

## Strength-Based Design Assessment of an Additively Manufactured Pusher-Duct Support Bracket for a Novel UAV Prototype Applicable to Agricultural Use

### Tarımsal Uygulamalara Uygun Yeni Nesil Bir İHA Prototipi İçin Katmanlı İmalatla Üretilmiş İtici Kanal Destek Braketinin Dayanıma Dayalı Tasarım Analizi

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#### ABSTRACT

Unmanned Aerial Vehicles (UAVs) are increasingly deployed in defence, surveillance, and precision agriculture, requiring lightweight yet robust structural components capable of withstanding demanding operational conditions. Ensuring the strength and reliability of additively manufactured support brackets is critical for UAV integrity. The aim of this study is to investigate the structural response of a pusher duct support bracket, designed for integration into a next-generation UAV prototype, under critical loading conditions. The investigation focused on bracket deformation during the UAV's immediate take-off phase, considered one of the most severe mechanical scenarios. A CAD/CAE-based workflow was adopted, integrating numerical simulation techniques. A parametric solid model of the bracket was created, and Finite Element Analysis (FEA) using SolidWorks Simulation was employed to assess stress distribution and deformation. FEA revealed the maximum von Mises equivalent stress as 14.951 MPa at fastener locations, with peak deformation of 0.378 mm at the front tip. The minimum Factor of Safety (FoS) was 1.739 at the flange of the front fastener, while other regions exhibited considerably higher FoS values. These findings demonstrate that the bracket is structurally adequate for its intended application, although stress concentrations remain evident. While the additively manufactured bracket performs safely under critical loading, reinforcing fastener flanges and applying topological optimisation could improve stress distribution and achieve mass reduction without compromising structural integrity.

#### ÖZET

İnsansız hava araçları (İHA'lar), savunma, gözetleme ve hassas tarım gibi alanlarda giderek daha yaygın biçimde kullanılmaktadır. Bu araçların, zorlu işletme koşullarına dayanabilecek hafif ancak yüksek mukavemetli yapısal bileşenler kullanılarak tasarlanması gerekmektedir. Bunun için karbon fiber içerikli malzemelerin kullanıldığı katmanlı imalat (AM: Additive Manufacturing) yöntemiyle üretilen destek elemanları iyi bir alternatif olarak görülmektedir. Ancak bu tip elemanların dayanım ve güvenilirliğinin sağlanması, İHA sistem bütünlüğü açısından kritik öneme sahip olmaktadır. Bu çalışmanın amacı, yeni nesil bir İHA prototipine entegrasyon için tasarlanan bir itici kanal destek braketinin kritik yüklemeye koşulları altındaki yapısal davranışını incelemektir. Çalışma özellikle İHA'nın kalkış anında en şiddetli mekanik yüklemeye senaryolarından biri olarak değerlendirilen yüklenme durumunda ortaya çıkan brakete ait yapısal gerilme dağılımlarına ve deformasyona odaklanmaktadır. Çalışmada sayısal simülasyon tekniklerini içeren Bilgisayar Destekli Tasarım/Mühendislik (CAD/CAE: Computer-Aided Design/Engineering) tabanlı bir iş akışı benimsenmiştir. Braketin üç boyutlu parametrik katı modeli oluşturulmuş ve gerilme dağılımı ile deformasyon davranışını değerlendirmek amacıyla SolidWorks Simulation yazılımı kullanılarak Sonlu Elemanlar Analizi (FEA: Finite Element Analysis) gerçekleştirilmiştir. FEA sonuçları, bağlantı elemanları bölgelerinde en yüksek gerilme dağılımlarına ve deformasyona odaklanmaktadır. Çalışmada sayısal simülasyon tekniklerini içeren Bilgisayar Destekli Tasarım/Mühendislik (CAD/CAE: Computer-Aided Design/Engineering) tabanlı bir iş akışı benimsenmiştir. Braketin üç boyutlu parametrik katı modeli oluşturulmuş ve gerilme dağılımı ile deformasyon davranışını değerlendirmek amacıyla SolidWorks Simulation yazılımı kullanılarak Sonlu Elemanlar Analizi (FEA: Finite Element Analysis) gerçekleştirilmiştir. FEA sonuçları, bağlantı elemanları bölgelerinde en yüksek von Mises eşdeğer gerilmesinin 14.951 MPa olduğunu ve en yüksek deformasyonun braketin ön uç noktasında 0.378 mm olarak meydana geldiğini göstermiştir. En düşük Güvenlik Katsayısı (FoS: Factor of Safety) değeri ön bağlantı flanşında 1.739 olarak hesaplanmıştır; diğer bölgelerde ise belirgin biçimde daha yüksek FoS değerleri gözlemlenmiştir. Tüm nihai değerlendirmeler neticesinde, katmanlı imalat yöntemiyle üretilen braketin kritik yüklemeye koşulları altında güvenli bir performans sergilediği, bununla birlikte, bağlantı flanşlarının güçlendirilmesi ve topolojik optimizasyon yöntemlerinin uygulanmasıyla, yapısal bütünlükten ödün vermeden gerilme dağılımının iyileştirilmesi ve kütlenin azaltılması mümkün görünmektedir.

## **1. INTRODUCTION**

Unmanned aerial vehicles (UAV), colloquially referred to as drones, have experienced remarkable advancements in design, functionality, and operational scope over the past two decades (Ariante & Del Core, 2025). These advancements have been driven largely by breakthroughs in aerodynamics, materials science, electronics, and software, culminating in UAV platforms that are lighter, more efficient, and capable of executing increasingly complex tasks. Initially developed primarily for military reconnaissance and surveillance, UAVs have rapidly proliferated across a broad array of civil, healthcare, scientific, and commercial domains. Among these, agricultural applications have emerged as particularly transformative, wherein UAVs are employed for precision farming, crop monitoring, aerial spraying, and soil analysis—facilitating data-driven, sustainable agricultural practices (Mogili & Deepak, 2018; Tsouros et al., 2019). Beyond agriculture, UAVs play indispensable roles in border surveillance, environmental monitoring, infrastructure inspection, and disaster response. Their ability to access remote or hazardous regions without endangering human operators makes them ideal for missions in conflict zones, post-disaster assessments, and wildlife tracking (Colomina & Molina, 2014; Erdelj et al., 2017). In defence and national security, UAVs have transitioned from simple observational tools to platforms capable of strategic and tactical operations, incorporating advanced payloads and autonomous functionalities. The evolution of UAV autonomy reshapes military operational strategies, enabling rapid response and minimising human risk in high-threat environments. Moreover, ethical considerations surrounding autonomous engagement in combat scenarios are gaining attention, necessitating discussions on accountability and operational protocols (Barros et al., 2024; Jordan, 2021; Joshi, 2018). The expanding scope of UAV applications has, in turn, intensified the demand for structurally robust, lightweight, and aerodynamically optimised components that ensure operational safety under diverse and often severe loading scenarios (Czyż et al., 2021; Mubina Shekh et al., 2025).

Recent advances in precision agriculture increasingly rely on lightweight UAV platforms capable of carrying multispectral sensors, variable-rate spraying modules, and real-time data acquisition systems while operating under repeated take-off and landing cycles in field environments. UAV structural subsystems therefore experience combined inertial, vibrational, and fatigue-inducing loads that differ markedly from generic civil or surveillance missions. Empirical evidence confirms that airframe stiffness and mount integrity directly influence flight stability, spray deposition uniformity, and georeferencing accuracy in agricultural operations (Gutierrez-Rivera et al., 2024; Mogili & Deepak, 2018; Tsouros et al., 2019). Accordingly, strength-based design of propulsion support structures is a prerequisite for reliable agricultural UAV deployment.

Central to the successful deployment of any UAV platform is the strength and reliability of its structural subsystems. These subsystems—including fuselage frames, wing spars, motor mounts, and support brackets—must be meticulously designed to withstand a multitude of mechanical loads experienced during various phases of flight such as take-off, cruising, and landing (Anderson, 2010; Raymer, 2018). Of these components, support brackets, although relatively modest in size and complexity, are structurally significant as they serve as critical load-transfer elements connecting propulsion systems, payload mounts, and control surfaces to the main airframe. Any failure or suboptimal performance of such components may compromise the UAV's structural integrity and operational reliability.

Given this context, strength-based design assessment assumes a pivotal role in the overall UAV design process. This approach involves quantifying stress and deformation responses under specified loading conditions to assess whether a component meets the requisite safety margins, typically defined by the Factor of Safety (FoS) and material yield or ultimate strengths (Nisbett & Budynas, 2020). Finite Element Analysis (FEA), a numerical technique for solving complex structural problems, is routinely employed to simulate and evaluate the mechanical performance of UAV components under operational loads (Bi, 2018; Moaveni, 2007). FEA enables detailed visualisation and quantification of stress distributions, strain localisations, and deformation patterns—allowing designers to predict potential failure regions and iteratively refine the component geometry to optimise performance and weight.

In light of increasingly stringent performance, endurance, and payload requirements, contemporary UAV design philosophies prioritise mass efficiency alongside structural integrity. Reducing the weight of structural elements without compromising their strength is critical, as it directly translates to improved endurance, manoeuvrability, and payload capacity (Austin, 2010; Bejan & Zane, 2012). Techniques such as topology optimisation, material substitution, and load-path alignment are routinely applied to realise lightweight, high-performance designs. This trend is particularly relevant to components such as the pusher duct support bracket, which must endure dynamic and potentially peak loading conditions—especially during take-off phases where propulsion thrust and vibration-induced loads are at their maximum.

In the ongoing pursuit of weight reduction and manufacturing efficiency in unmanned aerial vehicle (UAV) design, additively manufactured support brackets have emerged as a compelling solution. Utilising additive manufacturing technologies, these components offer notable benefits such as enhanced material efficiency, substantial design freedom, and accelerated prototyping—attributes particularly valuable in producing lightweight, structurally demanding parts with complex geometries. One of the key advantages of additive manufacturing lies in its ability to integrate topology-optimised lattice structures directly into bracket designs, thereby improving stiffness-to-weight ratios while simultaneously minimising mass—an essential consideration in aerospace applications (Samal et al., 2022). Research has affirmed the mechanical reliability of these brackets under variable dynamic loads, with porous or functionally graded architectures enabling tailored stress distribution and improved load management (Klippstein et al., 2018). Furthermore, the layer-wise fabrication approach of additive manufacturing eliminates the need for traditional tooling, allowing seamless transition from digital CAD models to physical parts. This capability supports the development of UAV-specific configurations that maximise internal volume usage and aerodynamic performance (Al-Haddad et al., 2024). As UAV platforms evolve toward greater autonomy and increased payload flexibility, the strategic importance of additively manufactured brackets is poised to grow, offering not only structural efficiency but also streamlined production workflows and rapid design iteration—crucial advantages in the fast-paced aerospace sector (Najmon et al., 2019).

Recent advancements in UAV structural design have emphasised strength-based analysis of critical support components (Mishra et al., 2020). Studies employing FEA and fluid-structure interaction (FSI) simulations have demonstrated the efficacy of advanced materials, such as epoxy-carbon composites and hybrid aluminium alloys, in optimising fuselage and rotor designs for enhanced stiffness and fatigue resistance (Raja et al., 2023). Furthermore, the integration of parameterised finite element method (FEM) tools in the early design phase of lightweight civil UAVs allowed designers to dynamically reshape internal structures, achieving optimised configurations that passed safety factor requirements with due

consideration to international design standards (Giannakis & Savaidis, 2016). Research on composite UAV wings highlights the role of ply orientation and material anisotropy in stress distribution, offering guidelines for optimising load-bearing structures in agricultural and surveillance applications (Kierzkowski et al., 2025).

Kanesan et al. (2014) validated an FEA model of a composite UAV wing by comparing simulated deflections under aerodynamic loads with experimental data, achieving discrepancies as low as 0.3% at the wingtip (Kanesan et al., 2014). Xing et al. (2012) conducted a lightweight design and analysis of a UAV engine support structure using MSC-Patran and MSC-Nastran software, performing static strength and modal analyses to ensure structural integrity (Xing et al., 2012). Gutierrez-Rivera et al. (2024) designed and analysed a hexacopter frame for precision agriculture applications, utilising FEA to assess critical structural components and conducting experimental tests to validate mechanical responses (Gutierrez-Rivera et al., 2024). Xv et al. (2023) investigated the aerodynamic characteristics of ducted UAVs, analysing the effects of structural parameter changes on performance and providing guidance for future UAV designs (Xv et al., 2023). These studies collectively underscore the critical role of strength-based design analysis in developing UAV support structures that are both lightweight and capable of withstanding operational stresses.

This study contributes to the evolving discourse on UAV structural optimisation by focusing on the strength-based design assessment of an additively manufactured pusher duct support bracket tailored for a next-generation UAV prototype. The bracket in question supports the propulsion duct in a pusher-type UAV configuration, where the propulsion unit is located at the rear of the fuselage, pushing the UAV forward. This configuration offers aerodynamic advantages, particularly in terms of reducing interference drag with payloads or sensors typically mounted at the nose (Babinsky, 2003). However, it also introduces structural challenges due to the complex loading at the rear fuselage section. To this end, the present research employs a CAD/CAE-integrated methodology involving parametric solid modelling and FEA via SolidWorks Simulation code. The analysis simulates the peak load scenario encountered during take-off—an event often associated with high vibrational and inertial loads. The output metrics include equivalent stress (von Mises), total deformation, and the factor of safety, all of which inform the bracket's ability to safely support the duct assembly during high-stress flight conditions. Accordingly, the present study does not seek to provide application-specific agricultural performance metrics; rather, it presents a strength-based engineering design assessment of a structural component belonging to a UAV platform that is adaptable to agricultural and logistics operations. The findings aim to guide design enhancements, particularly in stress distribution and potential mass reduction through topology optimisation, thereby contributing to the broader goal of realising structurally sound yet lightweight UAV components.

## **2. MATERIALS AND METHODS**

### **2.1. Pusher Duct Support Bracket for a New-Design UAV prototype**

The bracket examined in this study was developed specifically for a novel UAV prototype named JUPITER, conceived and constructed by the Soton UAV team at the University of Southampton. This multidisciplinary team—comprising academic staff, postgraduate researchers, and undergraduate students—focuses on the research-driven design, manufacture, and operation of UAVs. The bracket is part of a registered design and integral to the JUPITER platform, which is currently undergoing a patent application process. As a result, comprehensive technical specifications and full visual representations

are withheld from publication at this stage. Designed within the CAA’s A2 Open Category for UAVs under 25 kg, JUPITER’s standout feature is its distributed propulsion architecture, comprising fifteen independently controlled motors that provide thrust redundancy and enhance platform resilience. The system is further augmented by a bespoke health monitoring framework for the powertrain, contributing to its operational safety and reliability. The aircraft’s aerodynamic configuration is optimised for gust tolerance, aided by a sleek, low-drag profile and multiple redundant control surfaces that maintain stability in adverse weather conditions. Safety considerations have been central to the design philosophy, evident in the fully enclosed propellers and user-friendly loading interface. Furthermore, JUPITER is compatible with National Health Service (NHS) in England-standard Small Versapak containers, facilitating seamless medical integration. The platform is also designed with scalability in mind, with a 100 kg variant currently under development, capable of transporting a 15 kg payload over distances up to 100 km (McLeod et al., 2024; Theobald et al., 2023; Zhu et al., 2023). Beyond healthcare logistics, the JUPITER platform shows promising adaptability for different applications such as agricultural practices, underscoring its versatility and forward-looking design philosophy. Meticulous engineering of pusher duct support brackets is crucial to achieving an optimal balance between structural integrity and aerodynamic performance in UAV systems. In this context, the pusher duct support bracket has been specifically designed to securely accommodate both the pusher duct and the stern thruster assembly, while also contributing positively to the overall aerodynamic profile of the aircraft during flight. The design process prioritised compatibility with the aerodynamic flow field to minimise drag and ensure structural resilience under operational loads. Selected visual and dimensional features of the bracket are illustrated in Figure 1 to provide a clearer understanding of its form and functional integration.

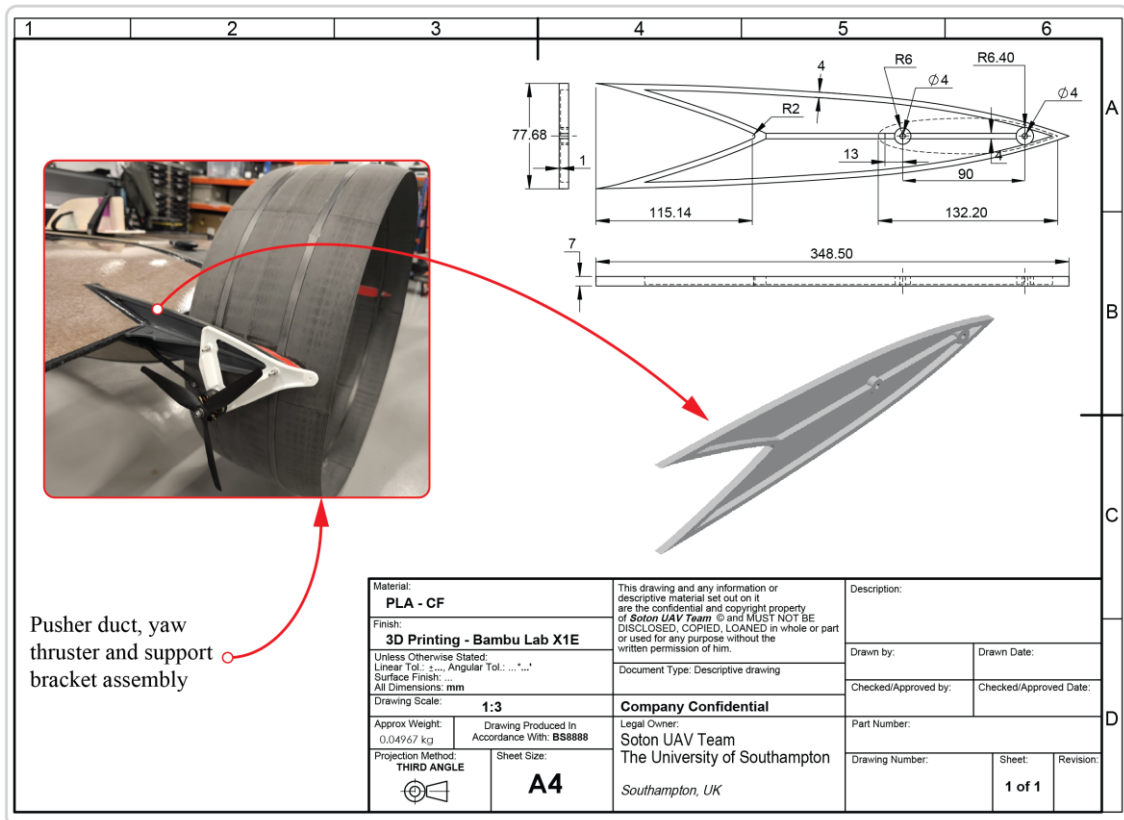


Figure 1. Dimensional details of the bracket.

## 2.2. Application Algorithm

In this study, a dedicated application algorithm was developed to conduct a strength-based design assessment of an additively manufactured specific component. The design analysis was subsequently carried out in accordance with the procedural steps outlined in this algorithm. The application flowchart is presented in Figure 2.

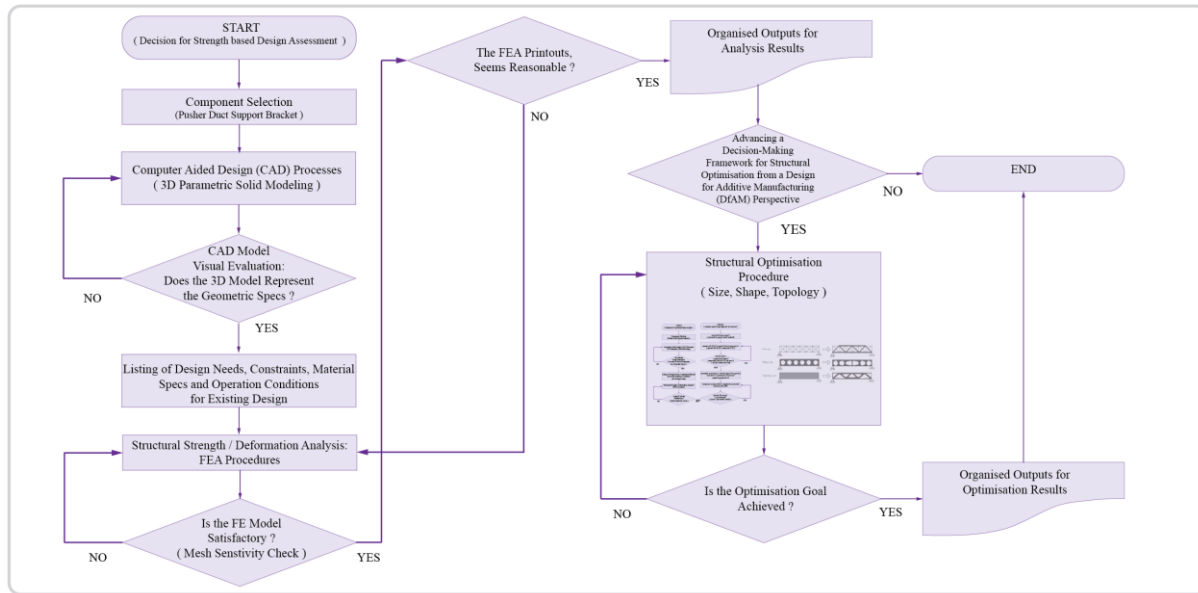


Figure 2. Application algorithm

## 2.3. Material Properties of the Bracket

The support components of the JUPITER prototype were manufactured using additive manufacturing technology with the Bambu Lab XE1 printer. The component, fabricated using a carbon fibre-reinforced polylactic acid (PLA-CF) composite through fused filament fabrication (FFF), developed by Bambu Lab, is a custom-engineered composite that incorporates carbon fibres into a toughened PLA matrix. The addition of carbon fibres enhances the material's hardness and flexural modulus while maintaining the ease of fabrication and dimensional stability characteristic of standard PLA. The fabricated components exhibit a matte surface finish with minimal visible layer lines, rendering them particularly suitable for prototyping applications where a high-quality, non-glossy aesthetic is desired (Bambu Lab, 2025). During the fabrication process, a filament with a diameter of 1.75 mm was used in conjunction with a 0.4 mm nozzle. The layer height was set to 0.25 mm, and the printing temperature was maintained at 220 °C. A consistent printing speed of 50 mm/s was applied throughout the procedure. The component was printed with 100% infill and fully solid perimeters to ensure maximum structural integrity and material continuity. In the FEA, the bracket material was represented as a homogeneous, isotropic, and linearly elastic solid, in accordance with standard modelling assumptions for engineering-grade materials. The mechanical properties employed in the simulation—such as modulus of elasticity, Poisson's ratio, density and yield strength—are detailed in Table 1. These parameters were selected to accurately reflect the expected behaviour of the material under operational loading conditions and to ensure the validity of the numerical results.

**Table 1.** Material properties assigned in the FEA

<b>Material Properties*</b>		
Modulus of Elasticity	(MPa)	2790
Poisson's Ratio	( - )	0.394
Yield Strength	(MPa)	29
Ultimate Tensile Strength	(MPa)	38
Density	(kg m <sup>-3</sup> )	1220

\* FEA definition - Homogenous isotropic linear elastic material model

#### 2.4. Loading Scenario and Boundary Conditions

The loading scenario for the bracket was defined based on the maximum structural loading condition of the JUPITER platform, which, for the purposes of this study, was assumed to occur during take-off. Under this scenario, the yaw thruster exerts a maximum thrust force of 30.9 N directed towards the pusher duct. The total mass of the pusher duct and associated components, which is fully vertically supported by the side brackets, is 0.650 kg. A maximum design flight load factor of +6.5g was applied to account for vertical forces acting on the duct mountings during flight, while aerodynamic forces were deliberately neglected. This simplification is justified on the basis that aerodynamic effects on the pusher duct are presumed to be less significant than those induced by the maximum landing load factor and, in fact, would serve to partially offset the peak flight load. The bracket-wing joint was modelled as fixed, and gravitational acceleration was incorporated into the analysis using a standard value of 9.81 m s<sup>-2</sup>. To simulate the actual structural behaviour as closely as possible, the connections between the bracket and both the duct and wing were modelled as elastic supports in the FEA. In establishing these supports, both normal and tangential stiffness values were calculated based on the elastic modulus and shear modulus of the support materials, along with the respective joint element’s thicknesses. The relevant formulations are presented in Equations (1) and (2) (Popov et al., 2019; Takabatake, 2019). Description of the loading scenario and boundary conditions is illustrated in Figure 3.

$$\text{Normal stiffness : } k_{n_i} = \frac{E_i A_i}{t_i} \tag{1}$$

$$\text{Tangential stiffness : } k_{t_i} = \frac{G_i A_i}{t_i} \tag{2}$$

Where;  $k$ : Stiffness (n: normal, t: tangential) (N mm<sup>-1</sup>),  $E$ : Modulus of elasticity (MPa),  $G$ : Shear Modulus (MPa)  $A$ : Joint contact area (mm<sup>2</sup>),  $t$ : Joint thickness (mm).

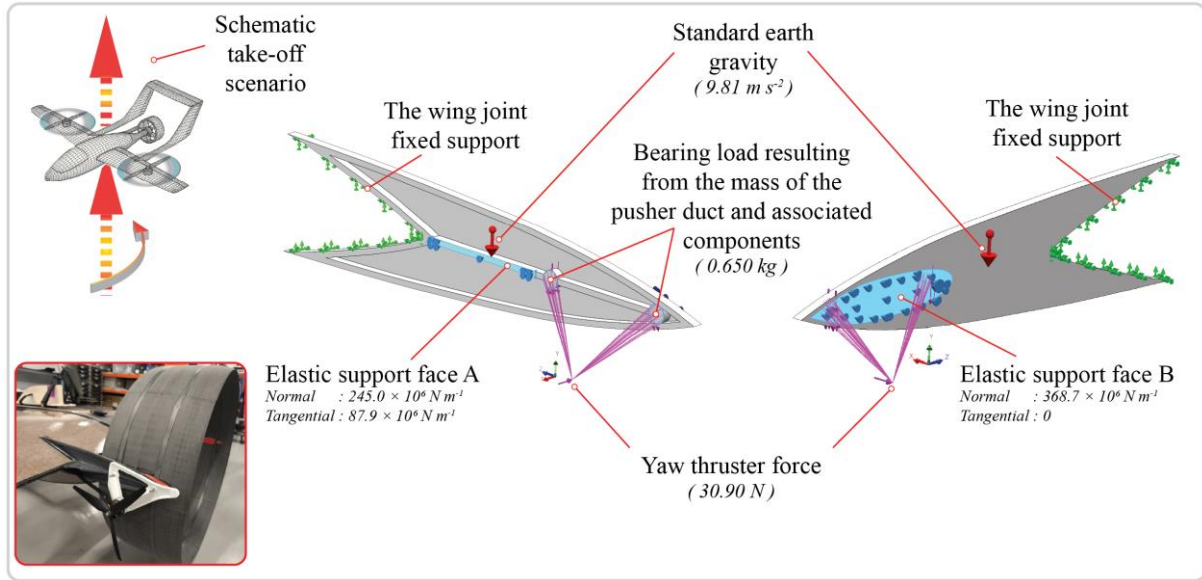


Figure 3. Description of the loading scenario and boundary conditions

## 2.5. FE Modelling (Mesh Structure) and Verification

The Finite Element (FE) Model (mesh structure) was constructed using the meshing functions of the FEA code. A mesh sensitivity study was conducted to determine the optimal element size for achieving accurate deformation results without incurring excessive computational cost. The analysis involved progressively refining the mesh, with element sizes ranging from 6 mm to 0.5 mm, corresponding to total element counts from 4,896 to 2,709,241. As shown in Figure 4, the resultant deformation increased with mesh refinement and gradually approached a stable value. Significant changes were observed with coarser meshes, particularly between 4,896 and 55,676 elements. However, beyond approximately 351,113 elements (element size: 1 mm), the deformation value plateaued at approximately 0.378 mm, indicating that the solution had converged. Further refinement to 0.5 mm (2,709,241 elements) did not yield any appreciable difference in the results. This confirms that an element size of 1 mm provides a reliable balance between accuracy and computational efficiency for this FE model.

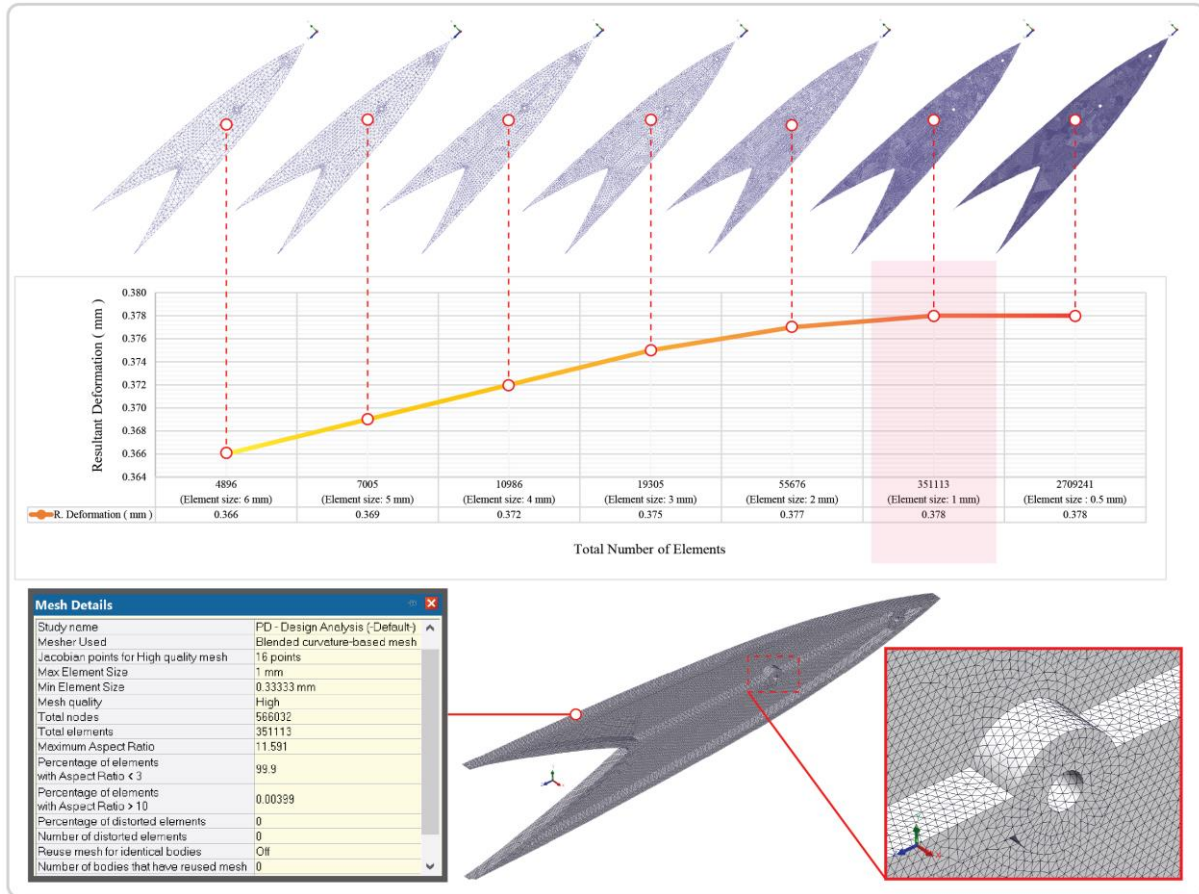


Figure 4. Mesh sensitivity analysis and FE model of the bracket

### 3. RESULTS AND DISCUSSION

The FEA conducted on the Pusher Duct Support Bracket demonstrated a characteristic structural response under peak loading conditions, representative of the UAV's stimulated take-off phase. This phase is generally acknowledged as the most mechanically strenuous stage of operation, primarily due to the simultaneous influence of thrust-generated forces, gravitational loads, and inertial effects acting on the structure. The combined action of these loads creates a critical stress state that provides valuable insight into the component's performance under extreme operational conditions. The detailed FEA results illustrating this response are presented in Figure 5.

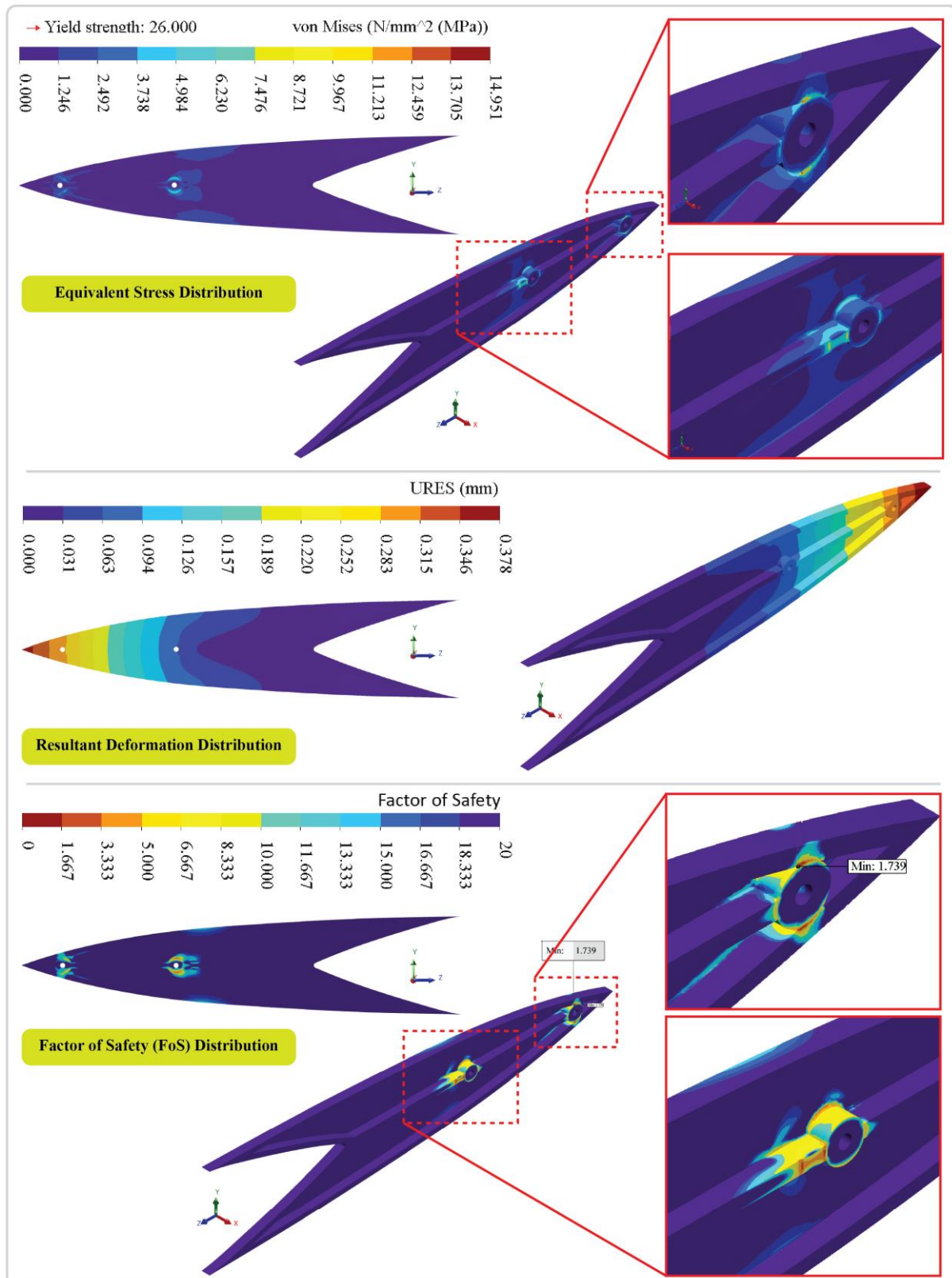


Figure 5. FEA outputs

The von Mises equivalent stress distribution demonstrated a maximum value of 14.951 MPa, predominantly localised around the front fastener interface. Given that the yield strength of PLA-CF is 26 MPa, this stress level utilises approximately 57.5% of the allowable limit, suggesting an acceptable stress margin for structural reliability. This outcome aligns with the findings of Xing et al. (2012), who identified that UAV engine mounts and support elements frequently exhibit localised high stresses at fastener or anchor points, underscoring these regions as natural loci for fatigue initiation or structural degradation (Xing et al., 2012). The current study corroborates these observations by reinforcing the notion that fastening regions, while compact in geometry, bear disproportionate mechanical demand and must be prioritised during structural validation.

A maximum resultant displacement of 0.378 mm was observed at the tip of the bracket's free end. While numerically modest, this deflection carries functional implications for components that interact with propulsion subsystems, such as pusher ducts. Excessive deflection in such components could impair thrust alignment or induce aerodynamic inefficiencies. This highlights the need for displacement control as a design objective—not merely to prevent failure but to maintain the performance characteristics of the UAV system. Al-Haddad et al. (2024) reinforced this concern by showing that minor structural deformations in quadcopter frames could yield disproportionate effects on aerial stability and vibrational harmonics (Al-Haddad et al., 2024). Given the structural role of the bracket within the propulsion mount subsystem, maintaining its positional fidelity is critical not only for static support but also for dynamic thrust vector control. Future studies could investigate modal behaviour and vibration modes of the bracket under variable flight conditions.

The minimum factor of safety (FoS) was 1.739, located again at the critical front flange. This value, while above the minimum required threshold (typically 1.5–2.0 for polymer-based UAV components), indicates that this region is the structural bottleneck under peak loading. The remainder of the bracket exhibited significantly higher FoS values, with large zones bearing minimal or no load. This points to a structurally conservative design—adequate from a safety perspective but not optimised in terms of mass efficiency. Aribowo et al. (2023), observed similar design inefficiencies in UAV fuselage structures prior to applying topology optimisation, achieving considerable material savings while maintaining safety thresholds (Aribowo et al., 2023). In light of this, the present bracket could benefit from a topological refinement process to redistribute material towards the critical regions (i.e., fastener interfaces) while reducing mass in structurally redundant areas.

The bracket's manufacture via FFF using PLA-CF is emblematic of a growing trend in UAV structural development—leveraging the capabilities of additive manufacturing for rapid prototyping and low-volume production. While PLA-CF provides improved stiffness and heat resistance over standard PLA, its mechanical performance remains below that of aerospace-grade composites or aluminium alloys. Nevertheless, DfAM offers substantial design freedoms. Egan (2023), highlighted that structural elements designed from first principles with additive constraints in mind can outperform their traditionally designed counterparts in both strength-to-weight ratio and manufacturability (Egan, 2023). The current bracket, though dimensionally sound, does not yet exploit these freedoms. For instance, internal lattice infills or functionally graded geometries could be introduced within the low-stress interior volumes identified in the FEA, thereby reducing mass without compromising strength. Such design practices are well documented in additive manufacturing literature and are especially relevant in UAV applications where each gram saved directly impacts endurance and range. Additionally, advanced slicing algorithms now enable path-aware infill and layer-wise reinforcement, allowing

material to be deposited preferentially along principal stress directions. These computational strategies, when paired with structural simulation feedback loops, pave the way for smart manufacturing of mechanically aware components—a paradigm well suited to the current use case.

At the FEA set up assumptions, the current study employed a linear elastic isotropic material model for PLA-CF, which while sufficient for initial validation, may under-predict true stress states in service—especially if temperature or fatigue effects become non-negligible. Future investigations might incorporate anisotropic modelling or experimental characterisation to improve fidelity, particularly given the directional reinforcement imparted by embedded carbon fibres in the PLA matrix.

A detailed examination of the stress and deformation fields reveals extensive regions of structural underutilisation, suggesting considerable scope for mass reduction via topology optimisation. This approach is particularly relevant for UAV applications where the total take-off weight is a design-limiting parameter. Studies such as Ye et al. (2025), have shown how topology-optimised UAV brackets and arms can achieve up to 40% weight savings while preserving stiffness and modal integrity, using fibre-reinforced additive manufacturing (Ye et al., 2025). In this context, topology optimisation may be employed subsequent to the FEA to refine the internal geometry of the bracket in alignment with principal stress trajectories, thereby yielding a structurally ‘intelligent’ component. Moreover, integrating the optimisation process with the material’s inherent anisotropy—such as the fibre orientation in PLA-CF—can further enhance directional stiffness in load-critical regions. This approach is becoming increasingly viable with the advent of advanced multi-axis additive manufacturing technologies. It is important to recognise, however, that the mechanical performance of the bracket must also be evaluated in light of its aerodynamic environment, particularly in UAV configurations where structural components protrude into the propeller slipstream. Although the present FEA study does not incorporate aerodynamic loading, future investigations should adopt fluid–structure interaction (FSI) models. This will ensure that the optimised geometries do not inadvertently compromise aerodynamic efficiency through increased drag or induce undesirable flow instabilities.

#### **4. CONCLUSION**

This study presented a specific strength-based design assessment of a additively manufactured pusher duct support bracket developed for a new-generation UAV prototype, integrating CAD modelling, FEA, and material characterisation of PLA-CF composite for additive manufacturing. The simulation results confirmed that the bracket can safely endure the peak loading scenario of UAV take-off, with a maximum von Mises stress of 14.951 MPa and a minimum FoS of 1.739—indicating that the structural configuration meets baseline integrity requirements. Nonetheless, critical insights were derived regarding the localisation of stress near fastener regions and the non-uniform material usage across the bracket's geometry. These observations point to potential for structural optimisation, especially through topology optimisation techniques that redistribute material toward high-stress zones while reducing bulk in underutilised regions. Given the increasing role of additive manufacturing in UAV component design, this study highlights the untapped potential of DfAM principles—such as internal lattice structures, anisotropic material orientation, and load-aligned geometry refinement. The findings also underscore the importance of not only meeting mechanical strength thresholds but also ensuring deformation control, which is vital for maintaining propulsion alignment and aerodynamic performance. While the linear elastic isotropic model sufficed for initial evaluations, future studies should integrate

anisotropic and fatigue-aware simulations to reflect the real-world behaviour of carbon-reinforced polymers.

From an agricultural engineering perspective, the validated structural performance of the pusher duct support bracket is directly relevant to UAV platforms employed in crop monitoring, precision spraying, and soil variability mapping, where propulsion stability is critical for trajectory accuracy and uniform field coverage. Structural failure or excessive deformation in such components has been shown to degrade spray pattern consistency and sensor geolocation precision in precision farming systems. The present findings therefore support the transferability of this bracket design framework to agricultural UAV architectures requiring lightweight, robust, and repeatable structural performance under cyclic field operations.

This research provides a case studied workflow that UAV designers and engineers can adapt for the iterative refinement of structurally critical components. By merging FEA-based digital validation with additive manufacturing constraints and advanced optimisation routines, future UAV systems can achieve improved efficiency, reliability, and mission readiness, especially where component mass and mechanical robustness are both mission-critical.

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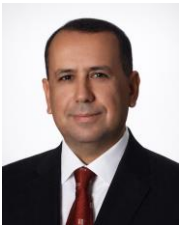


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