Conceptual Design and Analysis of a Rotorcraft UAV-Based Payload Deployment System

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ABSTRACT

The increasing adoption of unmanned aerial vehicles (UAVs) in defence and security operations has created a demand for reliable and precise payload delivery mechanisms. This project focuses on Conceptual Design and Analysis of a Rotorcraft UAV-Based Payload Deployment System capable of carrying and releasing multiple payloads in a controlled and safe manner. The proposed system is intended for integration with a multirotor UAV platform and is designed to minimize aerodynamic imbalance, structural stress, and interference with the drone's flight control and endurance. The project involves the development of 3-payload and 6-payload variants compatible with a hexacopter UAV, specifically the EFT E616P platform. An Experimental Payload Unit (EPU) is considered for the study, with design assumptions made due to confidential operational data. The mechanism incorporates a conveyor system, screw-based positioning mechanism, servo-actuated claws, and a dropper assembly to ensure accurate alignment and sequential release of payloads. An independent release-control unit with isolated power supply and battery management system (BMS) is employed to ensure safe operation without affecting the UAV's onboard electronics. Detailed CAD modelling using SolidWorks and Analysis by using ANSYS software was carried out for the mechanical structure, payload housing, and mounting arrangements. The electronic architecture includes microcontrollers, stepper motors, servo motors, power distribution boards, and communication interfaces to enable precise control and synchronization with the flight controller. Emphasis is placed on modular design, universal mounting compatibility, vibration isolation, and centre-of-gravity management to maintain UAV stability during flight. The project outcomes include validated conceptual designs, electronic architecture planning, safety considerations, and a structured work plan for fabrication and testing. The developed system demonstrates the feasibility of a scalable, reliable, and safe payload-release mechanism for rotorcraft UAVs, with potential applications in defence training, research, and future autonomous aerial delivery systems.

Keywords— Unmanned Aerial Vehicles, Battery Management System, Experimental Payload Unit, Payload Deployment System.

1 Introduction

Unmanned Aerial Vehicles (UAVs) have gained significant attention in recent years due to advancements in lightweight materials, embedded electronics, navigation systems, and intelligent control technologies. UAVs are widely used in applications such as surveillance, precision agriculture, infrastructure inspection, environmental monitoring, disaster management, and payload transportation. Among various UAV configurations, multirotor platforms are particularly attractive because of their vertical take-off and landing (VTOL) capability, hovering performance, and precise maneuverability.

Rotorcraft UAVs offer considerable advantages for payload deployment operations, as they can maintain stable flight while accurately positioning and releasing payloads. Hexacopter platforms are especially suitable for such applications due to their higher payload capacity, enhanced stability, and propulsion redundancy compared to conventional quadcopters. These characteristics make them effective platforms for integrating payload deployment mechanisms.

Despite the growing use of UAVs in delivery and deployment missions, the integration of payload release systems presents several engineering challenges. Sudden payload release can alter the vehicle's center of gravity, affecting flight stability and control. Furthermore, deployment mechanisms must be lightweight, structurally reliable, and compatible with the UAV frame without significantly reducing flight endurance. Therefore, careful structural design and evaluation are essential to ensure safe and efficient operation.

To address these challenges, this study presents the conceptual design and structural analysis of a modular payload deployment mechanism integrated with a hexacopter UAV. The proposed system emphasizes lightweight construction, modular architecture, and ease of integration while maintaining adequate structural strength. Finite Element Analysis (FEA) is employed to evaluate stress distribution and deformation characteristics under operational loading conditions. The findings provide insights into the structural feasibility of the proposed design and its potential suitability for UAV-based payload deployment applications.

2 Literature Review

Recent advancements in Unmanned Aerial Vehicle (UAV) technology have led to increased research on payload deployment systems for applications such as aerial delivery, surveillance, disaster response, and precision agriculture. Payload deployment mechanisms are designed to securely retain a payload during flight and release it accurately at the desired location. Modern systems commonly employ servo-actuated locking mechanisms, pin-release devices, hook-based arrangements, and rotary latching systems due to their compact design, low power consumption, and ease of integration with multirotor UAV platforms.

Multirotor UAVs, particularly hexacopters, are widely preferred for payload deployment because of their ability to hover, perform vertical take-off and landing (VTOL), and maintain stable flight during payload release. Previous studies have shown that centrally mounted payloads improve vehicle stability by minimizing disturbances caused by changes in the center of gravity. However, improper structural integration can introduce vibration, increase mechanical stress, and adversely affect flight performance.

Structural reliability is a critical consideration in the design of UAV payload mechanisms. Components such as mounting brackets, support frames, and actuator interfaces experience static and dynamic loading during operation. Consequently, Finite Element Analysis (FEA) has become a widely adopted tool for evaluating stress distribution, deformation, and structural integrity before fabrication. Lightweight materials, including aluminum alloys, carbon fiber composites, and engineering polymers, are commonly selected to achieve an optimal balance between strength and weight.

Although significant progress has been made in UAV payload deployment technology, many existing systems remain platform-specific, mechanically complex, and insufficiently optimized for modular integration. Furthermore, limited attention has been given to the combined effects of structural safety, vibration resistance, and UAV compatibility within a single design framework. To address these limitations, the present study proposes a lightweight and modular payload deployment mechanism integrated with a hexacopter UAV. The proposed design is evaluated using CAD modeling and finite element analysis to assess its structural feasibility and suitability for practical UAV payload deployment applications.

3 Problem Statement and Methodology

The growing adoption of multirotor Unmanned Aerial Vehicles (UAVs) for payload transportation and deployment has highlighted the need for lightweight, modular, and structurally reliable payload release mechanisms. Many existing systems are limited by excessive weight, complex mechanical configurations, and poor adaptability to different UAV platforms. Furthermore, payload release can introduce sudden changes in the center of gravity, resulting in transient disturbances that affect flight stability, positional accuracy, and overall operational safety. These challenges emphasize the need for an efficient payload deployment mechanism that combines structural integrity, ease of integration, and reliable actuation.

The objective of this study is to develop a conceptual modular payload deployment mechanism for a hexacopter UAV and evaluate its structural performance through numerical analysis. The work includes the development of a three-dimensional CAD model, selection of suitable lightweight materials, assessment of structural behavior under operational loading conditions, and evaluation of stress and deformation characteristics using Finite Element Analysis (FEA). In addition, the proposed design considers mounting compatibility with the UAV platform and incorporates a controlled actuation concept to enhance operational reliability.

A systematic engineering methodology was adopted to achieve these objectives. Initially, a comprehensive literature review was conducted to identify existing payload deployment techniques and their limitations. Based on the findings, a modular deployment concept was developed and modeled using SolidWorks. Appropriate engineering materials were selected considering strength-to-weight ratio and manufacturability. Structural performance was then evaluated using ANSYS Workbench through finite element analysis to determine stress distribution, deformation, and overall structural safety. The simulation results were analyzed to assess the feasibility of the proposed design and its suitability for integration with a hexacopter UAV.

The proposed conceptual framework provides a basis for the design of lightweight and modular UAV payload deployment systems and offers valuable insights for future prototype fabrication, experimental validation, and practical implementation in UAV-based payload delivery applications.

4 System Requirements and Design Specifications

The design of the proposed UAV payload deployment mechanism is based on a set of functional, structural, electrical, and operational requirements to ensure reliable integration with a hexacopter platform. The primary functional requirement is to securely retain the payload during all phases of flight and release it only upon receiving an authorized control command. The release mechanism must provide smooth and controlled actuation, prevent accidental deployment, and allow rapid resetting for subsequent operations.

From a structural perspective, the mechanism is required to withstand both static and dynamic loads generated during flight and payload release while maintaining adequate strength and stiffness. Structural deformation must remain within acceptable limits to ensure consistent operation and preserve the integrity of the mounting assembly. Additionally, the design should minimize weight to maximize UAV endurance without compromising structural safety.

The electrical control system is designed to operate independently of the UAV flight controller to prevent interference with onboard avionics. A microcontroller-based actuation system, powered through a dedicated battery with an integrated Battery Management System (BMS), is considered for reliable operation. The control architecture supports standard communication protocols and incorporates fail-safe features, including manual override and emergency shutdown, to enhance operational safety.

For the conceptual analysis, an experimental inert payload with an assumed mass of 400–500 g and dimensions of approximately 120 mm × 60 mm is considered. The deployment mechanism is intended for integration with a medium-class hexacopter having a maximum take-off weight of approximately 30 kg, a payload capacity of 7.5 kg, six propulsion units, and a Lithium Polymer (LiPo) battery power source. These assumptions provide the basis for structural analysis, mounting design, and compatibility assessment.

Overall, the defined system requirements establish the design constraints for developing a lightweight, modular, and structurally reliable payload deployment mechanism suitable for hexacopter UAV applications while ensuring safe and controlled payload release.

Experimental Payload Unit (EPU)

Payload Specifications (Assumed Data)

PARAMETER	CONSIDERATION
Dimensions	120mm * 60mm (height* max dia) #
Weight	500g # 400g #
Operational & Storage Temperature Range	-20 to +55°C
Release Force	4.5 kgf ± 0.5 kgf #

The "#" specifies that the data has been assumed for the study as the actual data is confidential.

EFT E616P 16L Hexacopter

UAV Specifications

Item	Value / requirement
Payload mass (reported)	7.42 kg
Total take-off weight (with payload)	30 kg
Required total thrust (at TWR 1.5)	≈441.5 N (≈45 kgf)
Required thrust per motor (6 motors)	≈73.6 N ≈7.5 kgf
Payload fraction of TOW	7.42 / 30 = 24.7%
Max allowable lateral CG offset	±20 mm (recommended)
Max allowable longitudinal CG offset	±30 mm (recommended)
Electrical supply requirement (payload)	6S LiPo 6000 mAh (separate) — nominal 22.2 V
Safety margin (recommended)	Keep operational payload ≤ 80% of tested payload capacity

5. Conceptual Design of the Payload Release System

The proposed payload release system is designed as a lightweight, modular unit that can be integrated beneath a hexacopter UAV for controlled payload deployment. The overall architecture consists of three primary subsystems: a mechanical payload handling mechanism, an electronic control unit, and a dedicated power supply. The payload release system operates independently of the UAV flight controller, receiving only release commands while maintaining electrical isolation from the primary avionics to improve operational safety and system reliability.

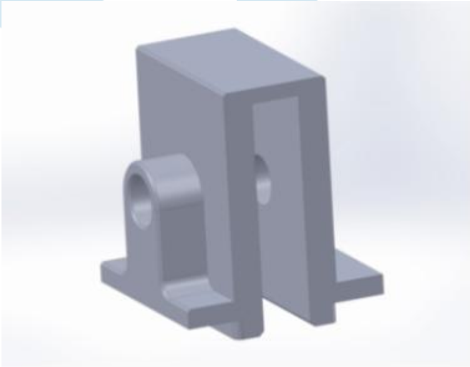
The design philosophy emphasizes modularity, scalability, structural simplicity, and compatibility with medium-class multirotor UAV platforms. A common structural frame supports interchangeable payload modules, allowing the system to accommodate different mission requirements without significant redesign. The modular architecture enables both three-payload and six-payload configurations while maintaining a common control and mounting interface.

Payload handling is achieved through a conveyor-based mechanism that transports individual payloads from their storage positions to the designated release point. Accurate positioning is provided by a lead screw mechanism driven by a stepper motor, ensuring precise alignment before deployment. The payload is securely retained using a servo-actuated gripping mechanism, which releases the payload only upon receiving an authorized control command. The release mechanism is designed with a fail-safe locking configuration to prevent unintended deployment during power loss or system malfunction.

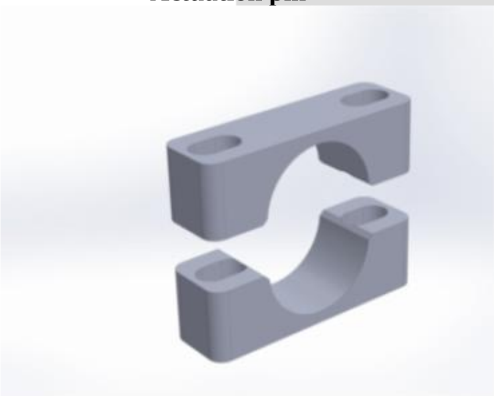
To facilitate integration with different UAV platforms, the system incorporates a universal mounting interface with standardized mounting points and adjustable slots. Elastomeric vibration isolation elements are included to reduce the transmission of rotor-induced vibrations to the payload mechanism, thereby improving structural durability and release accuracy.

A dedicated microcontroller coordinates the operation of the stepper and servo motors using sequential control logic to ensure that payloads are positioned and released in the correct order. The control architecture also provides status feedback and supports both manual and autonomous release commands. By combining lightweight construction, modular architecture, controlled actuation, and universal mounting, the proposed conceptual design offers a flexible and structurally reliable solution for UAV-based payload deployment. The developed concept serves as the basis for CAD modeling, structural analysis, and future experimental validation.

Actuation pin



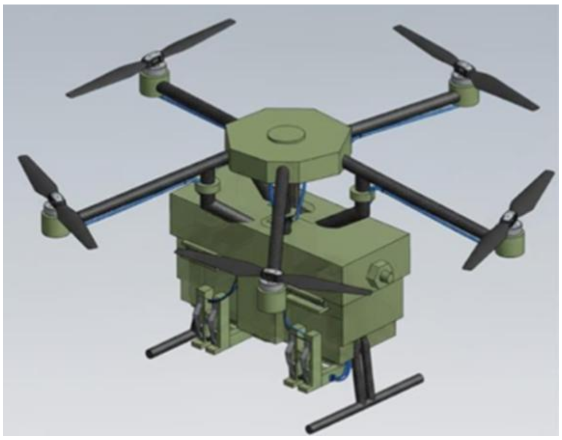
Pin Guide



Mounting Clip

Actuation Gears

Payload Housing



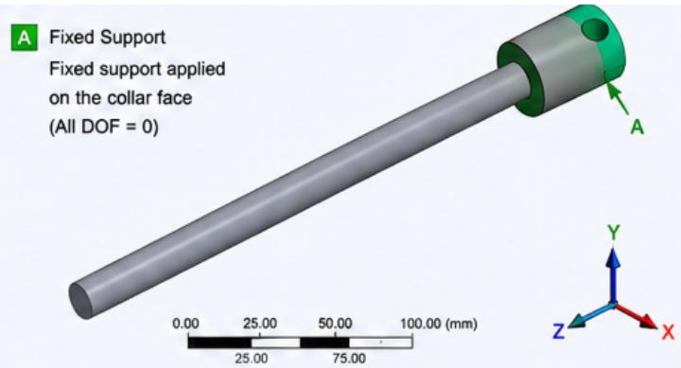
Isometric View of a Payload Mechanism

Front View of a Payload Mechanism

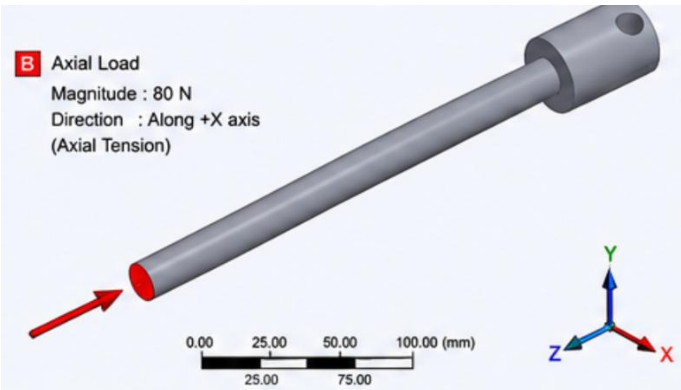
6. Finite Element Analysis

Finite Element Analysis (FEA) was conducted to evaluate the structural performance of the proposed UAV payload release mechanism under operational loading conditions. The analysis was performed using ANSYS Workbench to determine the stress distribution, deformation characteristics, and structural safety of the critical components. The primary objective was to verify that the proposed design could safely withstand payload and operational loads while maintaining adequate structural integrity.The CAD models of the actuation gear set, mounting clip, pin guide bracket, and actuation pin were developed in SolidWorks and imported into ANSYS Workbench for static structural analysis. All components were assumed to be manufactured from Aluminium Alloy 6061-T6 owing to its high strength-to-weight ratio, corrosion resistance, and suitability for aerospace applications. The material properties used in the analysis included a Young's modulus of 69 GPa, Poisson's ratio of 0.33, density of 2700 kg/m^3, and yield strength of 275 MPa.The finite element model employed tetrahedral elements with local mesh refinement applied in regions expected to experience high stress gradients, including gear teeth, mounting holes, fillets, and pin interfaces. Appropriate boundary conditions were assigned to each component by constraining the mounting regions and applying representative operational loads corresponding to the payload deployment mechanism. A payload mass of 7.42 kg was considered, resulting in a static load of 72.79 N. To account for dynamic effects during flight and payload release, a dynamic load factor of two was adopted, giving a total design load of 145.58 N.

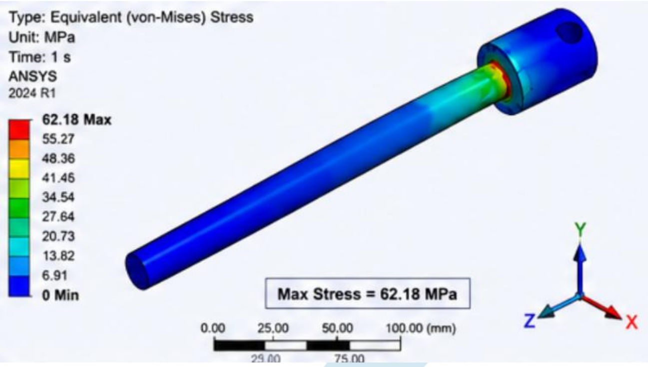
The structural response was evaluated in terms of equivalent (von Mises) stress, total deformation, and factor of safety. The highest stress values were observed near mounting interfaces, pin-hole regions, and gear contact surfaces, while the maximum deformation remained within acceptable limits. In all analyzed components, the maximum von Mises stress was below the yield strength of Aluminium Alloy 6061-T6, and the minimum factor of safety exceeded 1.5, indicating satisfactory structural performance. Furthermore, the design is considered suitable for UAV operation provided that the first natural frequency remains sufficiently separated from the rotor excitation frequencies, thereby minimizing the risk of resonance. These results confirm the structural feasibility of the proposed payload release mechanism for conceptual hexacopter UAV applications.



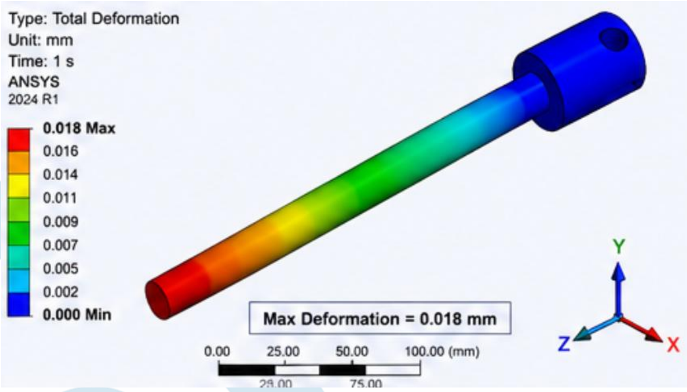
Applying fixed support on Actuation pin



Applying Axial Load on Actuation pin



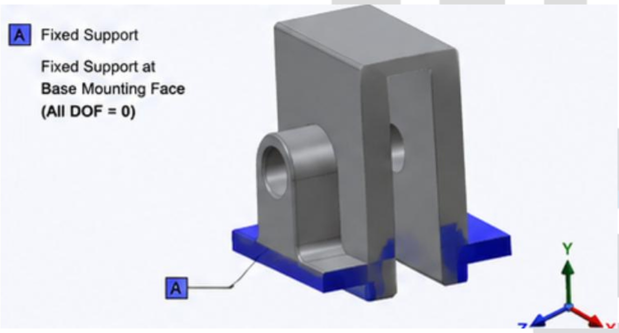
Equivalent (von-Mises) Stress of Actuation pin



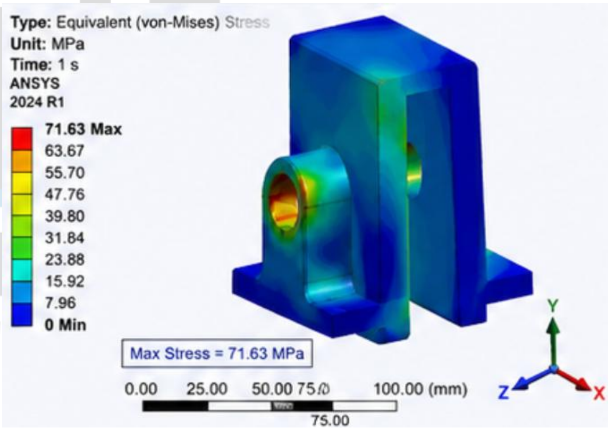
Total Deformation of Actuation pin

Analysis result of Actuation pin

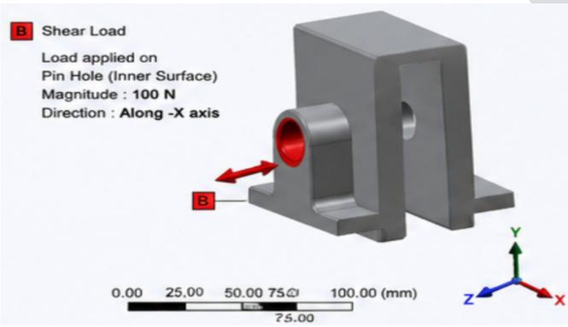
Parameter	Value	Unit	Remarks
Material	Aluminium Alloy 6061-T6	-	-
Yield Strength	275	Mpa	-
Applied Load (Axial)	80	N	Tension (+X)
Max Von-Mises Stress	62.18	Mpa	-
Max Deformation	0.018	mm	-
Min Factor of Safety	4.42	-	**> 1.5 (Safe)**



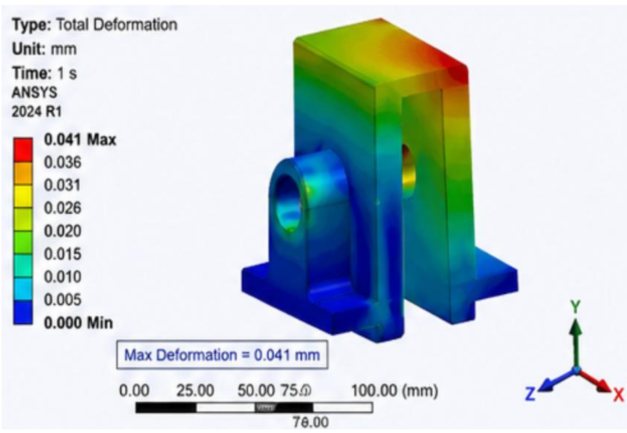
Applying fixed support on Pin Guide



Equivalent (von-Mises) Stress of Pin Guide



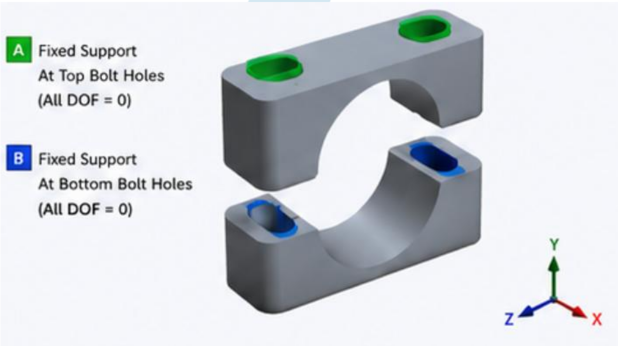
Applying Shear Load on Pin Guide



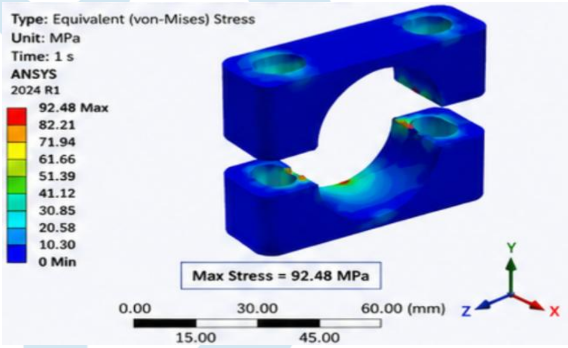
Total Deformation of Pin Guide

Analysis result of Pin Guide

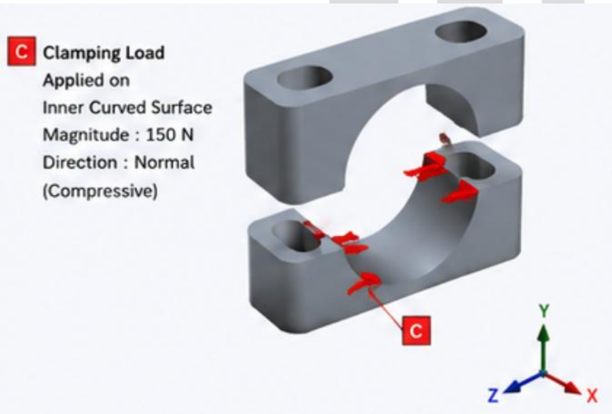
Parameter	Value	Unit	Remarks
Material	Aluminium Alloy 6061-T6	-	-
Yield Strength	275	Mpa	-
Applied Load (Shear)	100	N	At Pin Hole
Max Von-Mises Stress	71.63	Mpa	-
Max Deformation	0.041	mm	-
Min Factor of Safety	3.84	-	**> 1.5 (Safe)**



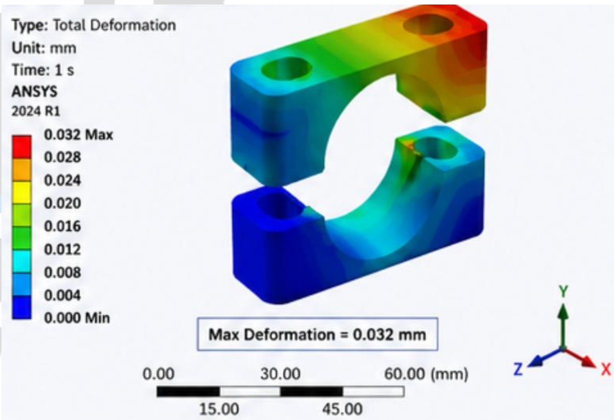
Appling fixed support on Mounting Clip



Equivalent (von-Mises) Stress of Mounting Clip



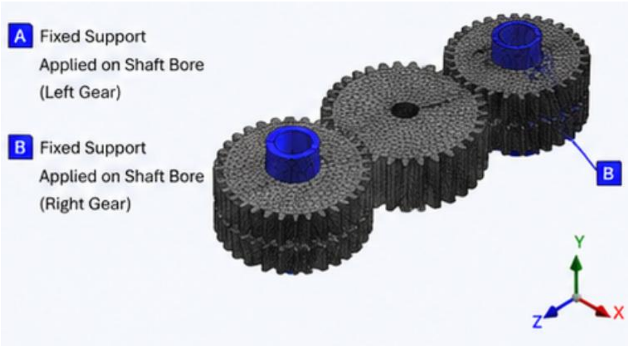
Appling Clamping Load on Mounting Clip



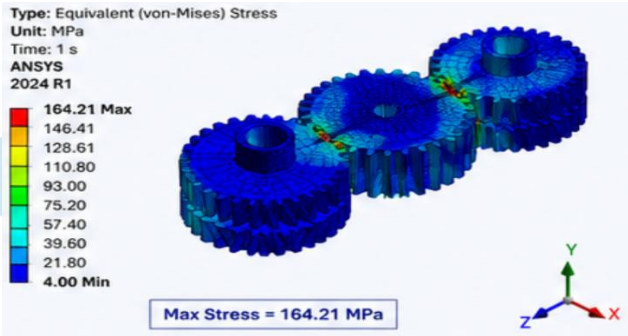
Total Deformation of Mounting Clip

Analysis result of Mounting Clip

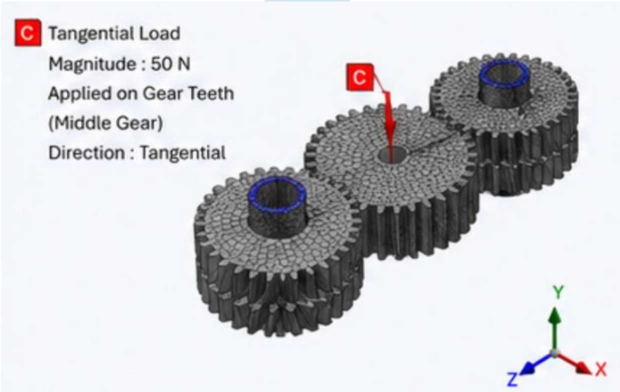
Parameter	Value	Unit	Remarks
Material	Aluminium Alloy 6061-T6	-	-
Yield Strength	275	Mpa	-
Clamping Load (Compressive)	150	N	On Inner Surface
Max Von-Mises Stress	92.48	Mpa	-
Max Deformation	0.032	mm	-
Min Factor of Safety	2.97	-	**> 1.5 (Safe)**



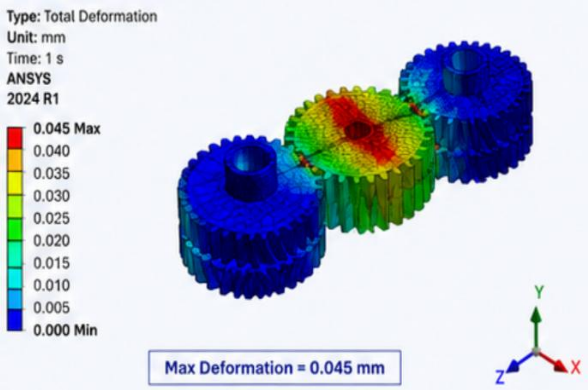
Fixed Support Applied on Actuation Gears



Equivalent (von-Mises) Stress of Actuation Gears



Tangential Load Applied on Actuation Gears



Total Deformation of Actuation Gears

Analysis result of Actuation Gears

Parameter	Value	Unit	Remarks
Material	Aluminium Alloy 6061-T6	-	-
Yield Strength	275	Mpa	-
Tangential Load	50	N	On Middle Gear
Max Von-Mises Stress	164.21	Mpa	-
Max Deformation	0.045	mm	-
Min Factor of Safety	1.67	-	**> 1.5 (Safe)**

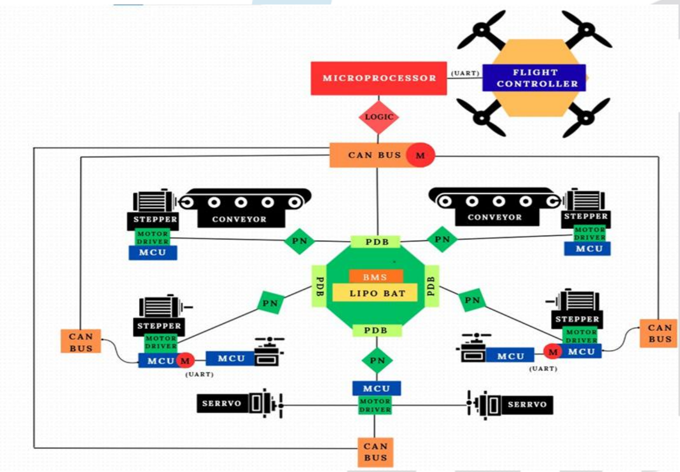
7. Electrical Architecture and Operational Principle

The proposed payload release system employs an independent electrical and electronic architecture to ensure reliable actuator control while preventing interference with the UAV's primary avionics. A dedicated Lithium Polymer (LiPo) battery powers the payload deployment subsystem through a regulated power distribution unit integrated with a Battery Management System (BMS), providing protection against overcurrent, overvoltage, and deep discharge. This independent power configuration enhances operational reliability and preserves the performance of the UAV flight control system.

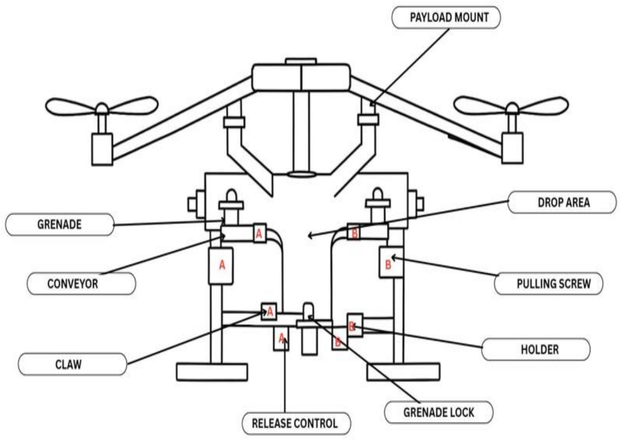
A microcontroller-based control unit coordinates the operation of the payload handling mechanism by processing release commands received from either the UAV flight controller or a ground control station. Stepper motors, driven through dedicated motor drivers, are used to actuate the conveyor and lead screw mechanisms for accurate payload positioning, while a servo motor controls the gripping mechanism responsible for payload release. Communication between the payload subsystem and the UAV is achieved through standard interfaces such as PWM, UART, or CAN, enabling reliable command transmission and system status monitoring.

The operational sequence begins with manual loading of payloads into the designated payload bays, followed by system initialization and diagnostic checks. The payload release mechanism remains in a locked state until both hardware and software arming conditions are satisfied. Upon receiving a valid release command, the microcontroller actuates the conveyor and lead screw mechanisms to position the selected payload at the release location. Once positional verification is completed, the servo-actuated gripper releases the payload in a controlled manner, after which the mechanism automatically resets for the next deployment cycle.

The system supports both manual and autonomous modes of operation. In manual mode, payload release is initiated by the operator through the ground control interface, whereas in autonomous mode, release commands are generated by the flight controller based on predefined mission parameters such as waypoint location, altitude, or GPS coordinates. To enhance operational safety, the control architecture incorporates electrical isolation, dual-arming logic, fail-safe locking, emergency shutdown capability, and fault detection mechanisms. In the event of power loss or communication failure, the payload remains securely locked, preventing unintended deployment. This integrated electrical architecture and operational strategy provide reliable, safe, and repeatable payload deployment suitable for modular UAV applications.



Electronic Architecture



Payload Loading Procedure

8. Results and Discussion

The structural performance of the proposed modular payload release mechanism was evaluated through finite element analysis to verify its suitability for UAV-based payload deployment. The simulation results indicate that the selected components can safely withstand the applied operational loads while maintaining structural integrity. The von Mises stress distribution revealed that the maximum stresses were concentrated around the mounting interfaces, pin-hole regions, and gear contact surfaces, which are typical locations of stress concentration in mechanically actuated assemblies. However, the maximum stress values remained below the yield strength of Aluminium Alloy 6061-T6, confirming that no yielding is expected under the prescribed loading conditions.

The deformation analysis showed that the maximum displacement of the critical components was relatively small and within acceptable design limits. The limited deformation indicates that the payload positioning and release mechanisms are capable of maintaining dimensional stability during operation, thereby supporting accurate and repeatable payload deployment. The calculated factor of safety for all major components exceeded the minimum design requirement of 1.5, demonstrating adequate structural reliability for the proposed application.

The modular configuration of the system offers additional advantages by simplifying installation, maintenance, and future scalability. The universal mounting arrangement facilitates integration with medium-class hexacopter UAV platforms, while the independent control architecture minimizes interference with the primary flight control system. Furthermore, the servo-actuated release mechanism and sequential payload handling concept contribute to controlled payload deployment, reducing disturbances associated with sudden mass redistribution during release.

Overall, the finite element analysis confirms the structural feasibility of the proposed payload release mechanism. The combination of lightweight construction, modular architecture, and satisfactory structural performance demonstrates the suitability of the proposed design for conceptual UAV payload deployment applications. Future work will focus on prototype fabrication, experimental validation, vibration characterization, and flight testing to further verify the performance of the proposed system under real operating conditions.

9. Conclusion

This study presented the conceptual design and structural evaluation of a modular payload release mechanism for integration with a hexacopter UAV. The proposed system was developed with emphasis on lightweight construction, modular architecture, reliable payload handling, and compatibility with medium-class multirotor platforms. The design incorporates a conveyor-based payload positioning mechanism, servo-actuated release system, universal mounting interface, and an independent control architecture to ensure safe and controlled payload deployment.

The structural performance of the critical components was assessed using Finite Element Analysis (FEA) in ANSYS Workbench. The simulation results demonstrated that the maximum von Mises stresses remained below the yield strength of Aluminium Alloy 6061-T6, while the observed deformations were within acceptable limits. Furthermore, the calculated factor of safety for all analyzed components exceeded the minimum design requirement, confirming the structural feasibility of the proposed mechanism under the assumed loading conditions.

The modular configuration simplifies integration, maintenance, and future scalability, making the proposed design suitable for a wide range of UAV payload deployment applications. Overall, the study demonstrates that the proposed payload release mechanism satisfies the essential requirements of structural integrity, operational reliability, and UAV compatibility, thereby providing a practical foundation for future UAV-based payload handling systems.

Future work will focus on prototype fabrication, experimental validation, vibration and modal analysis, hardware-in-the-loop testing, autonomous control integration, and flight trials using inert payloads. Further optimization through lightweight composite materials and improved actuation strategies may enhance payload capacity, energy efficiency, and overall system performance for practical UAV deployment applications.

References

[1] Austin, R., *Unmanned Aircraft Systems: UAVS Design, Development and Deployment*, John Wiley & Sons, 2nd Edition, 2010.

[2] Valavanis, K. P., and Vachtsevanos, G. J., *Handbook of Unmanned Aerial Vehicles*, Springer, Dordrecht, 2015.

[3] Beard, R. W., and McLain, T. W., *Small Unmanned Aircraft: Theory and Practice*, Princeton University Press, 2012.

[4] Nonami, K., Kendoul, F., Suzuki, S., Wang, W., and Nakazawa, D., *Autonomous Flying Robots: Unmanned Aerial Vehicles and Micro Aerial Vehicles*, Springer, 2010.

[5] Bouabdallah, S., Murrieri, P., and Siegwart, R., “Design and Control of an Indoor Micro Quadrotor,” *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, New Orleans, USA, 2004, pp. 4393–4398.

[6] Pounds, P., Mahony, R., and Corke, P., “Modelling and Control of a Quad-Rotor Robot,” *Proceedings of the Australasian Conference on Robotics and Automation*, 2006.

[7] Waharte, S., and Trigoni, N., “Supporting Search and Rescue Operations with UAVs,” *Proceedings of the International Conference on Emerging Security Technologies*, IEEE, 2010, pp. 142–147.

[8] Shakhatreh, H., et al., “Unmanned Aerial Vehicles: A Survey on Civil Applications and Key Research Challenges,” *IEEE Access*, Vol. 7, 2019, pp. 48572–48634.

[9] Gupta, S. G., Ghonge, M. M., and Jawandhiya, P. M., “Review of Unmanned Aircraft System (UAS),” *International Journal of Advanced Research in Computer Engineering & Technology*, Vol. 2, No. 4, 2013, pp. 1646–1658.

[10] Kim, J., Kang, M., and Park, S., “Design and Analysis of a Payload Release Mechanism for Multirotor UAVs,” *International Journal of Aeronautical and Space Sciences*, Vol. 18, No. 3, 2017, pp. 425–434.

[11] FAA, *Unmanned Aircraft Systems (UAS) Operational Guidelines*, Federal Aviation Administration, USA, 2016.

[12] ICAO, *Manual on Remotely Piloted Aircraft Systems (RPAS)*, International Civil Aviation Organization, Doc 10019, 2015.