Jurnal ICT : Information and Communication Technologies, 16 (2) (2025) 451-459

Published by: Marq & Cha Institute

Jurnal ICT : Information and Communication Technologies

Journal homepage: www.ejournal.marqchainstitute.or.id/index.php/JICT

Lightweight modular transporter box: structural validation and flight-range assessment

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Article Info

Article history

Received : Oct 19, 2025
Revised : Oct 29, 2025
Accepted : Oct 30, 2025

Keywords:

Finite Element Method;
Hexacopter Drone;
Polyethylene Terephthalate;
Transporter Box;
UAV.

Abstract

Unmanned aerial vehicles (UAVs) are increasingly applied in logistics, yet their payload and endurance remain key constraints. This research addresses the problem by developing a lightweight modular transporter box for the DJI Matrice 600 hexacopter. The objective was to ensure structural reliability while maintaining operational flight range. A quantitative approach was applied: design requirements and objectives (DR&O) were established, five 3D design iterations were created, and finite element analysis (FEA) was performed to evaluate stress, deformation, and safety factors. Polyethylene terephthalate (PET) was selected as the construction material due to its strength-to-weight ratio and recyclability. Endurance analysis incorporated empirical flight speed and battery degradation models to assess the effect of payload integration. The final prototype achieved a mass of 1.79 kg, carried a 5 kg payload, and maintained a factor of safety of 4.46. Flight analysis confirmed an operational range of 18.8 km in 16.8 minutes, exceeding the minimum 11 km requirement. These results demonstrate that PET-based transporter boxes can provide lightweight, modular, and structurally safe payload solutions without significantly reducing UAV endurance. The study contributes to UAV logistics applications in defense and emergency delivery, and future work will involve prototype fabrication and experimental validation.

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1. Introduction

Unmanned aerial vehicles (UAVs) have become increasingly important in both civilian and defense applications, including logistics, surveillance, and disaster response. The use of UAVs for logistics operations is particularly promising, as it enables rapid delivery of critical items in areas where ground transportation is limited or hazardous. However, UAVs face key challenges in payload capacity, flight endurance, and range, which limit their widespread adoption for logistics missions(Garg et al., 2023; Jazairy et al., 2025).

In defense contexts, these limitations are even more critical. Military logistics demand fast, secure, and reliable transport of ammunition, medical supplies, and specialized equipment. Multi-rotor UAVs such as hexacopters are attractive for their vertical take-off and landing (VTOL) capability and maneuverability, but their endurance is often shorter than fixed-wing counterparts (Bauersfeld &

Scaramuzza, 2022, Saikong et al., 2025). Therefore, lightweight structural solutions that expand payload capacity without severely compromising endurance are essential.

Recent advances in drone payload systems have explored modular payload boxes, lightweight materials, and structural optimization methods. Finite element analysis (FEA) and computational modeling have been widely applied to validate UAV structures, ensuring safety under payload and aerodynamic loading (Guo et al., 2021; Gutierrez-Rivera et al., 2024; Mishra et al., 2022; Shelare et al., 2021). Meanwhile, research on battery endurance and flight optimization has provided analytical tools for predicting UAV range under different payload conditions (Jazairy et al., 2025).

This research addresses the gap by proposing a lightweight modular transporter box for the DJI Matrice 600 hexacopter. The objective is to design and validate a payload system that (i) satisfies structural safety requirements, (ii) minimizes additional weight, and (iii) preserves operational flight range. The transporter box is designed using polyethylene terephthalate (PET), a recyclable thermoplastic with favorable strength-to-weight ratio (Hossain et al., 2024; Khan & Riccio, 2024; Valvez et al., 2022). Structural performance is validated through FEA, and endurance impact is assessed using UAV flight range models.

The expected outcome is a transporter box that enhances the operational capability of hexacopter UAVs for logistics.This research contributes to bridging UAV design with logistics requirements by offering a validated lightweight payload solution that balances structural integrity and endurance performance.

2. Research Methodolgy

This research applies a quantitative and simulation-based approach to develop and validate a lightweight modular transporter box for the DJI Matrice 600 hexacopter. The methodology is organized into six stages: (i) definition of design requirements and objectives (DR&O), (ii) conceptual design and 3D modeling, (iii) material selection, (iv) finite element analysis (FEA), (v) flight range analysis, and (vi) evaluation through iterative design. A flow diagram of the process is presented in Figure 1.

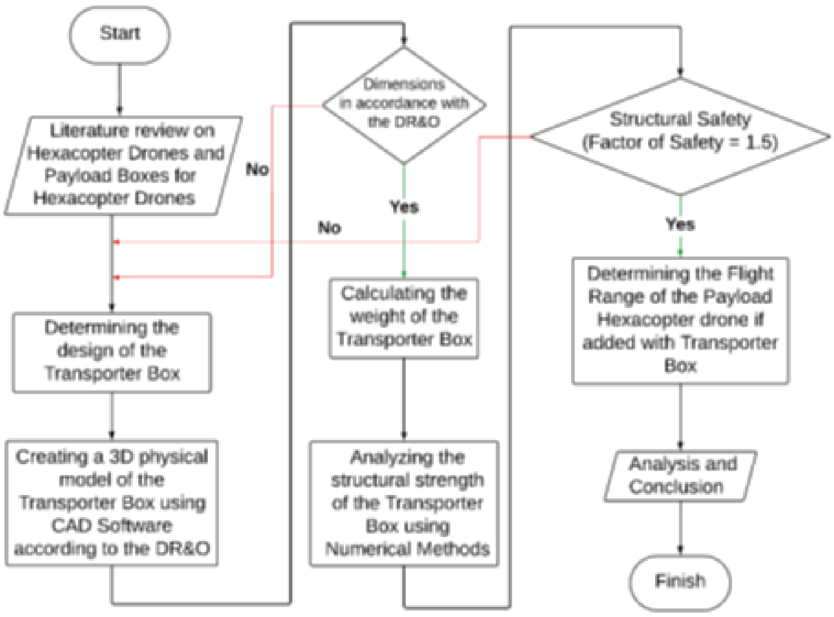

Fig 1. Research flow diagram

2.1 Design of Transporter Box

The DR&O establishes the functional boundaries for the transporter box, including minimum payload capacity, maximum allowable box weight, factor of safety, and endurance/range constraints. These were determined through a review of UAV logistics literature and mission requirements for defense applications (Garg et al., 2023; Suprapto et al., 2017). For this study, the box must carry at least 3 kg payload, remain below 2 kg self-weight, maintain a factor of safety ≥ 1.5, and ensure a minimum range of 11 km. The criteria are summarized in Table 1.

Table 1. DR&O of Transporter Box

Range	≥ 11 km
Endurance	15 menit
Maximum Take-off Weight	≥ 3 kg
Transportex Box Maximum Weight	2 kg
Factor of Safety	1.5

Five design iterations of the transporter box were created using CAD software. The geometry was defined as a rectangular prism with trapezoidal ends to maximize storage while minimizing aerodynamic drag. Iterations introduced modifications to reduce weight and improve manufacturability, including detachable hinges and actuator-based door systems. This stage followed practices in UAV structural modeling from Gutierrez-Rivera et al. and Guo et al.

2.2 Material Selection

The box was designed using polyethylene terephthalate (PET) due to its favorable strength-to-weight ratio, chemical resistance, and dimensional stability. PET has also been widely investigated for UAV applications through additive manufacturing (Martins et al., 2024). Table 2 summarizes the PET filament properties used in simulation, including tensile strength, elastic modulus, and Poisson's ratio.

Table 2. PET Filament Properties

Recycled Content	100%
E-Modulus	2898 Mpa
Poisson's Ratio	0.3887
Tensile Strength at yield	57 MPa
Print Temperature	220-250°C
Density	1.339 g/mL
Elongation at Break	70%
Flexural Strength	82.5 MPa

2.3 Finite Element Analysis

FEA was performed in three stages: pre-processing, solving, and post-processing, consistent with established simulation methodologies (Mishra et al., 2022).

- Pre-processing: The CAD model was imported into FEA software and discretized using tetrahedral elements due to geometric irregularity.
- Boundary conditions: Four clamps were modeled as fixed supports. Payload weight was applied as a distributed force on the bottom surface, and aerodynamic drag was applied to the rear face using bluff body drag coefficients [20].
- Evaluation metrics: Equivalent stress, total deformation, and factor of safety (FS) were calculated. Iterations continued until FS exceeded 1.5 while minimizing mass.

2.4 Flight Range Analysis

To evaluate the effect of the transporter box on UAV performance, a flight range analysis was performed. The analysis considered payload weight, aerodynamic drag, and battery endurance, ensuring that the final design satisfied the minimum range requirement of 11 km. The approach follows endurance and range estimation models widely used in UAV research(Suprapto et al., 2017).

First, the optimal flight speed V_"opt" was determined using the equation proposed by Bauersfeld and Scaramuzza.

$$\hat{v}_{[e|r]} = c_{0,r|e} + c_{1,r|e} v_{i,h} + c_{2,r|e} A \tag{1}$$

where $v_{i,h}$ is the induced velocity in hover, AAA is the vehicle reference area, and $c_{0,[r|e]}, c_{1,[r|e]}, c_{2,[r|e]}$ are regression coefficients that calibrated from simulation and experimental data. This relation has been shown to achieve high predictive accuracy ($R^2 \approx 0.97$), making it suitable for practical endurance and range estimation of multirotor UAVs. The value of the coefficients is shown in Figure 3.

Once the optimal speed was established, the maximum endurance t_e was estimated as (Gutierrez-Rivera et al., 2024):

$$t_e = \frac{C_{eff,e} \,.\, 3.7\,V \,.\, N_S \,.\, 3600\,s}{P_{mot,e}} \tag{2}$$

Endurance		Range		Battery	
$c_{0,e}$	0.10188	$c_{0,r}$	0.041546	d_0	0.9876
$c_{1,e}$	0.071358	$c_{1,r}$	0.041122	d_1	-0.0020
$c_{2,e}$	0.0007381	$c_{2,r}$	0.00053292	d_2	-5.2484e-05
				d_3	1.2230e-07
Wind, Speed		**Wind, Power**			
$c_{0,w}$	1.5730	$c_{0,P}$	2.4000		
$c_{1,w}$	0.5477	$c_{1,P}$	2.0998		
$c_{2,w}$	0.7732	$c_{2,P}$	0.8763		

Fig 2. Coefficients for Optimal Flight Speed Equation

where $C_{\text{eff},e}$ is the effective cell capacity (Ah), 3.7V is the nominal voltage of a Li-ion cell, Ns is the number of series-connected cells, and $P_{\text{mot},e}$ is the motor power consumption at endurance speed. The term in the numerator gives the total energy stored in the UAV's battery pack (Joules), while the denominator represents the required motor power. The ratio therefore yields achievable endurance in seconds. To capture the effect of payload and transporter box on available energy, the effective capacity was corrected using the load-dependent model (Saikong et al., 2025):

$$k = \frac{C_{eff}}{C} = d_0 + d_1 P_{cell} + d_2 P^2{}_{cell} + d_3 P^3{}_{cell} \tag{3}$$

where P_{cell} is the normalized power per cell and $d_0 \dots d_3$ are regression coefficients obtained from experimental battery testing. This ensures that endurance estimates reflect the nonlinear degradation of capacity with increasing load, providing a more accurate prediction of UAV flight time under operational conditions.

2.5 Iterative Evaluation

Five iterations were conducted to balance structural safety, weight, and endurance performance. At each iteration, FEA outputs (stress, deformation, FS) were compared against DR&O thresholds. Final evaluation confirmed whether the design simultaneously satisfied payload, structural, and range constraints

3. Results and Discussion

Several designs is presented along with the finite element analysis for each design. Several iterations to make sure that the design fulfill all the requirement of DR&O will be performed. A satisfactory design that fulfill all the requirements will be the end point of this work. Such design will be considered to be optimal.

In this opportunity, before the final design is presented, a “work-in-progress” design will be exhibited to show the reader the progression or changes of the design before it reach final point. As reminder, the final design cannot exceed certain weight, be able to carry minimum of 2kgs payload, with minimum factor of safety of 1.5.

3.1 Iteration Process and Finite Element Analysisn of Transporter Box Design

Five design iterations were performed to progressively reduce weight and optimize structural behavior while meeting the DR&O. Figures 5–10 illustrate the evolution of the transporter box geometry, including modifications such as reinforcement of clamps, addition of lock mechanisms, chamfered support bars, detachable hinges, and actuator-based door systems.

Finite element analysis (FEA) was conducted for each design. Figures 7 and 8 present the deformation and equivalent stress fields for the initial design, while Figures 11 and 12 show results for the final iteration. In the first design, deformation reached 0.659 mm, and equivalent stress was 5.7 MPa, yielding a factor of safety (FS) of 9.2. While structurally safe, the box mass was **2.78 kg**, exceeding the 2 kg limit.

Successive iterations reduced mass and redistributed stresses. The final design achieved a box weight of 1.79 kg while carrying a 5 kg payload. Equivalent stress increased to 11.8 MPa, deformation reduced to 0.53 mm, and FS converged to 4.46, comfortably above the required 1.5. These results are consistent with previous studies where UAV structures were validated through FEA, demonstrating the method’s reliability for lightweight aerospace components [8]–[11].

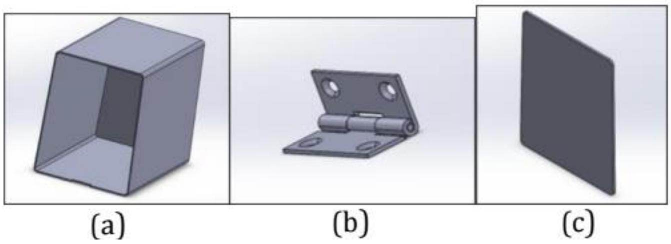

Fig 5. Initial design of transporter box (a)Body (b) Hinge (c) Door

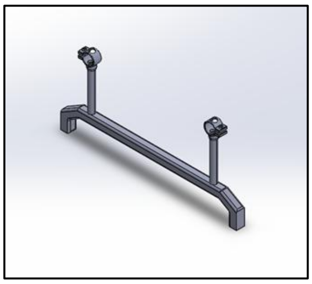

Fig 6. Initial design: Hanger and clamps

Figure 5 shows the initial design of transporter box. The design is intended to carry as much as possible within the operational limit, light, easy to be manufactured, and fit in the dimension of the hexadrone.A finite element analysis is then carried out and Figure 7 and Figure 8 show the total deformation and equivalent stress of the box respectively. The box endures various load from the weight itself, payload, and aerodynamic load. It can be seen that maximum deformation occurs on the bottom of the box with maximum value of 0.65941 mm and maximum equivalent stress of 5.7Mpa. From such maximum stress, it is obtained factor of safety of 9.2 which far more than minimum required factor of safety value (1.5). However the weight of the box is 2.784 Kg which exceeds maximum requirement for weight, hence further iteration(s) to reduce the weight is needed.

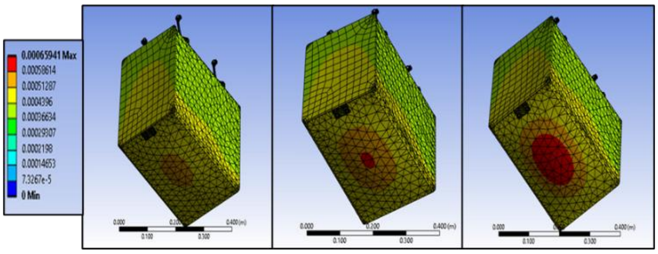

Fig 7. Total deformation of transporter box: Initial design

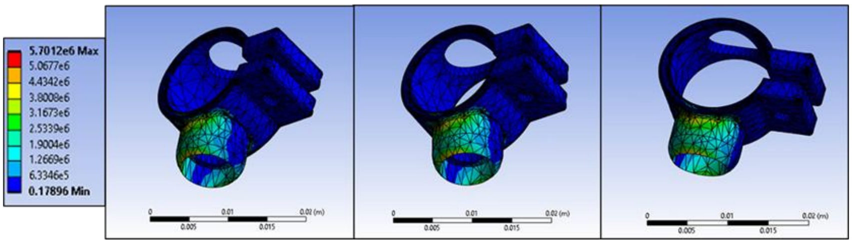

Fig8. Equivalent Stress of transporter box: Initial design

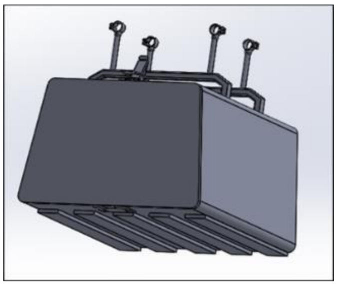

Fig 9. Second iteration; reinforcement at the bottom of box and lock mechanism added

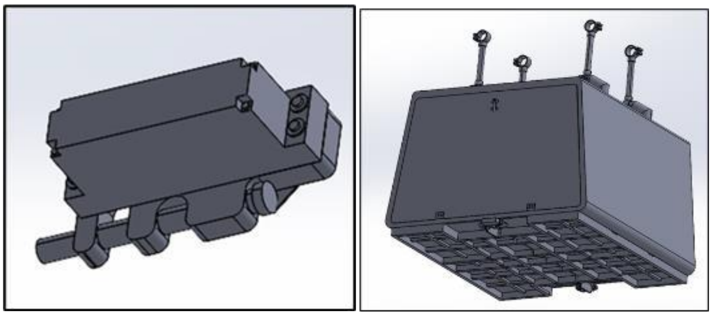

Fig 10. (a) door actuator (b) final design of transporter box

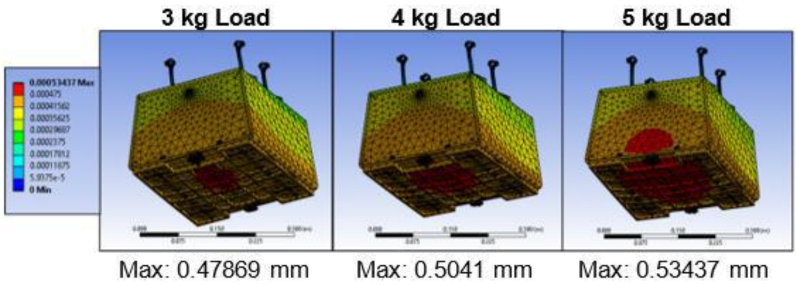

Fig 11. Total deformation of transporter box final design

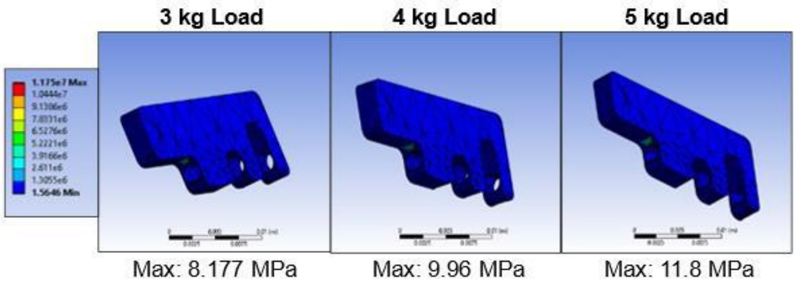

Fig 12. Equivalent stress of transporter box final design

3.2 Comparative Evaluation Across Iterations

Figures 13–15 compare the deformation, equivalent stress, and FS values for payloads of 3 kg, 4 kg, and 5 kg across all iterations.

- First design: High FS but excessive mass, unsuitable for mission requirements.
- Second and third designs: Improved rigidity with lower deformation, but weight reduction remained insufficient.
- Fourth design: Enhanced transportability with detachable hinges, yet FS margins decreased.
- Final design: Achieved the best trade-off between lightweight construction and safety, fulfilling all DR&O simultaneously.

This iterative approach highlights the importance of balancing safety and endurance in UAV structural design. Similar iterative optimization strategies are emphasized in UAV structural research [8], [11].

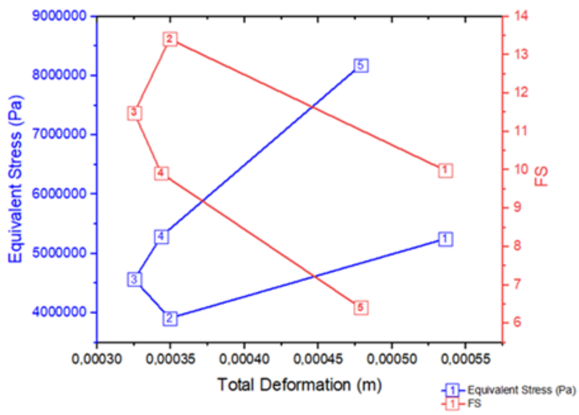

Fig 13. Payload of 3 Kg

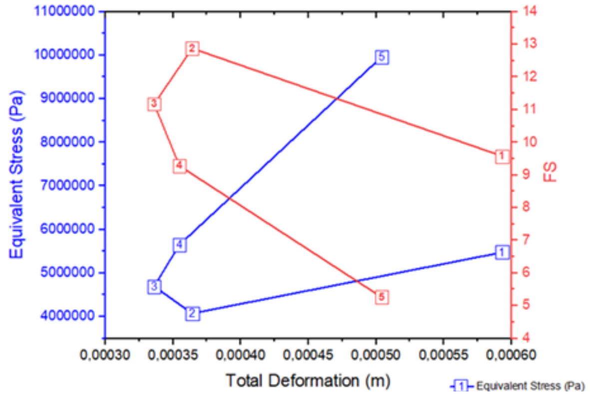

Fig 14. Payload of 4 Kg

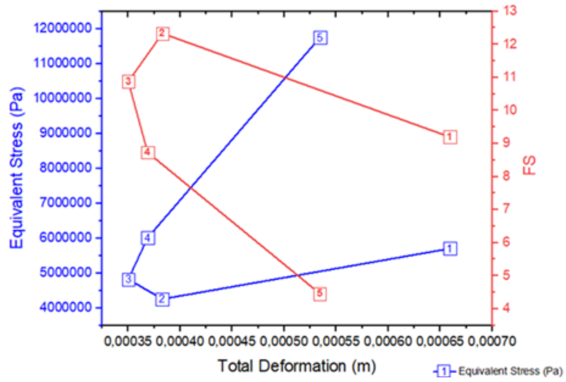

Fig 15. Payload of 5 Kg

3.3 Flight Range Analysis of Final Design

To verify that endurance requirements were met, flight range was calculated for the DJI Matrice 600 with the transporter box attached. Using endurance estimation methods [3]–[6], the UAV achieved a maximum range of 18.8 km with a flight duration of 16.8 minutes while carrying the transporter box and payload. This performance exceeded the minimum DR&O of 11 km range, confirming that payload integration did not critically compromise operational endurance.

These findings align with prior UAV endurance studies, which stress the need for balancing payload weight and power efficiency [3], [4], [6]. The results also demonstrate that lightweight structural solutions such as PET-based modular payload boxes can extend UAV capability for logistics without major redesigns of the UAV platform

4. Conclusion

This study presented the design and validation of a lightweight modular transporter box for the DJI Matrice 600 hexacopter. Through five iterations and finite element analysis, the final prototype achieved a mass of 1.79 kg, supported a 5 kg payload, and maintained a factor of safety of 4.46. Endurance modeling confirmed that the UAV retained a flight range of 18.8 km in 16.8 minutes, exceeding the minimum 11 km requirement. The research contributes a validated approach for integrating structural analysis and endurance estimation in UAV payload design, demonstrating the potential of PET thermoplastics for lightweight, reliable, and modular logistics solutions. The findings have direct implications for defense and emergency logistics, where rapid and secure aerial delivery is critical. Limitations include reliance on simulation and assessment for a single UAV platform. Future research should involve prototype fabrication, flight testing, and exploration of alternative lightweight materials.

ACKNOWLEDGEMENTS

Each author of this article played an important role in the process of method conceptualization, simulation, and article writing

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