International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Design and Development of Retractable VTOL Rotor Arms for Hybrid Drones.

Aarya Karlekar[1], Ashish Anthony[2], Prof. Dr C. S. Dharankar[3], Jiten Chordiya[4], Varun Joshi[5]

[1,2,4,5]Student, Department of Mechanical Engineering, AISSMS College of Engineering, Pune, India
[3]Assistant Professor, Department of Mechanical Engineering, AISSMS College of Engineering, Pune, India

Abstract:
This study focuses on the design, development, and optimization of retractable Vertical Take-Off and Landing (VTOL) rotor arms for unmanned aerial vehicles (UAVs). The goal is to create a VTOL mechanism that enhances aerodynamic efficiency, reduces drag during forward flight, and improves portability and storage by retracting the rotor arms when not in use. Retractable rotor arms offer promising applications, especially for hybrid drones used in long-range and high-speed missions, where minimizing drag and maximizing flight time is crucial. The project combines structural design principles, material selection, and dynamic analysis to develop a lightweight, durable, and reliable retractable rotor arm system. We incorporate mechanical and electronic control systems to allow seamless deployment and retraction of rotor arms. Structural and fatigue analyses ensure the mechanism's durability under various flight conditions. The optimization process uses a multi-objective approach, focusing on reducing drag, enhancing stability, and minimizing weight. Design parameters, including arm length, retraction angles, and material properties, are iteratively refined using machine learning-based optimization algorithms. Testing and validation of prototypes are conducted to assess real-world performance, with results indicating a significant reduction in drag and improved flight efficiency. This research demonstrates the feasibility of retractable VTOL rotor arms in advanced UAV designs, laying the groundwork for further enhancements in hybrid VTOL drone technology.

Keywords: Retractable rotor arms, Hybrid VTOL UAV, UAV structural design, Flight efficiency

1. INTRODUCTION:

Unmanned Aerial Vehicles (UAVs) have become indispensable across various sectors, including defence, agriculture, surveillance, and logistics. As UAV applications continue to grow, there is an increasing demand for aircraft that offer greater versatility and improved performance. Traditional UAVs typically fall into two main categories: Fixed-wing and VTOL configurations. Fixed-wing UAVs are renowned for their ability to cover long distances efficiently due to their aerodynamic lift, which allows for lower power consumption during sustained horizontal flight. However, they usually require runways or additional launching mechanisms for take-off and landing. Conversely, VTOL UAVs are prized for their vertical take-off and landing (VTOL) capabilities, making them ideal for missions in confined or rugged environments. The downside to rotary-wing designs is their limited flight range and endurance, mainly due to high energy demands during hover and low-speed operations.

To overcome the limitations inherent in each type of UAV, hybrid designs are being actively explored. These hybrid UAVs aim to combine the energy efficiency of fixed-wing flight with the operational flexibility of VTOL aircraft. A particularly innovative feature within these hybrid designs is the implementation of retractable rotor arms. This mechanism enables the UAV to transition seamlessly between vertical and horizontal flight modes. During take-off and landing, the rotors are fully deployed to allow VTOL operation. Once the UAV transitions into horizontal cruise flight, the rotor arms can retract, thereby reducing aerodynamic drag.

This reduction in drag has significant implications. It enhances fuel efficiency, increases cruising speed, and extends the overall flight range. The retractable rotor mechanism, however, introduces its own set of engineering challenges. It must be lightweight, durable, and capable of repeated deployment without failure. Material selection, often involving lightweight composites, also plays a vital role in ensuring the structural integrity of the rotor arms without compromising performance.

Retractable rotor arm UAVs represent a significant innovation in aerial vehicle design, offering a powerful blend of endurance, flexibility, and efficiency. They are poised to set new standards in the next generation of UAV development.

2. Literature Review:

Hybrid Vertical Take-Off and Landing (VTOL) Unmanned Aerial Vehicles (UAVs) represent a rapidly evolving field that combines the agility of rotary-wing platforms with the efficiency of fixed-wing flight. A critical innovation in this domain is the development of retractable rotor systems, which aim to minimize aerodynamic drag and improve overall performance during forward flight. This review synthesizes recent research focused on such UAVs, particularly those incorporating retractable or hybrid rotor configurations.

Recent Developments in Retractable Rotor UAVs

Anuar and Takesue (2025) presented a significant advancement in fixed-wing VTOL UAVs by introducing a four-retractable rotor propulsion system. Their study emphasized the structural integration and transition mechanisms required to retract the rotors post-takeoff, thereby reducing drag during cruise and enhancing endurance [1].

Similarly, Xiong et al. (2021) proposed a novel retractable rotor hybrid VTOL UAV. Their work combined preliminary design methodologies with extensive prototype testing, focusing on rotor deployment dynamics, structural constraints, and aerodynamic efficiency. Their research offers valuable insights into the practical challenges and system-level trade-offs involved in implementing retractable rotor mechanisms [2].

Design and Implementation of Hybrid VTOL Platforms

Sonkar et al. (2023) implemented a fixed-wing hybrid VTOL UAV aimed at asset monitoring applications. Although not primarily focused on retractable rotors, the study is crucial for understanding system integration, flight performance, and energy management in hybrid UAVs [3]. Their practical implementation contributes to the broader understanding of hybrid system architectures.

Çakir and Kurtuluş (2022) conducted a detailed aerodynamic analysis of a tilt-wing VTOL UAV, offering insights relevant to any hybrid UAV architecture that seeks to minimize drag and enhance aerodynamic efficiency—challenges also faced by retractable rotor systems [6].

Reviews of VTOL UAV Designs and Systems

Several review papers provide a broader context. Ducard and Allenspach (2021) offered a comprehensive survey of hybrid and convertible VTOL UAV designs, including retractable systems, tilt-wing, and tilt-rotor mechanisms. They analyzed flight control challenges and presented comparisons across various configurations, making this work foundational for any new development in the field [5].

Ucgun et al. (2021) reviewed rotary-wing UAV charging station applications, indirectly relevant for hybrid systems by highlighting operational challenges and logistical constraints which can influence design decisions, including retractable components [4].

Aerodynamic Considerations

Anuar et al. (2023) presented the aerodynamic analysis of a fixed-wing VTOL UAV, focusing on the design's impact on flight efficiency and stability. While not exclusively discussing retractable systems, their research contributes to understanding how different design elements influence overall aerodynamic performance [7].

Urakubo et al. (2023) studied the aerodynamic drag of tilt-rotor UAVs in forward flight, demonstrating how rotor placement and orientation significantly affect drag. These findings underline the importance of rotor retraction mechanisms, which aim to reduce the frontal area and improve lift-to-drag ratios during cruise [8].

3. Mechanism Design:

Specifications:

These are vehicle specifications which were to be considered while designing the mechanism.

Table 1 Design Parameters

Sr. No.	Particulars	Specifications
1.	Deployment/Retraction Time	3-6 sec
2.	Max Thrust per motor	125.17 N
3.	L*W*H (Approximated)	149
4.	Maximum take-off weight	15 kg
5	Battery Compatibility	6 Cell (22.2V)

Key considerations while designing the mechanism:

- The mechanism should be compact to fit into space constraints.
- The gear ratio must be optimized to ensure that minimum torque is needed to the motor for the actuation.
- There should be minimum stress on the electronic parts of the mechanism.
- The materials selected for the mechanism should have high strength to weight ratio to reduce weight but still provide structural integrity.

Concept of the design:

As per the specifications and demand, electro-mechanical systems could provide more reliability and structural integrity for the application. A gear system specifically designed to transmit optimum torque at the required speed can be used for actuation.

The rotor arms mounted with motor will rotate from a fixed pivot point with help of gears. The gear system will consist of 2 stages arranged, one below the other. The upper stage will consist of three gears, the main gear which will rotate with the help of motor and two arm rotating gears rotating two arms which ae diagonally opposite to each other. The other stage below the first stage consists of 5 gears, the main gear which is rotated by the motor for actuation, two gears which meshed with the main gear to change the direction of the motion and two arm rotating gears which will be responsible for rotating of the remaining diagonally opposite arms. The gear ratio between the main gear and arm rotating gears is 2. This will change the speed of rotation to 2.5 rpm from the initial motor speed of 5 rpm, resulting in the completion of 45 degrees rotation of arms in 3 seconds.

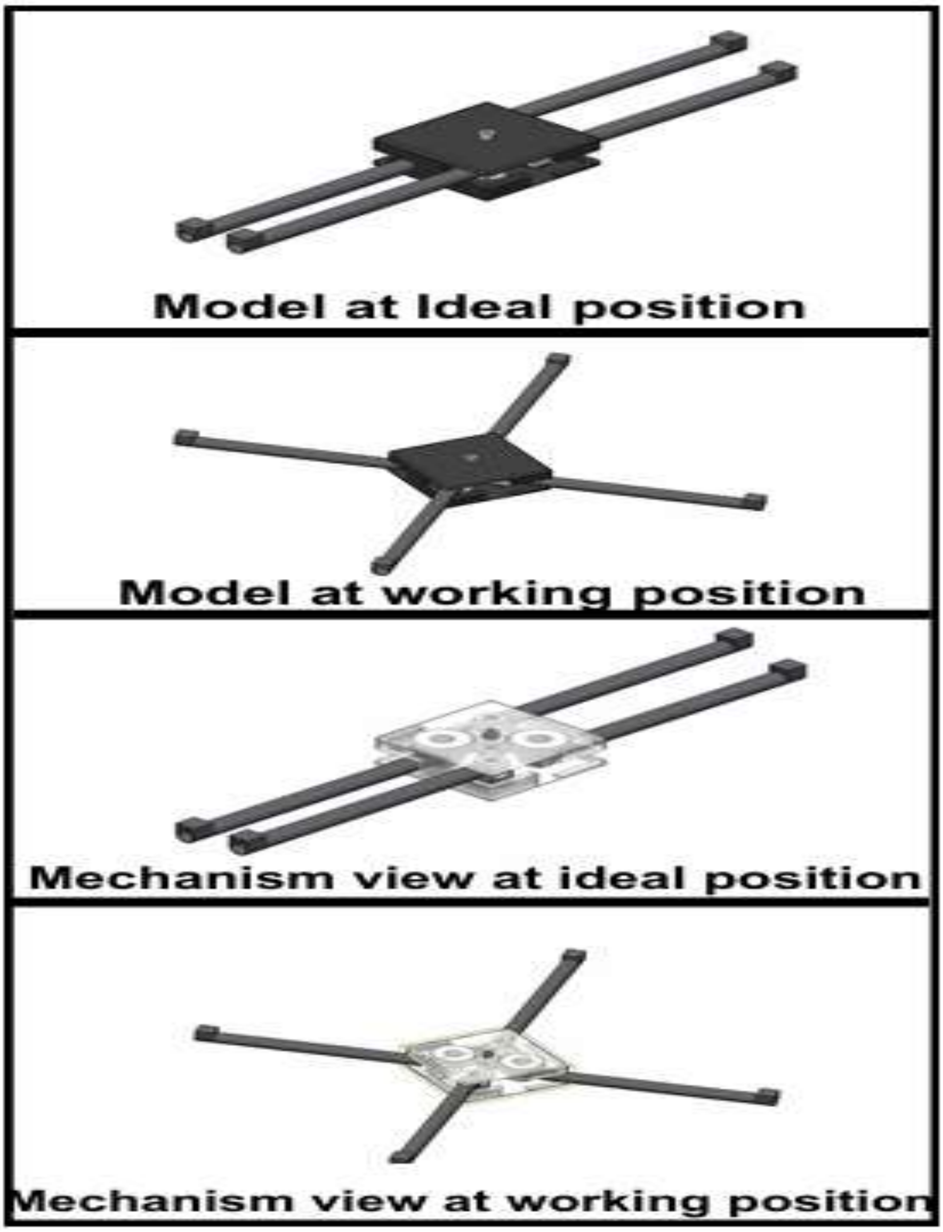


Figure 1 3d model of the mechanism.

Calculations of torque applied and bending stress on system:

Torque calculations were performed based on the gear ratios selected. The required torque (T) can be calculated using:

T =F × r T = F × r

where F is the force applied at the radius r of the gear system.

Calculation of Bending Stress of the System:

Bending stress **(σ)** in the carbon fiber tubes was calculated using: σ =My/I where M is the moment applied, y is the distance from the neutral axis to the outermost fiber, and I is the moment of inertia of the tube's cross-section.

σ = (Thrust * [a/2]) / (0.2*m [a^2- b^2])

m =mass of arm

a = outer diameter of arm

b = inner diameter of arm

σ = (125.17 * [a/2]) / (0.2*m [a^2- b^2])

Material Selection:

Material selected for the rotor arms is Carbon Fiber tubes due to its high strength to weight ratio.
Material Properties of Epoxy Carbon Woven (395 GPa) Prepreg.

Table 2 Properties of Carbon Fibre material

Property	**Value**	**Unit**
Coefficient of Thermal Expansion X direction	2.5×10^{-6}	C^{-1}
Coefficient of Thermal Expansion Y direction	2.5×10^{-6}	C^{-1}
Coefficient of Thermal Expansion Z direction	1.5×10^{-5}	C^{-1}
Zero Thermal-Strain Reference Temperature	20	°C
Tensile X direction	0.0086	(unitless strain)
Tensile Y direction	0.0055	(unitless strain)
Compressive X direction	0.0084	(unitless strain)
Compressive Y direction	0.0052	(unitless strain)
Shear XY	0.031	(unitless strain)
Shear YZ	0.018	(unitless strain)
Shear XZ	0.018	(unitless strain)
Density	1.4×10^{-9}	tonne/mm³ or 1400 kg/m³

Note* These properties are taken from ANSYS software.

As for the gears and gear housing, Aluminum alloy was finalized.

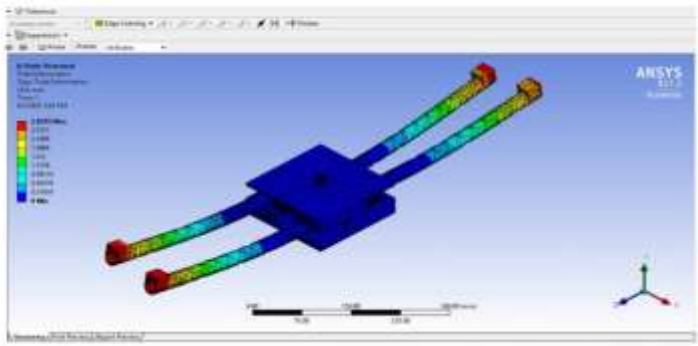
Table 3 Properties of Aluminium Alloy

Property	**Value**	**Unit**
Density	2770	kg/m³
Isotropic Secant Coefficient of Thermal Expansion	2.31×10^{-5}	C^{-1}

Young's Modulus	7.1×10^{10}	Pa
Poisson's Ratio	0.33	—
Bulk Modulus	7.09×10^{10}	Pa
Shear Modulus	2.74×10^{10}	Pa
Alternating Stress S-N Ratio	0.9	—
Tensile Yield Strength	2.8×10^{8}	Pa
Compressive Yield Strength	2.8×10^{8}	Pa
Tensile Ultimate Strength	3.1×10^{8}	Pa
Compressive Ultimate Strength	3.1×10^{8}	Pa

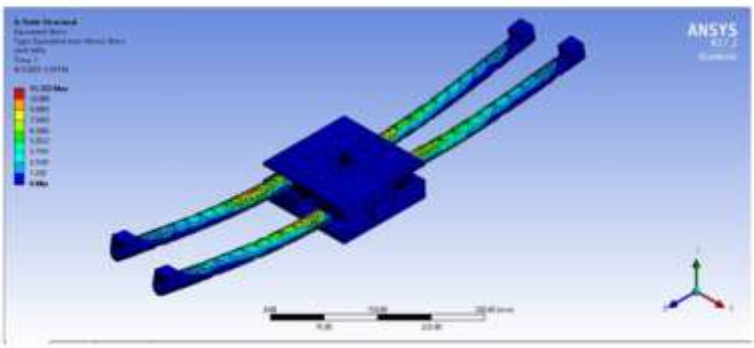
Structural Analysis:

Stresses due to thrust: Structural analysis was carried out on the mechanism to determine the stress values on the mechanism when the rotors apply thrust. During Von mises stress, the maximum stress on the mechanism was on the revolute joint of the arms. It was around 11.322 Mpa, which were under the safe limits since the material chosen for the arme was carbon fiber tubes. In the same analysis the max displacement due to stress was observed at the end of the arms of about 2.8 mm.



Displacement Results

Figure 2 Structural analysis displacement due to thrust



Stress Results

Figure 3 Structural analysis stress due to thrust

Torque Analysis: Torque analysis was carried out to observe the effects of torque applied by the motor on the mechanism. Maximum stress during Von mises stress analysis was observed on the main shaft of the mechanism which gave value of 0.8642 Mpa.

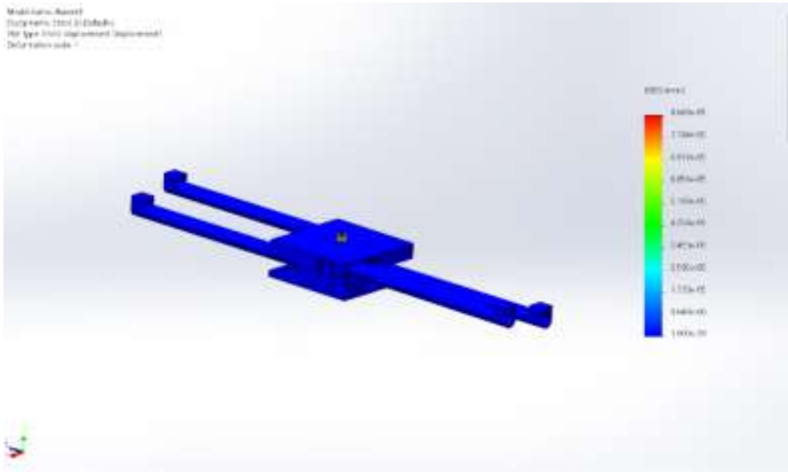


Figure 4 Structural analysis deformation due to torque of the motor

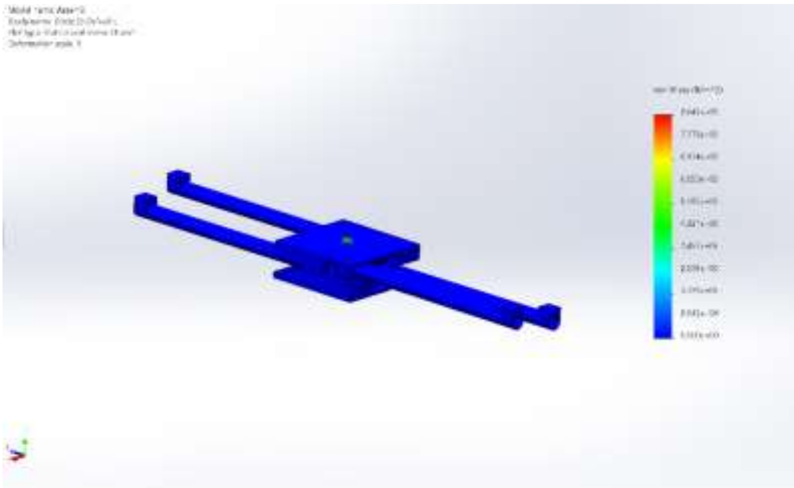


Figure 5 Structural analysis stress due to torque of the motor

Geometric Modifications:

To absorb the stresses on the revolute arm joint, the walls of the gear box were extended to avoid over bending of arms and causing failure. The thickness of the walls surface where the arms and gear box walls made contact were increased to distribute the force. This helped in decreasing the load on the shafts and the parts, avoiding part failure.

Figure 6 3d printed model

4. Results:

Based on the evaluated parameters, the proposed design successfully meets all specified requirements. The stress values obtained from simulation analyses remain well within the permissible limits, confirming the structural integrity and reliability of the mechanism.

Figure 7 3d printed model

5. Conclusion

In conclusion we successfully designed and tested (simulated) rotor arms which are retractable for a hybrid UAV. These retractable rotor arms give the UAV the advantage of taking off and landing vertically, also once the UAV is mid flight the rotor arms can be retracted inside the body for better aerodynamic fixed winged flight. These innovative arms are designed to enhance aerodynamic efficiency during forward flight operations. Traditionally, fixed rotor arms generate substantial drag, reducing flight performance and limiting range. By contrast, retractable arms can be pulled in once the drone transitions to fixed-wing mode.

A key enabler of this technology is a specially engineered gear mechanism. This mechanism is responsible for the smooth extension and retraction of the rotor arms. It is designed to operate efficiently within the limited space available inside the drone body. Balancing torque during arm movement is essential to maintain flight stability and safety. Precise mechanical coordination ensures the drone remains stable while switching flight modes. The gear system must be lightweight, compact, and robust enough to withstand repeated use. To achieve this, engineers selected advanced lightweight materials for construction. These materials offer high strength-to-weight ratios, ideal for aerial vehicles. By minimizing structural weight, the drone can carry greater payloads or larger battery packs. This further enhances the operational efficiency and mission capabilities. Careful integration of these materials also ensures long-term durability and performance. Such considerations are vital for drones operating in harsh or unpredictable environments.

References:

1. K. Anuar and N. Takesue, “Development of Fixed-Wing VTOL UAVs with the Four-Retractable Rotor Propulsion,” J. Robot. Mechatron., Vol.37 No.2, pp. 510-522, 2025.
2. Z. Xiong, Y. Xu, Z. Wang, X. Pian and Y. Wang, "Preliminary Design Method and Prototype Testing of a Novel Rotors Retractable Hybrid VTOL UAV," in IEEE Access, vol. 9, pp. 161141-161160, 2021, doi: 10.1109/ACCESS.2021.3131565. keywords: {Rotors;Aircraft;Aircraft propulsion;Payloads;Estimation;Automotive components;Atmospheric modeling;VTOL;UAV design;rotors retractable;flight test;prototyping;sizing},
3. S. Sonkar, P. Kumar, Y. T. Puli, R. C. George, D. Philip, and A. K. Ghosh, “Design & implementation of an electric fixed-wing hybrid vtol uav for asset monitoring,” J. of Aerospace Technology and Management, Vol.15, Article No.e0823, 2023. https://doi.org/10.1590/jatm.v15.1297
4. H. Ucgun, U. Yuzgec, and C. Bayilmis, “A review on applications of rotary-wing unmanned aerial vehicle charging stations,” Int. J. of Advanced Robotic Systems, Vol.18, No.3, Article No.17298814211015863, 2021. https://doi.org/10.1177/17298814211015863
5. G. J. J. Ducard and M. Allenspach, “Review of designs and flight control techniques of hybrid and convertible vtol uavs,” Aerospace Science and Technology, Vol.118, Article No.107035, 2021. https://doi.org/10.1016/j.ast.2021.107035
6. H. Çakir and D. F. Kurtuluş, “Design and aerodynamic analysis of a vtol tilt-wing uav,” Turkish J. of Electrical Engineering and Computer Sciences, Vol.30, No.3, pp. 767-784, 2022. https://doi.org/10.55730/1300-0632.3810
7. K. Anuar, W. Fatra, M. Akbar, N. Nazaruddin, S. Syafri, A. W. Sari, and R. R. Utama, “Design and aerodynamic analysis of fixed-wing vertical take-off landing (fw-vtol) uav,” J. of Advanced Research in Fluid Mechanics and Thermal Sciences, Vol.106, No.1, pp. 136-146, 2023. https://doi.org/10.37934/arfmts.106.1.136146
8. T. Urakubo, K. Wada, K. Sabe, S. Hirai, and M. Miwa, “Aerodynamic drag of a tilt-rotor uav during forward flight in rotary-wing mode,” J. Robot. Mechatron., Vol.35, No.2, pp. 417-423, 2023. https://doi.org/10.20965/jrm.2023.p0417