformation affecting aerodynamic performance	Decreased energy conversion efficiency resulting in lower power output	7	Blade damage or deformation caused by impacts, excessive loads, or exposure to harsh environmental conditions.	4	Regular visual inspections to identify any visible damage, deformation, or wear on the turbine blades.	4	112	Conduct routine visual inspections of the turbine blades to identify any damage, deformation, or signs of wear.
4	Shaft rotation	Misalignment of the shaft, resulting in friction or mechanical stress	Inefficient transfer of rotational energy to the generator, leading to decreased power output	8	Shaft misalignment caused by improper installation, excessive loads, or structural issues.	3	Shaft alignment checks and measurements during installation and regular maintenance to ensure proper alignment.	3	72	Ensure proper alignment during installation and conduct regular alignment checks during maintenance activities.

5	Voltage regulation	Voltage spikes or fluctuations leading to damage to connected devices	Damage to connected devices or systems due to voltage spikes or fluctuations	8	Voltage spikes or fluctuations caused by electrical grid instability, lightning strikes, or improper voltage regulation circuitry.	6	Voltage monitoring systems that continuously measure and analyse the turbine's output voltage for irregularities.	4	192	Implement voltage monitoring systems with alarms or automatic adjustment mechanisms to maintain stable voltage levels.
6	Environmental resistance	Structural damage due to high wind load or extreme weather conditions	Structural damage or collapse of the turbine due to extreme weather conditions	6	Structural damage caused by extreme weather conditions like strong winds, hail, or lightning strikes	4	Environmental sensors to monitor conditions such as wind speed, temperature, humidity, and precipitation.	4	96	Design turbine components with materials resistant to corrosion, moisture, and environmental degradation.
7	Portability	Fragile or weak components susceptible to damage during transportation	Difficulties in transportation and limited mobility due to fragile or damaged components	5	Fragile components prone to damage during transportation due to inadequate packaging or poor handling.	5	Visual inspections before and after transportation to check for physical damages or displacement of components.	3	75	Improve packaging and transportation methods to protect fragile components during transit.
8	Stability and safety	Tower or base instability leading to turbine tipping or falling over	Turbine tipping or falling over, causing property damage, injuries, or fatalities	8	Tower or base instability due to poor foundation design, improper installation, or inadequate structural integrity.	5	Wind speed sensors to monitor the wind conditions and activate safety mechanisms, such as automatic shut-off or braking systems, in case of high winds.	5	200	Conduct thorough engineering analysis and design calculations to ensure stability under various wind conditions.
9	Power output optimisation	Inefficient design leading to suboptimal energy conversion	Suboptimal energy conversion leading to reduced power generation and lower efficiency	5	Inefficient design resulting from inadequate aerodynamics, suboptimal blade geometry, or poor power electronics.	5	Real-time monitoring systems that measure and analyse the turbine's power output and compare it with expected values.	3	75	Continuously monitor and analyse turbine performance data to optimise power output in different wind conditions.
10	Maintenance and durability	Inaccessible or hard-to-reach components hindering maintenance and repairs	Difficulties in accessing and maintaining components, resulting in increased downtime and reduced productivity	4	Inaccessible components or poor maintenance access due to design limitations or lack of serviceability considerations.	4	Regular inspection schedules and checklists to identify any signs of wear, damage, or component degradation.	4	64	Establish a comprehensive maintenance program that includes regular inspections, cleaning, lubrication, and component replacement.

Table 6 - DFMEA of a Portable Wind Turbine

2.3.4. Considerations for Sustainability

Environmental and product life cycle factors should also be considered during the design and development work. This includes considering the recyclability of materials, energy consumption during manufacturing, and end-of-life disposal options. Designing for sustainability and optimising the product's life cycle can enhance the product's overall environmental performance (Tsai-C. Kuo, 2001). Along with recyclability, a new driver in the manufacturing industry is being carbon net zero. It is important to consider the supply chain to ensure the carbon emission are reduced as much as possible.

2.3.5. Further Techniques - Assembly Application Analysis

Assembly Application Analysis focuses on optimising the assembly process of a product. It can be applied to the portable wind turbine:

- Evaluate the current assembly process: Assess the existing assembly process to identify potential bottlenecks, inefficiencies, or sources of errors.
- Identify opportunities for improvement: Look for ways to streamline the assembly process, reduce the number of steps, or simplify component integration.
- Explore modular design: Consider designing the wind turbine components in a modular manner, allowing for easier assembly and disassembly.
- Enhance component compatibility: Ensure that the components are designed to fit together seamlessly, minimising the need for complex adjustments or modifications during assembly.
- Optimise fastening methods: Evaluate different fastening techniques, such as snap-fit connections or self-aligning mechanisms, to simplify the assembly process and improve reliability.
- Consider automation: Explore automation options for repetitive or labour-intensive assembly tasks to increase efficiency and reduce human error.

By applying Assembly Application Analysis, areas for improvement in the assembly process can be identified, and design adjustments can be made to optimise the ease and efficiency of assembly (Tsai-C. Kuo, 2001).

Conclusion

In conclusion, through design for additive manufacturing techniques, it is possible to increase the strength of an aircraft's bracket by 57% while reducing the mass by 70%.

The optimisation of design and manufacturing processes is paramount in realising the full potential of portable wind turbines as a viable and sustainable energy solution. By implementing techniques such as Design for Assembly (DFA), manufacturers can streamline the assembly process, reduce costs, and enhance overall productivity. The application of the SCAMPER technique encourages innovative thinking, leading to the exploration of alternative design elements and manufacturing methods that can improve performance and reduce expenses.

Risk management, through the utilisation of Failure Modes and Effects Analysis (FMEA), enables manufacturers to identify and mitigate potential failure modes, ensuring the production of reliable and safe portable wind turbines. By addressing potential risks early in the design phase, manufacturers can enhance product reliability and durability, instilling confidence in end-users.

Considering the environmental impact and product life cycle factors throughout the design and development process is crucial for creating sustainable portable wind turbines. By incorporating recyclable materials, minimising energy consumption during manufacturing, and exploring responsible end-of-life disposal options, manufacturers can reduce the overall environmental footprint of their products and contribute to a greener future.

The findings and methodologies discussed in this paper highlight the importance of design optimisation and efficient manufacturing processes for portable wind turbines. By implementing these strategies, manufacturers can improve the performance, reliability, and cost-effectiveness of these turbines, making them more accessible to a wider range of users and accelerating the transition towards renewable energy sources.

Overall, the exploration of techniques such as DFA, SCAMPER, FMEA, and sustainable design considerations provides manufacturers with a comprehensive framework to optimise their design and manufacturing processes for portable wind turbines. By embracing these methodologies, manufacturers can contribute to a more sustainable future, where portable wind turbines play a vital role in meeting the global demand for clean and renewable energy sources.

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