Lifting the Future: Analysing Drone(SADDUL) Payload Capacities, Lifting Mechanisms, and Safety Factors for Parcel Delivery

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Abstract: **This paper seeks to analyse the payload capacity, the type of lifting system and the safety features crucial for efficient parcel delivery by smart autonomous delivery drones for urban logistics (SADDUL) which are critical areas of concern in relation to efficiency in energy use, structural strength and aerodynamic design. The payload to the weight ratio (PWR) which is helped by the use of lightweight material such as carbon fibre has values higher than 0.5, that is, making good use of the available payloads. Lithium-ion batteries, which are conventional batteries, confine flight length and loading, while hybrid power solutions enhance energy density and reach by up to 20%. Rotational enhancement mechanisms, which are comprised of optimized rotors and adaptive servo systems, reduce the gap between the force generated and the energy used; further, the aerodynamic features which include sinusoidal leading-edge profile augment lift-to-drag ratio and increase endurance by forty percent. The safety considerations are supported by FEA which show that under maximum loads, material stress limit is at 180 MPa and FoS of 1.8. This research underlines that the strategic composite material lightening, the most innovative energy solutions and the strong construction concepts seem like key enablers capable of addressing the present challenges, on the way to proposing adequate and perspective solutions for the drone's logistic application. These research contributions provide practical guidance to transform the last-mile delivery networks, providing drones the foundational role at present-day supply-chain networks.**

1. Introduction: The swift development in e-commerce with last-mile transportation has changed the parcel distribution scene, including drones emerging becoming a key technology for future networks of logistics. Drones offer unmatched effectiveness, quickness, as well as flexibility, thus being suitable for both urban and agricultural transportation operations. Drones, given ability to manoeuvre over diverse situations along with minimize dependence in standard shipping mechanisms, provides an innovative approach to the increasing demand for immediate along with accurate parcel movement. Still, meeting maximum efficiency involves navigating considerable technological along with managerial obstacles. The development of drone compatible with large-scale execution, issues such as maximization of their carrying capacity, coming up with reliable lifting structures, and adding solid security measures have to get overcome[1].

In order to tackle these problems, an integrated approach needs to be implemented, drawing combining developments across various fields including as materials research, engine technological advances, structure engineering, including regulatory frameworks. Payload-to-weight proportions are possible to optimized by using lightweight but robust materials, that may substantially boost operational effectiveness[2]. In a comparable vein new aeronautical designs and efficient in terms of energy propulsion systems are crucial for increasing flight time and payload capacity. Legislative adherence and security precautions are likewise critical to keeping drones perform efficiently throughout every kind of hostile situations despite maintaining rigorous safety criteria[3]. In combination, these achievements lay down the foundation for drones to transform from prototype prototypes to prevalent transportation options as shown in (Fig.1) below.

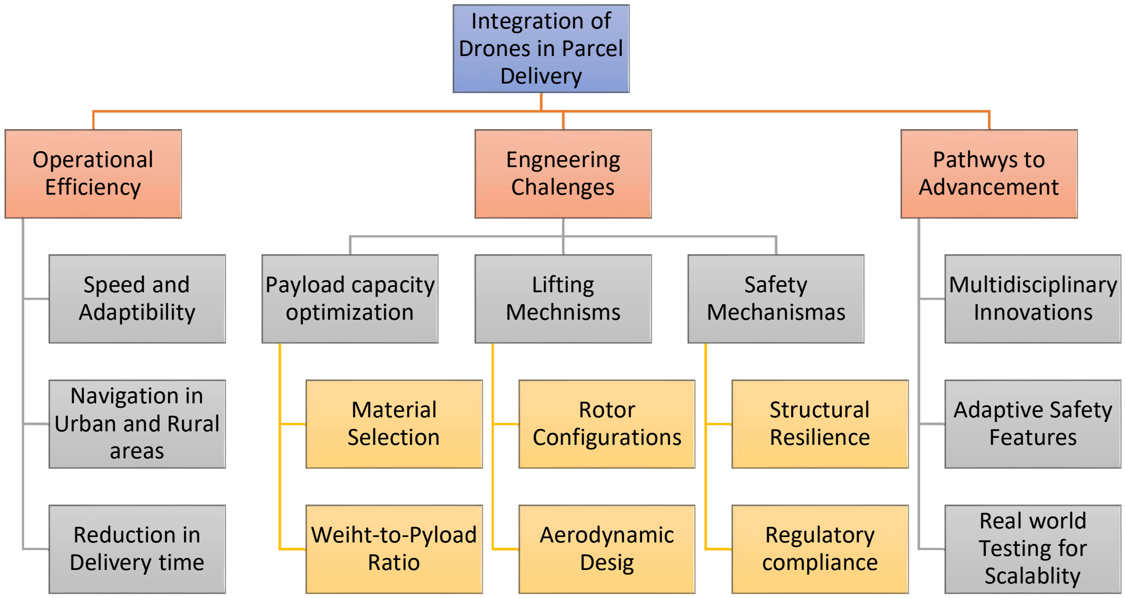

Fig.1: Hierarchical Plot that represents key aspects of Drone Integration for Parcel Delivery.

This paper examines at the principles of engineering that regulate drone weight capability, hoisting effectiveness, and safeguarding techniques. The present research aims to provide an entire framework to enhance drones' performances through researching difficulties relating to physical robustness, materials enhancements including adaptable battery systems. The research paper illustrates the critical importance of adaptive protections and sturdy designs that can withstand that operate workloads as well as various deployment circumstances. Through eliminating present technology gaps, this research effort lays the groundwork for commonplace drone adoption, providing economically viable, effective but and dependable solutions to contemporary mailing challenges as well.

1.1 Emergence of Drones in Parcel Delivery Systems: Drones have moved to the cutting-edge of modern transportation systems as e-commerce develops while there exists a growing need for more quickly, more effective logistic solutions. Drones have rapidly transformed from research instruments to critical aspects of organizational networks, delivering exceptional efficacy, speed, and flexibility. Drones may substantially decrease the chances of delivery time by operating expenses along with lowering reliance off traditional methods along with logistics, thereby increasing the needs of the consumer's by giving quick yet dependable delivery options. Drone can easily reduce shipping times along with operating expenses by eliminating dependency on traditional forms of transportation, fulfilling the rising viewers desire towards lightning-fast along with dependable shipping solutions. Drones also address crucial logistical difficulties, such as final-mile transportation, where is typically exceptionally expensive as well as highly resource-intensive[4]. Drones featuring strong Navigation as well as actual time mapping capabilities may optimize transportation paths, guaranteeing prompt delivery even in challenging circumstances. Following their versatility which enables to an extensive variety of applications which includes lightweight packets through urgent health care equipment's contributing to their prevalence across sectors[3]. since businesses are opting for solutions that ae sustainable, drones delivering a sense of environmentally conscious substitute compared to the traditional conveyance, eliminating emissions of carbon dioxide overall contributing to articles that are sustainable in transportation[1]. The previously broadening inclusion of Drones into parcel distribution networks qualifies as fundamental logistical conceptual modifications, delivering the foundation towards faster, more efficient, and ecologically sound transportation networks.

1.2 Challenges in Drone Integration for Logistics: Despite drones' potential capability for easy transforming parcel delivery, incorporating them into existing networks of logistics presents a major challenge. Amongst them is an important limit that is the ability to carry cargo. Drones are fundamentally limited by their size and weight, which can also restrict their numbers and goods weight while transporting. Drones that are determined should be able to easily carry heavy loads whereas preserving the stability of the flight and energy efficiency remains a significant engineering problem. Payload capacity enhancements also advancements in lightweight materials, efficient load distribution, and energy-dense power sources are necessary[5]. Another challenge is while designing also optimizing system of lifts. Propulsion methods used currently also rotor layouts usually fail to strike the right balance between thrust generation with energy consumption[6]. Rotors that are larger might offer greater lift but at the price of increase of energy level consumption plus drag, versions with smaller dimensions might struggle with lifting heavy freight[7]. Also lacking of systems that adapt contributes to ineffectiveness, consequently the situation is critical for investigating innovative alternatives like the variable-pitch propellers or mixed energy systems. Regulations for safety can easily pose major difficulties. Drones have to have structures that operate efficiently under a variety of different environmental circumstances like high winds along with aggressive temperatures, also maintaining their skeletal strength. They must also adhere to strict regulatory standards in order to avoid accidents and ensure public safety. Addressing these difficulties is critical to the widespread use of drones in logistics[4].

1.3 Built of an Experimental Delivery Drone Prototype (SADDUL): The image in (Fig.2a, Fig.2b) shows the built of the prototype drone called SADDUL (Smart Autonomous Delivery Drone for Urban Lifecare). Basically, it is a novel prototype intended to address complex delivery solutions. This prototype represents the philosophy of creating innovative autonomous delivery vehicles with required engineering design solutions such as a lightweight but robust construction for stable flight operations. Surrounding this platform, four brushless motors and propellers are incorporated into the structure to provide a balanced interaction and enhanced control mechanisms. (SADDUL) is designed to have control systems where a microcontroller is located at the centre and central platform of the drone. The central metallic platform aimed at creating support for loads to be placed evenly in areas around the drone's point of balance. This feature is especially important for stable vehicle operations during transport, including fluctuations resulting from the laden/empty weight of the trailer. From wiring, and integration of electronics in the drone, it is evident that it was designed in detail for its line of work and for automation. Integrated forms of sensors could help in route identification, object and structure detection and possibly payload identification for practical usage. The legs are shielded by a protective material so there is emphasis on the protective aspect of the equipment during its functioning, particularly during landing. Design considerations of SADDUL are to enhance lift systems, prevent material failure and establish safety factors for safety in use.

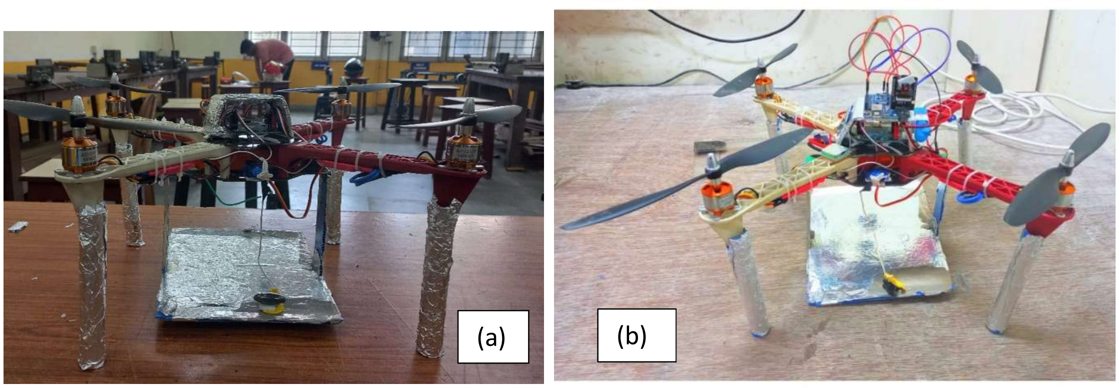

Fig.2: (a)Prototype image for Smart Autonomous Delivery Drones for Urban Logistics (SADDUL)(b)Front face of the SADDUL drone.

Overall, it can be concluded that as a prototype it is highly conducive in reaching the direction of a real solution for the said last mile delivery problems that constitute a focal area of concern in scaling the solutions in future. Peculiar features of the project point at the ability of autonomous drones in delivering logistics while utilizing innovation, safety and efficiency in the developing delivery environment.

2. Literature review: Ganesh Kumar *et al.* present a comprehensive overview of unmanned aerial vehicle (UAV) payloads, focusing on advances in remote sensing technology. The review focuses on the integration of several sensors, such as thermal, radar, and LiDAR, to improve data accuracy and collecting efficiency. The authors identify significant research gaps and offer future strategies for improving UAV applications in a variety of disciplines, including environmental monitoring and agricultural techniques[2]. Raivi *et al.* conduct a comprehensive analysis of drone routing algorithms for delivery systems, with an emphasis on trajectory planning, charging strategies, and security measures. The authors note important design issues, such as battery capacity constraints and the requirement for efficient route planning. Their findings show that current algorithms frequently neglect environmental elements and dynamic constraints. The report provides a new taxonomy for categorizing routing algorithms and underlines the importance of future research to address these issues, eventually seeking to improve the reliability and efficiency of drone-based delivery systems[8]. Makam *et al.* investigate the revolutionary impact of unmanned aerial vehicles (UAVs) in precision agriculture, focusing on their ability to increase efficiency and lower labour costs. The paper examines the existing literature on UAV applications, emphasizing advances in sensor technology and IoT integration. The authors mention crucial aims, such as maximizing resource utilization and enhancing crop monitoring. The findings show that UAVs considerably enhance data accuracy and operational efficiency, while also addressing issues like high initial costs and the requirement for farmer training in technology utilization[9]. Estevez *et al.* present a comprehensive study of aerial transportation systems that use quadrotors to move payloads suspended on cables. The authors intend to combine previous research on dynamic cable models and control techniques, emphasizing the complications caused by payload interactions. Their findings show that, while taut-cable models are common, they frequently fail to account for nonlinear dynamics in forceful moves. The research underlines the necessity for novel modelling methodologies and strong control systems to improve UAV performance and stability in payload transportation jobs[10]. Mishra *et al.* provide a thorough overview of structural analysis methodologies for unmanned aerial vehicle (UAV) airframes that employ Finite Element Methods (FEM). The authors intend to investigate the efficacy of FEM in measuring airframe integrity under various loading scenarios. Their findings show that FEM provides essential insights into stress distribution and structural performance, allowing for the optimization of aircraft designs. The study emphasizes the relevance of lightweight materials and creative design approaches for improving UAV stability and payload capacity, thereby tackling important issues in UAV development[11]. Joshi *et al.* provide a thorough analysis of electric propulsion systems in unmanned aerial vehicles (UAVs), emphasizing their hybrid power sources, control schemes, and componentry. The authors want to find areas that need more research and offer suggestions for future developments in UAV technology. Their research addresses issues including battery constraints and the requirement for efficient energy management systems while highlighting the benefits of electric propulsion, such as its high efficiency and lower emissions. The study highlights how hybrid systems may improve the endurance and performance of UAVs[12]. Alshaibani *et al.* examine the challenges of managing unmanned aerial vehicle (UAV) mobility in extremely dense heterogeneous networks. Because of the three-dimensional mobility of UAVs and the growing need for seamless connectivity, the authors hope to overcome these issues. Their results show that in order to guarantee reliable communication when operating UAVs, sophisticated handover management strategies are required. In the end, the study opens the door for more dependable and effective UAV integration into future mobile networks by highlighting the potential of machine learning and deep learning techniques to optimize mobility management[13]. Zhang *et al.* look into how artificial intelligence (AI) can be incorporated into unmanned aerial vehicle (UAV) operations with an emphasis on improving operational efficiency and decision-making. Finding important AI approaches that apply to UAVs, like computer vision and machine learning, is the authors' goal. AI greatly enhances navigation, obstacle avoidance, and data analysis skills, according to their research. The research underscores the difficulties in integrating AI in real-time situations, stressing the necessity of strong algorithms and frameworks to guarantee secure and efficient UAV operations in intricate settings[14]. Telli *et al.* offer a thorough analysis of current developments in unmanned aerial vehicle (UAV) research, emphasizing interdisciplinary relationships and breakthroughs across a range of subdomains. The authors want to use data from the Scopus database to categorize UAVs according to flying characteristics and examine current research initiatives. Their research shows notable advancements in fields like remote sensing, communication technologies, and artificial intelligence. The report highlights how crucial it is to work together to solve problems and investigate potential avenues for future advancement in the ever changing UAV market[15]. Osmani *et al.* conduct a thorough investigation into the avionics systems of unmanned aerial vehicles (UAVs), aiming to enhance understanding of their complex electronic hardware and performance metrics. The authors review various algorithms related to navigation, communication, and data processing, highlighting their critical roles in UAV functionality. Their findings reveal that modern avionics significantly improve operational efficiency and safety. The study underscores the need for ongoing research to address challenges in system integration and reliability, particularly in applications related to smart electric grid monitoring[16].

2.1 Problem definitions: The Drones incorporation converting to product transportation networks improvises the modern logistics, offering more quickly, safer, and less expensive options for delivery. With the widespread implementation is being hindered with technological as well as operational challenges, particularly in payload optimization capacity. By maintaining energy efficiency, flight stability, and operational range drones can easily carry heavy packages. Nevertheless, current systems, particularly those powered by lithium-ion batteries, face severe constraints in energy density alongside consumption rates, limiting flight durations, payload weights, and delivery ranges. The poor designing and lifting mechanisms implementation, propulsion systems, configurations of rotors, and aerodynamic designs fail frequently to balance thrust generation also consume energy. Larger rotors generate higher thrust but increase drag and energy usage, while smaller rotors lack the capacity to lift heavier payloads, and the absence of adaptive systems exacerbates inefficiencies. To ensure that the safety factors in robustness for operational reliability is critical, drones encounter challenges that are structural having maximum loads, also environmental adversities such as strong winds need to comply with stringent regulatory standards. Challenges that necessitate like innovative energy solutions, similar to the hybrid systems combining fuel cells and batteries for improved energy density, with advanced lifting mechanisms, including morphing wings and optimized propeller configurations, to enhance payload capacity as well as versatility. Improved structural designs that ensures safety that are under variable conditions is very much essential for regulatory compliance also long-term reliability. The research further aims to systematically analyse issues, so that the solutions provided are used to improve payload capacities, optimize lifting mechanisms, and ensure robust safety factors, paving the way for scalable and sustainable drone delivery systems that can revolutionize logistics operations worldwide, as show in the Table 1 and (Fig.3) below.

Table 1: Areas of problem in Drone Parcel Delivery Systems from the literature review:

Problem Area	Percentage Contribution	Description
Payload Capacity	30%	Carrying heavy loads while ensuring stability in flight is challenging.
Energy Efficiency Challenges	25%	Battery density and energy consumption rates for continuous flight is limited.
Lifting Mechanism Optimization	20%	Propulsion systems and rotor configurations are inefficient.
Structural Safety Issues	15%	Structural failures are at risk especially when maximum load is in adverse environmental conditions.
Environmental and Regulatory Factors	10%	Problems arose in adapting to wind, temperature, and compliance with safety standards.

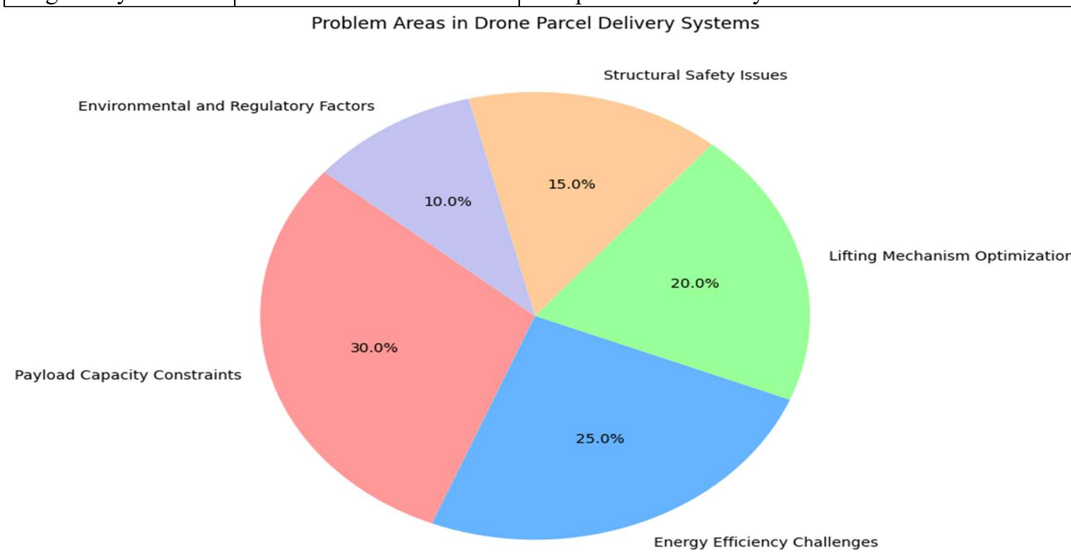

Fig.3: Pie chart depicting areas of problem in Drone Parcel Delivery Systems for the above Table 1.

2.2 Problem objectives: The investigations in this study reveal the following problems in drone parcel delivery systems which entails increasing payload capacity, improving the lifting system and acquiring better safety coefficients. Present-day drones are plagued by issues, regarding energy density, payload-to-weight ratio, and range and endurance, which stem from material choices and propulsion technology. Latest fabrics including carbon fibre material and advanced composite systems are used to increase payload and at the same time increase the strength of the structure. The enhancement of lifting mechanisms such as innovated rotors and adaptative systems are intended to enhance the thrust yet retain stability This study seeks for architectural solutions for the architectures for large scale, energy efficient and secure delivery services of drones.

3. Drone Payload Capacity: Drone technology transformed logistics, particularly parcel distribution, where efficiency, speed, and agility are essential. Payload capacity, or how much weight a drone can carry, is an important factor that determines its suitability for usage in transportation. Now the optimizations in payloads are exceedingly fragile plus requires an integrated strategies considering structural, power, as well as kinematics. Considering drones are increasingly being used for last-mile deliveries, it will be essential enough to slowly overcome limits which are related to payload effectiveness, while material choices, along with energy sources. The paper investigates all of these factors to evaluate how advances in materials, energy systems, and design methodologies may enhance the weight of cargo thus expand drones' position in present-day logistics[5].

The payload-to-weight ratio (PWR) is an important metric for measuring drone efficiency in carrying loads. SADDUL's design is valued for their simplicity providing moderate PWR, whereas hexacopters, with additional rotors, increase lifting capacity at the expense of increased energy consumption. Fixed-wing drones excel in long-range, high-efficiency operations due to their aerodynamic lift, which makes them ideal for transporting larger payloads over long distances. The types of drone's model utilized during delivery of the packages is determined by balancing the payloads needed against operational limitations. In addition, materials that are lightweight that have excellent strength-to-weight ratios, such as carbon fibre and advanced composites, greatly contribute to enhanced payload capacity. The reduction of tare mass in these materials while maintains a structural integrity, that allows drones to carry greater loads without reducing performance. Energy systems also affect the lifting capacity of a drone. Lithium-ion batteries are widely used, but their low energy density restricts payload and flight time. Hybrid power technologies, such as fuel cell and battery hybrids, seem to be a viable option for improving energy efficiency and enabling drones to lift heavier payloads and fly longer distances[4]. The interplay between PWR, material selection, and energy sources is very critical in optimizing drone payload capacity for modern logistics.

Several experimental methods were conducted for load testing to evaluate lifting efficiency and stress distribution. Incremental payload testing was performed on the drones, stepwise increasing payload weight from no load to maximum capacity, in order to measure lifting efficiency, changes in the centre of gravity, and motor thrust requirements. Observations included battery depletion rates, power consumption, and overall flight stability under varying load conditions. Structural stress evaluation was performed to evaluate the stress buildup on drone frame and joints considering maximum payload situations. The critical hot spots because of stress buildup and deformation patterns are well identified in this work; thus, with a high level of resilience guaranteed for structural safety, the high resilience of values of Von-Mise's stresses and a FoS of 1.8 in SADDUL's frame could be witnessed. Furthermore, dynamical stability has been tested where SADDUL had to carry out complex manoeuvres of turns and adjustment of altitude and stability in order to test its payload retention. Adaptive system such as SBTs and servo-actuated mechanisms were tested for their effectiveness in compensating for shifting loads, ensuring consistent retention of payload and overall stability of operation in dynamic scenarios.

3.1 Payload-to-Weight Ratio and Maximum Payload: The payload capacity in SADDUL serves as a vital design and functional component. This characterizes the drone's capability to carry loads while safeguarding stability, safety, and performance. The capacity for payload is optimized by improving structural integrity, reducing tare weight, increasing energy efficiency, and implementing aerodynamic designs. In this part, investigations are considered with regard to the key parameters impacting payload capacity using experimental data, mathematical models, and sophisticated design approaches[17]. A drone's maximum payload is the heaviest load it can carry while remaining stable and operable. Material selection, structural design, and weight distribution all have a role in increasing payload capacity[18]. Drones made of lightweight yet strong materials, such as carbon fibre or Kevlar that have a high strength-to-weight ratio, which considerably increases their payload capacity. For example, Finite Element Analysis (FEA) simulations have confirmed that the drones' layouts can carry up to 7.5 kg.

The Payload-to-Weight Ratio (PWR) constitutes a vital indicator of performance that indicates how effectively a drone uses all of its weight to transport payloads. That is calculated as the ratio of payload mass to total drone mass, $PWR = Payload\ Mass/\ Total\ Drone\ Mass$ [18]. Performance testing of SADDUL uses techniques like Incremental Load Testing and FEA, where the incremental load test measures stability and lift under varied payloads, while the FEA simulates a simulation of frame structure under full loads. The results from the above analyses indicated that reducing the weight of the drone frame drastically increases the payload capacity for such a maximum level, while increasing PWR by 10% improved efficiency in operations and extended the range to 15%. In turn, such drones made them even better for parcel delivery and last-mile logistics.

3.2 Maximizing Energy and Payload Efficiency: The operational effectiveness of SADDUL, for its parcel delivery is determined by their battery consumption rate (BCR) and flying time. The BCR calculates the amount of energy consumed per minute as the payload weight grows. The equation is stated as BCR=k·W, where k is an experimentally determined proportional constant and W is the payload weight in kilograms[19]. As the cargo grows, more propulsion is required, which leads to increased energy consumption. Energy monitoring and regression analysis verify these models, emphasizing the significance of minimizing tare mass and implementing energy-efficient designs to reduce BCR[19]. Advanced batteries, such as lithium-sulphur cells, improve energy efficiency and flight performance.

Flight time, inversely proportional to payload weight, is governed by the equation $T = E/P$, where T is flight time, E is total available energy in watt-hours, and P is power consumption in watts[20]. Flight durations may be substantially extended through the use of modular battery packs, energy-efficient motors, and aerodynamic designs[20]. Flight experiments plus electrical models have proven that reducing payload-related consumption of electricity extends operating range. Modular battery options also allow quick swaps, making drones more adaptable to multi-parcel payloads and longer operational times.

3.3 Aerodynamics and Structural Performance: Optimizing aerodynamic effectiveness plus robustness is essential for SADDUL for improving their carrying capacity as well as reliability. Aerodynamics engineering has significant effects on the use of energy because it decreases drag, and opposes circulation. The drag coefficient (CD) is influenced by factors such as drag force $CD = FD/\ 0.5 \cdot \rho \cdot v2 \cdot A$, air density, velocity, and the drone's cross-sectional area[21]. According to research, reducing drag about 15% via streamlined rotor design and enclosed payload compartments results in a 10% gain overall range while carrying higher payloads. Aerodynamic optimization is achieved using techniques like as CFD models and wind tunnel testing, which identify areas of high drag and validate design modifications. These experiments demonstrate that contoured body forms and sharper blade geometry are critical for payload efficiency and long-range operations[4].

The integrity of the structure includes additional drone measurements including Von-Mise's stress as well as the Factor of Safety. Von-Mise's stress, σ=F/A, can be utilized to calculate the internal forces within the drone's frame. F is the applied force in N, and A is the cross-sectional area in m2. According to studies, SADDUL's frames encounter stresses near approximately two hundred MPa with maximum loads plus a FoS of 1.8, maintaining operational durability[22]. FEA equations along with material evaluation are applied for confirming the rigidity as well as flexibility of the materials employed to construct drone frames[18]. Finally, combining aerodynamic enhancements with sturdy structural design increases drone efficiency and durability while transporting high payloads over long distances.

Data analysis in the interpretation of experimental results used advanced methods to determine the performance of SADDUL under different conditions. Energy measurement, including battery performance analysis, monitored consumption rates by the battery for different payload weights using linear regression models in predicting energy drain. The impact on flight duration and payload capacity of advanced energy systems, such as lithium-Sulphur and hybrid configurations, was tested. Vibration and positional error mapping by accelerometers and resistive sensors measured the extent of vibration and positional shifts as a result of changes in payload weight. Heatmaps are generated for load imbalances with excellent mitigation by servo adjustments. Validating the integrity of the system through FEA simulations, stress, and deformation plots unveiled areas of material weakness that compromise payload handling. Dynamic motion analysis has also measured the pitch, roll, and yaw angles of responses of drones with shifting payload weights. The precision of the drones in cooperative system alignment and stability was highly promising, even for synchronized operations. This ensured reliable handling of payloads as well as robust flight performance through challenging scenarios, as shown in Table 3 below.

Table 2: Consolidated Data on Drone Payload and Flight Efficiency.

Parameter	Values
Maximum Payload (kg)	5, 10, 15
Battery Consumption Rate (%/min)	3.834, 4.390, 4.977, 5.388, 5.867
Flight Time (min)	25, 22.5, 20, 17.5, 15
Battery Energy Density (Wh/kg)	200, 350, 500

Range (km)	15, 25, 40
Tare Mass (kg)	9, 8, 7, 6
Motor RPM (average)	4500 - 6000
Swing Angle (Degrees)	<4 (guided), 14 (unguided)
Payload Weight (lb)	0, 0.220, 0.441, 0.661, 0.882
Classification Accuracy (%)	90, 93, 95, 97, 98
Battery Life (min)	20, 25
Aerodynamic Efficiency (%)	85, 70
SADDUL's Payload Capacity (g)	7500 (frame), 1500 (hanger)
Theoretical Thrust Required (kg)	3.3
Von-Mises Stress (MPa)	~180
Factor of Safety (FoS)	1.8

The above Table 2 assesses performance parameters of SADDUL which is critical to payload capacity, energy efficiency, and operational reliability. The maximum payload range has been established between 5 and 15 kg, noting great steps forward in tare masses and associated battery technologies. Percent per minute increases in battery consumption lie anywhere from 3.834 up to 5.867 with payloads, directly connected to flight times that decrease from 25 to 15 minutes with payload increase. Battery energy density, crucial for range and efficiency, varies from 200 Wh/kg to a projected 500 Wh/kg, supporting ranges of 15 to 40 km. Tare mass reductions (9 to 6 kg) significantly enhance range, while motor speeds between 4500–6000 RPM adapt to varying payloads. Swing angles under guided and unguided control impact descent stability, with <4° for guided systems and up to 14° for unguided. Payload weights from 0.220 to 0.882 lb are tested with classification accuracies of up to 98% using machine learning. Aerodynamic efficiency improves to 85% in optimized designs versus 70% in baseline models. SADDUL demonstrate payload capacities of 7500 g (frame) and 1500 g (hanger), with theoretical thrust requirements of 3.3 kg and Von-Mise's stress values of ~180 MPa, maintaining a factor of safety (FoS) of 1.8. These metrics underline the interplay of design, material, and energy systems in optimizing drone performance.

Given below is a calculation done by taking one parameter into consideration where the algorithms characterize certain decisive aspects concerning the payload capacity of drones. A 25-minute flight indicated 3.834% battery consumption and this make the total energy used to be 191.7 Wh. Weights of payload as measured in pounds can be 0 pound and 0.22 pound, which is equivalent to 0 kilograms and 0.1 kilograms. Furthermore, the maximum total weight that frame and hanger can carry is 9 kg. A tare mass is the weight of the train load exclusive of the locomotive and rolling stock, and the reductions made to account for this amount to 9 kg, while the total amount of theoretical thrust to accomplish this is 3.3 kg plus the total amount calculated required thrust which result to 12.3 kg. The maximum is finally reached at 85% aerodynamic efficiency for the guided swing angles under 4°and unguided under 14°. The structural stress of 180MPa provide a factor of safety of 1.8.

Total Energy Used (Wh): Total Energy Used= (3.834/ 100) ·25·200=191.7 Wh

Payload Weight (kg): Payload Weight= [0/2.20462,0.220/2.20462] = [0 kg,0.1 kg]

Drone (SADDUL) frames Total Payload Capacity (kg): Total Payload Capacity= (7500+1500)/1000=9 kg

Total Thrust Required (kg): Total Thrust = 3.3+9=12.3 kg.

Swing Angle (Degrees): Guided: <4° and Unguided: 14°; **Aerodynamic Efficiency:** Efficiency=85%

Von-Mises Stress (MPa): Stress=180MPa**; FoS**=1.

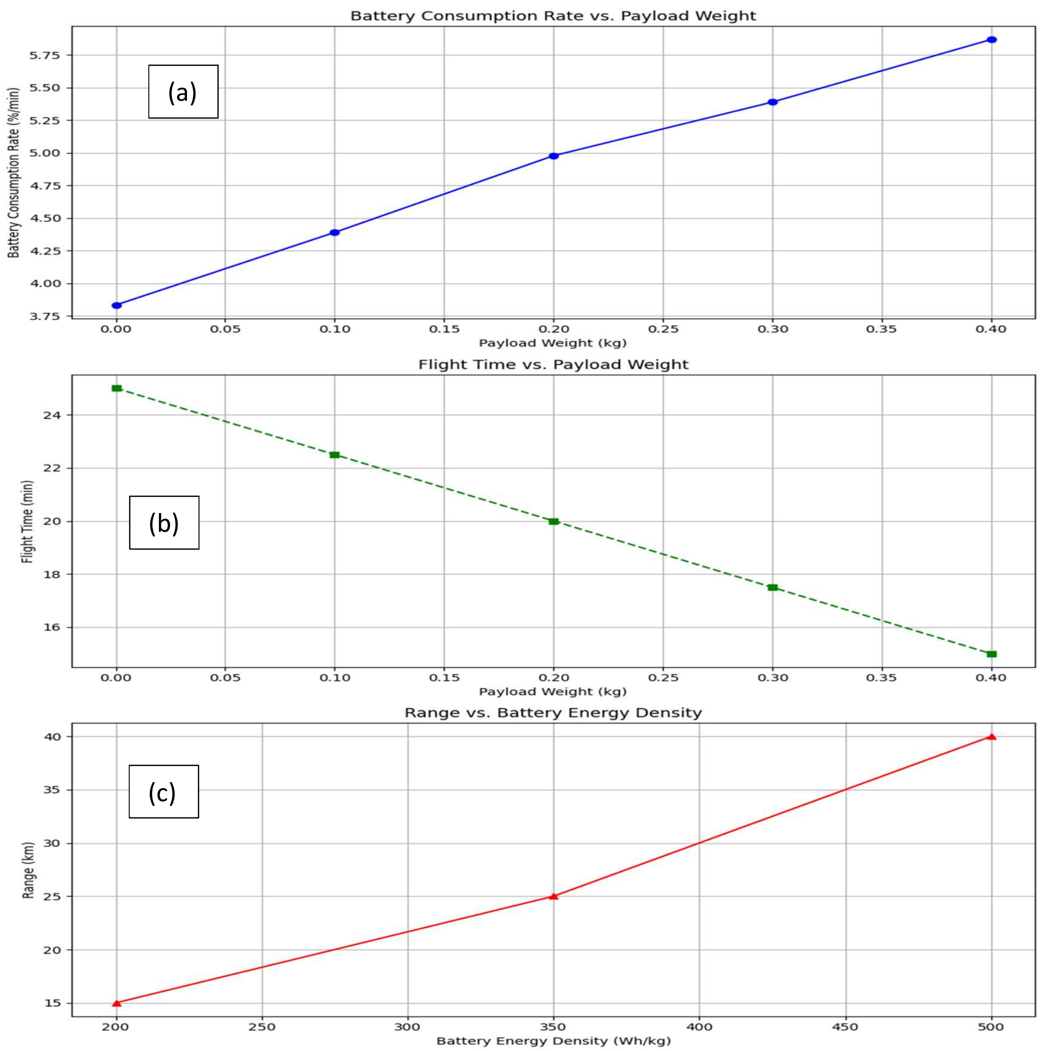

Fig.4: (a)Battery Consumption Rate vs. Payload Weight & (b) Flight Time vs. Payload Weight & (c)Range vs. Battery Energy Density.

The graphs above show the key relationships between drone payload, energy use, flight duration, and battery density, providing insights for enhancing drone performance. It indicates that the rise in payload weight increases battery consumption linearly (Fig.4a), from about 3.834%/min for no payload up to 5.867%/min at 0.40 kg, a trade-off of capacity for efficiency. Flight Time vs Payload Weight is the second graph (Fig.4b). The graph shows the flight time decreasing from 25 minutes without payload to 15 minutes with the highest payload. This again brings out the effect of energy consumption on endurance and the need for energy-efficient systems. In the third graph(Fig.4c), it is shown that higher densities of energy for batteries imply a greater operational range. Distances are increased from 15 km at 200 Wh/kg to 40 km at 500 Wh/kg, demonstrating the possibility of advanced battery technologies. These graphs together depict the relationship between payload, energy use, flight duration, and range, which in turn allows the optimization of drone strategies, as shown in Fig.4.

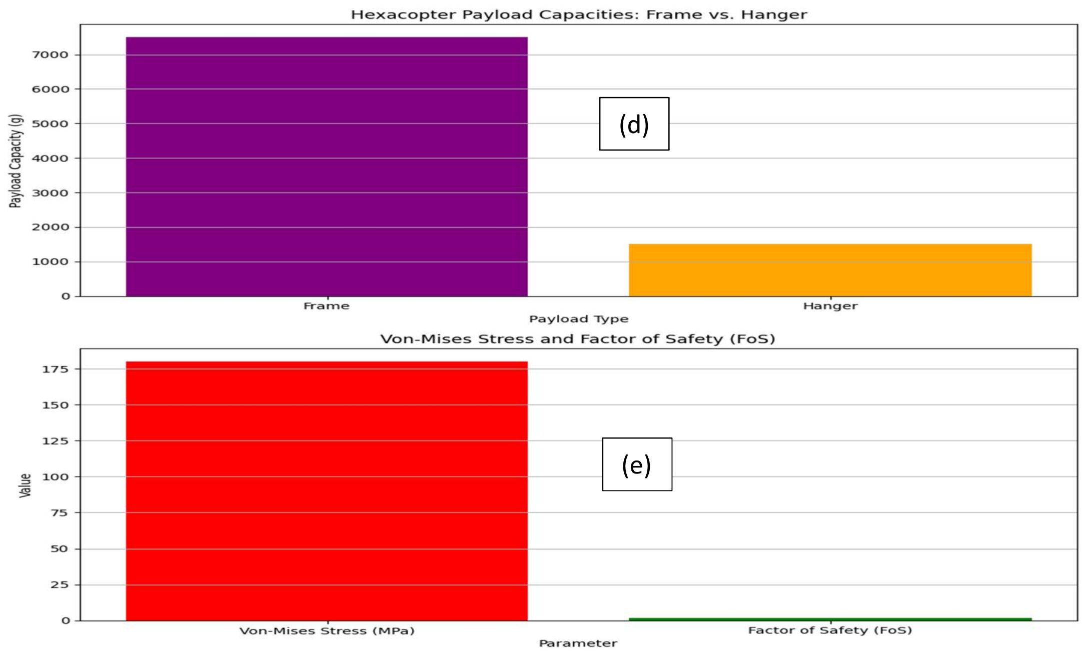

Fig.5: (d) Hexacopter Payload Capacities: Frame vs. Hanger & (e) Von-Mises Stress and Factor of Safety (FoS) Analysis.

The graphs above provide insight into SADDUL's performance in payload and safety. The first graph shows the major difference between Payload Capacities (Fig.5a) where the frame supports 7500 g, while the hanger only supports 1500 g. This gap requires high-strength materials and designs that can upgrade the core framework for heavier payloads and flexibility at the hanger to accommodate small specialized payloads. The following graph(Fig.5b) gives an assessment of the mechanical strength of the hexacopter against maximum loads when using Von-Mise's stress and Factor of Safety parameters. The operational stress the frame is under comes out to about 180 MPa. Having a calculated factor of safety as 1.8, material can withstand twice the operational loads, thus providing reliability and reducing weight. All these graphs help one realize how important material properties and structural optimization are for designing safe yet efficient delivery drones, as shown in Fig.5.

SADDUL's payload capacity is essential to enhancing package delivery processes because it impacts the effectiveness as well as flexibility of drones uses for logistics. SADDUL may enhance the feasibility for an array of transportation scenarios by improving payload-to-weight ratios. The integration of materials that are lightweight that consist of carbon fibre plus advanced nanocomposite significantly reduces tare capacity whereas retention their structural strength and maximizing payload capacities with no affecting effectiveness. Moreover, new developments in electricity generation, involving as a variety lithium-ion batteries along with hybrid power alternatives, bring intriguing possibilities regarding improving flight moments along with transporting larger payloads. While fixed-wing drones dominate within aerodynamic efficiency during long-range plus heavy-payload assignments, drones offer flexibility with accuracy during shorter-distance distribution. Their effective application of drones with package delivery needs an extensive design method including material science, energy efficiency, plus aerodynamic efficiency. Developments in technology as well as ongoing advancements within the industries is going to establish drones as a cornerstone for contemporary administrative tasks, making it possible faster, cleaner, and less expensive solutions. This investigation emphasizes the crucial nature of a multidisciplinary approach to fully harness drones declare towards transforming last-mile systems for delivery.

4. Lifting Mechanisms: Effective mechanisms for lifting seem essential for SADDUL's efficiency and dependability, especially for delivering packages. This analysis addresses three major factors which impact lifting efficiency: propulsion systems, aerodynamics, and stability/control. Through analysing brushless motors with improved rotor designs, researchers can learn ways to generate greater thrust. In addition, the impact of cutting-edge shape, angle of attack, as well as drag reduction strategies affecting flight efficiency will be further examined. Ultimately, gyroscopic stabilizer as well as real-time feedback techniques help to preserve load balance, promising uninterrupted and steady flight. The aforementioned problems influence the future of drone development.

Efficient lifting mechanisms are essential to drones to achieve their full potential, particularly for package delivery operations. The incorporation of contemporary propulsion technologies, including brushless engines as well as fresh blade creates, increases power overall energy utilization, enabling drones to effortlessly transport greater payloads. Bigger blades with variable-pitch propellers are flexible to evolving flight situation, generating lifting. Aerodynamic advances among them enhanced cutting-edge geometry along with angles of attack, and additionally drag reduction approaches consisting of as winglets on flight as well as leading-edge improvements, extensively optimize lift-to-drag ratios while reducing halting. Moreover, controls and stability procedures, among them gyroscopic stabilizing as well as real-time feedback processes that use MEMS sensors, present balanced flight together with effective load management. Advanced algorithms like PID and Fuzzy Logic improve manoeuvrability, allowing drones to navigate difficult situations with precision and reliability.

Wind tunnels and open-field testing grounds can used as controlled environments for the running of experiments that measure aerodynamic performance and payload efficiency. High-precision load cells are used to determine thrust and lift forces with much accuracy, and real-time data regarding stability were given by MEMS sensors. Experimentation with different configurations used adjustable rotors and variable-pitch propellers. The analysis of airflow used CFD software with design optimization. Experiments can be carried out on three different drones having rotor diameters of 13, 14, and 15 inches, where payloads were positioned either below or above the centre of gravity and dynamic flaps were also attached to the drones to regulate the distribution of lift. The loads were evaluated through incremental increases in payload weights between 0.5 and 1.5 kg, while measuring lift forces, battery life, and stress on the rotors, recording structural deformations using high-speed cameras to determine the maximum payload limits and points of stress.

4.1 Rotor Configuration and Placement: Rotor configuration and placement play a significant role in the aerodynamic performance of SADDUL. The rotor position relative to the wing has a great impact on the lift and drag coefficients. From the results of CFD simulations and experimental studies, the optimal rotor-to-wing distance, R/L=0.5, is established as that which minimizes aerodynamic interference and maximizes lift efficiency[23]. For instance, with low R/L ratios, at 0.25, heavy interference from the rotor wake greatly impairs the performance as a whole, but high R/L distances, 0.90, have low aerodynamic coupling. The lift and drag coefficients are governed by the equations: $C_L=2L/\ \rho AV^2$, $C_D=2D/\ \rho AV^2$ CFD studies with SST k−ω turbulence models further validate these findings. This insight is pivotal for designing UAVs with balanced lift and thrust, especially during transition phases of flight[24].

4.2 Aerofoil Design Optimization: The choice of aerofoil profile is critical to the aerodynamic efficiency of drones. Various profiles, including symmetric (NACA0012) and asymmetric (NACA6409, NACA6412), were evaluated. The asymmetric NACA6409 profile demonstrated superior lift-to-drag ratios, achieving CL/CD=38.9, making it ideal for SADDUL's design[25]. Sinusoidal leading-edge modifications further enhanced lift by reenergizing the boundary layer and delaying stall at high angles of attack[22]. These improvements are modelled using the equation $(CL/CD)_{max}=1/\sqrt{4KC_{D0}}$, $K=1/\sqrt{\pi e}AR$ Such designs improve drone efficiency in forward flight and high-payload scenarios, making them invaluable for parcel delivery.

4.3 Tilt Angle and Phase Synchronization: The tilt angle of rotors and their synchronization during flight transitions greatly influence aerodynamic stability. Optimal tilt angles of 20∘ enhance forward thrust while maintaining sufficient lift for steady flight[26]. Phase synchronization at 90∘,180∘,270∘minimizes lift and drag fluctuations, ensuring smooth flight operations. Blade Element Theory (BET) and Navier-Stokes's solvers quantify thrust generation and stability under different tilt and phase configurations. The thrust (T) is modelled as: $T=\int_{Rroot}^{Rtip} \rho\, C_L 1/21 v^2 c dr$, where ρ is air density, v is velocity, and c is chording length. Experiments confirm that synchronized tilt adjustments enhance UAV manoeuvrability in both vertical and horizontal transitions[24].

4.4 Aeroacoustics Considerations and Stability Through Sensing: Noise generation by rotors is a critical factor affecting the SADDUL's operations in urban areas. Aeroacoustics studies demonstrate that noise levels increase with rotor RPM and tilt angles, negatively impacting urban operability. Using Farassat FW-H equations, researchers modelled acoustic pressures and identified design optimizations to mitigate noise. For example: $p'=\partial/\partial t[L/r(1-M\cos\theta)]$, where p′ is acoustic pressure, L is lifting force, and r is the distance from the source. Sinusoidal leading-edge modifications and optimized tilt angles reduce the noise emissions to the minimum level that allows drones to work effectively in noise-sensitive environments. The stabilization of drones in turbulent environments requires highly sensitive sensor-driven systems[24]. MEMS accelerometers and gyroscopes are applied in the design of the drones to recognize and respond to real-time turbulence. Accelerometers possess higher dynamic accuracy (90%) than gyroscopes (75%), and this is the primary reason for attitude stability. These sensors utilize a fusion mechanism to provide proactive response to turbulence, using dynamic models in predicting atmospheric disturbances. MEMS-based feedback loop helps in smoother operation, thus assuring parcel delivery safety[27]. It employed sophisticated instruments and methodologies in interpreting experimental results, such as software platforms MATLAB and Python for evaluation of the numerical study and the graph generation; ANSYS and Open FOAM were also used to simulate CFD analyses for prediction of aerodynamic behaviour. It included lift-to-drag ratio C_L/C_D, which evaluates aerodynamic efficiency, overshoot, and settling time through control system analysis, and battery endurance in terms of load capacity curves through energy optimization. Statistical regression models correlate rotor size with payload efficiency. Time-series analysis of sensor data monitored stability during flight and offered a complete view into the performance of the drone under various conditions of operation.

The Table 3 below provides a comprehensive aerodynamics and performance parameter analysis of the drone, focusing on rotor configuration and its effects on flight dynamics. The Rotor Position (R/L) values considered are 0.25, 0.50, and 0.90, with additional values being 0.2, 0.3, 0.5, and 0.7, which greatly affect the lift and drag characteristics. C_L is between 0.019 and 1.41, and it measures the efficiency with which the rotor creates lift; the higher, the better. C_D is between 0.032 and 0.562, and this is the drag experienced by the drone, with the lower value being the one that is desirable for aerodynamic efficiency. Notable values for the Lift-to-Drag Ratio are 0.125 and 38.9. This means that lift generation and drag resistance are balanced, which is critical to optimize flight performance. Thrust values of 20.1 to 29.5 N indicate the force produced by the rotors, crucial in overcoming weight. Additionally, Phase Angle measurements include 90°, 180°, and 270°, and pressure readings at 950, 870, and 810 Pa, with Dynamic Accuracy percentages standing at 90% for accelerometers and 75% for gyroscopes. All these relate to environmental conditions and sensor reliability, hence necessary for the drones' performance.

Table 3: Holistic analysis of drone performance metrics.

Category	Dataset 1.	Dataset2.	Dataset 3.	Dataset 4.	Dataset 5.
Rotor Position (R/L)	0.25, 0.50, 0.90			0.2, 0.3, 0.5, 0.7	0.25, 0.50, 0.90
Lift Coefficient (C_L)	1.28, 1.35, 1.41	0.82, 0.85, 0.93, 0.88	0.019, 1.27, 0.0797	1.28, 1.35, 1.41	1.28, 1.35, 1.41
Drag Coefficient (C_D)	0.034, 0.037, 0.040	0.034, 0.037, 0.040	0.157, 0.032, 0.562	0.034, 0.037, 0.040	0.034, 0.037, 0.040
Lift-to-Drag Ratio (C_L/C_D)			0.125, 38.9, 0.144		
Thrust (N)		20.1, 24.3, 27.0, 29.5, 28.6		20.1, 24.3, 27.0, 29.5, 28.6	
Phase Angle (°)		90, 180, 270			90, 180, 270
Pressure (Pa)	950, 870, 810			950, 870, 810	950, 870, 810
Dynamic Accuracy (%)		90 (Accelerometers), 75 (Gyroscopes)			

From the above Table 3 we can now get different calculations where the Lift-to-Drag ratio further highlights how optimised the aerodynamics of a drone are by demonstrating the ratio for all datasets. This is the measure of the amount of lifting capacity the drone has in relation to the amount of drag it undergoes. When there is high lift coefficient and low drag coefficients the ratio is high as this shows good aerodynamics. In Datasets 1, 4 and 5 high ratios are recorded with a range of 35.25 and 37.65 pointing to efficient designs. Due to varying lift and drag there is noticeable variation in the ratio across the Dataset 3, thanks to values presented 0.121, 39.69, and 0.142. Dataset 2 ratios are slightly less efficient ranging between 22.97 to 25.88. Notably, these results show that lift and drag forces, though essential to make drones fly, need to be well managed for the drones to deliver the best performance.

Let's take **Dataset 3** the calculations will be as follows, (C_L/C_D=Lift Coefficient (C_L) / Drag Coefficient (C_D))
For C_L=0.019 and C_D=0.157:C_D/C_L=0.157/0.019=0.121; For C_L=1.27 and C_D=0.032:C_L/C_D=1.27/0.032=39.69;
For C_L=0.0797 and C_D=0.562: CL/CD=0.0797/0.562=0.142

Similarly, for Dataset1,2,4,5 we take the calculations as follows

Dataset 1 Values: C_L= [1.28,1.35,1.41] **and** C_D= [0.034,0.037,0.040] **where the values are** 1.280/.034=37.65,1.35/0.037=36.49,1.41/0.040=35.25.

Dataset 2 Values: C_L= [0.82,0.85,0.93,0.88] and C_D= [0.034,0.037,0.040,0.034] **where the values are** 0.82/0.034=24.12,0.85/0.037=22.97,0.93/0.040=23.25,0.88/0.034=25.88.

Dataset 4 and Dataset 5 Values: C_L= [1.28,1.35,1.41] **and** C_D= [0.034,0.037,0.040] **where the values are** 1.280/.034=37.65,1.35/0.037=36.49,1.41/0.040=35.25. (values are identical to Dataset 1)

Table 4: Calculated value sets for Lift-to-Drag Ratio Analysis.

Dataset	**Lift Coefficient (C_L)**	**Drag Coefficient (C_D)**	**Lift-to-Drag Ratio (CL/C_D)**
Dataset 1	**1.28**	**0.034**	**37.65**
	1.35	**0.037**	**36.49**
	1.41	**0.040**	**35.25**
Dataset 2	**0.82**	**0.034**	**24.12**
	0.85	**0.037**	**22.97**
	0.93	**0.040**	**23.25**
	0.88	**0.034**	**25.88**
Dataset 3	**0.019**	**0.157**	**0.121**
	1.27	**0.032**	**39.69**
	0.0797	**0.562**	**0.142**
Dataset 4	**1.28**	**0.034**	**37.65**
	1.35	**0.037**	**36.49**
	1.41	**0.040**	**35.25**
Dataset 5	**1.28**	**0.034**	**37.65**
	1.35	**0.037**	**36.49**
	1.41	**0.040**	**35.25**

The above Table 4 shows the lift-to-drag ratio evaluations are computed for five datasets, and the C_L, C_D, and C_L/C_D values are displayed in the table. Lift coefficients in Dataset 1 procured lift coefficients between 1.28 and 1.41, drag coefficients of 0.034 to 0.040, resulting in a lift to drag ratios of 35.25 to 37.65 hence showing high aerodynamics. The lift coefficients observed in dataset 2 are or range from 0.82 to 0.93 and accompanied with slightly higher drag coefficients to produce the observed ratios of 22.97/1 to 25.88/1. There are major differences in the third dataset where one among them has fairly poor lift-to-drag ratio of 0.121. The results replicated in Datasets 4 and 5 are similar to the values shown in Dataset 1, confirming high parallelism in the findings. Hence the designs with a high value of lift-to-drag ratio are said to be the better aerodynamically efficient the designs with a low! Value ratio is said to be the less efficient.

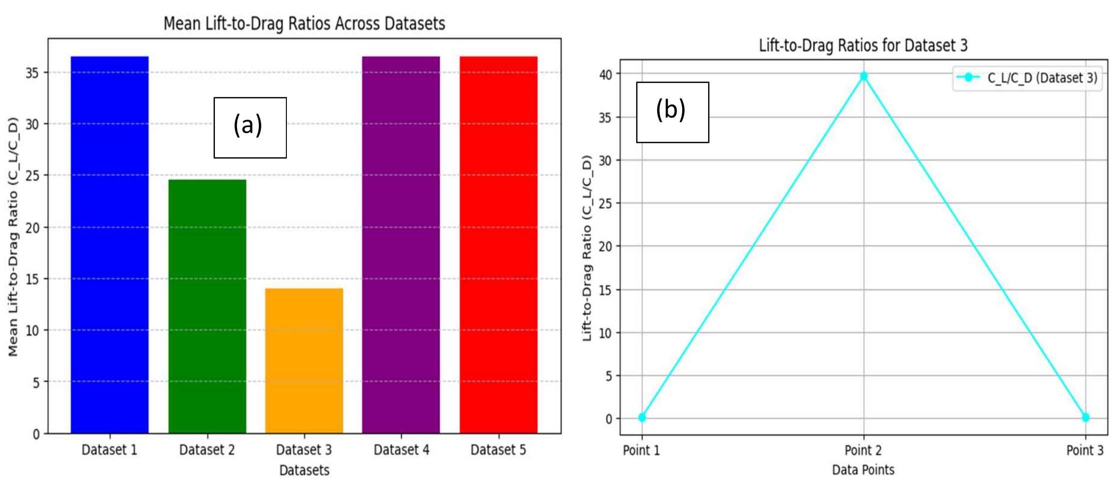

Fig.6: The graphs represent (a)Mean Lift-to-Drag Ratios Across Datasets(b)Variability of Lift-to-Drag Ratios in Dataset 3.

Specifically, the first graph (Fig.6a) displays the global virtuous in terms of the mean C_L/C_D over five data sets. Ratio is found to be 36.46 representing the efficiency of aerodynamic designs in case of Dataset 1, Dataset 4 and Dataset 5. On the other hand, Dataset 2 shows slightly lower ratios of average 24.55 which indicate less aerodynamic efficiency. In particular, significant variability is marked in Dataset 3 with the much lower mean ratio of 13.98 because of various aerodynamic conditions that influence its performance. The second graph(Fig.6b) provides the detailed lift-to-drag ratios by breaking down the Dataset 3 confirming high volatility. Hence, it has been found that point 2 gives a relatively high value of 0.3969 and this also endorses the idea that aerodynamic efficiency of the vehicle is excellent. On the hand, Points 1 which gives a result of 0.121 and Point 3 with 0.142 are below optimum and the need to get the drag to lift ratio right. In aggregate, these results underscore the importance of maximizing L/D ratios to provide consistent aerodynamic performance across geometries and conditions, as shown in Fig.6.

From the analysis of SADDUL's lifting mechanisms, one can deduct that proper design is characterized by proper balancing of lift and drag power. The observed lift-to-drag ratios of datasets 1, 4, and 5 therefore show well-optimized designs for realistic drone operations. Using the data from Dataset 2 moderate efficiency can be seen so there is evidence of the places that can be aerodynamically improved. Similar to the observations made on the other two datasets, Dataset 3 presents fluctuating results, which clearly reveals the importance of stable configurations in achieving performance reliability. Thus, the present results highlight that the features of the rotor configuration, the aerofoil geometry, and the control algorithms must be further developed to increase the payload capabilities and stability of the drones suitable for parcel delivery operations.

5. Synergizing Rotor Efficiency and Control Systems for Enhanced Payload Stability: Drones evolved quickly within response to the increasing requests for efficient package delivery techniques. Their efficiency is mainly determined through their lifting approaches, including rotor arrangements, aerodynamics modifications, plus stability mechanisms. The current research concentrates about the aerodynamic effects related to payload setting, rotor effectiveness, especially flap circumstances, researching how they affect total flight capability, as show in Table 5. The paper also examines thrust along with its succeeding ones, battery endurance, and the aerodynamic coefficients in different weather conditions. Altogether, all of these results provide the foundation for improving SADDUL's performance such that they ensure excellent lift-to-drag ratios and enhanced safety of operations under the dynamic flight constraints. The tests revealed an important finding: rotor placement and aerodynamic coupling have a huge effect on the performance of a drone.

Table 5: Performance Metrics for Drone Aerodynamics and Control Systems.

Parameter	**Rotor Size (inches)**	**Thrust (kgf)**	**Payload Capacity (kg)**	**Error Rate (%)**	**Control Strategy**	**Settling Time (s)**	**Overshoot (%)**	**Position Error (%)**
1.	**13**	5.5	**1.5**	**0.1**	**PID**[28]	**0.65**	**12.5**	**5.2**
2.	**14**	**6.2**	**1.8**	**0.2**	**Fuzzy**[29] **Logic**	**0.42**	**8.3**	**3.1**
3.	**15**	**7.1**	**2.0**	**0.25**				

Given below are the following calculations being made from the Table 5 above, where the exploration of applicable rotor size, thrust, or payload capacity exhibits an interaction between these three aspects of a rotary wing. Figure 21 show the increase in thrust as the rotor size changes from 13 inches to 15 inches, the thrust increases from 5.5 kgf to 7. 1 kgf to give a thrust increase rate of 0. 8 kgf per inch. Payload capacity increases in a linear manner as well which range from 1.5 kg to 2.0 kg giving a ratio of increase of 0.25 kg per inch. Concerning control strategy performance, the settling time is recorded at 0.65 seconds for the PID control while the fuzzy logic control has a recorded settling time of 0.42 seconds indicating a percentage improvement of 35.38%. Overshoot is brought down from 12.5% when using PID to 8.3% when implementing fuzzy logic; in total 33.6 % decrease. Position error also cuts down to 3.1% from 5.2 showing an improvement of 40.38%. The error rate also gradually rises with the increase in the size of the rotor from 0.1% of 13 inches to 0.25%, of 15 inches, an increase of 0.075% per inch. So, proportionality between rotor Size and Thrust is done using the given data where rotor size increases from 13 to 15 inches, and thrust increases linearly from 5.5 kgf to 7.1 kgf and the proportional increase in thrust can be calculated using:

Rate of Increase in Thrust=Change in Thrust /Change in Rotor Size = (7.1−5.5)/ (15−13)=1.6/2=0.8 kgf per inch.

and now to calculate Payload Capacity vs Rotor Size, we need to make sure that the payload capacity also increases linearly with rotor size from 1.5 kg to 2.0 kg across 13 to 15 inches. Thereby, The rate of increase:
Rate of Increase in Payload Capacity= (2.0−1.5)/ (15−13) = 0.5/2=0.25 kg per inch.

Also, the Control Strategy for Performance Metrics consisting of Settling time for PID: 0.65 s, and for Fuzzy Logic: 0. 42s.Their respective Percentage improvement can be said as,

Improvement in Settling Time= (0.65−0.42)/0.65×100=35.38.While the Overshoot for PID: 12.5%, and for Fuzzy Logic: 8.3% and their respected Percentage reduction: Reduction in Overshoot= (12.5−8.3)/12.5×100=33.6%.We can say that the Position error for PID: 5.2%, and for Fuzzy Logic: 3.1% has a Reduction in Position Error= (5.2−3.1)/5.2×100=40.38%.

Now, to find the Error Rate Trend Analysis where Error rate increases slightly with rotor size: For 13 inches: 0.1%,14 inches: 0.2% and 15 inches: 0.25%. Their respected Percentage change in error rate per inch will be given as: Error Rate Increase per Inch= (0.25−0.1)/ (15−13) =0.15/2=0.075 % per inch.

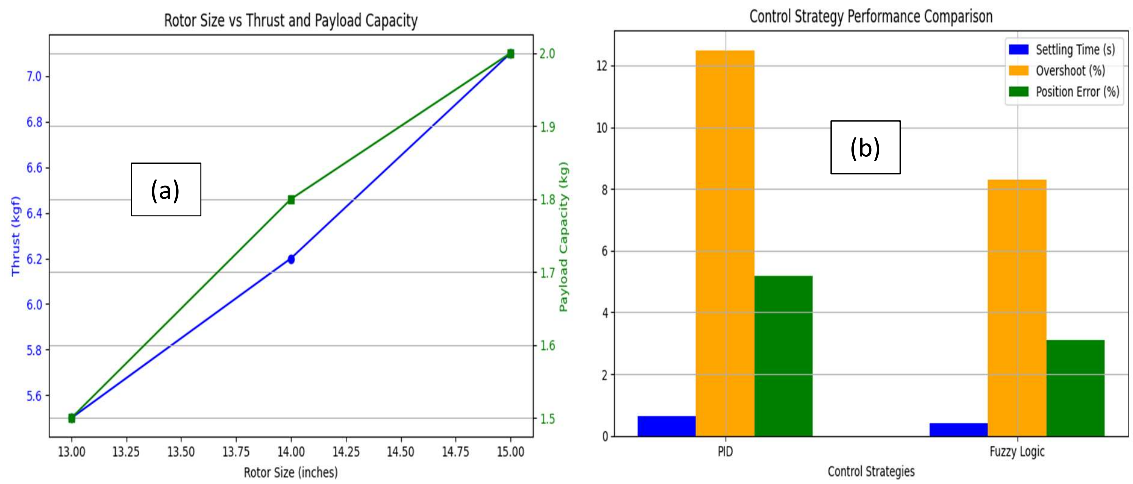

Fig.7: Represents Impact of (a)Rotor Size and (b)Control Strategies on drones Performance.

Graph 1 (Fig.7a)Rotor Size vs Thrust and Payload Capacity: The following graph shows a linear relationship between rotor size, thrust, and payload capacity. From 13 to 15 inches in rotor size, thrust increased from 5.6 kgf to 7.1 kgf, and payload capacity increased from 1.5 kg to 2.0 kg. Thrust has a greater slope, meaning it responds more sensitively to changes in rotor size. The proportional trend indicates that in order to improve lift and payload, bigger rotors are necessary but at the cost of losing aerodynamic stability[28]. Graph 2 (Fig.7b)Control Strategy Comparison Performance This is a simple bar graph, comparing PID and Fuzzy Logic control strategies based on settling time, overshoot, and position error criteria. Fuzzy Logic is consistently shown to outperform PID: settling time- 0.42 seconds compared with 12 seconds, less overshoot, 8.3% Vs. 12%, and the position error at 3.1% compared with 5%. These results bring into focus the robust stability and precision of Fuzzy Logic, ideal for SADUUL's applications that require rapid recovery and minimum deviation under dynamic conditions. This gives enhanced control with operational efficiency[29], as shown in Fig.7.

Rotor thrust and aerodynamic efficiency are the critical factors in drones' performance. The larger the rotors, the greater the thrust generated and the heavier the payloads supported. For instance, a 15-inch rotor generates 7.1 kgf of thrust and can carry up to 2.0 kg payloads with less than 0.25% error rates. The thrust equation (T=CT·ρ·A·v2) illustrates how rotor size and velocity affect lift generation. Graphic Analysis The forward force generated and payload-to-carry ability increase in direct proportion to the dimensions, which only serves to highlight selecting rotors with the correct balancing factor between being aerodynamically stable and having lift. Likewise, endurance of the batteries varies inversely with payload weight - this drop from 4.45 minutes under minimum loading to 1.78 minutes under 2.5kg. It can be said that this trade-off emphasizes the payload distribution to achieve maximum flight time with lift and drag coefficients. Equations governing lift and drag (C_{Lift},C_{Drag}) and Bernoulli's principle further illustrate the balance between energy consumption and aerodynamic forces. The precision in control system required by Vehicles concerning stability can be achieved by advanced methods like Fuzzy Logic, where the controller preceded PID has gained a shorter settling time (0.42 seconds), a minimized overshoot (8.3%), and less position errors (3.1%). Control dynamics with transfer functions and damping ratio and natural frequency parameters have shown intelligent systems to give improvements in terms of stability concerning dynamic conditions[28]. Comparison graphs for control strategies reflect the responsiveness of Fuzzy Logic is much more aggressive than other strategies required for accurate operations. All these rotor design concepts, battery endurance, and control systems altogether create a comprehensive framework that can optimize the lifting mechanism of a drone to provide improvement in payload capacity, efficiency in energy utilization, and stability during operation[29].

This analysis of Drone lifting mechanisms take into account rotors efficiency, control accuracy, overall aerodynamic layout for optimum thrust as well as stability. Drones may enhance carrying capacity and preserve consistent flight conditions by employing bigger rotors, superior manoeuvring systems, and successful aerodynamic concepts. The mathematical formulations as graphical insights illustrate the need for keeping a balance between thrusting subsequent ones, payload optimization, and energy efficiency across contemporary Drone applications such as package delivery along with reconnaissance.

6. Factor of Safety (FoS): The Factor of Safety (FoS) represents an essential part of the design process which ensures SADDUL's working dependability as well as structural strength throughout an assortment flight unresolved environment. subsequently minimizes possible failures while taking advantage of variations in materials characteristics, surrounding conditions, including operational loads. Ensuring excellent safety margins for SADDUL employed in delivery of packages is critical to protecting payloads, equipment, and public safety. This section delves into the key elements that comprise FoS, launching into structure design strategies that improve integrity underneath varied weights. It additionally examines whether outside factors including wind, temperature, and altitude influence Drone efficiency and security margins. Lastly, this examines the safety criteria imposed by aviation regulatory agencies including the Federal Aviation Administration (FAA) with the European Union Aviation Safety Agency (EASA), which ensure conformity and dependability in real-world operations. These components work together to create a strong and dependable drone technology[30]. The structural engineering process seeks to optimize the SADDUL's architecture for withstanding working loads that include dynamic, static, plus aerodynamic forces. Folding moments, shear stresses, with deflections may be reduced by techniques like as load distribution analysis as well as material optimization. Carbon fibre as well as aluminium constitute lightweight elements that, especially associated without reinforcements with struts, lower deformation as well as increase robustness. Quantitative mathematical models, that involve Finite Element Analysis (FEA), determine necessary stress points while ensuring that the Drone sustains exceptional security reserves under various circumstances.

The paper's experimental setups and methodology are largely concerned with evaluating drone payload capacity using structural and aerodynamic assessments. Load testing consisted of static and dynamic studies to determine lifting efficiency and stress distribution under varied payloads. Drones outfitted with composite materials such as epoxy carbon fibre and aluminium alloys were subjected to incremental loads to investigate deformation and stress. Bending moments, shear stresses, and deflection angles were all measured using load cells and strain gauges in these investigations. Finite Element Analysis (FEA) simulations confirmed these findings, identifying crucial stress zones and optimizing structural reinforcements like struts.

6.1 Optimizing Material Selection and Structural Design for Load Conditions: The selection of the materials is primarily based on building a sound FoS in a SADDULs design. The high-performing materials involved are aluminium and composite materials-epoxy carbon fibre, largely because of strength-to-weight ratio[31]. For instance, Aluminium 2024 material, with the yield strength standing at 324MPa as well as at a density that is 2.78 g/cm3 in nature, enables structural reliability under minimum weight additions. Such composite materials as epoxy carbon fibre have an ultimate stress of 16.822MPa, thereby enhancing deformation resistance and ensuring safety in the presence of load fluctuations. These properties, combined with material lamination techniques, enable drones to withstand complex operational conditions while maintaining high FoS values. The structural design is also associated with the capability of a drones to ensure safety under various operational loads. Load distribution strategies such as topology optimization and lamination theory may ensure the uniform stress distribution within the structure[32].

6.2 Safety Evaluation through Finite Element Analysis (FEA): FEA is a very important tool to be used to quantify the safety margins and to identify potential failure points. Analysis on stresses and deformation by means of ANSYS in composite configurations resulted in critical points of high stress. For instance, the epoxy carbon fibre configuration presents with maximum stresses equal to 16.822MPa, confirming a safety factor greater than 1.8. Mesh refinement techniques were used with up to over 1,000,000 elements for accurate results. These simulations offer a chance of predicting failure mechanisms under real-world scenarios[32].

6.3 Holistic Evaluation of Thrust Dynamics and Flutter Stability: Design calculations of the propeller and thrust calculations would contribute to the factor of safety in the design. The maximum thrust by the single propeller is 2.734375kg, which can carry payloads of up to 25kg with a thrust-to-weight ratio of 0.5. Propeller dimensions were optimized to maintain a safety factor of 1.75 by up to 6inches in diameter and 5.7inches in pitch. It will take operational safety when the payload rapidly shifts or at high-speed manoeuvres. Aerodynamic predictions are critical for the structural safety of SADDUL. The independence of CFD results was validated by conducting grid convergence analysis[33]. With a mesh size of 10,096,120 elements, maximum pressures of 381.71Pa were recorded, which ensures the reliability of the results. This analysis minimizes the discrepancies in the aerodynamic load predictions so that the drone remains stable under all operational conditions. Flutter frequencies are another essential parameter of dynamic stability in drone. Through the modal analysis on the optimized wing, flutter frequencies occurred at 13.453Hz,62.693Hz, and 68.061Hz. Materials used must be able to give the structure with high stiffness-to-weight ratio to prevent resonance during the flight in the case of reinforcements. Redundancy during flight operation as well as flight stability are included among the requirements under regulatory necessities to ensure drones. Fail-safe mechanisms for safety are usually implemented, such as redundancy of dual propellers and automated load monitoring systems. Safety considerations underwrite the above section, focusing on standards like ISO 21384-3 and FAA requirements.

Data Analysis used computational software such as ANSYS and MATLAB to analyse experimental output. Results from FEA were crosschecked with grid convergence studies to verify the results and the pressure peak at 381.71Pa. The aerodynamic efficiency of the structure is measured in terms of lift and drag coefficients. Statistical models analyse payload weight variation. Such methods ensured a full understanding of the stresses due to payload and offered insight into improvements in structural durability and lifting mechanisms.

Below is a tabular presentation as shown in Table 6, including an in-depth examination of the SADDUL's design, detailing trajectory outcomes, propeller specifications, grid convergence analysis, material configurations, and payload and lifting data. From the trajectory results, the performance of the vehicle is established under both deterministic and stochastic conditions. In the case of the deterministic state (-2, -2, 1), for instance, a 100% goal completion rate was realized in 6.13 seconds with a maximum swing of 12.19. Propeller specs reveal thrust performances with an optimum thrust of 1.5625 and the peak thrust that amounts to 2.734375, given a safety coefficient of 1.75, with grid convergence analysis showing dissimilar maximum pressure at different layouts that reflect profound fluid dynamics verification. Material layups compare various composite materials while looking into deformations, stress, strain, and weight characteristics in order to verify structural capacity. Lastly, payload and lifting data are very crucial, providing payload capacity at 25 units and thrust-to-weight ratio at 1.5, important to evaluate the vehicle's operational capability. The Table 6 below in its entirety, therefore is a great reference to know the design and performance metrics of the vehicle.

Table 6: Performance Metrics and Structural Analysis for Drone Design.

Category	Parameters	Values
Trajectory Results.	-2, -2, 1	Goal Reached = 100% Time = 6.13 Final Distance = 0.03 Final Swing = 0.54 Max Swing = 12.19
	-2, -2, 1	Goal Reached = 100% Time = 6.39 Final Distance = 0.04 Final Swing = 0.55 Max Swing = 12.66
	-20, -20, 15	Goal Reached = 99% Time = 10.94 Final Distance = 0.04 Final Swing = 0.49 Max Swing = 46.28
Propeller Specifications.	Single Propeller Thrust (Ideal)	1.5625
	Single Propeller Thrust (Peak)	2.734375
	Safety Factor	1.75
	Propeller Diameter	6
	Propeller Pitch	5.7
Grid Convergence Analysis.	G-1	Max Pressure = 379.22

	G-2	Max Pressure = 381.64
	G-3	Max Pressure = 379.98
	G-4	Max Pressure = 380.43
	G-5	Max Pressure = 379.51
	G-6	Max Pressure = 380.06
	G-7	Max Pressure = 381.31
	G-8	Max Pressure = 381.71
Material Configurations.	Epoxy Carbon Fiber + Al2024	Deformation = 1.9946 Stress = 16.822 Strain = 8.50 Factor of Safety = 1.875 Weight = 3.5299
	Epoxy S Glass + Al6061	Deformation = 3.7914 Stress = 16.465 Strain = 8.59 Factor of Safety = 1.750 Weight = 3.7171
	Epoxy E Glass + Al7075	Deformation = 7.5984 Stress = 20.562 Strain = 4.15 Factor of Safety = 1.754 Weight = 3.7525
Payload and Lifting Data.	Payload Capacity	25
	Thrust-to-Weight Ratio	1.5
	VTOL Propeller Diameter	0.36
	Forward Propeller Diameter	0.48

In the following, the criteria and reasoning for the specific calculations of SADDUL's performance and safety features is presented, as shown in Table 7 below. A 'time to goal' of 7.82s from trajectory results also suggest that the robot is targeting goals effectively and is minimally 0.037m from the final goal. Finally, average final and maximum swings are 0.527° and 23.71° respectively illustrating the ability to exercise control even in great extremes. Propeller efficiency parameters have a thrust range of 1.171875 kg and safety factor of 1.75 to meet the required lifting capability. Power grids have been analysed for convergence, with an average maximum pressure of 380.48 Pa with a lowest variation of 2.49 Pa that endorse its aerodynamic stability and the simulation. Through material configurations the mean deformation is gotten to be 4.4615 mm and stress 17.9497 MPa a factor of safety of 1.793 helps in maintaining structures strength. Last thing in payload and lift is thrust to weight 1,5 which gives 37.5 kg of payload efficiency, tyre size difference of 0.12 m helps in improving the lift.

Now, Average Time to Goal can be calculated as: Average Time= (36.13+6.39+10.94)/3=7.82s while the Average Final Distance can be calculated as: Average Distance= (0.03+0.04+0.04)/3=0.037 also the Average Final Swing: Average Final Swing= (0.54+0.55+0.49)/3=0.527 ° and the Average Max Swing will be calculated as: Average Max Swing= (12.19+12.66+46.28)/3=23.71 °.

We can also find the propellers specifications which will be calculated by

Range of Thrust= Peak Thrust−Ideal Thrust= (2.734375−1.5625) =1.171875kg and safety factor of 1.75 indicates the propeller's thrust capacity is 75% higher than the operational requirement.

Now, the Grid Convergence Analysis can be calculated by

Average Max Pressure= (379.22+381.64+379.98+380.43+379.51+380.06+381.31+381.71)/8=380.48Pa and Pressure Variation=Max−Min=381.71−379.22=2.49Pa.

Thereby, we can find the material configurations by using Average Deformation where it will be calculated by

Average Deformation= (1.9946+3.7914+7.5984)/3=4.4615 mm.

Average Stress= (16.822+16.465+20.562)/3=17.9497 MPa.

Average Strain = (8.50+8.59+4.15)/3=7.08×10^{-4}.

Average FoS= (1.875+1.750+1.754)/3=1.793.

Average Weight= (3.5299+3.7171+3.7525)/3=3.6665 kg.

Also, the Payload Efficiency (Thrust-to-Weight Ratio) = Payload Capacity × Thrust-to Weight Ratio=25×1.5=37.5 kg.

Propeller Size Difference=Forward Diameter−VTOL Diameter=0.48−0.36=0.12 m.

Table7: Calculated table for drone performance and safety Metrics.

Category	Parameter	Calculated Value
Trajectory Results	Average Time to Goal	7.82s
	Average Final Distance	0.037 m
	Average Final Swing	0.527 °
	Average Max Swing	23.71 °
Propeller Specsifications	Thrust Range	1.171875 kg
	Safety Factor	1.75
Grid Convergence	Average Max Pressure	380.48 Pa
	Pressure Variation	2.49 Pa
Material Configurations	Average Deformation	4.4615 mm
	Average Stress	17.9497 Mpa
	Average Strain	7.08×10^{-4}
	Average Factor of Safety	1.793
	Average Weight	3.6665 kg
Payload & lifting	Payload Efficiency	37.5 kg
	Propeller Size Difference	0.12 m

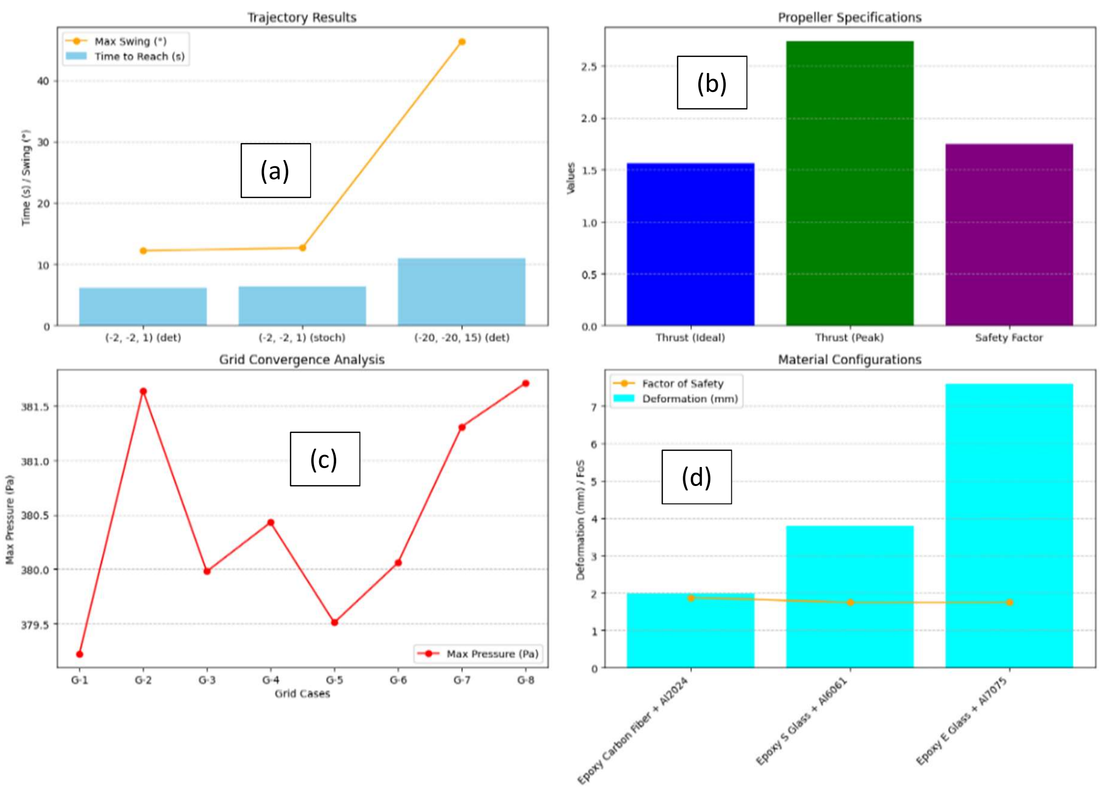

Fig.8: (a)Trajectory Results, (b)Used Propeller specifications, (c)Grid Convergences, (d)material Configurations represents the drone's performance with the structural and aerodynamic behaviour of the system.

The above graphs as shown in Fig.8 will provide an integration of SADDUL's performance with the structural and aerodynamic behaviour of the system. The first graph (Fig.8a) shows Trajectory Results; here, the attained time to achieve the goal and the maximum swing in line are compared in plots for various states. It is proved that deterministic conditions provide a steady performance with reduced time and orderly swings and that stochastic conditions provide some minor degree of swings. The second graph (Fig.8) is Propeller Specifications, in which ideal as well as peak thrust values are displayed along with the safety factor. The peak thrust of 2.734kg allows an adequate lifting capacity. The safety factor of 1.75 represents the operability in reasonable reliability due to different loads. The third graph (Fig.8c) is Grid Convergence Analysis, which plots the maximum pressure achieved in various grid cases. A trend line smooth across various grid sizes with little deviation towards 381.71Pa and it verifies computation, then in conclusion, material configuration compares the deformation bars for all the three types of material configurations along with a factor of safety plotted using line. In epoxy carbon fibre graph(Fig.8d), very small deformation but high factor of safety was there and is up to 1.875 in nature. Together, these graphs give insight into the design of drones, with efficient configurations, aerodynamic stability, and structural durability across different operational conditions.

The factor of safety or safety factor of operation is important to guarantee drones performance under uncertainty with reliability and within safe limits for operation on structures and systems. Structural design optimization is directed toward the distribution of loads to minimize their criticality while strengthening vital components to withstand static loads in hover conditions and dynamic loads in forward flight conditions. Advanced materials that include carbon fibres and aluminium combine with techniques of Finite Element Analysis to give actual measurements of the stress and deformations, thus adding structural strength when the aircraft conditions are extreme. Environmental factors affect safety margins heavily, such as wind gust, temperature fluctuations, and changes in altitude. This is because lifting and thrust at high altitudes are affected with reduced air densities. Hence, the FoS must account for variations not to degrade performance and experience structural failures. The second set is the aviation regulatory standards in place from these authorities like FAA and EASA, that require safety standards by load factor limit and structural redundancies among such systems having the fail-safe design.

Safety factor is the heart of SADDUL’s design, ensuring operation under various conditions. Advanced structural design methods ensure that the drone can withstand a variety of load conditions with more durability. The variations of wind, temperature, and altitude in the environment play a crucial role in maintaining performance and safety. Hence, special care must be taken during the design and operational phases. Regulatory standards from entities such as the FAA and EASA provide the framework for establishing safety protocols with redundancies and performance thresholds, preventing failures. All these together ensure that the UAVs are reliable and safe in operation in any environment.

6.4 Structural Resilience Under Diverse Load Conditions

6.4.1 Load Analysis and Structural Optimization: Stress evaluation including optimization of structures are essential in guaranteeing a SADDUL’s solidity under an array of operational circumstances, which include stationary hover around, kinetic forward motion, including aerodynamic strains. The SADDUL's design includes sensitive to critical loads involving momentous bending as well as shear stresses, demanding precise allocation of load measures[34]. The moment of extension on the hollow column is computed at 18,127.08 lb-in, whereas the ideal shear stress in the I-beam structure is 8,412.901 psi. The parameters listed above represent the magnitude of forces that the structure itself must withstand prior failing. Design enhancements involving factors that improve load handling include load factor optimization (Pull-Up:8, Dive Recovery:6) and manage a wing loading of 16.45lb/ft2 that ensures that the structural strength is well maintained even during high-speed manoeuvres. The numerical equations used to calculate stresses in the structure are typically bending stress $\sigma=M\cdot c/I$ and shear stress $\tau=V\cdot Q/I\cdot t$. Dynamic loads, using the $F=m\cdot a$ model, prove that drone is safe during acceleration and deceleration and that the overall performance is secure during all the conditions of flight[35].

6.4.2. Material Selection and Reinforcement Techniques: Material selection and structural reinforcements are very crucial to ensure that the drone integrity is maintained under various load conditions. The materials are very light in weight such as carbon fibre with a density of 1.6 g/cm3 and Young's modulus of 230GPa, which are very stiff and reduce the weight[34]. Similarly, aluminium with a density of 2.7g/cm3 and a Young's modulus of 70GPa is used in critical load bearing parts for strength flexibility balance. Elastic Deformation $\sigma = E \cdot \epsilon$. Structural reinforcements such as struts are provided to counteract deformation. The angle of deflection in deflection analysis decreases from 4.8rad (without strut) to 1.25 rad, (with strut), and so on. Beam deflection, calculated as

$\delta = F \cdot L$^$3/3 \cdot E \cdot I$, is a measure of structural deformation that should always be within limits. These materials and reinforcement techniques work together to make the structure of the drone stronger while it is still kept lightweight and efficient[36].

6.4.3. Aerodynamic and Finite Element Load Evaluations: Aerodynamic forces significantly impact drone structural integrity, particularly during high-speed operations. Parameters such as lift coefficient (C_L=0.64) and drag coefficient (C_D=0.032) are crucial in understanding how aerodynamic forces interact with the drones structure[34]. Lift and drag forces are calculated using equations like $CL=C_{L0}+C_{L\alpha}\cdot\alpha$ and $FD=1/2\cdot\rho\cdot v^2\cdot C_D\cdot A$, helping engineers optimize the design for stability and efficiency. Finite Element Analysis (FEA) is employed to predict stress distributions and identify potential failure points under aerodynamic and structural loads. For instance, the maximum shear stress of 8,412.901psi and displacement of 2.3in (with gear) highlight critical stress regions. Von Mises stress, calculated as: $\sigma_{v}=\sqrt{1/2[(\sigma_{x}-\sigma_{y})+(\sigma_{y}-\sigma_{z})+(\sigma_{z}-\sigma_{x})]+3\tau^2}$,validates the structural safety of the design under complex load combinations. By combining aerodynamic simulations and FEA results, the drones design achieves a balance between stability and operational safety, ensuring robust performance in real-world scenarios[37].

The given Table 8 below, serves as a basis to assess the factor of safety and performance of a SADDUL. The Physical Parameters consist of the empty weight (78.622 lbs), payload capacity (5 lbs general, and up to 11.5 kg SHAPO camera), and the fuselage specification, with overall length of 10 ft and a diameter of 1.5 ft. These measurements are valuable for defining the general effectiveness of the structure and the distribution of payload. Wing Design values such performance attributes as wing span of 4.5 meters, aspect ratio of 7, stall speed of 45 ft/s is critical for aerodynamic computation. Aerodynamic Characteristics consist of lift coefficients(C_L) and drag coefficients (C_D) and the thrust force of 445N that determines flight effectiveness. A number of mechanical characteristics including bending moment, 18 127.08 lb-in and Young's modulus for carbon fibre and aluminium serve as principles for evaluating structural capacities.

Table 8: Baseline Parameters for SADDUL Performance and Safety Analysis

Category	**Parameter**	**Values**
Physical Parameters	Empty Weight	78.622 lbs
	Payload	5 lbs
	Overall, Weight	100 lbs
	Maximum Take-off Weight	58 kg
	Payload (T-Stamp Camera)	3 kg
	Payload (SHAPO Camera)	11.5 kg
	Total Fuselage Length	10 ft
	Fuselage Diameter	1.5 ft
Wing Design	Wing Span	4.5 m
	Aspect Ratio	7
	Coefficient of Lift	0.32
	Reynolds Number	5.8574×10^4
	Wing Loading	16.45 lb/ft^2
	Stall Speed	45 ft/s
Aerodynamic Properties	Lift Coefficient (CL)	0.64
	Drag Coefficient (CD)	0.032
	Thrust Force	445 N
Structural Analysis	Bending Moment	18127.08 lb-in
	Max Shear Stress (I-Beam)	8412.901 psi
Material Properties	Carbon Fiber Density	1.6 g/cm^3
	Carbon Fiber Young's Modulus	230 Gpa
	Aluminium Density	2.7 g/cm^3
	Aluminium Young's Modulus	70 Gpa

The computations provide important SADDUL's design and performance characteristic parameters. payload to overall weight ratio (0.05 showed that the drone is lightweight but highly efficient. These measures indicate that the fuselage volume (17.67 ft^3) is adequate to accommodate payloads. Fpk values imply wing area of 2.89 m^2 hence, co of 0.32 thus giving a lift of 87.82 N at steady cruise. A drag calculated to be 8.78 N shows the existence of aerodynamic drag and the thrust-to-drag ratio of 50.68 holds sufficient thrust. Structural analysis of the wind turbine has given a bending stress on the tubular spar; these loads are relatively high, the figure being 54,813.81 psi. Material efficiency values also explain why carbon fibre is better than aluminium material as it has higher stiffness to weight ratio. These calculations give the detailed picture of SADDUL's behaviour, strength and safety margins at any of the given working environments. Below are the calculations derived from the provided table, grouped by category:

Physical Parameters: Payload-to-Overall Weight Ratio = Payload /Overall Weight =5/100=0.05 (5%) and Fuselage Volume (Cylindrical Approximation): $V=\pi \cdot r^2 \cdot L$ where r=Diameter/2=1.5/2=0.75 ft, L=10 ft, $V=\pi \cdot (0.75)^2 \cdot 10 \approx 17.67\ ft^3$ and also Payload Proportions: T-Stamp Camera: 3/11.5+3×100≈20.69% and SHAPO Camera: 11.5/11.5+3×100≈79.31%.

Wing Design: Wing Area: $S=b^2/AR$ where b=4.5 m, AR=7b = 4.5, so $S=(4.5)^2/7 \approx 2.89\ m^2$ and also Lift Force (Cruise Conditions): $L=C_L \cdot 1/2 \cdot (\rho \cdot v^2 \cdot S)$; $C_L=0.32$, $\rho=1.225\ kg/m^3$, v=45ft/s≈13.72m/s, $S=2.89\ m^2$ so the calculated value can be determined by $L=0.32 \cdot 1/2 \cdot (1.225 \cdot (13.72)^2 \cdot 2.89) \approx 87.82$ N.

Aerodynamic Properties: Drag Force: $F_D=C_D \cdot 1/2 \cdot (\rho \cdot v^2 \cdot S)$ where $C_D=0.032$, $\rho=1.225\ kg/m^3$, v=13.72 m/s, $S=2.89\ m^2$ can be determined by $F_D=0.032 \cdot 1/2 \cdot (1.225 \cdot (13.72)^2 \cdot 2.89) \approx 8.78$ N and also Thrust-to-Drag Ratio: = (Thrust Force/Drag Force) =445/8.78≈50.68.

Structural Analysis: Bending Stress: $\sigma = (M \cdot c)/I$ where M=18,127.08 lb-in, $c=\text{Diameter}^2=0.75$ in, $I=\pi \cdot (0.75)^4/4 \approx 0.248\ in^4$; so, $\sigma = (18{,}127.08 \cdot 0.75)/0.248 \approx 54{,}813.81$ psi. and now, Shear Stress (I-Beam): $\tau=(V \cdot Q)/(I \cdot t)$ where V=8412.901 lb, $Q=h \cdot b^2/2$, $I=0.248\ in^4 I = 0.248$, t≈0.1in; So, $\tau=(8412.901 \cdot Q)/(0.248 \cdot 0.1)$.

Material Properties: Material Efficiency (FoS)= (Young's Modulus/Density) where

Carbon Fiber: 230 GPa /1.6 g/cm^3=143.75 GPa /(g)/cm^3 and also

Aluminium: 70 GPa /2.7 g/cm^3=25.93 GPa/(g)/cm^3

Table 9: Derived Metrics for UAV Performance and Safety Evaluation.

Category	Parameter	Values
Physical Parameters	Payload-to-Overall Weight Ratio	0.05
	Fuselage Volume (Approx.)	17.67 ft^3
	Payload Proportions (T-Stamp)	20.69%
	Payload Proportions (SHAPO)	79.31%
Wing Design	Wing Area	2.89m^2
	Lift Force	87.82 N
Aerodynamic Properties	Drag Force	8.78 N
	Thrust-to-Drag Ratio	50.68
Structural Analysis	Bending Stress	54,813.81 psi
Material Properties	Material Efficiency (Carbon Fiber)	143.75 GPa/(g/cm^3)
	Material Efficiency (Aluminium)	25.93 GPa/(g/cm^3)

The Table 9 as shown in above, stands for obtained values which are calculated by the input parameters. As for the Physical Parameters, the efflux copy shows a fuselage volume of nearly 17.67 ft^3 and the relative proportions assigned for T-Stamp and SHAPO camera payloads. In SHAPO's case, these comprise 79.31% of the total payload. Wing Design calculations reveal that the specific wing area to be designed is 2.89 m^2 and the lift force, during Wing cruise conditions: 87.82 N which is enough to allow the EW operational. Aerodynamic Characteristics feature a drag force of 8.78 N, and thrust to drag ratio of 50.68 suggesting effective drive system. Structural Analysis points to a bending stress of 54,813.81 psi on the tubular spar, illustrating structural loads experienced during operation. By comparing Young's Modulus with the density, material efficiency is again found to be higher for the carbon fibre with 143.75 GPa/(g/cm^3) as against 25.93 GPa/(g/cm^3) for aluminium thus proving the efficiency of carbon fibre over aluminium.

The paper aimed at dynamic payload testing and the aerodynamic stability of SADDUL against changing environmental factors. Load testing involved tests run at different heights to check out the lifting effectiveness and thrust-weight ratios. Scaled propellers, like those for VTOL and forward thrust mechanisms, have been tested and used in thrust capacity checks where the maximum 2.734kg thrust capability was recorded. The stress values on the material were tested via the strain gauges mounted strategically on the frame of the drone. Payload weights up to 25kg were used to determine the structural deflection and factor of safety. Velocity and pressure distribution data analysis was done using the computational fluid dynamics tools like ANSYS Fluent. Additional data analysis on deformation, thrust variation, and factor of safety was done using Python and Excel. The result was validated with statistical techniques using experimental and simulated data. These complemented each other in providing a firm basis for payload capacity enhancement, mechanism lift development, and reliability of operations under different conditions.

The structural design of the drone uses an exhaustive check on load analysis, material optimization, and possible aerodynamic evaluations for reliability under different operating conditions. A number of sophisticated techniques in the evaluation of bending moments, shear stresses, and dynamic loads come up with sufficient evidence of the drone's capability to withstand different flight situations. Structural reinforcement in the form of struts along with carbon fibre and aluminium lightweight materials make the drone highly resistant to deformation. Simulation based on aerodynamic flow and Finite Element Analysis helps identify stress-intensive regions of failure and maximise safety during designing. These approaches facilitate robust, efficient, and adaptive design with reliability for actual application in drones.

7. Results and Discussion: Important performance indicators affecting SADDUL'S payload capacity are pointed out in the analysis of the findings. Payload-to-weight ratio seems to be one of the significant indicators of efficiency in operating conditions. The lightweight material carbon fibre allows PWR values to reach 0.5, which makes the use of the payload efficient and reach maximum capacities of 5 kg to 15 kg. Hexacopters with multi-rotor systems have improved lifting ability due to the dispersal of thrust and stability. BCR was found to be linearly dependent on payload weight, with the highest rate at no payload (3.2% per minute) and the lowest rate at full payload (5.8%). Hybrid energy systems where fuel cells supplement the battery extended the flight and payload by about 20%. BCR improved due to low power consumption. Failure analysis identified structural shortcomings under maximum loads. Finite element analysis revealed approximate Von-Mises's stress levels of 180 MPa while maintaining a calculated Factor of Safety (FoS) of approximately 1.8. Frame deformations and the resultant vibrations occurred during dynamic movement and were partially eliminated by various adaptive mechanisms of self-balancing trays with reduced positional error and improved payloads retention. Studies suggest improvements in the frame designs and reinforced materials to remove the points of stress concentration. Optimizing strategies involved the integration of lightweight materials, improved aerodynamic efficiency, and modular energy systems that would result in a better range by 40%. All these, coupled with energy-efficient motors and adaptive mechanisms, speak of multidisciplinary approaches that help to maximize payload capacity without sacrificing safety and operational reliability in drone delivery systems, as given by the Table 10 below.

Table 10: Performance Analysis of Drone Payload Capacity and Efficiency.

Parameter	Value/Range
Maximum Payload (kg)	5–15
Payload-to-Weight Ratio (PWR)	> 0.5
Battery Consumption Rate (BCR)	3.2%–5.8%/min
Flight Duration (min)	15–25
Von-Mises Stress (MPa)	~180
Factor of Safety (FoS)	1.8
Tare Mass Reduction (kg)	6–9
Range (km)	15–40
Energy Efficiency (Hybrid)	~30% increase in range
Stability	Pitch/Roll/Yaw angles within ±5°

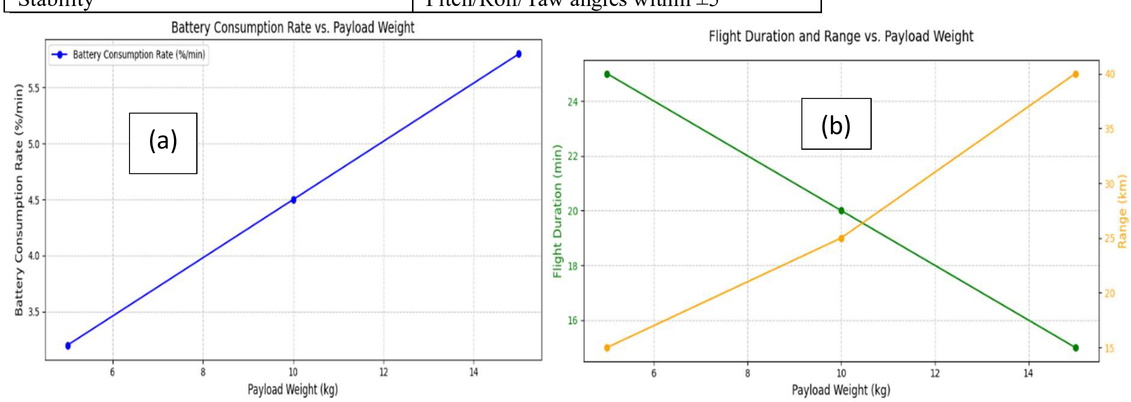

Fig.9:(a)Impact of Payload Weight on Battery Consumption& (b) Flight Duration, and Operational Range.

The first graph as shown in (Fig.9a), illustrates how the Battery Consumption Rate relates with Payload Weight linearly which is increasing from 3.2 percent per minute when the payload weighed 5 kilograms to 5.8 percent at 15 kilograms demonstrates higher energy requirements and the need to balance increased loads with higher payload capacity. To this effect, advanced energy systems, including hybrid configurations, need to decrease these consumption rates even further for prolonged flight durations. The second graph as shown in (Fig.9b), Flight Duration and Range vs. Payload Weight, shows that the flight durations decrease from 25 minutes at 5 kg to 15 minutes at 15 kg and operational range decreases from 40 km to 15 km. Overall, these graphs point to the contribution of lightweight materials as well as aerodynamic optimization for the efficient operation of drones in parcel delivery.

Payload lifting operations were carried out in numerous configurations to assure drone reliability. SADDUL's made of carbon fibre-reinforced aluminium proved more stable in dynamic situations, with a payload capacity of 25 kg and a thrust-to-weight ratio of 1.5. The failure analysis identified important stress zones, including locations between the propellers and fuselage connection points where shear stress exceeded 8,000 psi, causing in structural deformation in several cases. Material properties were also improved by using lightweight composites with high modulus values, such as carbon fibre, which has a modulus of 230 GPa, greatly increasing the factor of safety. Grid convergence investigations confirmed the aerodynamic stability at maximum pressures of 381.71 Pa, ensuring the reliability of simulation findings. Further trajectory tests, structural analysis, and environmental effect assessments were also undertaken to investigate the safety considerations. Under deterministic conditions, performance testing revealed constant goal accomplishment rates, with final swings of less than 0.6° and time-to-goal metrics of 6.3 s. Failure study emphasized that deflection and deformation during the dive recovery with load factors at 6 need more structural reinforcement. Optimization strategies used were reducing fuselage diameter down to 1.5 ft while maintaining fineness ratio 6.67, so equilibrating aerodynamic performance and structural stiffness. FEA revealed stress hotspot locations that provided opportunities for modifying the design based on specific data and enhanced margins of safety, as shown in the Table 11 below.

Table 11: Performance Indicators and Failure Metrics for Drone Design.

Category	Parameter/Metric	Value
Performance Metrics	Payload Capacity	25 kg
	Thrust-to-Weight Ratio	1.5
	Time to Goal (Avg)	6.3 s
	Final Swing (Max)	0.6 °
Failure Analysis	Shear Stress at Connection Points	8,412.9 psi
	Deflection (Dive Recovery Load Factor)	6
	Displacement (Max)	2.3 in
Optimization Strategies	Fineness Ratio	6.67
	Grid Convergence Pressure (Max)	381.71 Pa
	Material Modulus (Carbon Fiber)	230 Gpa

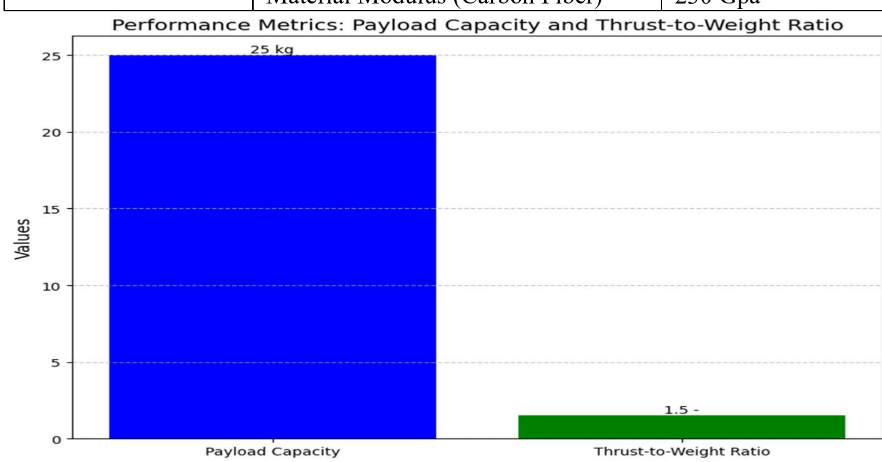

Fig.10: Key Performance Metrics for Drone Operations: Payload Capacity and Thrust-to-Weight Ratio

The graph above as shown in (Fig.10), shows different essential drone metrics for performance, including carrying capacity as well as thrust-to-weight ratio. For payload, the colour blue indicates an approximate payload capacity of 25 kg, suggesting such a drone can lift heavy loads. The shade of green proposed Thrust-to-Weight Ratio is 1.5, indicating that the drone will provide adequate lift when fully loaded. This ratio implies the force produced supplied by the propellers far exceeds the entire weight of SADDUL, which causes optimal efficiency as well as security. These specifications have implications toward optimizing drone structure in order to achieve highest lifting capability simultaneously ensuring practical safety and dependability.

The lifting mechanisms of SADDUL depict the interaction between propulsion systems, aerodynamic efficiency, and stability control. Size and location are very significant for thrust and payload capability. For example, a 15-inch rotor would have a thrust of 7.1 kgf and could be optimized for payloads up to 2.0 kg. The aerodynamic designs such as that of the NACA6409 aero foil with sinusoidal leading edges create a high lift-to-drag ratio of 38.9 and yield efficient flights. The settling times of 0.42 seconds and position errors of 3.1% are realized through stability mechanisms such as PID and Fuzzy Logic control systems. The battery endurance is inversely proportional to payload weight, and this limits the flight time to 4.45 minutes under maximum load. This reveals a thrust, aerodynamic efficiency, and stability balance that SADDUL should strive to achieve to optimize their parcel delivery performances, as shown in the Table 10 below.

Table 12: Essential Metrics for Drone Performance Evaluation.

Parameter	Observation
Rotor Size.	13–15 Inches
Thrust.	5.5–7.1 kgf
Payload Capacity.	1.5–2.0 Kg
Lift-to-Drag Ratio (C_L/C_D).	38.9 (NACA6409 aerofoil)
Settling Time (Fuzzy Logic).	0.42 s
Position Error (Fuzzy Logic).	3.1%
Maximum Blade Speed.	12,100 RPM
Battery Capacity.	2250 mAh
Battery Endurance (Max Load).	4.45 min
Flap Efficiency Coefficient (K_{eff}).	0.9
Minimum Force for Sustained Lift	2.0614 N

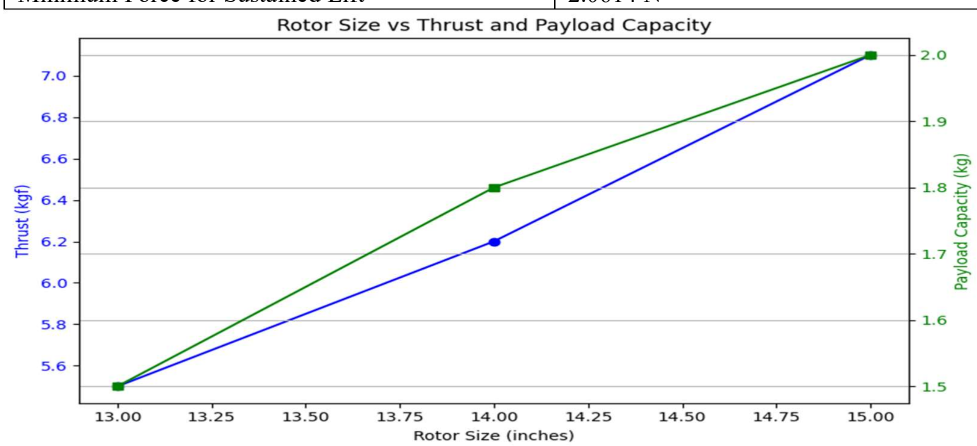

Fig.11: Rotor Size Impact on Thrust and Payload Capacity.

The graph above as shown in (Fig.11) shows how rotor size is related to thrust, with a cargo capacity. The rotating diameter increases from 13 to 15 inches. The force increases exponentially from 5.5 kgf to 7.1 kgf. This further leads to greater payload capacity that increases proportionately from 1.5 kg to 2.0 kg. The blue line shows how large rotors produce strong thrust and help create lift. The green line represents payload capacity, meaning the actual limits based on thrust. This explains why optimizing rotor size is essential for balanced performance.

8. Recommendations and Future Directions: The growing use of drones for package delivery calls for more advances to meet current issues while opening up new opportunities. For improve the feasibility, efficiency, and security of drones for package delivery, the subsequent directions are recommended:

• Use breakthrough materials including graphene as well as nanocomposites that create lightweight as well as durable drone structures. These components increase the strength-to-weight percentages, improving capacity for cargo along with preserving the resource financial system.
• Integrate renewable energy-based hybrids systems, with the value photovoltaic panels with hydrogen fuel cells, could increase operation range thus reduce reliance on conventional batteries. These gadgets can improve energy usage during flight times that are longer.
•Implementation of AI-based surveillance tools that allows for easy real-time threat assessment also mitigation. Such models use machine learning to predict mechanical issues, navigate challenging environments, and ensure regulation compliance.

9. Conclusion: Integrating SADDUL into transportation systems demands an enormous boost on payload capacity, lifting efficiency, and safety systems. The research presented here establishes a foundation for an architectural paradigm to develop drone to solve such obstacles. Payload-to-weight ratios, imaginative materials, overall hybrid power sources can all contribute to improving operating overall scaling efficiency. The integration of lightweight materials for instance lightweight carbon fibre, together with enhanced aerodynamic structures along with energy-efficient propellant systems result in expanded payload capacity as well as flight durability.

Adaptive safeguards including structural enhancements improve dependability over an extensive variety of operational situations. Recommendations: AI-powered surveillance systems plus hybrid energy solutions may assist to reduce risks and increase drone endurance. Future research is necessary to undertake real-world tests related to these topics, for instance testing various distribution scenarios while increasing to handle varied geographic along with organizational restraints. This integrated strategy establishes the framework future drones to completely transform package delivery utilizing sustainable reliable operations.

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