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TOUCHING THE SKIES:

Pioneering Innovations and Cutting-Edge Advances in UAV Design, Control, and Delivery

[1]Srawanee S, [2]Sravanthee S, [3]M. Sreenivasa Rao
[1]Asst. Professor, [2]Asst. Professor, [3]Sr. Professor
[1]Department of Mechanical Engineering
[1]JNTUH, Hyderabad, India

Abstract: This paper provides a comprehensive review of recent advancements and innovations in unmanned aerial vehicles (UAVs), focusing on technological developments in aerospace design, control systems, and optimization techniques. It explores various classifications of drones based on size, weight, range, and endurance, highlighting the latest trends in quadcopter control systems and flight dynamics. The review delves into emergency control, structural reconfigurability, and miscellaneous UAV designs that push the boundaries of current technology. Particular emphasis is placed on drone delivery applications, examining the integration of generative design methodologies and techniques. Through an extensive literature survey, this paper aims to present a holistic view of the multifaceted developments in UAV technology. It offers insights into the future trajectory of drone innovations and their diverse applications.

***Index Terms* - UAV Tech Innovations, Advanced Aerospace Design, Smart Quadcopter Systems, Next-Gen Drone Deliveries, Adaptive Drone Structures, Generative Design Techniques, Precision Drone Optimization, CAD for UAVs.**

I. INTRODUCTION

In numerous critical applications, a highly versatile and efficient tool becomes indispensable. The rapid delivery of medical supplies and food to remote or inaccessible areas, significantly when traffic congestion hampers traditional transport methods, is crucial for saving lives and ensuring well-being. In agriculture, monitoring extensive crop fields swiftly and comprehensively is essential for optimizing yields and ensuring food security. During disaster response, the capability to survey affected regions quickly and gather real-time data is vital for coordinating effective rescue operations. Furthermore, reducing delivery times and minimizing greenhouse gas emissions are imperative for economic efficiency and environmental sustainability.

Aerial transportation is a pivotal solution in these scenarios, offering unparalleled speed and flexibility. Among various aerial systems, unmanned aerial vehicles (UAVs) stand out due to their efficiency, versatility, and adaptability to diverse environments. These UAVs, commonly known as drones, have revolutionized numerous fields by providing rapid and precise solutions that traditional methods cannot match. With their advanced design and optimization, drones present a compelling case for effectively addressing these critical challenges.

Drones are widely used in the military for search operations, disaster management, videography, aerial surveys, consumer goods delivery of food and medicine, tracking on-road containers, and also as toys for kids to play around. With this research, we could make these applications even more effective and open up new possibilities for drone technology.

1.1 Background And Motivation

History, And Evolution of Uavs

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have evolved significantly since their inception. Military applications primarily drove the early developments in UAV technology. The first recorded use of UAVs dates back to World War I, when rudimentary designs like the Kettering Bug, a pioneering UAV designed for surveillance and targeted bombing missions, were developed. This marked the beginning of UAV technology. However, it was not until the late 20th and early 21st centuries that UAV technology saw substantial advancements due to aerodynamics, materials science, and control systems innovations.

The evolution of UAVs has been marked by several key milestones, including the development of the General Atomics MQ-1 Predator in the 1990s, which set a new standard for endurance and surveillance capabilities. The advancement of UAV technology continued with the introduction of multi-rotor designs, particularly quadcopters, which have become popular due to their stability, ease of control, and versatility.

In recent years, UAVs have found applications beyond the military, extending into commercial, recreational, and humanitarian domains. They are used for aerial photography, agricultural monitoring, disaster response, and logistics, among other applications. This widespread adoption underscores the importance and relevance of UAVs in modern times. It also highlights the urgent need for continuous innovation and optimization in their design and development, making the significance of your work even more pronounced.

1.2 Significance Of Quadcopters In Uav Technology

Quadcopters, characterized by their four rotors arranged in a cross-like configuration, offer distinct advantages over other UAV configurations. Their vertical take-off and landing (VTOL) capability and precise hovering and maneuverability make them suitable for various applications. Unlike fixed-wing UAVs, quadcopters can operate in confined spaces and perform tasks that require stable flight at low altitudes.

The versatility of quadcopters has made them popular in various fields. In the commercial sector, they are used for aerial photography, surveying, and infrastructure inspection. In agriculture, quadcopters facilitate crop monitoring and precision farming practices. During disaster response, they provide real-time aerial imagery and assist in search and rescue operations. The recreational use of quadcopters has also surged, with hobbyists and enthusiasts exploring their capabilities for personal enjoyment and competitive events.

Their innovation potential further highlights the significance of quadcopters in UAV technology. Integrating advanced design optimization techniques can enhance their performance, making them more efficient, durable, and adaptable to different missions. This potential for improvement drives the motivation for this research, which aims to leverage generative design and other optimization methods to create a high-performance quadcopter UAV.

II. CLASSIFICATION OF DRONES

Drones, also known as unmanned aerial vehicles (UAVs), are classified based on size and weight, range and endurance, application, wing configuration, level of autonomy, number of rotors, and rotor configuration. Each classification is described below.

2.1 Classification based on Size and Weight:

Nano Drones: Weighing less than 250 grams, these drones are used for recreational purposes, indoor use, and simple tasks like photography.

Micro Drones: With a weight range of 250 grams to 2 kilograms, these drones are ideal for hobbyist activities, small-scale photography, and research.

Mini Drones: Weighing between 2 and 20 kilograms, mini drones are used for commercial photography, inspection, and minor delivery tasks.

Small Drones: Weighing from 20 kilograms to 150 kilograms, small drones are utilized in agriculture, surveillance, and environmental monitoring.

Medium Drones: With a weight range of 150 kilograms to 600 kilograms, these drones are used for military applications, extensive surveying, and industrial tasks.

Large Drones: Weighing over 600 kilograms, large drones are employed for cargo transport, long-range surveillance, and heavy-duty industrial operations.

2.2 Classification based on Range and Endurance:

Very Short-Range Drones: These drones have a range of up to 5 kilometers and an endurance of less than 30 minutes, making them suitable for indoor use, proximity tasks, and recreational flying.

Short-Range Drones: With a range of 5 to 50 kilometers and an endurance of 30 minutes to 2 hours, short-range drones are used in agriculture, minor inspections, and short-distance deliveries.

Medium-Range Drones: These drones have a range of 50 to 200 kilometers and an endurance of 2 to 6 hours, making them ideal for surveillance, large-area mapping, and medium-distance deliveries.

Long-Range Drones: With a range of 200 kilometers to 800 kilometers and an endurance of 6 to 24 hours, long-range drones are used for extensive surveillance, search and rescue operations, and large-scale agricultural monitoring.

Very Long-Range Drones: These drones have a range of over 800 kilometers and an endurance of more than 24 hours, making them suitable for military operations, long-haul cargo transport, and persistent surveillance.

2.3 Classification based on Application:

Recreational Drones: Used for hobby flying, personal photography, and recreational activities.

Commercial Drones: Employed for aerial photography, real estate, media, and event coverage.

Agricultural Drones: Utilized for crop monitoring, spraying, soil analysis, and precision agriculture.

Industrial Drones: Used for infrastructure inspection, construction monitoring, and industrial surveying.

Surveillance Drones: Employed in law enforcement, border patrol, and security monitoring.

Delivery Drones: Used for package delivery, medical supply transport, and logistics.

Environmental Drones: Utilized for wildlife monitoring, ecological research, and disaster response.

Military Drones: Employed for reconnaissance, combat missions, surveillance, and target acquisition.

Search and Rescue Drones: Used for disaster response, locating missing persons, and delivering emergency supplies.

2.4 Classification based on Type of Wing Configuration:

Fixed-Wing Drones: With an airplane-like design and wings, these drones are used for long-range missions, surveillance, and mapping.

Rotary-Wing Drones: Featuring a helicopter-like design with one or more rotors, these drones are ideal for vertical take-off and landing, precise hovering, and urban environments.

Hybrid Drones: Combining fixed-wing and rotary-wing designs, hybrid drones are used for versatile missions requiring both long-range flight and vertical take-off/landing.

2.5 Based on Level of Autonomy:

Manual Drones: Fully controlled by a human operator, these drones are used for recreational purposes, training, and basic commercial applications.

Semi-Autonomous Drones: Combining manual control with automated functions, these drones are suitable for complex tasks requiring human intervention, such as inspections and surveillance.

Fully Autonomous Drones Operate independently based on pre-programmed instructions or real-time data. These drones are used for long-range missions, persistent surveillance, and advanced commercial applications.

2.6 Classification based on number of rotors:

Single-Rotor Drones:

Single-rotor drones, with a main and tail rotor, are efficient, long-flying, and can carry heavy payloads. However, they are complex and prone to mechanical failure.

Dual-Rotor Drones:

Dual-rotor drones have two rotors, usually placed in tandem or side-by-side. They provide increased lift capacity and are suitable for carrying heavier loads.

Tri-Rotor Drones:

Tri-rotor drones have three rotors, usually arranged in a triangular configuration. They offer better stability and redundancy than single-rotor drones. However, they are less common and may have balance issues.

Quadcopter Drones:

Quadcopter drones have four rotors arranged in a square or rectangle. They provide high stability, are easily controlled, are widely available, and are versatile. However, they have limited lift capacity compared to drones with more rotors.

Hexacopter Drones:

With six rotors, hexacopter drones offer greater lift and stability, remaining stable even if one rotor fails. However, they are more complex and expensive and have shorter flight times due to more motors.

Octocopter Drones:

Octocopter drones have eight rotors arranged in an octagonal configuration. They offer the highest lift capacity and maximum stability and can carry heavy payloads with redundancy. However, they are the most complex and expensive and have the shortest flight time due to high power consumption.

Multicopter Drones (More than Eight Rotors):

Multicopter drones have more than eight rotors, such as decacopters (ten rotors). They offer extreme lift capacity, exceptional stability, and high redundancy. However, they are very complex, expensive, and have limited battery life due to high power consumption.

2.7 Classification based on rotor configuration:

Coaxial Rotor Drones:

Coaxial rotor drones have two rotors stacked one above the other on the same axis, rotating in opposite directions.

Tricopter Configuration:

Tricopter drones have three rotors, usually with one rotor at the front and two at the back, with the rear rotors tilting for yaw control.

Quadcopter Configuration:

Quadcopter drones have four rotors, typically in an "X" or "+" configuration.

Hexacopter Configuration:

Hexacopter drones have six rotors, typically arranged in a hexagonal pattern.

Octocopter Configuration:

Octocopter drones have eight rotors, typically in an octagonal configuration.

Tandem Rotor Configuration:

Tandem rotor drones have two large rotors, usually mounted one in front of the other on the drone body. They offer increased lift capacity and efficient power use but have complex control systems and larger sizes.

Tiltrotor Configuration:

Tiltrotor drones have rotors that can tilt to transition between vertical take-off/landing and forward flight. They offer vertical take-off and landing capability combined with efficient forward flight but have complex mechanics and higher maintenance needs.

Hybrid VTOL (Vertical Take-off and Landing) Configuration:

Hybrid VTOL drones combine fixed-wing and rotor-based designs, allowing vertical take-off and efficient forward flight. They offer vertical take-off/landing, long-range flight, and versatile mission profiles but are complex and higher in cost.

Cyclocopter Configuration:

Cyclocopter drones use cycloidal rotors (blades rotating around a horizontal axis) for lift and control. They offer precise control and the ability to generate thrust in any direction but have a complex design and are less common.

2.8 Reasons for the Popularity of Quadcopters:

The quadcopters are the most widely used among all the types of drones. This popularity spans both consumer and commercial applications due to several key factors, as listed below:

Quadcopters are popular due to their ease of control, affordability, versatility, availability, portability, and community support. Their four-rotor design offers stable flight and simple maneuverability. They are cost-effective to manufacture and maintain, with models available for various budgets and uses, including photography, agriculture, and search and rescue. Many are compact and portable, with foldable arms for easy transport.

Typical Applications of Quadcopters:

They are commonly used for inspection and surveying, agriculture, search and rescue operations, food and medicine delivery, aerial photography and videography, and recreational purposes like toys.

Types of Configurations in Quadcopter:

1. Plus (+) Configuration has four rotors arranged in a plus shape, with one rotor at the front, one at the rear, and one on each side. It is easy to control but has less stability in yaw compared to the X configuration. It is used as a basic hobbyist drone for simple photography and educational purposes.

2. X Configuration has four rotors arranged in an X shape, with each rotor positioned at the corners of an imaginary X. This design provides better stability and more balanced control in all directions, and it is a common one for many applications. It is generally used for recreational flying, professional photography, inspection, and versatile commercial applications like delivering food and medicines.

3. H Configuration has four rotors arranged in an H shape, with a central body connecting two pairs of rotors. The model will have a clear distinction between front and rear, good stability, and ample space for mounting cameras and sensors, but the frame structure is complex and potentially heavier. This is used for professional photography, videography, and applications requiring clear front-facing orientation.

4. V-tail configuration has two front rotors in a standard position and two rear rotors angled upwards to form a V shape. This unique design offers distinctive yaw control and aesthetic appeal. It has more complex flight dynamics and is used for specialized applications, experimental designs, and hobbyist drones.

5. Deadcat (Stretched X) Configuration has front rotors positioned wider apart than the rear rotors, forming a stretched X shape. It is optimized for aerial photography and videography and minimizes propellers in the camera's field of view, but it is less common for general applications.

6. Y4 configuration has four rotors, three of which are positioned in a Y shape, and the fourth rotor is located centrally at the rear. It combines aspects of tricopter and quadcopter designs and has unique control dynamics. Due to the complexity of controlling, it is less common. It is used as an experimental design and in niche applications requiring specific flight characteristics.

III. LITERATURE REVIEW

The literature survey is classified based on the following research areas in drone technology:

1. Technological Advances and Innovations in Aerospace Design
2. Computer-Aided Design and Modeling Techniques for Drone Design and Optimization
3. Quadcopter Control Systems and Flight Dynamics
4. Emergency Control and Structural Reconfigurability
5. Miscellaneous UAV Designs
6. Drone Delivery Applications
7. Generative Design Methodologies and Techniques

3.1 Technological Advances and Innovations in Aerospace Design:

Andrea Ponza et al. [1] formulated drone-assisted parcel delivery through the trucks as mixed integer programming. The problem was solved with the Simulated Annealing metaheuristic to provide suitable solutions for real-world applications using the combination of truck and drone instead of truck-only delivery.

Sven Maricic et al. [2] implemented optimum additive technologies design for unmanned aerial vehicle by comparing commercial drones with the shape optimized drone to produce a high rotor distance-to-weight ratio and achieve better take-off weight than commercial drones

K. Anilkumar et al. [3] conducted live tests to study discrepancies between the theoretical and experimental values of flight time and load-bearing capacity.

Prajwalkumar et al. [4] modeled a quadcopter to carry heavy payloads. Structural and aerodynamic analyses were performed, and the best design was manufactured. Aluminum, carbon fiber, and balsa wood are considered to make quadcopters. During fabrication, the simulation results accurately matched the experimental results.

Nagadurga Srinivas Sripada [5] applied a topology and lattice structure optimization methodology of a cargo drone motor mount to reduce the component's total mass and displacement with minimum compliance constraints. NURBS surfaces are used in topology-optimized results and are also manufacturable. The tetrahedral lattice structures impart strength while being lightweight.

Swapnil Yemle et al. [6] designed a multi-functional frame by replacing the carbon fiber pipe with an aluminum pipe to reduce the weight and cost of the octocopter frame. The design is made given manufacturability and ease of assembly, converting the frame from quadcopter to octocopter without compromising the assembly of payload, battery, motors, propellers, electronic control units, etc.

Pan Wei et al. [7] designed a quadcopter frame to study the role of finite element analysis in design. The frame's static analysis has significantly improved the understanding of the design criteria.

Omkar Tatale et al. [8] studied the stability of quad configuration compared to others from the perspective of engineering principles in terms of balancing and stability. They identified that quad has more excellent stability than other configurations.

Akash et al. [9] conducted several analyses on different UAVs to find the most effective and stabilized design with a better place for assembly components and better payload capacity at a lesser weight with propeller guards. The analysis also identifies UAVs that require less maintenance and are fit for multiple applications.

Yukai Chen et al. [10] presented a model for finding the battery's non-linear characteristics to estimate its actual state of charge. For this purpose, several simulations of different delivery tasks are made using varying distances traveled, payloads carried, and horizontal speeds.

Ganesh Redde et al. [11] conducted an experimental investigation to analyze the vibration stability of the quadcopter frame and propeller. The analysis was made to find the thrust coefficient, power coefficient, and efficiency for a low advance ratio. As per the experiments, the analysis results are satisfactory and reliable, which is crucial for drone working conditions.

Endrowednes et al. [12] modeled and analyzed a quadcopter frame. The analysis helped identify the right rotor and propeller to achieve flight acceleration. The resulting thrust and the distance between each rotor propeller, apart from the frame rigidity, influence quadcopter flight stability.

Ahmed et al. [13] designed a quadcopter considering its important aerodynamics aspect, of which modeling and analysis are two key areas involved in its manufacturing. Modeling and analysis of the proposed design were safe with minimal deformations.

Nvss et al. [14] applied a structural compliance matrix and mass matrix to obtain the optimum product design layout. The developed topologically optimized unified quadcopter structure reduced the assembly time to zero and achieved superior structural integrity. Integrating topology optimization and additive manufacturing has proved to be a practical approach to reducing weight.

3.2 Computer-Aided Design and Modeling Techniques for Drone Design and Optimization:

Javir et al. [15] studied the aerodynamic effects of the quadcopters in terms of all the aspects of quadcopter, starting from mechanical design to electronics being used. A theoretical investigation is carried out to compare the results obtained from finite element analysis of the frame designed.

Driessens et al. [16] constructed a four-rotor configuration named ‘Y4’ or ‘triangular quadrotor. It has a single fixed-pitch main rotor and three smaller rotors on booms, providing counter-torque and maneuverability. This reduced the power required for hovering by 20% compared to a conventional quadrotor.

Yee Ling Yap et al. [17] applied topology optimization to produce an optimized structure of a lightweight quadcopter made of PA12 material with a Z-split configuration. The obtained design was 3D-printed and tested to validate FE simulation results based on static loading conditions.

Swarna et al. [18] optimized the design of a drone jammer antenna made of Al alloy 6061, with a suitable fixture based on the antenna's center of gravity, to reduce stresses and deformations that occur in the drone antenna while jamming the communication system.

M Urdea [19] simulated to analyze the static conditions of the drone frame in various situations. Dynamic analysis was also conducted to explore the simulations in multiple conditions and find aerodynamic forces like lift. The drone frame was also analyzed to determine its vibrational stability.

MohamedZain et al. [20] simulated a drone to determine its parts' stress, displacement, and weight. In addition, the concept shapes generated were compared by performing a trade-off study, where the weight of the part should be low enough without sacrificing structural strength. The variants assessed were the parts' mass, displacement, and stress.

Ivan Palinkas et al. [21] worked to optimize the drone by optimizing the drone arm. PLA and ABS thermoplastic materials were considered for drone arms with different shapes to achieve higher rigidity with a lesser mass.

Ali Magdi Sayed Soliman et al. [22] conducted experiments to see how drones can fight fire using a remote-controlled rotary wing made of metal alloys. A payload drop mechanism was used to carry and drop fire extinguishing balls in the affected area, and the drone was proved successful.

Muhammad et al. [23] designed quadrotor frames using Aluminum casting type A356.0-T6.0-T6, using a standard frame design from the market. They saw a good improvement in the strength of the design, a high safety factor, and little Von Mises stress compared to what is available in the market, and found that Aluminum casting is a good choice.

S. Meivel et al. [24] worked to design and develop a quadrotor utilizing aluminum throwing type A356.0 T6.0-T6, which is more economical than the models available on the market. A design that gained high factor of safety and less von mises stress is obtained with this material.

Mohammad Shaqura et al. [25] developed an automated software system for designing and modeling quadcopter UAVs. The application uses a user interface to determine the difference between quadcopter simulations and actual experimentation.

T.R. Costa et al. [26] presented the development of an optimized MAV frame. Topological optimization allowed the study of complex geometries, reaching improved structural properties. Minimizing compliance enabled the optimization of geometry for the loads considered here.

Jed Flippin [27] designed, analyzed, and tested a 3D-printed drone frame to meet all functional requirements presented. All 3D-printed parts have been designed and manufactured according to the specified design. All parts were tested to withstand routine flight and crash conditions.

He Zhu [28] used traditional techniques, CFD, and experiments to enhance octocopter drones' aerodynamic efficiency and performance. Five different models were considered, and CFD simulations were used to investigate the impact of rotor blade size, wind effects, and rotor interference. The new design proved to be successful.

A. Le Pape [29] optimized blade shape parameters such as twist, chord, sweep, and anhedral distribution. The method was validated and tested with the ERATO rotor, whose demonstration proved effective.

Spyridon G. Kontogiannis [30] discussed developing and evaluating a lightweight UAV for aerial photography, urban mapping, and traffic monitoring. Aerodynamic and stability analyses were conducted, and propeller performance was assessed.

Boschetti [31] employed a multifaceted strategy that combined theoretical analysis of aerodynamic drag, extensive wind tunnel experiments with scale models, and a numerical model based on Prandtl's Lift Line Theory to enhance the ANCE design. Adjustments to the landing gear and wing tip twist resulted in a theoretical efficiency gain and an experimental increase, with drag reductions.

Andrzej Majka [32] applied advanced optimal design methods to address the growing importance of improving UAV technical and performance efficiency. This work involved developing a precise calculation model, identifying critical parameters, establishing limits, and selecting optimization criteria.

Wei [33] examined recent progress in optimization methods employing neural networks and polynomial-based response surfaces. This covered topics such as constructing response surfaces, designing economical experiments, and optimizing procedures while comparing the effectiveness of polynomials and neural networks.

Zhu [34] reviewed recent advances in topology optimization, focusing on density-based approaches for designing aircraft and aerospace structures. The review identified ongoing opportunities and challenges in applying topology optimization to more demanding scenarios.

3.3 Quadcopter Control Systems and Flight Dynamics:

Kyaw Myat Thu et al. [35] designed and modeled a quadcopter system using L1 adaptive control. This control system catered to the real-world flight system, where the feedback mechanism is of utmost importance for the full benefit of flight, which was easy to apply.

Gene Patrick et al. [36] modeled and implemented quadcopter autonomous flight based on alternative methods to determine propeller parameters. The study applied different strategies to find different thrust and torque relationships of the quadcopter's propellers to study the aerodynamics.

Gordana Ostojić et al. [37] represented the development of a quadcopter system with hovering stability. Empirical methodology is used to develop control algorithms for quadcopter systems.

Waqas Malik et al. [38] developed an intelligent quadcopter using mathematical models and control algorithms. This work aimed at improving the quadcopter's stability. A drone's stabilization factors are obtained by simulating angular velocities and displacements. The final design achieved improved flight dynamics and stability.

Lee et al. [39] developed the mechanics and control of quadrotors for tool operations, such as using a screwdriver and vertical jack attached to the quadrotor. The controls were operated without compromising the system's dynamic stability. Theoretical results validated simulated results.

Hoffman [40] designed, fabricated, and tested a quadcopter aiming to optimize performance. Parameters such as rotor diameter, motor specifications, electrical systems, frame, and control system design were considered. Adjustments to the landing gear and wing tip twist enhanced efficiency and reduced drag.

Oosedo [41] presented the design of a quadrotor tail-sitter combining quad rotors with a fixed wing to enable both helicopter-like hovering and airplane-like cruising. The simulations revealed that the proposed UAV uses about half the power during level flight as it does when hovering and can travel three times the distance of a conventional quad-rotor helicopter, emphasizing its enhanced energy efficiency.

S.Selvaganapathy [42] developed an autonomous human organ drone delivery system designed to locate and land at designated stations while transporting organs. This system bypasses traffic and extends its operational range by using recharging checkpoints. It includes PID stabilization, lift and monitoring sensors, live transmission remote control, and sonar technology for detecting and avoiding obstacles.

3.4 Emergency Control and Structural Reconfigurability:

A. R. Merheb [43] proposed a fault-tolerant control strategy for quadrotors facing a complete actuator failure by converting them into tri-rotors. The presented approach redistributes control efforts to the functioning rotors using a standard PID controller, allowing the UAV to continue its mission or execute an emergency landing despite actuator loss. Experiments with the AR Drone 2 was successful.

D. Vey [44] examined the reconfigurability of four- and six-rotor UAVs when faced with rotor blockage or loss. This work presents a structural reconfigurability analysis method, showing that quadrotors cannot maintain hovering with a failed rotor. In contrast, hexrotors' ability to manage rotor loss depends on rotor configuration.

3.5 Miscellaneous UAV Designs:

A. Samba Siva [45] presented the research and development of a Mini Unmanned Aerial Vehicle (UAV), including its implementation with sensors, a small camera, ZigBee, and a microcontroller. Key performance parameters such as lift, drag, centrifugal force, endurance, and altitude were evaluated, and the results were satisfactory.

Ram Rohit Vannarth [46] designed a UAV with a payload fraction of 0.7 and a weight of 350g, using XFLR5 software for 2D airfoil analysis. This research provided analytical methods used in the UAV's design, and the outcomes were satisfactory.

Raja Sekar [47] presented the structural design, analysis, and optimization process for reducing the weight of a UAV wing. The work focused on a semi-monocoque wing structure, optimizing components like ribs, spars, and skin for minimal weight while maintaining strength. The optimization process significantly reduced the wing's weight while improving the strength-to-weight ratio.

Abdus Samad [48] optimized a medium-sized surveillance UAV wing, focusing on aerodynamic and structural analysis. The wing's design was assessed using SolidWorks and Design Foil software to simulate aerodynamic and structural loads, and the model succeeded.

Tomáš [49] designed a control law for a quadcopter prototype for indoor flights. The prototype lacked autonomous control loops and used camera vision as a navigation reference. The developed control system was successfully implemented and tested on the real quadrotor.

Saifur Rahman Bakaul [50] presented the design and fabrication of a micro-class UAV that maximizes payload with minimum weight. The design incorporated multidisciplinary optimization to balance weight and performance and improved payload capacity, validated by wind tunnel and flight tests.

Varadaramanujan [51] proposed integrating a quadcopter drone with an end-effector arm to lift and pick fruits from elevated positions. The design includes an end-effector with suction cups for improved grip and a manually adjustable stationary arm. The drone is successfully being controlled remotely.

Bappy, Reasad [52] simulated drone operations to study roll, pitch, and yaw control using a 2.4 GHz RF transmitter and receiver that provides live audio-visual feedback and GPS tracking through an Android device. This work enhanced surveillance capabilities to deliver lightweight products while providing real-time monitoring and video transmission.

Olaiya O. [53] designed a drone for agricultural purposes to carry a payload of about 3 liters, allowing for safer, more efficient spraying from a distance, reducing health risks, labor, time, and costs. The drone could improve crop production and reduce chemical waste by enhancing accuracy and resource management.

Saric [54] designed and analyzed hexacopters using real components. Analytical load calculations for the landing and take-off mechanisms were conducted with accurate load data and were validated successfully by the FEM analysis conducted.

M. Aswath [55] developed and conducted a dynamic analysis of a hexacopter prototype. The study examined the hexacopter's stability in flight with and without payloads. Implementing and verifying computer vision algorithms and visual SLAM for environmental localization were also successfully completed.

H. X. Pham [56] presented a framework using reinforcement learning (RL) for UAVs to conduct search and rescue missions in unknown environments. The UAVs were trained with a PID+ Approximated Q-learning algorithm and successfully navigated to locate missing persons without needing a precise environmental model. The study demonstrated the algorithm's effectiveness successfully.

G. Capitta [57] designed and analyzed a 7.5-meter airship drone for transporting natural gas. This work highlighted the drone's structural and technical features, like autonomy, cargo capacity, energy efficiency, and environmental impact. It concludes that advances in materials and technology will improve its safety and performance.

3.6 Drone Delivery Applications:

Nguyen [58] studied the effect of personal innovativeness, outcome expectancy, anticipated emotions, and perceived risk on customer willingness to use drone delivery services in Vietnam. Six hundred-two survey responses were analyzed, and it identified that outcome expectancy has the highest impact on customer willingness to use drones for delivery.

Xu [59] explored delivery drones' current and future state, focusing on technological advancements, design challenges, and operational factors. The work covered propulsion, navigation, and payload capacity innovations, addressing safety, range, and environmental impact. The report reviewed regulatory frameworks, safety standards, practical considerations like logistics and cost-effectiveness, and anticipated future trends in drone technology and its delivery applications.

Stolaroff [60] considered multi-copters in the range of about 4km. It is emphasized that although drones consume less energy per package-km than delivery trucks, the additional warehouse energy required and the longer distances drones travel per package significantly increase the life-cycle impacts. This work suggested that drone-based delivery could reduce greenhouse gas emissions and energy consumption.

Aniket [61] reviewed the delivery drone market, explored several opportunities and barriers, and advocated the application of drones for lightweight package deliveries. It featured a quadcopter (QC) equipped with an Android device for navigation and demonstrated its ability to deliver packages and return to the starting point.

Tsouros [62] explored the role of emerging technologies like the Internet of Things (IoT) in smart farming and precision agriculture for real-time environmental data acquisition. This work presented the recent UAV applications in Precision Agriculture, data acquisition methods, and image processing techniques, mentioning the advantages and limitations of each.

3.7 Generative Design Methodologies and Techniques:

Mariam Md Ghazaly et al. [63] focused on designing a 6-axis UAV drone structure using generative design to optimize materials and manufacturing methods, thereby reducing costs and design time. It achieved an optimized maximum stress, maximum displacement, and production time, which were advantageous compared to traditional designs, apart from enhancing weight optimization.

Jerrin Bright et al. [64] studied a generatively designed frame and found it has minimum displacement compared to a traditionally designed drone frame. The generative designing technique, along with additively manufactured frames, yields better frames with improved resistance to fracture and minimum displacement compared to the traditionally designed DJI flame wheel F450 drone frame.

Martin Pollák et al. [65] worked on utilizing generative design tools to design components necessary for 3D printing done by a robot. This work mentioned several software procedures to obtain generative design. It resulted in favor of generative design as it is proven to have high potential to become a sought-after tool for component development and production.

Emmanuel et al. [66] applied generative design, an evolutionary approach to developing robotic manipulators. Their work contributed to an approach for designing connected and rapid prototyped robotic manipulators. The methodology considered software and hardware development required for implementing a robotic manipulator. Using this approach, the links between robot joints are designed.

Nikos Ath. Kallioras et al. [67] investigated the difference between the generative design approach and the shape optimization technique. They found that generative design is based on deep learning. It can produce a population of prototype designs, with the only necessary inputs being the domain dimensions, the support and loading conditions, and the desired final volume. It can propose designs that satisfy all designer-defined constraints in an automated procedure.

Jelena et al. [68] applied generative design for large-scale nonhomogeneous structures. This work illustrated the methodology for the application-driven design of non-homogeneous structures with tailored responses to different external load conditions. The applied generative and parametric design methods produced lightweight structures apart from maintaining structural integrity.

S. Bagassi et al. [69] contributed to finding the workings of generative design with respect to topological optimization. Generative design is a novel approach to automatically optimizing component design, in which the design process has to be designed to achieve the optimal solution within the specified design parameters, requirements, and limitations.

Wojciech Skarka et al. [70] used generative modeling methods to design thin-layer composite load-bearing aircraft structures. Automating UAV wing design allowed for early identification of optimal solutions and verification of structural strength, buckling, instability, rigidity, and aeroelasticity. The approach was demonstrated by designing a super-light, ultra-flexible wing for a high-altitude Endurance UAV.

Tristan Briard et al. [71] proposed a methodology for generative design for additive manufacturing in the automotive industry. The work proposed a generic workflow for generative design tools alongside the challenges it poses while developing a new design for additive manufacturing methodology. A seatbelt bracket was selected to test the method, which was successful.

Vinay Yadav et al. [72] applied generative design principles to optimize UAV frame structure. With the advent of additive manufacturing techniques, it is possible to manufacture any design. The work created a unique design by applying a generative design algorithm, which was far more durable than that obtained by traditional design principles.

Srawanee et al [73] [74] applied shape optimization design to create a quadcopter and obtained a better model compared to traditional design concepts. The simulation results in terms of structural analysis and vibrational analysis were satisfactory alongside keeping the weight of the component low.

Srawanee et al [75] applied generative design to create a quadcopter and obtained a better model compared to traditional design concepts. The stress analysis results were satisfactory, and the displacement analysis results were excellent. The results were within limits while reducing the total weight of the component.

IV. TAKEAWAYS FROM LITERATURE REVIEW

The literature review shows that researchers have focused more on reducing the weight of the component by varying different parameters. The parameters include different materials used and different design ideas. The literature review shows the importance of design optimization methodologies for obtaining optimal designs to obtain lightweight components without sacrificing the structural strength of the component. The summary of a study of the literature is pictorially represented in Figures 1, 2, 3, 4, and 5.

Figure 1 shows the different types of UAVs that various researchers have considered and researched. As per the literature review, quadcopters are mainly considered for domestic purposes, while octocopters are primarily used for agricultural purposes, which carry heavier payloads.

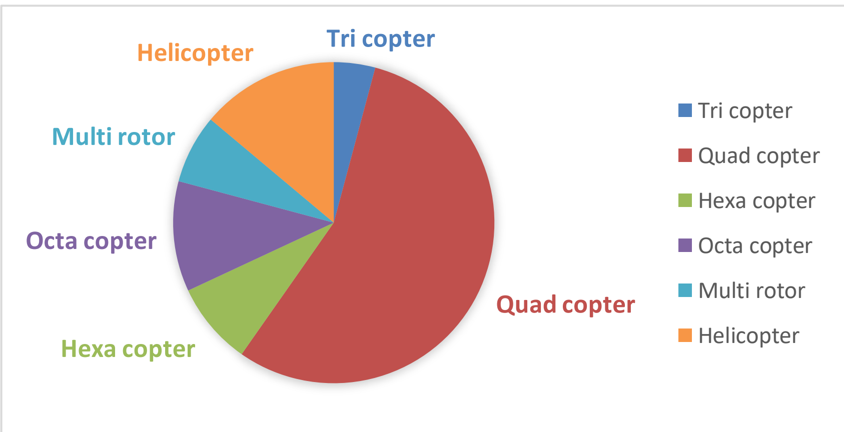

Fig 1 Different types of UAVs used by various researchers

Figure 2 illustrates different types of materials used to manufacture different drone frames. Most drones available commercially in the market are made of carbon fiber. Most of the research is focused on Aluminium alloys and plastics.

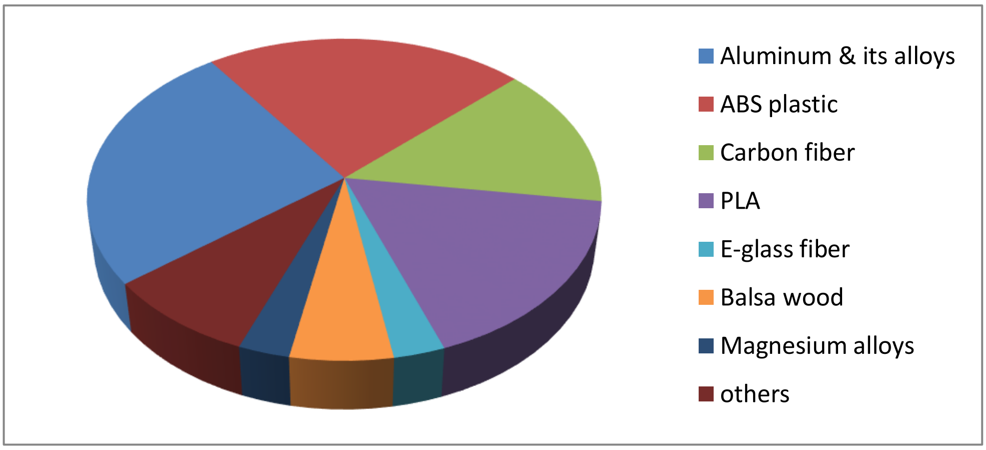

Fig 2 Different materials used for making drone frame

Different types of configurations are used by various researchers, which is illustrated in Figure 3. It can be seen that of all configurations, X configuration is majorly considered by several researchers.

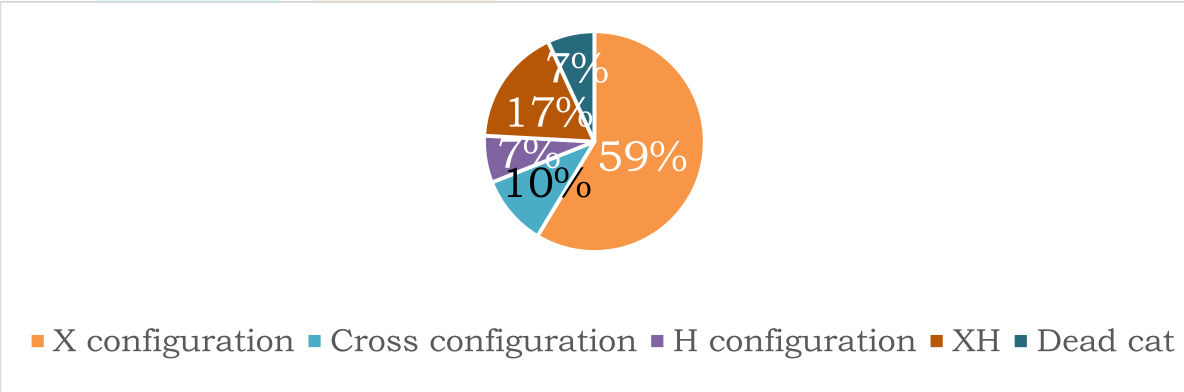

Fig 3 Different configurations applied to Quadcopters

Different researchers employ many methodologies, and the researchers are developing and employing several design optimization strategies like topology optimization, mathematical modeling, and generative design. Optimization is applied in several dimensions, like electronics, control systems, etc. Figure 4 illustrates the techniques used by various researchers to optimize the design of structural components, majorly for weight reduction in aerospace applications. Often, researchers redesign to obtain a stiffer and lighter design, for which most researchers focus on reducing the maximum deformation, stress, and component mass, as seen in Figure 5.

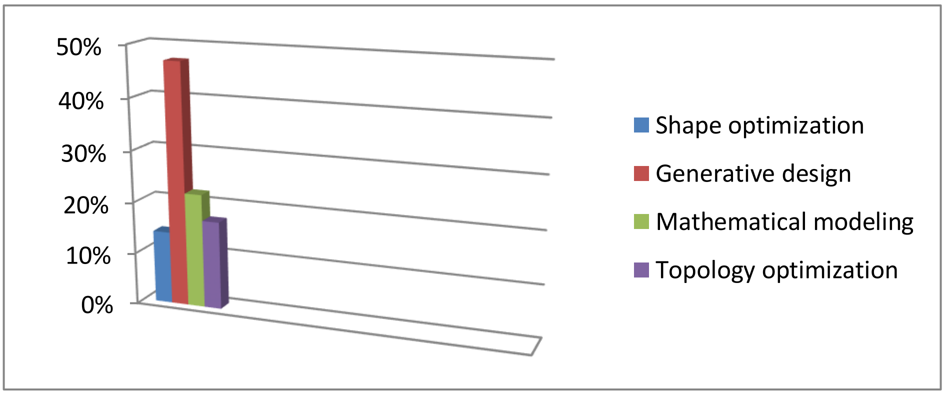

Fig 4 Various methodologies applied for design optimization of frames

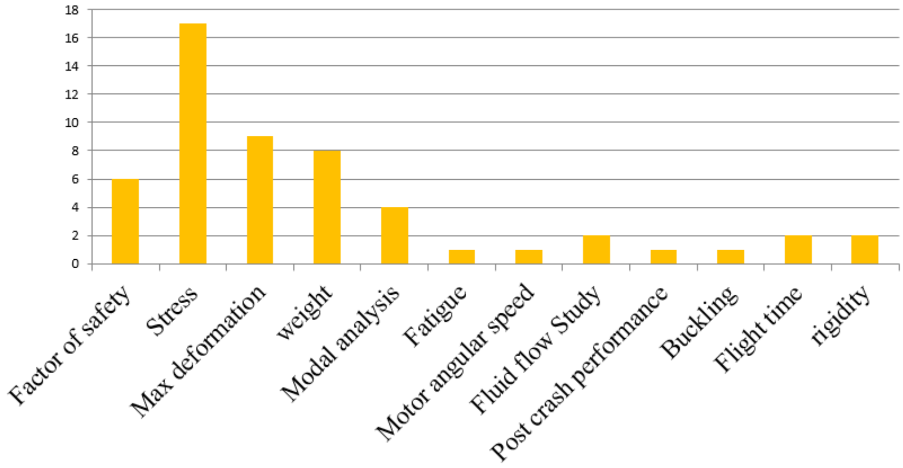

Fig 5 Significant parameters that affect the performance of drones

V. CONCLUSIONS

Despite drones' significant advantages, their current applications have notable limitations. Payload capacity and the physical size of drones are critical factors that significantly influence their effectiveness in various applications. Most commercially available drones are designed to carry relatively lightweight payloads, typically ranging from a few hundred grams to a few kilograms. This limitation restricts their ability to transport heavier items such as medical equipment, larger food supplies, or substantial agricultural inputs. Consequently, their utility in critical delivery services is often constrained by the weight and volume of the cargo they can handle.

The size of the drone also plays a crucial role. Smaller drones, while more agile and accessible to deploy, have limited payload capacities and shorter flight durations. On the other hand, larger drones, which can carry heavier loads and have longer flight times, often face operational challenges such as requiring more space for take-off and landing, increased visibility, which can affect stealth operations, and stricter regulatory controls. Additionally, larger drones are more susceptible to adverse weather conditions, which can compromise their stability and performance.

VI. SCOPE FOR FUTURE WORK

To fully leverage the potential of drones in critical applications, advancements in payload capacity and drone size must address these limitations. Innovations in materials, reducing the size and weight of drones with improved payload capacity, sturdy frames that are stable in adverse weather conditions, and aerodynamics are essential to enhance the performance and reliability of drones, enabling them to carry out more demanding tasks effectively.

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